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*Full Length Research Paper*

# 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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**The aim of this research is to characterize non point pollutants and their dispersion in Lake Victoria. 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 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, electrical conductivity (EC) total dissolved solids, temperature and dissolved oxygen instantaneously at point of sample collection while Wagtech methods was used to measure nutrients. Total suspended solids (TSS) were measured using gravimetric method. 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. The criterion to be maximized is the R-squared ($R^2$) value, which is expressed in percent. The values obtained from $R^2$ in this study reflect the percentage of output (that is, concentrations of ammonia, phosphorus, nitrates and nitrites) variation explained by the model. Optimization of $R^2$ value is important to avoid model over fitting during model identification. Over fitted models produce poor fits during model validation. The results generally show runoff during wet season increases the concentrations of ammonia, phosphorus, nitrites and nitrates. Ammonia varied from 0.1 to 0.19 mg/L, phosphorus from 0.01 to 0.18 mg/L, nitrites from 0.01 to 0.05 mg/L and nitrates 0.02 to 0.36 mg/L. Field measurements confirmed that nutrient concentrations decrease as one move deeper from the shores into the lake due to dilution.**

**Key words:** Control applications in environmental processes, batch process modeling and control, water quality, nutrients, Lake Victoria.

## INTRODUCTION

Lake Victoria is the second largest fresh-water lake, with 17 tributaries (Nicholson, 1998). It is also the source of the Nile which is its only outflow exiting at Jinja, in Uganda. Lake Victoria has a total surface area of 68,870 km$^2$ and a total catchment area of 180,950 km$^2$ (Machiwa, 2008). The lake water is shared by Kenya, Tanzania and Uganda but the lake basin covers parts of Kenya (21.5%), Tanzania (44%), Uganda (15.9%), Rwanda (11.4%) and Burundi (7.2%). Additionally, the catchment of the principal affluent river, the Kagera, runs through the countries of Rwanda and Burundi. The Nile river outflow is an extremely important freshwater resource for the Nile Basin countries of Uganda, Sudan, and Egypt (Odada et al., 2004). Lake Victoria supports over 30 million people in the three East African countries (Banadda et al., 2009). The population is growing rapidly and heavily concentrated near the lake (Cohen et al., 1996; Makundi, 2001; Campbell et al., 2004)) with a population growth rate of the riparian municipalities of the three countries at above 6% per annum, among the highest in the world. The lake basin nevertheless provides resources for the livelihoods of the basin

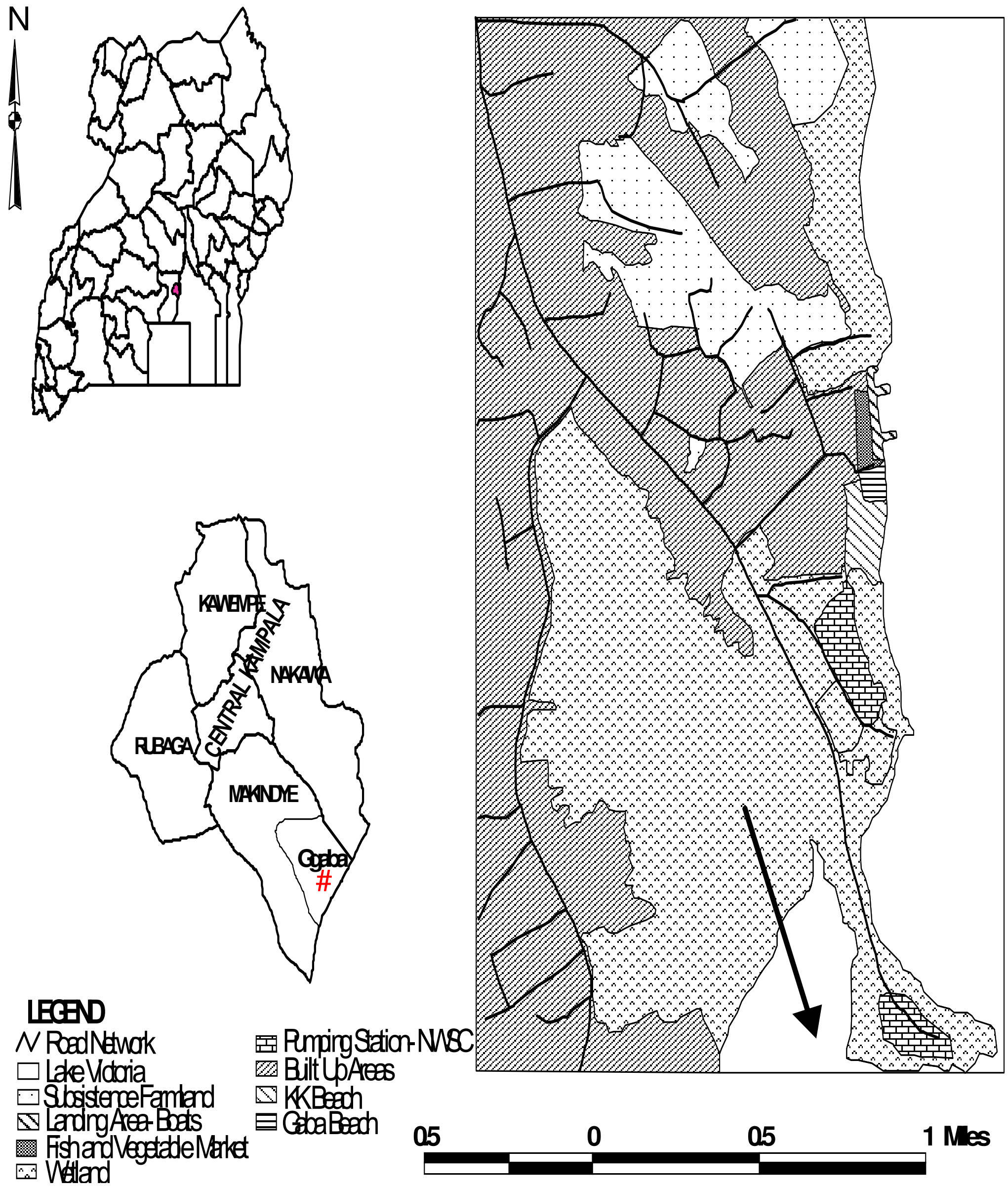


**Figure 1.** Land use activities in Gaba, Kampala (Uganda).

population, with the lake used as a source of food, energy, drinking and irrigation water, shelter, transport (Kayombo and Jorgensen, 2006; Matagi, 2002) and as repository for human and industrial wastes. For 70% of the population in the catchment area of the three riparian countries is engaged in agricultural production mostly as small-scale farmers, for crops such as sugar, tea, coffee, maize, cotton, horticultural products and livestock keeping (Kayombo and Jorgensen, 2006). The near annual flash floods on the Lake Victoria plains have been linked to such forces emanating from point and non-point processes (Gichuki, 2003). Stimulated by these nutrients, phytoplankton growth in the lake waters has been phenomenal and the once clear lake waters are now cloudy near the surface and sterile on the bottom due to eutrophication-induced deep-water oxygen loss. This has also yielded algal blooms in the lake waters. Therefore the need to understand the dispersion of pollutants cannot be overemphasized. This research aims at characterizing non point pollutants and their dispersion in Lake Victoria.

## MATERIALS AND METHODS

### Study area

The study was carried out at Gaba landing site located in Makindye division, Kampala (Uganda) as shown in Figure 1. It is a landing

**Table 1.** Spatial average concentrations ±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±6.40 - 62.9±5.64 | 170.0±1.80 - 40.8±1.47 |
| TSS (mg/l) | 32.6±2.04 - 2±1.77 | 0.00 |
| EC (µS/cm) | 313±64.02 - 103.9±22.42 | 368.6±23.9 - 91.2± 28.60 |
| pH | 6.63±0.46 - 7.69±0.43 | 7.02±0.72 - 8.98±0.69 |
| T (°C) | 24.32±1.33 - 25.3±1.95 | 25.9±1.02 - 26.7±1.07 |

site for fishing boats, and National Water and Sewerage Corporation pumping station which supplies water to Kampala City areas. The choice of the site for implementation of the study is based on the fact that there are high economic activities (e.g., fishing, fish processing) and its being a strategic concentration point for runoff originating from inland sources.

### 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 at 7°C and transported within less than 2 h 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 was used to measure ammonia, nitrite, nitrate and phosphate. TSS was measured using gravimetric method. Meanwhile, within the lake, samples were taken at horizontal transects of 10 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, 1.0 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.

### Optimization criterion

The criterion to be maximized is the R-squared ($R^2$) value, is often expressed in percent as shown in Equations (1). Optimization of $R^2$ value is important to avoid model over fitting during model identification. Over fitted models produce poor fits during model validation. The values obtained from this criterion in this work reflect the percentage of output variation explained by the model.

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

With y(t), the measured output (that is, concentrations of ammonia, phosphorus, nitrates and nitrites) at discrete time t and $y_h(t)$ the model output of ammonia, phosphorus, nitrates and nitrites at discrete time, t. The performance index is used to evaluate the adequacy of the model.

## RESULTS AND DISCUSSION

### Physico-chemical variables within Lake Victoria

The dissolved oxygen (DO) level in surface runoff was 16.70 mg/L. In the Lake water, its value ranged from 6.20 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 ranged 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 170 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 µS/cm, still lower than the maximum recommended value of between (1000 to 2000 µS/cm). The concentration values ranged from 313.00 µS/cm, at the shore, to 105.83 µS/cm at 50 m mark, and 105.31 µS/cm at vertical depth of 1.5 m at the same 50 m mark. The EC value concentrations were higher during rain seasons as compared to 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 contribute

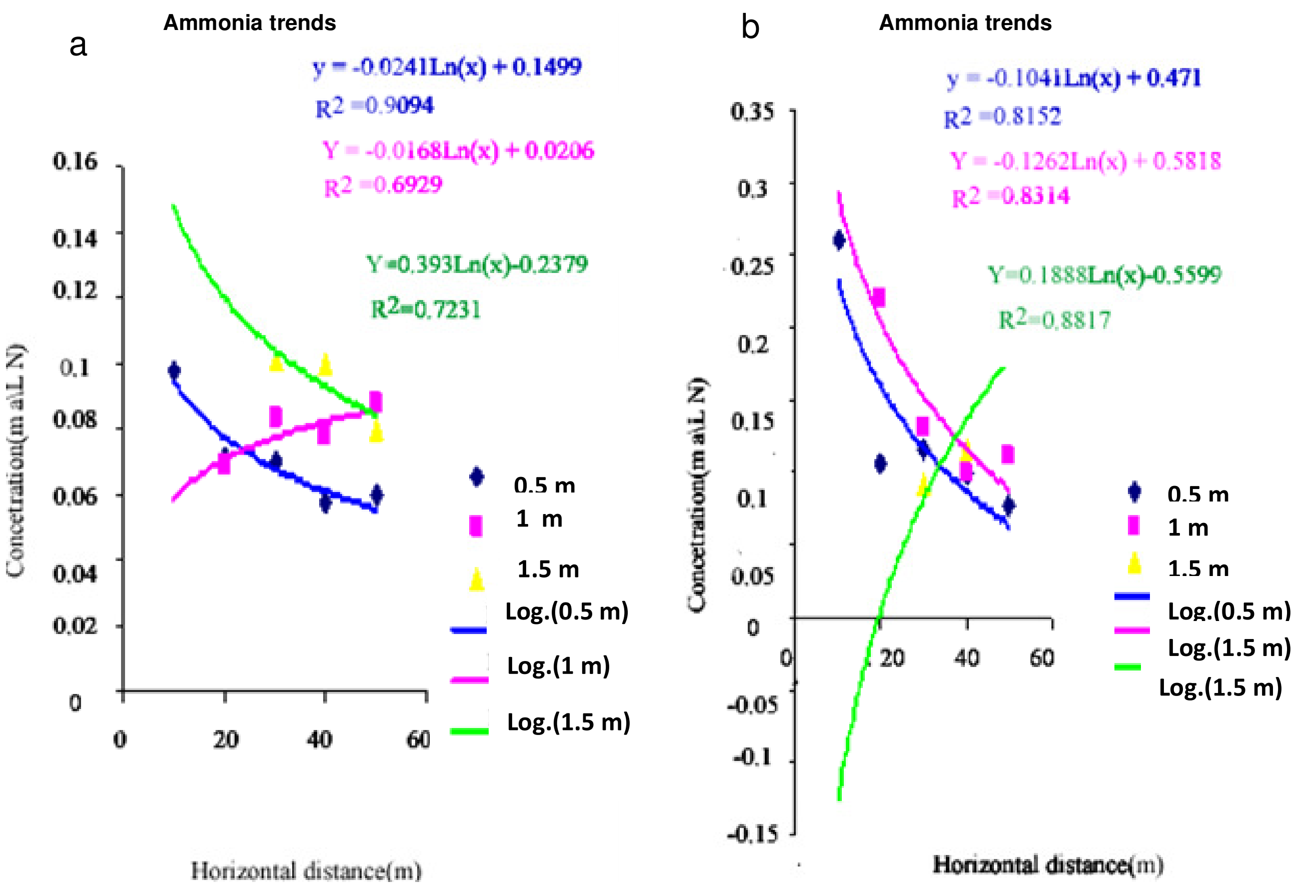


**Figure 2.** Variation of ammonia at vertical depth of 0.5, 1.0 and 1.5 m during (a) dry season and (b) wet season.

to the EC values. 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 bottom of the lake at 1.5 m vertical depth, the concentration was almost constant as shown in Figure 4. The increase in the vertical direction can be attributed to terminal velocity of heavier particles trying to settle to the bottom of the lake. 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 traverse 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℃ and varied from 24.6℃ at shore to 25.3℃ at 50 m horizontal distance. In the vertical direction at 1.5 m, the temperature was 24.6℃. The water temperature in dry season was higher than during rainy season.

## Nutrient dispersion within the Lake

### *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 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 Figure 2a, $R^2$ values at vertical distances of 0.5, 1 and 1.5 m are 81.52, 83.14 and 88.17%, respectively. During the wet season, at vertical depths 0.5 and 1.5 m, every unit logarithmic increase in horizontal distance shows a 0.02 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 Figure 2b, $R^2$ values noted at vertical distances of 0.5, 1 and 1.5 m are 90.4, 69.29 and

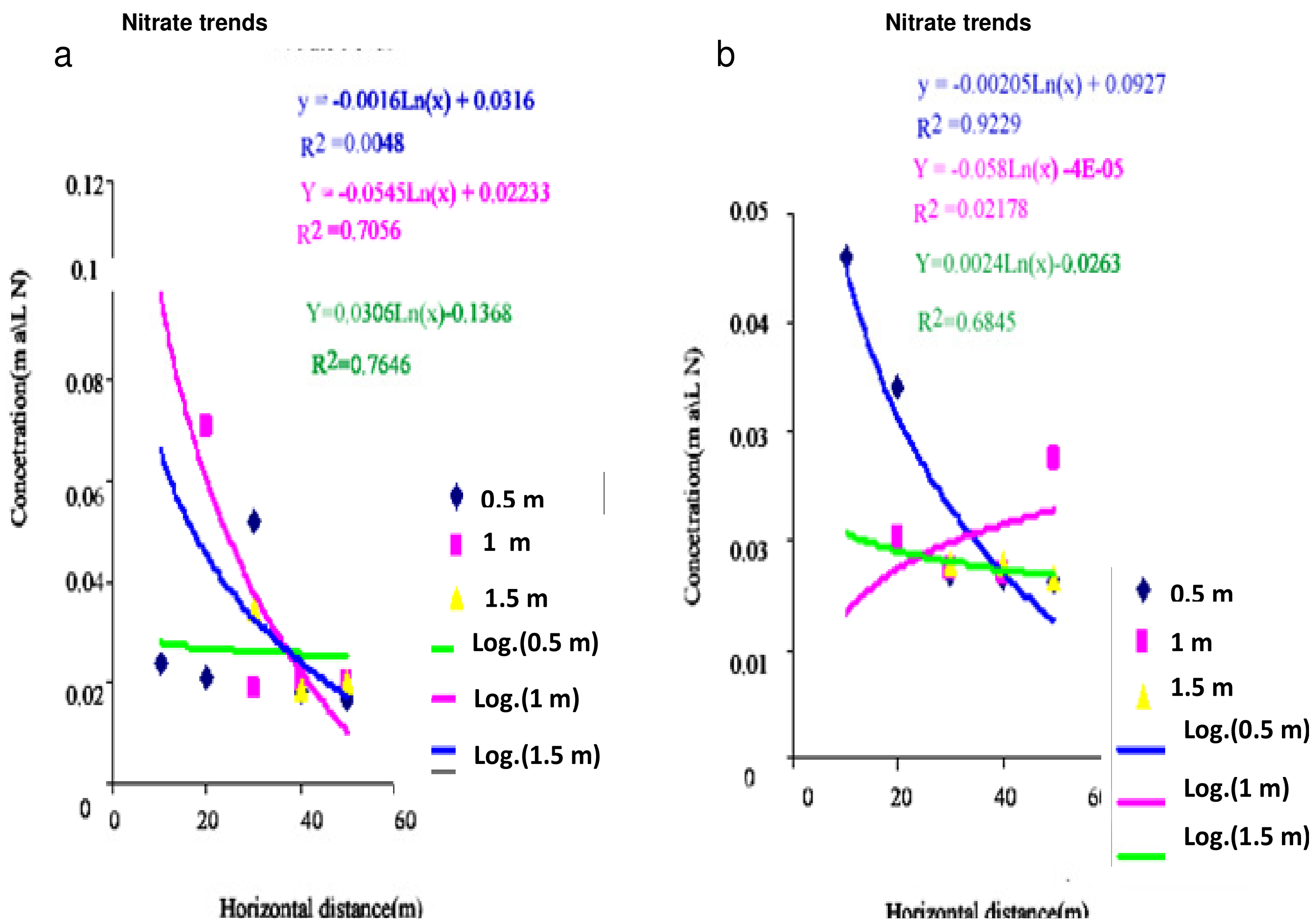


**Figure 3.** Variation of Nitrites at vertical depth of 0.5, 1.0 and 1.5 m during (a) dry season and (b) wet season.

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. $R^2$ values are greater during dry days than wet days which imply that ammonia disperses more during dry days.

### *Variation of nitrite concentration*

Unit logarithmic increase in horizontal distance decreases nitrite concentration at 0.5, 1 and 1.5 m by 0.01, 0.05 and 0.03 mg/L during dry period. As depicted in Figure 3a, $R^2$ values at 0.5, 1, 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 and 0.01 mg/L N at vertical depth of 0.5 and 1.5 m, respectively but increases at a depth of 1 m by 0.01 mg/L. As seen in Figure 3b, $R^2$ values at 0.5, 1 and 1.5 m are 92.29, 21.78 and 68.45%, respectively for wet season.

### *Variation of nitrate concentration*

Nitrate concentration decreases by 0.02 and 0.02 mg/L at 0.5 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 0.5, 1 and 1.5 m are 64.71, 25.29 and 73.49%, respectively as shown in Figure 4a. Nitrates decrease by 0.02 and 0.02 mg/L at vertical depth of 0.5 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, 1 and 1.5 m, respectively as depicted in Figure 4b.

### *Variation of phosphate concentration*

As depicted in Figure 5a, $R^2$ values at 0.5, 1 and 1.5 m are 10.44, 0.28 and 75.31%, respectively during dry season. Phosphate concentration decreased by 0.02 and 0.01 mg/L N at a depth of 0.5 and 1 m respectively but increased at 1.5 m by 0.18 mg/L for unit logarithmic

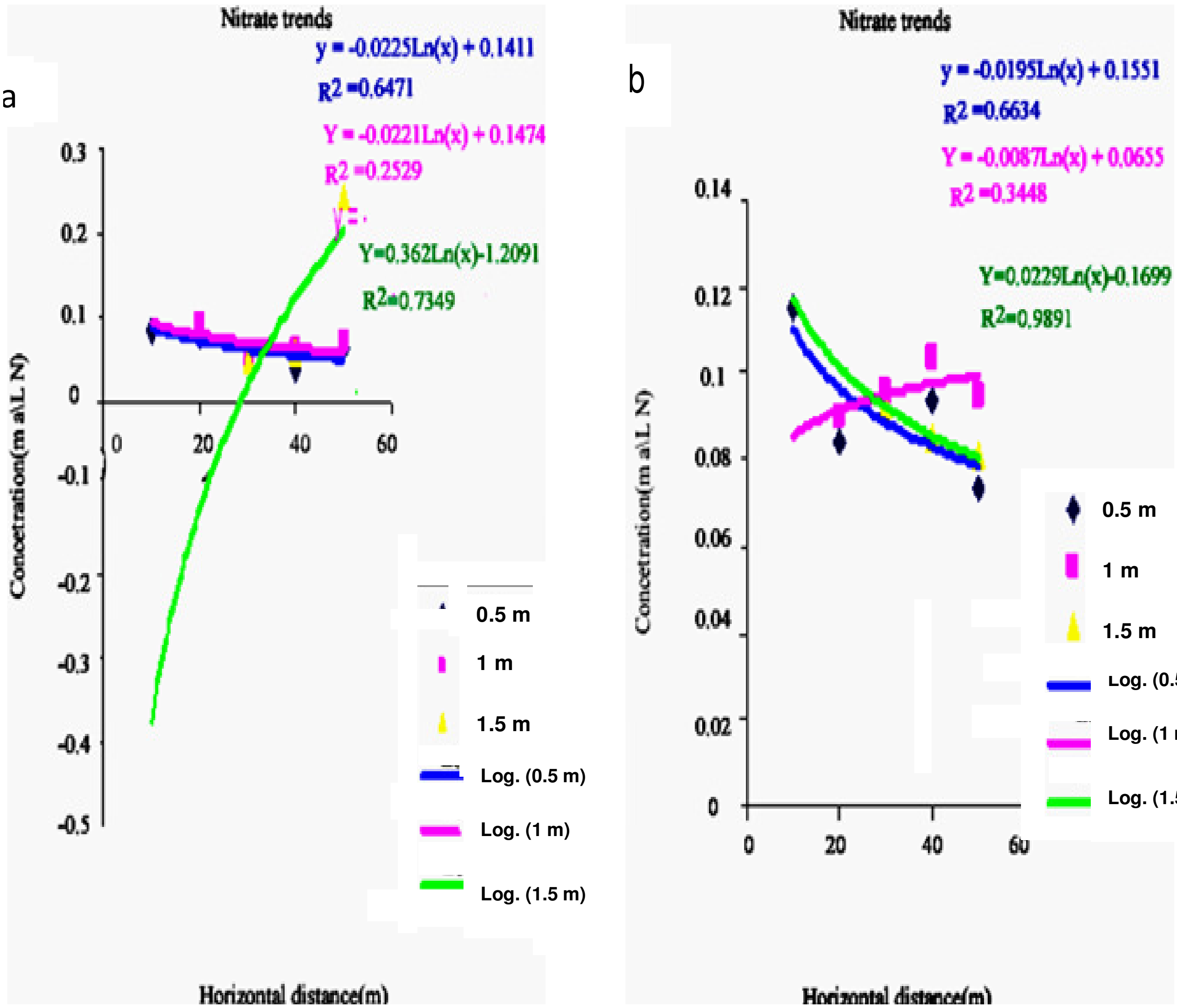


**Figure 4.** Variation of nitrates at vertical depth of 0.5, 1.0 and 1.5 m during (a) dry season and (b) wet season.

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, 1 and 1.5 m, respectively as can be seen in Figure 5b.

## Conclusion

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 move 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, it is shown that the level of some of 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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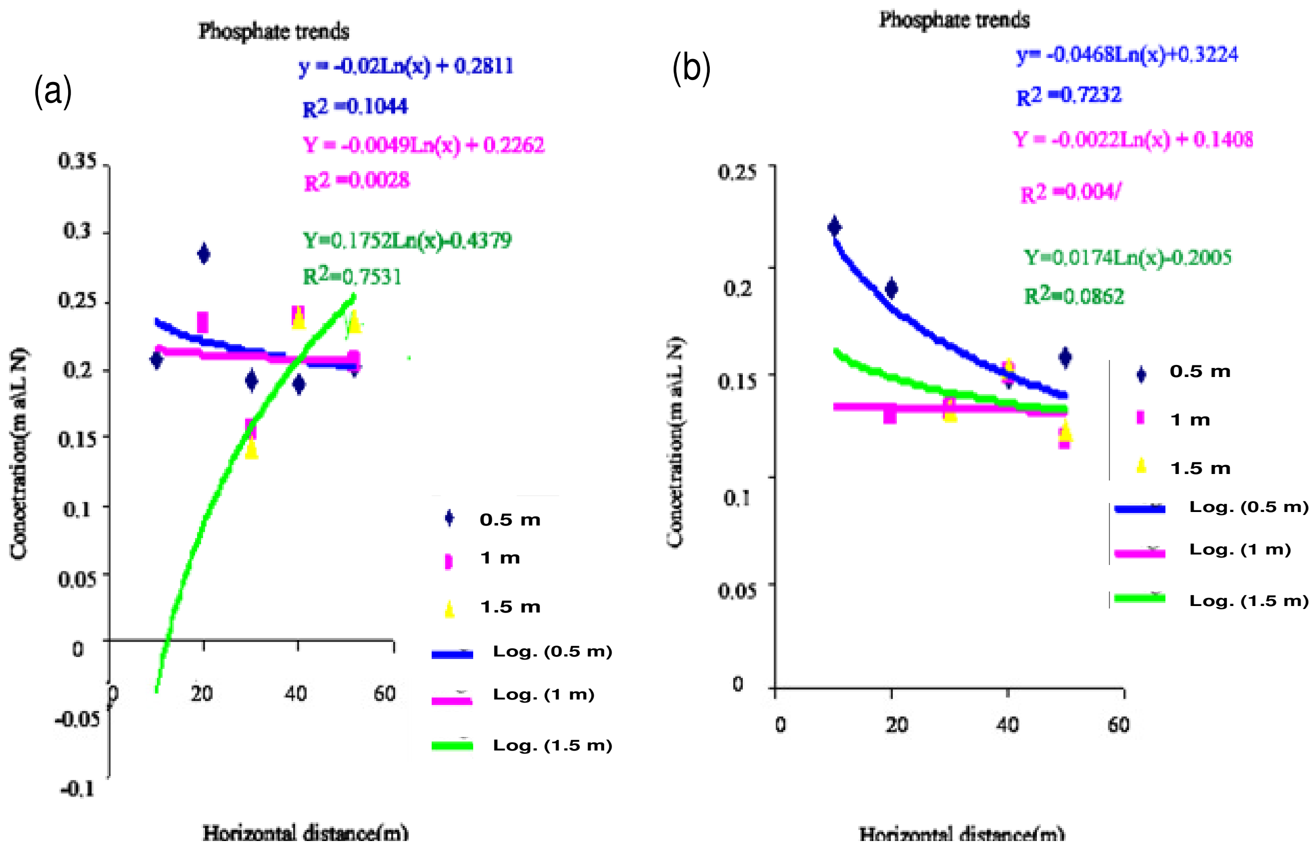


**Figure 5.** Variation of phosphates at vertical depth of 0.5, 1.0 and 1.5 m during (a) dry season and (b) wet season.

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