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Pollution of Lake Victoria: What Is Next?

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Abstract: The natural resources of the Lake Victoria basin support livelihoods of over 30 million people. Although, a number of researchers have studied, the effects of non point source pollution on water quality in Lake Victoria basin such published studies are often carried out for short periods of 6 months or less due constraints in resources such as time and funds, etc. The consequence of this is that indicative parameters are instantaneously measured or monitored as a basis for generic conclusions and/or recommendations that cannot be supported. In order to positively influence policy and policy makers, credible data measured over a realistically long period is needed. In this study, Non-Point Source pollution (NPS) was monitored, measured and characterized with a view of understanding bioaccumulation of Lead (Pb) in fish and nutrient pollutant loading in the lake for a period of 4 years and 6 months (January, 2007 to June, 2011). The study was conducted at Ggaba landing site, Makindye division and Kampala district. All samples were analyzed for nutrients, namely, ammonia, nitrite, nitrate and phosphate using standard methods for Examination of Water and Wastewater. A total of 520 samples were collected at Ggaba landing site in Uganda and were analyzed for nutrients, namely, Ammonia, Nitrite, Nitrate and Phosphate. In addition, portable meters were used to measure Total Dissolved Solids (TDS) and Dissolved Oxygen (DO) instantaneously at point of sample collection. Within the lake, samples were taken at for horizontal transects of 10 m interval over a distance of 50 m from the shore where surface runoff was released. At each 10 m sampling point, three samples were drawn at vertical distances of 0.5, 1.0 and 1.5 m from water surface using a hand pump with graduated delivery pipe. In general, the results showed that nutrient concentrations were highest at the shore and water surface. The 2010 yearly average concentration of 3.8 mg L^{-1} phosphate was the highest followed by ammonia at 2.1 mg L^{-1}, nitrite at 1.11 mg L^{-1} and nitrates at 0.38 mg L^{-1}. Interestingly, the nutrient loading has doubled during the last 4 years. In conclusion, the traditional habit of drawing water on the surface especially between distance 0 and 0.5 m exposes water users to the highest pollution loads while Pb levels of exceed maximum daily permissible Pb uptake in water.

Key words: Land use, non-point source of pollution, nutrients loadings, sediment loadings, water quality, Lake Victoria

INTRODUCTION

Lake Victoria is the world's second largest fresh water lake by surface area. It is bordered by Tanzania, Kenya and Uganda. The lake is one of the most important shared natural resources of Eastern Africa. It holds the world's largest fresh water fishery largely based on the introduction of Nile Perch which supports an economically and socially important export fishery for the riparian countries around the lake. This fishery is a major source of income to the fishing communities, government tax revenue and protein for the local communities. The gross economic product in the lake catchment is of about US$ 3-4 million annually and supports an estimated population of 25 million people at average incomes in the range of US$ 90-270 $annum^{-1}$. The population density in the lake basin is above the national average in all countries and the populations of the riparian communities

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grow at rates that are among the highest in the world. The ecological health of Lake Victoria has been affected profoundly because of a rapidly increasing human population due to migration to the area by plantation workers, clearance of natural vegetation along the shores to establish plantations of coffee, tea, horticulture, sugar cane, prolific growth of algae and dumping of untreated effluent by several industries (Banadda *et al*., 2009). Agricultural activities require the usage of large amounts of fertilizers and pesticides to acquire higher yields (Banadda *et al*., 2010). The nutrient loads generated in agricultural areas are carried away with the run off causing eutrophication of the lake. Large amount of organic matter enters the lake in the form of crop debris. Although, a number of researchers (Chege, 1995; Matagi, 2002; Rwetabula *et al*., 2005; Dubi, 2006; Banadda *et al*., 2009) have documented pollution as one of the largest problems causing water quality deterioration in the Lake Victoria basin, the problem persists. Partly, this is due to the fact the researchers and researchers alike use data collected over a short time (6 months or less) to make long-term projections that cannot be supported. In previous research of researcers such as Makundi (2001) and Campbell *et al.* (2003, 2004) various nutrient and heavy metals loading trends have been profiled and presented over short periods of >6 months. It is against this background that this study presents two fold objective to characterize and quantify nutrient and heavy metal loading and to quantify lead accumulation in fish muscle, liver and gills over a period long enough to enable sound judgement and/or invention at policy level.

MATERIALS AND METHODS

Study area: The study was carried out at Gaba landing site located in Makindye division, Kampala (Uganda) as shown in Fig. 1. The choice of the study area was informed by the high socio-economical activities in the area and the importance of the area in as far as being a water source for Kampala city dwellers.

The land use coverage within the area consists of built up areas and subsistence farmland which occupy each about 0.3%, bush 0.04%, Swamp 0.09%, Grassland 0.11% and open water (Lake Victoria) which covered most

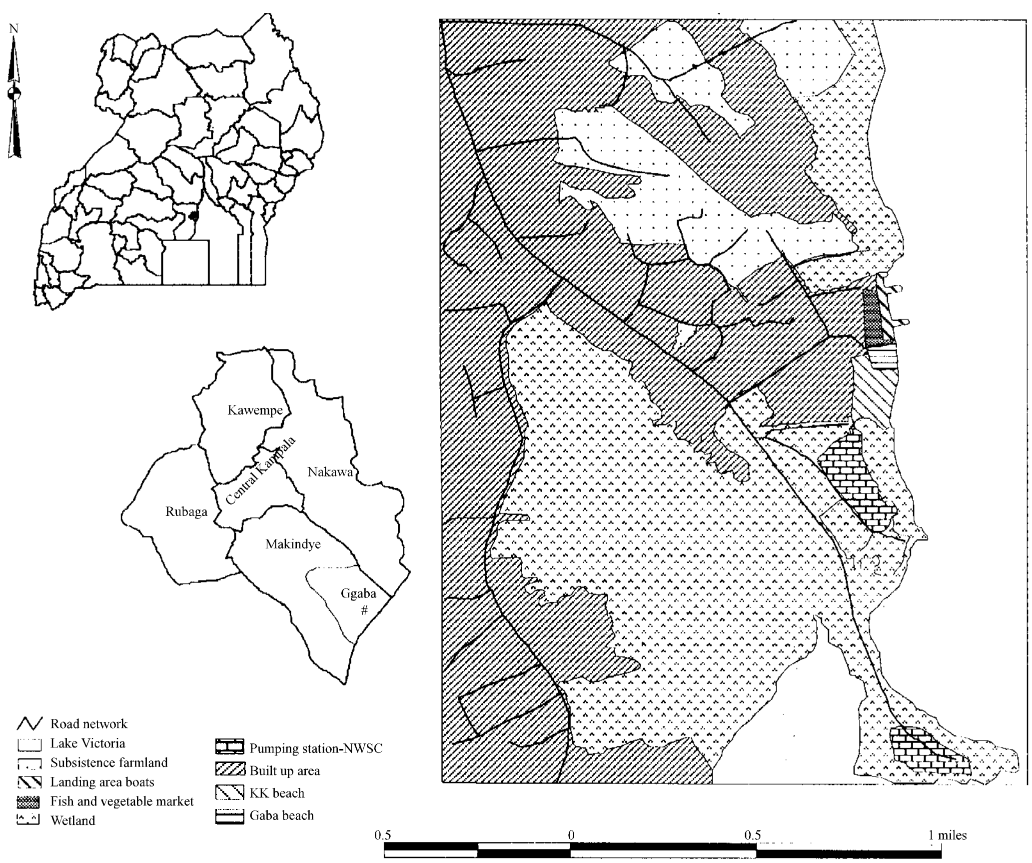

Fig. 1: Land use activities in Ggaba, Kampala (Uganda)

of the area was 99.31%. Bush as a land use is a degraded swamp by the population and is a leading pathway for runoff from upper catchment area into the lake. During rainy season, the area displays characteristics of a swamp. Subsistence farmland, Grassland and other land uses are rapidly being changed into built up areas and is characterized by residential and commercial buildings scattered all over the area.

Selection of hotspots and sampling stations: The selection of sampling points was based upon inflow and outflow regions of the lakes, geographical location of industrial units in relation to their effluent discharges, proximity of residential sites located on the banks of the wetland systems, drainage patterns and accessibility towards the lakes.

Water sample collection and analysis: In this study, 520 samples were collected over a period of 4 years and 6 months (January, 2007 to June, 2011) at Ggaba landing site in Uganda. In order to understand seasonally variation of NPS loading, 50% of the samples were taken during a rainy season and the other in the dry season. To ensure that samples were always taken from the same spot within the lake, mapping of the sampling points were done using GPS on a boat ride. The sampling coordinates were stored in a GPS and later traced during subsequent sampling. In the case of rainy seasons, the mapping was done after rain event in order to locate the path/areas these runoff normally follow when released into the lake. Samples were stored in a cooler and transported to Makerere University within <2 h for lab analysis which include nutrients (ammonia, nitrite, nitrate and phosphate). Total Dissolved Solids (TDS) and Dissolved Oxygen (DO) were measured instantaneously at points of sample collection using a probe. Furthermore, pollutant loads were also analyzed for heavy metals, specifically Lead (Pb) at selected hotspots. Meanwhile, within the lake samples were taken at for horizontal transects of 0±0.05, 30±0.05 m interval and 50±0.05 m starting from the shore as shown in Fig. 2. For the same sampling points within the lake, samples were drawn at vertical distances of 0.5±0.05, 1.0±0.05 and 1.5±0.05 m from water surface using a hand pump with graduated delivery pipe so as to take samples at the required vertical depth. The samples were analysed for nutrients according to the standard methods for examination of water and wastewater (APHA, 1995).

Fish sample collection and analysis: A total of 24 whole fresh fish (Tilapia) were randomly brought at the open fish market at Ggaba landing site. The fish was transported in cooler boxes for immediate Pb analysis at Makerere University. The fish was dissected and different parts namely muscle, gills and the liver of interest in this study were isolated. Then was followed by a digestion procedure. A weight of 2.5±0.05 g of either part was placed into a digestion flask. Then, 5±0.05 mL conc. H_2SO_4 was added. The mixture was gently refluxed for 1±0.05 h and cooled then, 4±0.05 mL of 1:1 nitric acid added through the condenser. The mixture was boiled without cooling water until white fumes appeared in the flask. Heating continued for 10±0.5 min followed by cooling to room temperature. The 1±0.05 mL of the cooled mixture was then diluted to 25±0.05 mL. Finally, 9±0.05 mL of 25 mL was put in a flameless AAS Model 902, Atomic Absorption Spectrophotometer (Model 902) cell for determination of Pb in fish muscle, liver and gills.

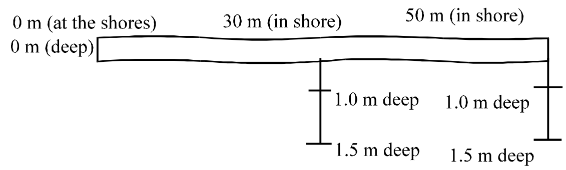

Fig. 2: Schematic of the sampling points

Data analysis: The data obtained were analyzed using descriptive statistics in Microsoft Excel. The results were expressed in terms of mean and standard deviation. The results were compared with standard water quality guidelines. A one-way analysis of variance test was used to compare the difference between means.

RESULTS AND DISCUSSION

Vertical and horizontal dispersion trends of NPS within the lake: Results in this study revealed that there was a significant influence of horizontal distance on the concentration of pollutants ($p<0.05$) for all samples taken from the shore up to 50±0.05 m offshore. At the Lakeshore concentration of pollutants was very high due to discharge of nutrients into the lake by surface runoff. Sampling time and depth had no significant influence on concentration of pollutants. The dispersion of NPS trends are clearly in the wet season. Generally, NPS decrease as one moves horizontally in the lake due to dilution factor of the lake. However, vertical measurements up to a depth of 1.5±0.05 m indicate that generally nutrients decrease with increasing depth. However, nitrites and nitrates have an inverse relationship. As one increases, the other decreases. This observation was also confirmed by Ezeonu and Okaka (1996). In the surface water, DO concentration is high enough to oxidize nitrites to nitrates. The U.S. Public Health Service has established 10 mg L^{-1} of nitrate-nitrogen as the maximum contamination level allowed in public drinking water,

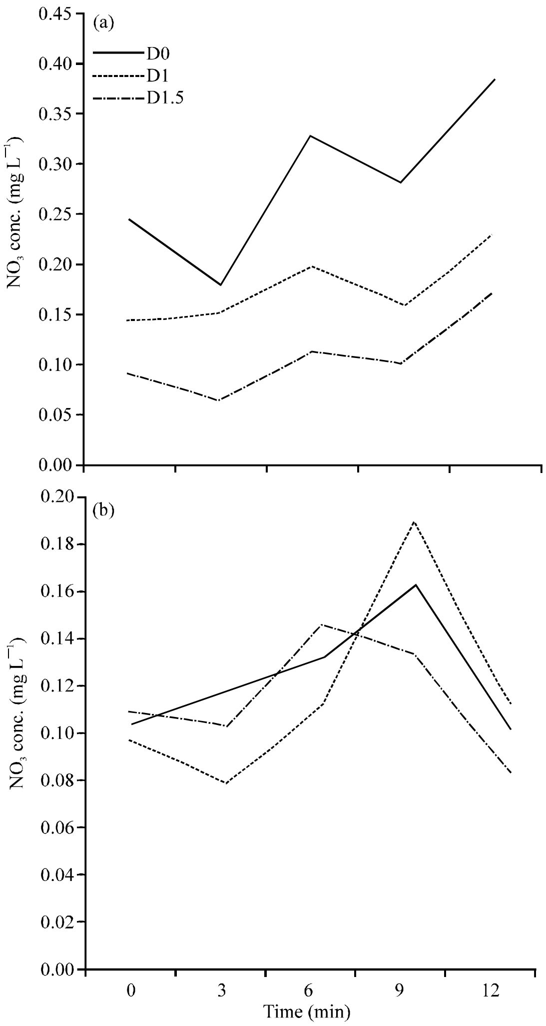

Fig. 3: Nitrate profiles at the Lake Victoria shore at depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

there basing on this standard it can be concluded that the water is not harmful to humans as far as nitrates are concerned.

Nitrate profiles: Nitrates are a major ingredient of farm fertilizer and are necessary for crop production. When it rains, varying nitrate amounts wash from farmland into nearby waterways. Nitrates also get into waterways from lawn fertilizer run-off, leaking septic tanks and cesspools, manure from farm livestock, animal wastes (including fish and birds) and discharges from car exhausts. Nitrates stimulate the growth of plankton and waterweeds that provide food for fish. This may increase the fish population. However, if algae grow too wildly, oxygen levels will be reduced and fish will die. Schnoor (1996) noted that nitrates are much more efficiently transported by moisture. Figure 3 shows the nitrate profiles at the

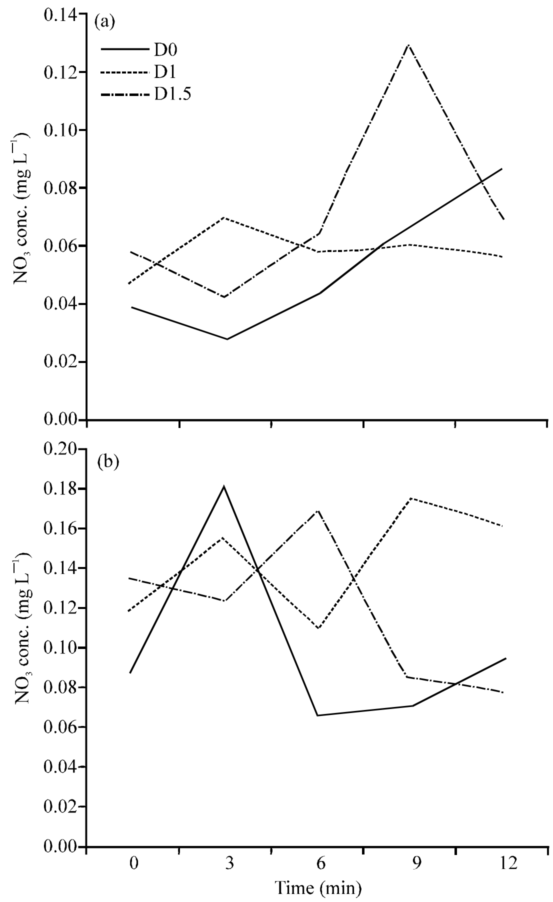

Fig. 4: Nitrate profiles at horizontal distance of 30 m from the shore and depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

shore (reference distance of 0 m) at depth of 0±0.05 m (surface), 1.0±0.05 m (D1) and 1.5±0.05 m (D1.5) during the wet season and dry season. During the wet seasons, nitrate levels were highest at the water surface (DO) at all the sampling times and lowest at a depth of 1.5±0.05 m (D1.5). Generally, there has been a marked increase in nitrate values over the last 4 years. Specifically, nitrate concentrations in the lake have increased from an average of 0.05-0.31 mg L^{-1} in the last 4 years. According to Chapman (1999) nitrate concentrations in excess of 0.2 mg L^{-1} NO_3-N within lakes tends to promote algal growth, an indication of possible eutrophic conditions. It is therefore, evident that runoff process contributes to nutrient input into the Lake Victoria during wet season and that the near shore areas of Lake Victoria are the most highly affected. Note worthy is the fact that nitrate concentration decrease as depth increases. The trends are more evident in wet seasons than in dry ones. Nitrate values during the dry season are almost half those in the wet season. Figure 4 shows the nitrate profiles at

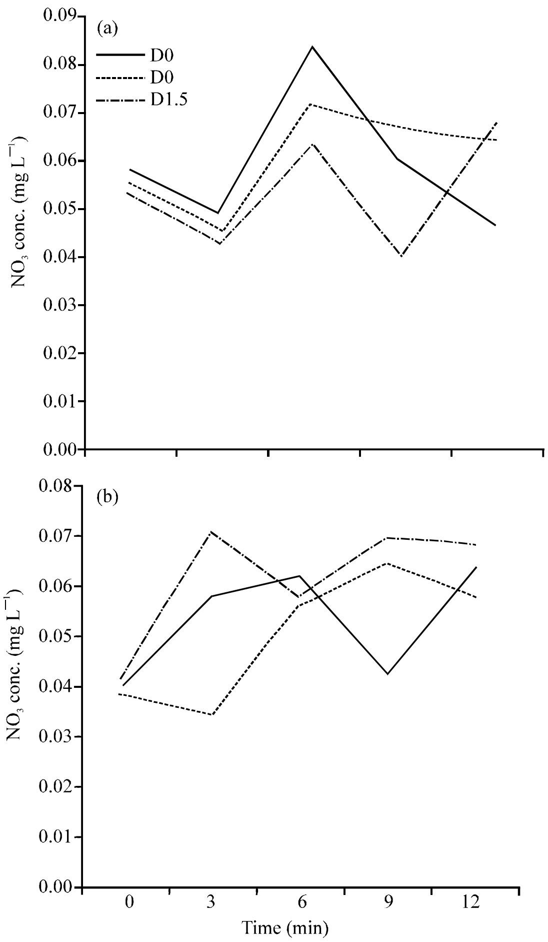

Fig. 5: Nitrate profiles at horizontal distance of 50 m from the shore and depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

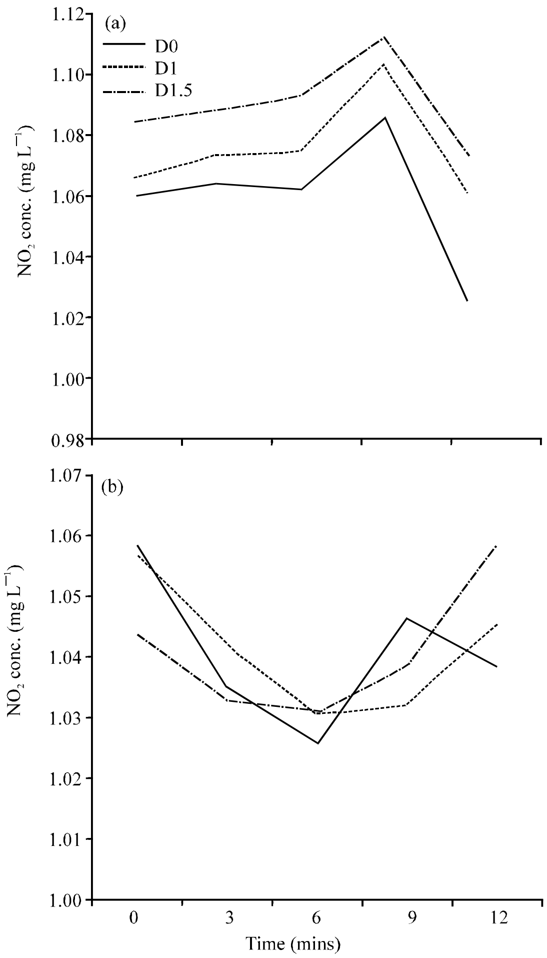

Fig. 6: Nitrite profiles at the Lake Victoria shore at depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

horizontal distance of 30 m from the shore and depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season. A comparison of nitrate values in the wet season (Fig. 3) shows that there is decrease in concentration as one moves horizontally in the lake. In other words, nitrate concentrations were relatively low at horizontal distance of 30 m (H30) compared to the shore (H0) there was a significant influence of concentration of nitrates on distance ($p = 0.014$). On average, in the wet season, the highest amount of nutrients (0.13 mg L^{-1}) was at a depth of 1.5 m from the water surface. The nutrient concentration at the surface (D0) was increasing with time whereas that at 1 m (D1), it was decreasing with time though statistical analysis did not show a significant difference. Interestingly, nitrate concentrations in the dry season were relatively higher than in the wet season. The highest nitrate concentration of 0.18 mg L^{-1} was at the water surface, D0 while the lowest of 0.07 mg L^{-1} was still at water surface (D0). Figure 5 shows the nitrate profiles at horizontal distance of 50 m from the shore and depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season. In the wet season, nitrate concentrations at horizontal distance (50 m) were relatively low compared to horizontal distance of 30 m (H30) and the shore (H0). Concentrations were highest at the water surface (D0) and lowest at depth of 1.5 m (D1.5).

Nitrite profiles: Figure 6 shows the nitrite profiles at the shore (Reference distance of 0 m) at depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season. There were high levels of nitrite at depth of D1.5 and the highest concentration was 1.11 mg L^{-1} while the lowest levels of the nutrient were at the water surface. Nitrites are relatively short lived for they are quickly converted to nitrates. Comparable nitrite concentrations were measured in the dry season. The

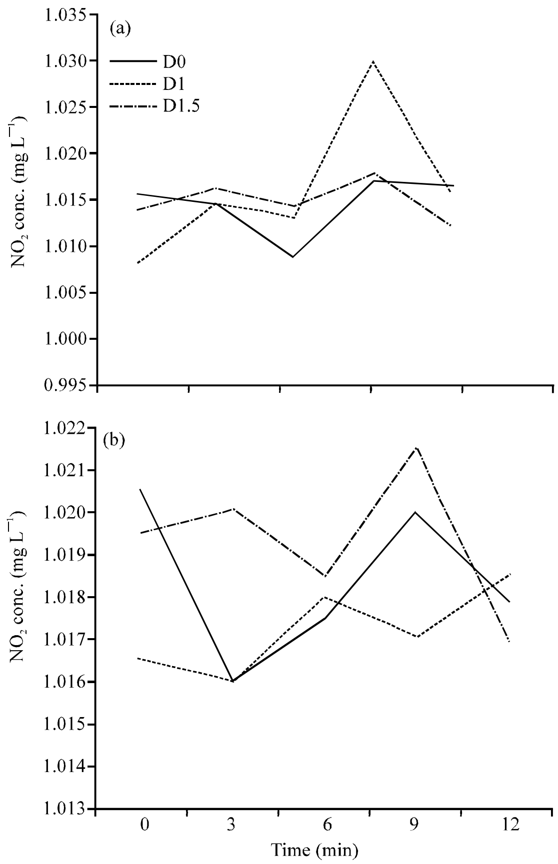

Fig. 7: Nitrite profiles at horizontal distance of 30 m from the shore and depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

highest concentration of nitrites was noted at depth of 1.5 m (D1.5). A comparison with nitrate results are shown in Fig. 3, one can deduce that average the lake has more nitrites than nitrates.

Figure 7 shows the nitrite profiles at horizontal distance of 30 m from the shore and depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season.

In the wet season, nitrite concentrations were relatively lower than at H0 (at the lakeshore). The recorded highest nitrite concentration is 1.03 mg L^{-1}. The lowest nitrite concentration is 1.008 mg L^{-1} at depth 0 m (D0).

In the dry season, nitrite concentrations were highest at depth of 1.5 m and lowest at depth of 1 m. The highest concentration was 1.024 mg L^{-1} at depth of 1.5 m and lowest, 1.016 mg L^{-1} at depth of 1 m. Interestingly, the nitrite concentration in both seasons are comparable at horizontal distance of 30 m.

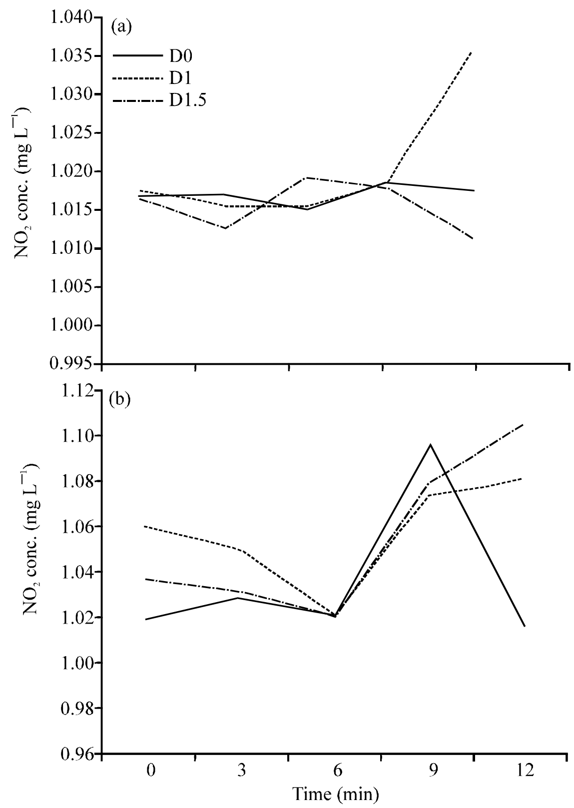

Fig. 8: Nitrite profiles at horizontal distance of 50 m from the shore and depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

Figure 8 shows the nitrite profiles at horizontal distance of 50 m from the shore and depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season.

At horizontal distance of 50 m, nitrite concentrations in the wet season were relatively lower than in the dry season. In the wet season, the highest concentration was 1.04 mg L^{-1} at 1 m depth and lowest at 1.5 m depth with 1.01 mg L^{-1}.

In the dry season nutrient concentrations were relatively high with high, up to 1.10 mg L^{-1} compared to the wet season's 1.04 mg L^{-1}.

The lowest concentration was 1.01 mg L^{-1}. These values were higher than those obtained at horizontal distance of 30 m.

The maximum allowable nitrite nitrogen levels in the WHO drinking standards (WHO, 2006) are 0.05 mg L^{-1} and therefore, the water in both the dry and wet seasons is not safe for drinking purposes and is not favourable for the protection of fresh water fish.

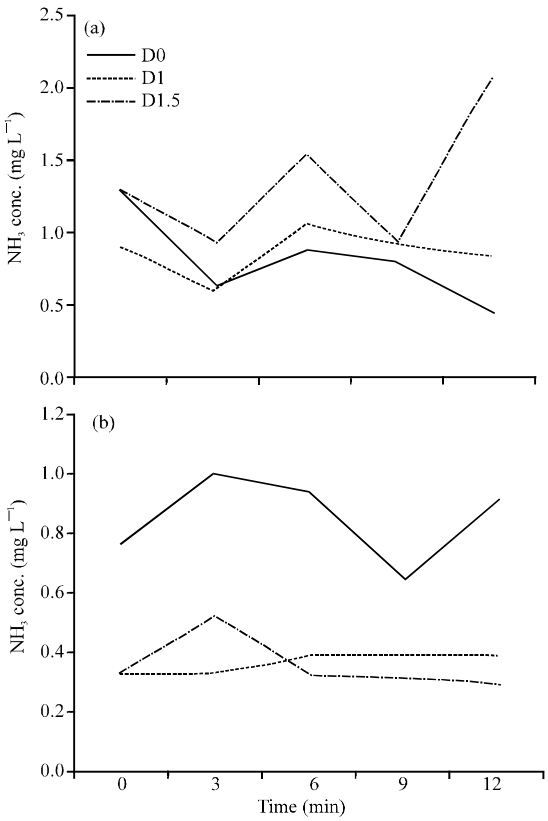

Fig. 9: Ammonia profiles at the Lake Victoria shore at depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

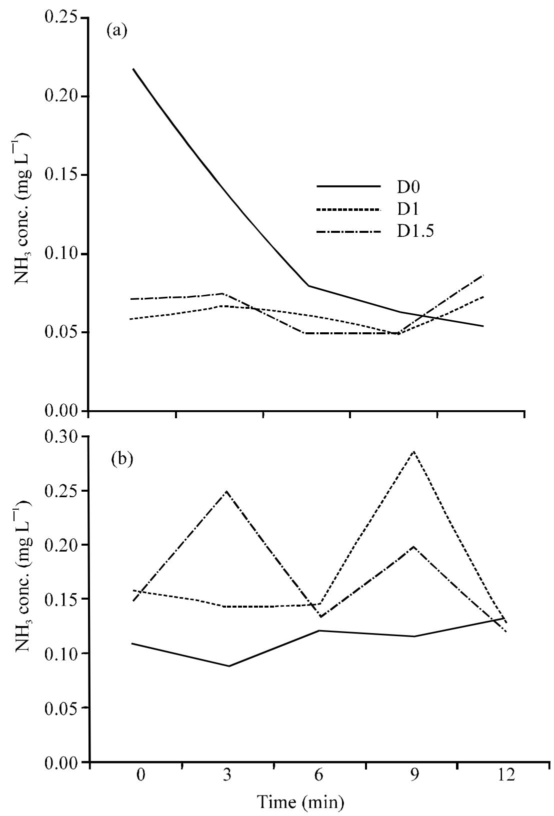

Fig. 10: Ammonia profiles at horizontal distance of 30 m from the shore and depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

Ammonia profiles: Figure 9 shows the ammonia profiles at the shore (Reference distance of 0 m) at depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season. In the wet season at a depth of 1.5 m, the highest concentrations of ammonia were recorded while at the water surface, D0, the lowest concentrations 0.4 mg L^{-1} was noted. In the dry season, the highest ammonia concentration were measured at the water surface (D0).

In Fig. 10, ammonia profiles at horizontal distance of 30 m from the shore and depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season are shown. During the wet season and at the water surface (D0), ammonia concentration dropped from 0.23 mg L^{-1} at the shore to 0.06 mg L^{-1} after 12 min.

At a depth 1.5 m, the highest concentration of ammonia was measured. In the dry season, the water surface (D0) had the highest concentrations at all times compared to other depths with the highest, 1 mg L^{-1} and lowest 0.61 mg L^{-1}. D1.5 had the lowest ammonia concentration. The concentrations at H0 (at the shore) were higher than at horizontal distance 30 m. The concentration at the water surface (D0) dropped drastically from the highest concentration (0.23 mg L^{-1}) to the lowest (0.05 mg L^{-1}) while at D1 and at depth of 1.5 m the concentrations were low and changing with time. Ammonia concentrations during the wet season ranged from 0.23 and 0.05 mg L^{-1}.

In the dry season, the concentrations were fluctuating with time. The lowest concentrations were observed at the water surface D0 for all sampling times. In Fig. 11, ammonia profiles at horizontal distance of 50 m from the shore and depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season are depicted. The ammonia concentrations at H50 in Fig. 11 were lower than at H30 as shown in Fig. 8. Ammonia concentrations in the dry were higher than in the wet season. This could be due to less dissolved oxygen during the dry season. Furthermore, decaying plants during the dry season also contribute to ammonia

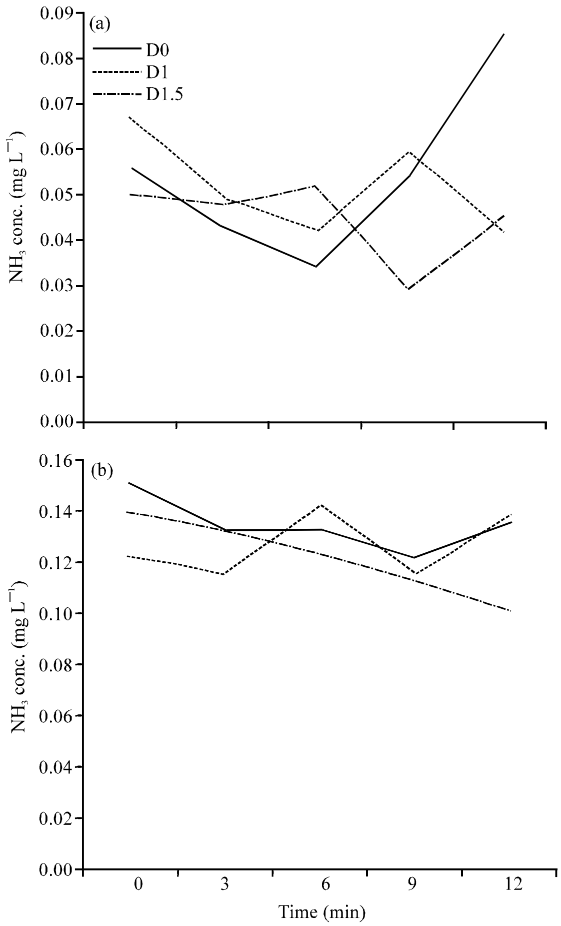

Fig. 11: Ammonia profiles at horizontal distance of 50 m from the shore and depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

concentration. Banadda *et al.* (2011) reported that winds and waves are stronger and more frequent in the dry season and these drive pollutants off shore as supported by comparison of Fig. 11 and 9.

Phosphate profiles: Figure 12 shows the phosphate profiles at the shore (Reference distance of 0 m) at depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season.

On one hand, phosphate concentrations in the wet season were higher than in the dry season. During the wet season there were averagely high phosphate concentrations of the nutrient at D1.5 with the highest, 3.8 mg L^{-1} and the lowest 2.3 mg L^{-1}. On the other hand, phosphate concentrations in the dry season were highest at the water surface, DO compared to other depths. This could be explained by the use of soaps and

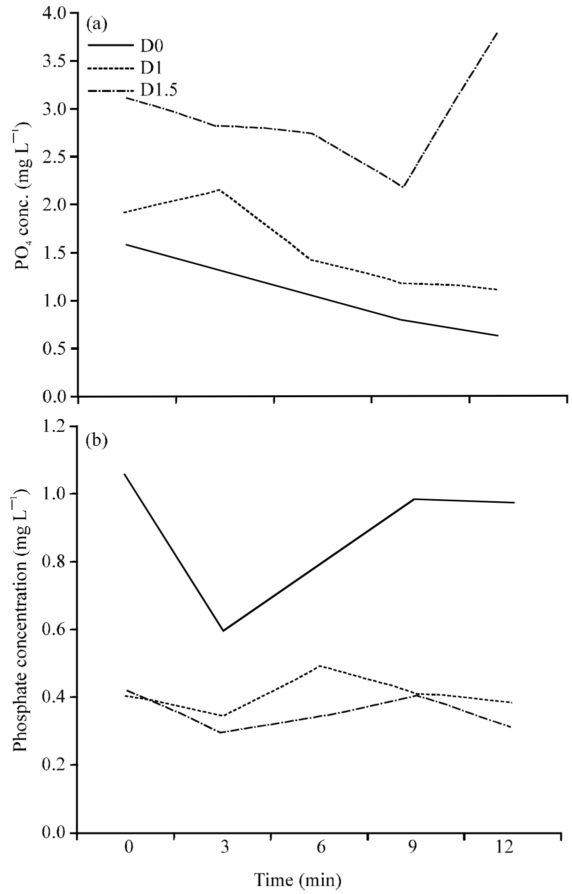

Fig. 12: Phosphate profiles at the Lake Victoria shore at depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

detergents to wash cars, clothes and dishes, etc. The highest concentration at the water surface (D0) was 1.1 mg L^{-1} while the lowest was 0.6 mg L^{-1}. Figure 13 shows the phosphate profiles at horizontal distance of 30 m from the shore and depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season.

During the wet season, nutrient concentrations were fluctuating with time. Phosphate nutrients concentrations at D1.5 were increasing with time and recorded the highest amount of 0.26 mg L^{-1}. In the dry season, D1 had the highest concentration of 0.23 mg L^{-1}.

In Fig. 14, phosphate profiles at horizontal distance of 50 m from the shore and depth of 0 m (surface), 1.0 m (D1) and 1.5 m (D1.5) during the wet season and dry season are depicted. Phosphate concentrations in the dry season were relatively higher than in the wet season. Phosphate concentrations are comparable in both seasons although, the values during the wet season increased over time.

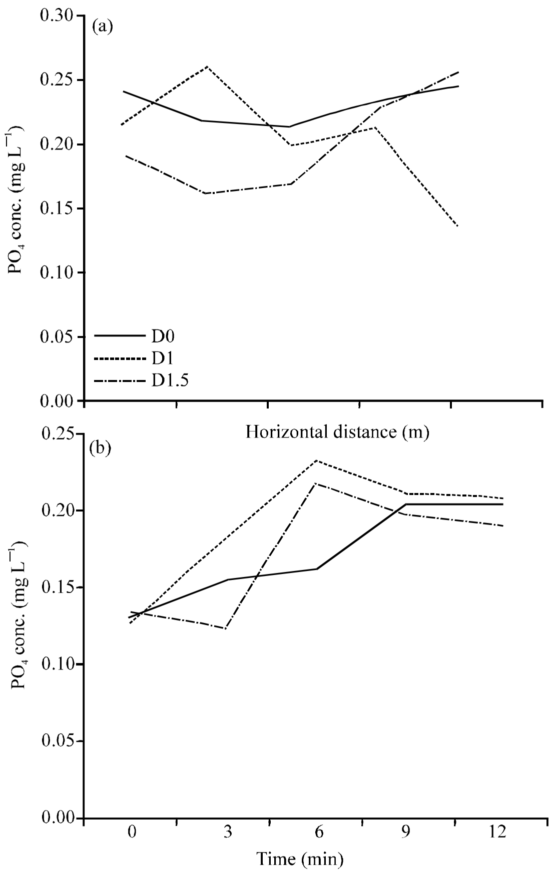

Fig. 13: Phosphate profiles at horizontal distance of 30 m from the shore and depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

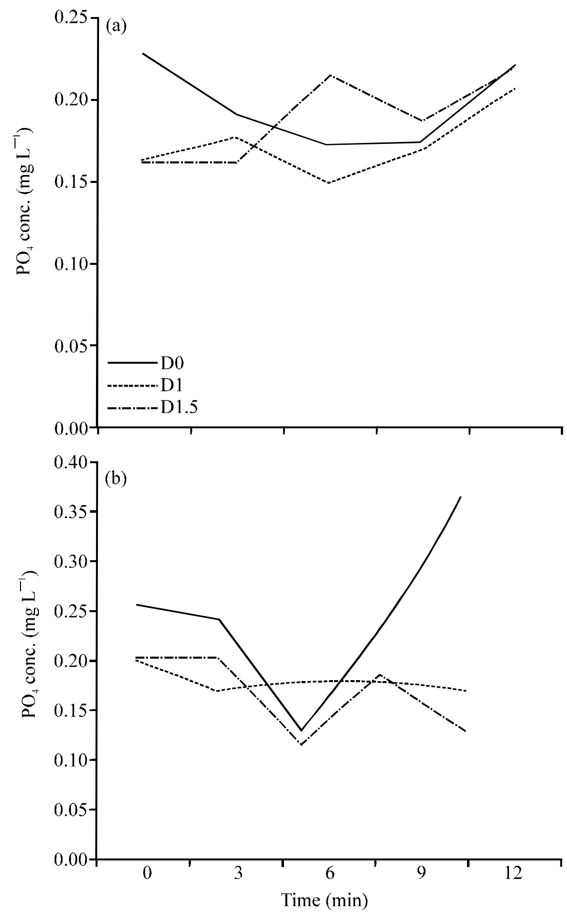

Fig. 14: Phosphate profiles at horizontal distance of 50 m from the shore and depth of 0 m (surface = D0), 1.0 m (D1) and 1.5 m (D1.5) during the (a) wet season and (b) dry season

Table 1: Average concentration of the lead measured in the fish samples (mg L^{-1})

Fish sample part	Concentration in wet season (mg L^{-1})	Concentration in dry season (mg L^{-1})
Liver	0.57	0.60
Muscle	0.23	0.12
Gills	0.97	0.86

Lead (Pb) measurements: Generally, the Pb concentration was higher in the fish muscle during the wet season as compared to the dry one. This was particularly of concern since most people do not eat the fish liver and the gills. In the wet season, fish sample parts analysed for Pb on average showed concentration of 0.97 mg L^{-1} in the gills, 0.57 mg L^{-1} in the liver and 0.23 mg L^{-1} in the muscle where in the dry season, value of 0.86 mg L^{-1} in the gills, 0.60 mg L^{-1} in the liver and 0.12 mg L^{-1} in the muscle were recorded as shown in Table 1. According to the WHO, the maximum daily permissible Pb uptake in water is 0.05 mg L^{-1}. Therefore, the average Pb concentration in all the three parts are above the maximum daily permissible Pb uptake in water.

CONCLUSION

With reference to the results obtained in this study the concentration of nutrients were high during the rainy season due to runoffs from agricultural areas implying that non point source significantly contributes to the increasing rates of pollution in Lake Victoria which in turn affect quality of the water which is in line with the results of Swallow *et al.* (2002) whose results indicated that continued addition of nutrients into the winam gulf occurred during rainy season and the nutrient concentration seriously affect water quality and aquatic systems. The study also clearly shows that seasonal variations in Lake Victoria catchments do greatly influence nutrient levels in the lake water with the wet season taking the lead more than the dry season. Generally nutrient concentrations decrease as one move further (horizontally) from the shores into the lake due to dilution effect of the lake water. There are also variations in nutrient levels vertically at depths of 0, 1 and 1.5 m. Though there is no defined trend, concentrations at the water surface were usually higher than the lower depths. The highest nutrient concentration were measured at the shore and on the water surface of namely 3.8 mg L^{-1} phosphate, 2.1 mg L^{-1} of ammonia, 1.11 mg L^{-1} of nitrite and 0.38 mg L^{-1} of nitrates during the wet season. In addition, the mean Pb concentration of 0.23 mg L^{-1} in fish muscle in the wet season exceeded 0.05 mg L^{-1} which is the WHO maximum daily permissible Pb uptake in water.

RECOMMENDATIONS

This study recommends that:

- The seasonal impact on the influx of nutrients into the Lake Victoria can be controlled by improving the agricultural practices in the catchment
- Enforce existing environmental protection rules and regulations
- Create farming buffer zones especially along the lakeshore
- Engage communities in the lake basin with periodic educational modules that promote good waste disposal mechanisms
- Centralize water research for the purposes of developing data banks on for the benefit of stakeholders

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