

Characterization of non point source pollutants and their dispersion in Lake Victoria: A case study of Gaba Landing site in Uganda

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Abstract: Lake Victoria is one of the largest freshwater bodies in the world. The lake is bordered by Kenya, Tanzania, and Uganda, and has streams and rivers stretching as far as Burundi and Rwanda feeding into it. A number of studies have reported deteriorating water quality due to pollution. In this study Non Point Source Pollution was the focus and such as 68 samples and 64 samples were collected over two rain seasons and dry season, respectively. All samples were analyzed for nutrients, namely, Ammonia, Nitrite, Nitrate, and Phosphate. Portable meters were used to measure pH, EC, Total Dissolved Solids, Temperature and Dissolved Oxygen instantaneously at point of sample collection while Wagtech methods used to measure nutrients. TSS was measured using gravimetric method. Within the lake, samples were taken at for horizontal transects of 10 metres (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 m, 1.0 m and 1.5 m from water surface using a hand pump with graduated delivery pipe. The aim of this research is to characterize non point pollutants and their dispersion in Lake Victoria. The criterion to be maximized is the *R-squared* (R^2) value, which is expressed in percent. The results generally show runoff during wet season increases the concentrations of Ammonia, Phosphorus, Nitrites and Nitrates and the associated dispersion is influenced by wind speed and direction, wave speed and direction. Furthermore, it was also noted that nutrient concentrations decrease as one moves deeper from the shores into the lake due to dilution.

Keywords: Control applications in environmental processes, Batch process modeling and control, water quality, nutrients, Lake Victoria

2.2 Sample collection and analysis

Two rain (wet) seasons in a year were used for data collection and one dry season was used for comparative purpose on the lake pollution levels between dry and rain season. 68 samples for each rain season and 64 samples for dry season were collected and analyzed for nutrients including Ammonia, Nitrite, Nitrates and Phosphates. One way ANOVA test was performed using SPSS Version 16 to establish any variability in the data collected both horizontally from shore into the lake and vertically downwards from water surface for both dry and rain 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. 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 within less than 2 hours for lab analysis which include nutrients. Portable meters were used to measure pH, EC, TDS, T and DO instantaneously at point of sample collection while Wagtech methods used to measure Ammonia, Nitrite, Nitrate and Phosphate. TSS was measured using gravimetric method. Meanwhile within the lake samples were taken at for horizontal transects of 10 metres (m) interval over a distance of 50 m starting from the shore where surface runoff was released. For the same sampling points within the lake, samples were drawn at vertical distances of 0.5 m, 1.0 m and 1.5 m from water surface using a hand pump with graduated delivery pipe so as to take samples at the required vertical depth.

2.3 Optimization Criterion

The criterion to be maximized is the *R-squared* (R^2) value, which is often expressed

in percent as shown in Equations (1). The values obtained from this criterion in this work reflect the percentage of output variation explained by the model.

$$R^2 = 100 \cdot \left(1 - \frac{\sum_{t=1}^N (y(t) - y_h(t))^2}{\sum_{t=1}^N (y(t) - \text{mean}(y(t)))^2} \right)$$

With $y(t)$ the measured output at discrete time t and $y_h(t)$ the model output at discrete time t . Both performance indexes are used to evaluate the adequacy of the model.

3. RESULTS AND DISCUSSIONS

3.1 Physico-Chemical variables within Lake Victoria

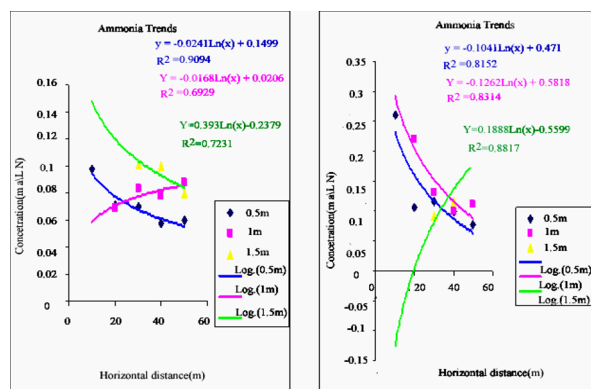
Table 1: Spatial average Concentrations \pm SD physico-chemical parameter concentrations within Lake Victoria over two rain seasons and two dry seasons.

Parameter	Within Lake Victoria	
	Rain season	Dry season
TDS (mg/l)	157.7 \pm 6.40 - 62.9 \pm 5.64	170.0 \pm 1.80 - 40.8 \pm 1.47
TSS (mg/l)	32.6 \pm 2.04 - 2 \pm 1.77	0.00
EC (μ S/cm)	313 \pm 64.02 - 103.9 \pm 22.42	368.6 \pm 23.9 - 91.2 \pm 28.60
pH	6.63 \pm 0.46 - 7.69 \pm 0.43	7.02 \pm 0.72 - 8.98 \pm 0.69
T ($^{\circ}$ C)	24.32 \pm 1.33 - 25.3 \pm 1.95	25.9 \pm 1.02 - 26.7 \pm 1.07

The Dissolved Oxygen (DO) level in surface runoff was 16.70 mg/l. In the Lake water, its value ranged from 6.20 mg/l to 9.92 mg/l, while in dry season the level ranged from 3.6 mg/l at the shore, to 7.60 mg/l at the 50 m mark, for vertical depth of 0.5 m. The low concentration of DO close to the shore can be attributed to high discharge of organic waste

emanating from human activities. This increases biological activity, and consumes oxygen in the process. There is slight drop in DO concentration from the water surface vertically downwards with an exponential decrease from point of surface runoff discharge into the lake. Overall its concentrations both in dry and rain seasons within the lake were still higher than the recommended minimum of 5.0 mg/l. TDS in runoff was 300 mg/l, lower than the maximum recommended value of 500 mg/l. In the Lake water, its average value ranges from 157.70 mg/l at the shore to 64.70 mg/l at the 50 m mark. In the dry season, its value ranged between 170mg/l and 40.80 mg/l and showed a slight decrease from water surface vertically downwards and an exponential decrease from shore into the Lake. There was slight increase in concentration in the vertical direction for rain season. The concentrations in rain seasons were still higher than the values for dry seasons. EC in runoff was 431.50 $\mu\text{S/cm}$, still lower than the maximum recommended value of between (1000-2000 $\mu\text{S/cm}$). The concentration values ranged from 313.00 $\mu\text{S/cm}$, at the shore, to 105.83 $\mu\text{S/cm}$ at 50 m mark, and 105.31 $\mu\text{S/cm}$ at vertical depth of 1.5 m at the same 50 m mark. There was an increase in the EC value concentrations during rain seasons than in dry season as summarized in Table 1 but in the horizontal direction, an exponential decrease was observed. This is possibly because runoff carries a lot of sediments loaded with ions that conduct an electric current. TSS concentration decreased from shore into the lake but in the vertical direction, the concentration increased from water surface inwards into the lake. Close to the lake bottom at 1.5 m vertical depth, the concentration was almost constant as shown in Fig 4. The increase in the vertical direction can be attributed to terminal velocity of heavier particles trying to settle to the bottom. In this process, lighter particles are left close

to water surface while heavier ones sink to the bottom. In horizontal direction, the reduction in concentration is due to dilution as the suspended solids traverses the horizontal distances. The pH of runoff was slightly alkaline (7.0). At the shore, the pH was 6.6 and increased to 7.1 at the 50 m mark and depth of 0.5 m. For the same points in dry seasons, at the shore the pH was 7.0 and increased to 9.0 at the 50 m. There was no clearly marked variation of pH in the vertical direction. The values in the dry season were found to be higher than during the rain seasons, and in the range of 6.8 to 8.4. This was an indication of possible biological impairment of the Lake functioning and its suitability for other purposes. The runoff temperature was 24.4°C and varied from 24.6°C at shore to 25.3°C at 50 m horizontal distance. In the vertical direction at 1.5 m, the temperature was 24.6 °C. The water temperature in dry season was higher than during rainy season.



(a) (b)
Fig 2: Variation of Ammonia at vertical depth of 0.5 m, 1.0 m and 1.5 m during (a) dry season and (b) wet season.

3.3 Nutrient dispersion within the Lake

3.3.1 Variation of Ammonia Concentration

At a depth of 0.5 m and horizontal distance of 10 m from the lake shore, ammonia concentration is highest during the dry season. At depths 0.5 and 1 m, for every unit

logarithmic increase in horizontal distance there is a 0.10 mg/l and 0.13 mg/l decrease in ammonia concentration, respectively. At a depth of 1.5 m, for every unit logarithmic increase in horizontal distance, there is a 0.19 mg/L N increase in ammonia concentration. As shown in Fig 2(a), R^2 values at vertical distances of 0.5 m, 1 m and 1.5 m are 81.52 %, 83.14% and 88.17%, respectively. During the wet season at vertical depths 0.5 m and 1.5m, every unit logarithmic increase in horizontal distance shows a 0.02 mg/l and 0.04 mg/l N decrease in ammonia concentration respectively. Exceptionally at a vertical depth of 1 m, every unit logarithmic increase in horizontal distance shows a 0.02 mg/L increase in ammonia concentration. As shown in Fig 2(b), R^2 values noted at vertical distances of 0.5 m, 1 m and 1.5 m are 90.4 %, 69.29% and 72.31%, respectively. Generally R^2 values for both seasons are above 50% which means that ammonia readily disperses to wide distances from the point of entry into the water body. However, on the whole, R^2 values are greater during dry days than wet days which imply that ammonia disperses more during dry days.

3.3.2 Variation of Nitrite Concentration

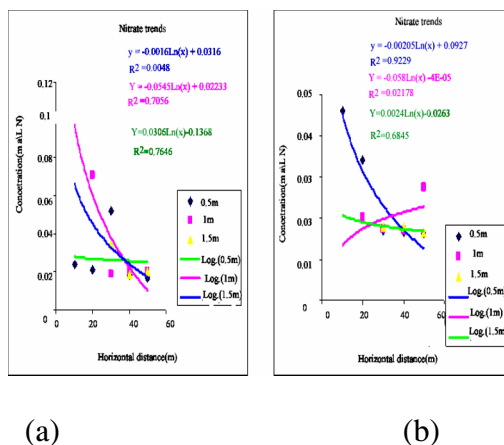


Fig 3: Variation of Nitrites at vertical depth of 0.5 m, 1.0 m and 1.5 m during (a) dry season and (b) wet season.

Unit logarithmic increase in horizontal distance decreases nitrite concentration at 0.5 m, 1 m and 1.5 m by 0.01 mg/l, 0.05 mg/l and 0.03 mg/L during dry period. As depicted in Fig 3(a), R^2 values at 0.5 m, 1 m, and 1.5 m are 0.048%, 70.56% and 76.46%. These values show that there is a significant nitrite concentration at vertical depth of 1.5 m. Unit logarithmic increase in horizontal distance resulting in decrease in nitrite concentration by 0.02 mg/l and 0.01 mg/L N at vertical depth of 0.5 m and 1.5 m respectively but increases at a depth of 1 m by 0.01 mg/L. As seen in Fig 3(b), R^2 values at 0.5 m, 1 m and 1.5 m are 92.29%, 21.78% and 68.45%, respectively for wet season.

3.3.3 Variation of Nitrate Concentration

Nitrate concentration decreases by 0.02 mg/l, 0.02 mg/L at 0.5 m and 1 m respectively with unit logarithmic increase in horizontal distance but increases by 0.36 mg/L N at a vertical depth of 1.5 m. The R^2 during dry season at 0.5m, 1m and 1.5 m are 64.71%, 25.29% and 73.49% respectively as shown in Figure 4(a). Nitrates decrease by 0.02 mg/l and 0.02 mg/L at vertical depth of 0.5 m and 1.5 m, respectively. At 1 m the concentration increases by 0.09 mg/L N for unit logarithmic increase in horizontal distance while R^2 values are 66.34%, 34.48% and 98.91% for 0.5 m, 1 m and 1.5 m, respectively as depicted in Figure 4(b).

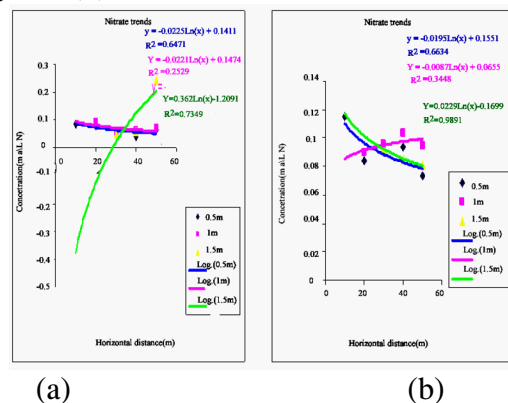


Fig 4: Variation of Nitrates at vertical depth of 0.5 m, 1.0 m and 1.5 m during (a) dry season and (b) wet season.

3.3.4 Variation of Phosphate Concentration

As depicted in Figure 5(a), R^2 values at 0.5 m, 1 m and 1.5 m are 10.44%, 0.28% and 75.31% respectively during dry season. Phosphate concentration decreased by 0.02, 0.01 mg/L N at a depth of 0.5 m and 1 m respectively but increased at 1.5 m by 0.18 mg/L for unit logarithmic increase in horizontal distance. On the other hand, R^2 values during wet season are 72.32%, 0.47% and 8.62% for 0.5 m, 1 m and 1.5 m, respectively as can be seen in Fig 5(b).

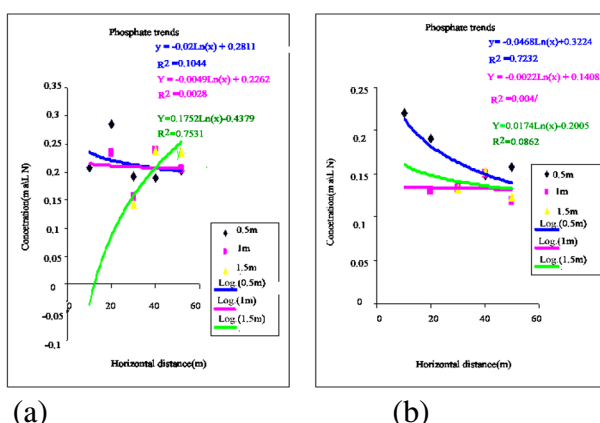


Fig 5: Variation of Phosphates at vertical depth of 0.5 m, 1.0 m and 1.5 m during (a) dry season and (b) wet season.

4. CONCLUSIONS

In summary, the results in this study show that the runoff during wet season increases the concentrations of all nutrients in turn affect water quality. The lake is a complex system with so many factors (such as wind speed and direction, wave speed and direction) determining the concentration and dispersion of pollutants. Generally nutrient concentrations decrease as one moves deeper

from the shores into the lake due to dilution. It was also noted that areas near the shores accumulated a lot of silt that after some time water sampling was not possible at a vertical depth below 0.5 m and horizontal distance of 10 m from the shore. The decrease in ammonia with depth may be attributed to ammonia being converted to nitrite and then nitrate in a series of reaction (nitrogen cycle) which is utilised by algae for their growth. From the results obtained they show that the level of some the nitrogen containing compounds like ammonia is higher during dry season than the levels in wet season may be due to the decaying plants and the strong effect of wave action that disperse the pollutants.

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