



*Final Project Report for 2006 START/ PACOM
African Global Change Research Grants*

**Title: MITIGATING PHOSPHORUS LOAD INTO
LAKE VICTORIA CATCHMENTS**

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Abstract

This project was carried out to identify the main sources of phosphorus load into the Kenyan part of Lake Victoria drainage basin. Water, soil and sediments were sampled in four different seasons representing the wet, dry and short rain seasons experienced in the Lake Victoria catchments. Sampling points covered lakeshores, river mouths and effluent discharge points and the parameters analysed included total reactive phosphates, total hydrolysable phosphates, total phosphate, sediment exchangeable phosphates, sediment bio-available phosphate and soil available phosphates. Soils from the catchments were found to contain ten to 100 times higher concentration compared to sediments and water samples. Water from both the rivers and the lake were found to contain phosphate levels much higher than the recommended guidelines for aquatic life indicating influence of anthropogenic sources. The seasonal average of total phosphate in the water were 4.61, 3.43, 2.45 and 2.30 mg/l for wet, short rain and dry seasons 1 and 2 respectively, whereas the total reactive phosphates had means of 2.22, 2.08, 1.12 and 1.61 mg/l in the same seasons. Sediment bio-available phosphates were higher than exchangeable phosphates with the highest mean concentrations of 24.45 and 8.22 mg/kg obtained during the dry season, whereas average of soil available phosphorus ranged between 639 and 1076 mg/kg. Pearson correlation analysis of the data indicated a strong positive correlation between the levels detected in the water for all the seasons implying increasing accumulation of the nutrients in the drainage basin.

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Table of contents

Table of contents	iv
List of figures.....	vi
Introduction.....	1
General objective	3
Specific objectives of the study	4
Methodology.....	4
1) Phosphorus in water samples.....	4
2) Soil available phosphorus	5
3) Sediment exchangeable phosphorus.....	6
4) Sediment bio-available phosphorus	6
5) Statistical analysis.....	6
Results and discussion	7
Speciation of phosphates in water from Lake Victoria catchments.....	7
Phosphate levels in water during wet season.....	7
Total reactive Phosphates in water during wet season.....	7
Total hydrolysable phosphates in water during wet season	7
Total phosphates in water during wet season	8
Phosphate levels in water during dry season.....	8
Total reactive Phosphates in water during dry season.....	8
Total hydrolysable phosphates in water during dry season.....	8
Total phosphates in water during dry season.....	8
Phosphate levels in water during short rain season.....	8
Total reactive Phosphates in water during short season	8
Total hydrolysable phosphates in water during short rain season	9
Total phosphates in water during short rain season	9
Phosphate levels in water during dry season2.....	9
Total reactive Phosphates in water during dry season2.....	9
Total hydrolysable phosphates in water during dry season2.....	9
Total phosphates in water during dry season2	10
Seasonal variations of phosphates in water samples	10
Phosphate levels in sediments collected from Lake Victoria drainage Basin.....	10
Sediment exchangeable phosphate in Lake Victoria drainage basin	11
Sediment bio-available phosphate in Lake Victoria drainage basin	11
Soil available phosphate in Lake Victoria drainage basin	12

Conclusion.....	14
Recommendations.....	14
Acknowledgement.....	14
References	16

List of figures

Figure 1: Map of the Kenyan part of Lake Victoria Drainage Basin	18
Figure 2: Phosphates in water during wet season	19
Figure 3: Phosphates in water during dry season 1	19
Figure 4: Phosphates in water during short rain season.....	20
Figure 5: Phosphates in water during dry season2	20
Figure 7: Seasonal variations of hydrolysable phosphates in water	21
Figure 8: Seasonal variations of total phosphates in water	22
Figure 9: Seasonal variations of exchangeable phosphates in.....	22
sediments from Lake Victoria catchments	22
Figure 10: Seasonal variations of sediments bio-available	23
phosphates in Lake Victoria catchments	23
Figure 11: Seasonal variation of available phosphates in soils.....	23
fromLake Victoria catchments	23

List of Tables

Table 1: GPS Locations of the sampling points.....	24
Table 2: Pearson Correlation analysis for phosphates in water ...	25

Introduction

Lake Victoria is the world's second largest freshwater lake by surface area, second to Lake Superior. It is shared among three riparian countries: Tanzania, Kenya and Uganda and stretches 412 km from north to south between latitudes 0°30'N and 3°12'S, and 355 km from west to east between longitudes 31°37'E and 34°53'E. The lake is situated at an altitude of 1,134 m above sea level, covers a total volume of 2,760 km³, and has an average and maximum depths of 40 m and 80 m respectively. The lake covers a total surface area of 68,800 km² and has catchments total area of 193,000 km². It contains numerous islands and a highly indented shoreline, which is estimated to be about 3460 km long. The flushing time (volume/average outflow) of the lake is 138 years whereas the residence time is 21 years. Lake Victoria draws 20 % of its water from the Kagera, Mara, Simiyu, Gurumeti, Yala, Nyando, Migori, and Sondu-Miriu rivers (Appendix Fig. 1) whereas the remaining 80% is from direct rainfall (LVEMP, 2003). Earlier studies attributed 86% of total water input to rainfall, whereas evaporative losses accounted for 80% of the water leaving the lake (Okonga 2001; COWI 2002).

The main issues in the Lake Victoria Basin include water quality and quantity concerns, water supply, availability and accessibility, low technological investment, exploration and assessment of fresh water potential, rampant waterborne diseases and trans-boundary water management concerns. Currently the lake is the final destination of factory effluents, oils and grease, and sewage from the urban centres as well as oil spillage from the extensive transport activities within the lake (UNEP, 2005). Other major challenges of concern include the unsustainable population pressure (which is currently estimated at 30 million people), poorly planned industrialization, water as source of energy which leads to drainage of large volumes of water to generate hydroelectric power, outdated cultural practices such as superstitions towards the use of pit latrines, unsustainable agricultural practices, loss of freshwater biodiversity, overexploitation of the fisheries resources and introduction of aquatic invasive alien species.

Deforestation coupled with poor agricultural practices have led to an accelerated rate of sediment transport and sedimentation in aquatic environments around the Lake. The high sedimentation rate has been contributed mainly to the Kenyan rivers and the Kagera River (UNEP, 2005). The quality of Lake Victoria's water is further exacerbated by large discharges of untreated sewer and chemical wastes from urban centres as well as micro-bacterial and nutrient runoff from pastoral and agricultural land, suburb-lands, forests and municipal slums. Pesticides residues from agricultural land have also been detected in some studies (Getenga et al., 2004; Henry and Kishimba, 2000) and could be contributing to the loss of biodiversity.

Eutrophication is high in Lake Victoria and has been attributed primarily to the landscape disturbance threatening fresh water ecosystems of the basin. Nutrient loads to the lake are according to one study (LVEMP 2002, Report) associated mainly with atmospheric deposition and land runoff from agricultural fields into the rivers draining into the Lake. These two account for about 90 % of the phosphorus and 94 % of the nitrogen inputs. These activities have been reported to affect water clarity and dissolved oxygen levels, as well as increased algal blooms since 1960s (Mugiddle, 1993). The use of agrochemicals is currently increasing in the basin in areas where large scale farming of coffee, tea, cotton, rice, maize, sugar and tobacco is practiced.

Due to eutrophication, nearly all the bottom of Lake Victoria has been reported to experience prolonged anoxia for several months of the year, compared to the 1960's when anoxia was localized and sporadic (Talling, 1965 and 1966; Hecky, 1993; LVEMP 2001, 2002, 2003). Algal concentrations are currently three to fivefold greater on the surface water today than in the 1960's reflecting higher rates of photosynthesis (Mugiddle, 1993).

A number of research activities are going on to establish the actual contribution of atmospheric deposition of phosphorus in the equatorial Africa. However, the actual sources and amounts of phosphorus load from industrial and agricultural discharges have not been properly delineated. The available data is based on research that only considered phosphorus load in the water column without the input from sediments phosphorus load.

Nitrogen and phosphorus are the two main nutrients associated with eutrophication of the water bodies. Of these two elements, phosphorus is the limiting factor, since nitrogen is highly abundant in the atmosphere and can be fixed by nitrifying bacteria present in aquatic systems. Phosphorus in rivers, lakes, and oceans occurs in three main forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Each compound contains phosphorus in a different chemical formula. Ortho forms are produced by natural processes and are found in sewage. Poly forms are used for treating boiler waters and in detergents manufacturing industries, and change to ortho form in water. Organic phosphates may result from the breakdown of organic pesticides that contain phosphates. They may exist in solution, as particles, loose fragments, or in the bodies of aquatic organisms.

The sources, dispersion, transport, and fate of phosphorus in the environment are highly complex because of the complexity of its forms and inter-conversions in the solid form. Inorganic phosphate levels in ocean waters and aerobic inland waters may be in the order of tens of micrograms of phosphorus per liter, whereas in anaerobic waters and sediments (or anaerobic bottom waters in lakes) they can reach hundreds of micrograms of phosphorus per liter.

High total phosphorus and nitrogen levels in conjunction with other necessary nutrients and favorable physical characteristics of aquatic environments can result in plant and algal blooms. After assimilation in plant and algal growth, microbial breakdown and other processes such as mineralization may transform organic and complexed phosphate forms through various steps into the readily available inorganic phosphate form. Processes such as runoff, stream-flow, and groundwater flow, transport most of the total phosphorus. Moreover, wind may also transport some components of total phosphorus around the landscape.

High phosphate concentrations in the aquatic systems stimulate the growth of plankton and aquatic plants that provide food for fish. This increased growth of planktons may cause an increase in the fish population and improve the overall water quality. However, as the excess of phosphate enters the waterway; algae and aquatic plants grow wildly, choke up the waterway, and use up large amounts of oxygen. This condition is known as eutrophication or over-fertilization of receiving waters. The rapid growth of aquatic vegetation causes death and decay of vegetation and other aquatic organisms because of the decrease in dissolved oxygen levels.

Previous studies conducted by LVEMP to establish the levels of nutrients in the lake gave critical values with nutrient loading from the urban areas amounting to be 6,955 t-BOD/y, 3028

t-Total-N/y and 2,686 t-Total P/y (LVEMP, 2001 and 2002,). However, this only included the pollution loading from the urban areas close to the lakeshore without consideration of the pollution loading originating from towns located far away from the lakeshore and which drain into Lake Victoria via streams and rivers. There is no doubt that rivers carry soil eroded from the catchments areas to the lake contributing to more turbid and shallow points that are currently observable at their outlets than other parts of the lake.

The LVEMP (2001 and 2002) estimated the nutrients input into the lake with atmospheric deposition contributing 102,000 t/y of Total-N and 24,000 t/y of Total-P. These values indicated that the atmospheric deposition is far the most significant contributor to the overall nutrient budget of the lake. Based on these results, the total atmospheric deposition (wet and dry deposition) contributes about 45% and 64% total nitrogen and total phosphorus loading, respectively. However, some local scientists have strongly disputed the figures attributed to atmospheric deposition. This is because municipal and industrial wastewater treatment plants (WWTPs) are known to be the major point sources of phosphorus in urban areas (Smith *et al.*, 1999). Waste disposal sites, construction sites, fertilizers and farmyards also make substantial contribution to the total phosphorus load (Hooda *et al.*, 2000; Morgan *et al.*, 2000; Sharpley *et al.*, 2000; Tunney *et al.*, 2000). However, all these have not been adequately evaluated.

The Challenges facing Lake Victoria are still enormous and more pertinent to the riparian communities and the region at large. Currently Lake Victoria is suffering from anoxia affecting fish and other aquatic organisms. The water hyacinth is not only a flourishing breeding habitat for the alternative host for the *Biomphalaria* snail causing schistosomiasis, but also a home for the vector mosquito for malaria, a haven for snakes, at the expense of commercial fish species. The eutrophication process is likely to accelerate production of toxins in the lake water. For instance, toxins produced by dinoflagellates such as *Pfiesteria* in marine environments and red tides in tropical waters are widely known to cause massive fish kills, leading to losses amounting to millions of dollars in seafood-related industries, human memory loss, paralysis, and even death (Silbergeld *et al.*, 2000). The bloom-forming species of cyanobacteria can also produce potent hepato-(liver) toxins termed microcystins known for poisoning domestic livestock, pets, wildlife, and susceptible humans. It is likely that human activities are contributing to the environmental change of the Lake Victoria ecosystem including deterioration of water quality, accumulation of toxic chemicals including pesticides and heavy metals, and increasing load of agrochemicals resulting into eutrophication and loss of biodiversity. Proper identification of the sources of phosphorus and the contribution of land use practices to the influx of phosphorus into the drainage system will help in controlling eutrophication of the lake ecosystem. This may also contribute to provision of good quality drinking water to the riparian communities and reduce the incidences of ill health arising from drinking contaminated water. This background contributed to the development of this project.

General objective

The general objective of this study was to identify the sources and sinks of phosphorus load into the Kenya part of Lake Victoria drainage basin and the impact of land use practices on water quality.

Specific objectives of the study

The specific objectives of this project were to identify sources and sinks of phosphorus load in the Kenyan catchments of Lake Victoria. To carry out background analysis of soils from the Lake Victoria catchments to determine phosphorus contents; and to establish the effects of land use practices and seasonal variations on phosphorus discharge into the Lake Victoria drainage system.

Methodology

The methodology followed involved development of the GIS maps of the catchments area to indicate the areas with different land use practices. The map developed was used to identify the areas for sampling as shown in the Attachment Figure 1 and table 1. Water, soil and sediments were sampled four times covering the wet season (June 2006), dry season1 (August 2006); short rain season (November 2006) and the dryseason2 (March 2007). Water samples were collected and transferred to pre-cleaned 2.5 l amber bottles and preserved with 40 mg/l mercuric chloride and stored in cooler boxes containing wet ice. Sediment samples were collected and transferred onto aluminium foil. The composite samples were divided into three replicates each approximately 500 g, packed in aluminium foil and wrapped in self-sealing polythene bags before being transferred into cooler boxes. Soil samples were collected from the farms near the river mounts, beaches and direct discharge points around the lakeshores. Once in the laboratory, sediment samples were transferred from the iceboxes and frozen in deep freezers at -20°C until time for extraction. Prior to extraction, the samples were brought to room temperature.

1) Phosphorus in water samples

Phosphorus occurs in natural water and wastewaters almost solely as phosphates. These are classified as orthophosphates, condensed phosphates (pyro-, meta- and other polyphosphates), and organically bound phosphates. They occur in solutions, in particles or detritus, or in bodies of aquatic organisms. These forms arise from a variety of sources. Small amounts of certain condensed phosphates are added to some water supplies during treatment, whereas larger amounts added to water during laundry or other cleaning processes because they form major constituents of many commercial cleaning preparations. Phosphates are used extensively in the treatment of boilers water. The orthophosphates are applied to agricultural land as fertilizers and may be carried to the surface water through storm runoff. Organic phosphates are formed mainly by biological processes and are contributed to sewage by body wastes and food residues. They may also be formed from orthophosphates in biological treatment processes or by the receiving water biota.

Phosphorus is essential to growth of organisms but can be the nutrient that limits the primary productivity of the body of the water. In most cases where phosphate is the growth limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage or certain industrial wastes may stimulate the growth of aquatic micro- and macro-organisms in nuisance quantities due to eutrophication. The phosphates that occur in the bottom sediments and biological sludge are precipitated into inorganic forms and incorporated into organic compounds.

Phosphate analysis in water samples in this report embodied two major steps: the conversion of the phosphorus into dissolved orthophosphates and calorimetric analysis of the dissolved phosphates. Three major classes of phosphates were analysed in the water samples: the reactive phosphates—the class of phosphate that responds to colorimetric test without preliminary hydrolysis or oxidative digestion of the sample and is mainly the measure of orthophosphates; hydrolysable phosphate—obtained after the acid hydrolysis at boiling water temperature to convert the dissolved and particulate condensed phosphates into dissolved orthophosphates; and thirdly the total phosphates—obtained after the oxidative destruction of all organically bound phosphates.

Total reactive phosphate in the samples was determined in triplicate per sampling point. To 50 ml samples 0.05 ml phenolphthalein indicator was added and the red color discharged by adding drops of 1:1 hydrochloric acid solution before diluting to 100 ml. Excess coloration was removed by shaking the sample with 200 mg activated carbon in 250 ml Erlenmeyer flask for 5 minutes and filtering through Whatman filter paper number 42. All the standards and the blanks were treated in the same manner to eliminate the interferences due to carbon. Color development in the sample was achieved by transferring 35 ml of the filtrate into 50 ml volumetric flask before adding 10 ml of Vanadate-molybdate reagent. The mixture was topped to the mark with distilled water and thoroughly mixed. Absorbance was measured after 15 at 470 nm using Shimadzu 1700, UV-Visible spectrophotometer for determination of total reactive phosphates.

Total hydrolysable phosphate in water samples was determined after preliminary hydrolysis with sulphuric acid solution. To 50 ml sample was added 0.05 ml phenolphthalein indicator and in case of the red colour observed, the red color of the samples was discharged with drops of 30 % sulphuric acid solution. To each sample 1 ml of 30 % sulphuric acid solution was added and diluted to 100ml. The samples were boiled for at least 90 minutes on a hot plate and the final digest reduced to 25 to 50 ml. To each digest, 6 N sodium hydroxide solution was added until faint pink color was observed. The faint pink colour was then discharged by adding 1:1 HCL and then proceeded to determination of the phosphate using vanadate-molybdate method as in the case of total reactive phosphate. Both the standards and blanks for determination of total hydrolysable phosphate were treated in the same manner as the samples.

Determination of the total phosphate in the water samples was conducted using the persulphate method. To 50 ml of the sample was added 0.05 ml phenolphthalein indicator and the red colour discharged by adding drops of 30 % sulphuric acid solution. The sample was then diluted to 100 ml and transferred into 250 ml Erlenmeyer flask. To each sample was added 0.5 g potassium persulphate and boiled on the hot plate for 90 minutes. The digest was treated with 6N sodium hydroxide solution until faint pink colour was observed and then discharged by adding drops of 1:1 hydrochloric acid solution before diluting to 100ml. 1 ml of 1:1 hydrochloric acid solution was added to all the samples and total phosphate determination conducted using the Vanado-molybdophosphoric acid calorimetric method.

2) Soil available phosphorus

Soil available phosphorus was determined following the BRAY 2 Method. The method involves combination of hydrochloric acid (HCL) and ammonium fluoride (NH₄F) to recover easily acid-soluble forms of phosphorus which are largely the calcium-phosphates and portions of aluminum

and iron bound phosphates. The NH_4F dissolves aluminium and iron phosphates by its complex formation with these metal ions in acid solution. Extraction was achieved by shaking 2.5 g of air-dried soil (previously sieved through 2 mm sieve) in 50 ml of 0.025 M HCl and 0.03 M NH_4F for 5 minutes. The sample was then filtered through double Whatman filter paper number 42. To 50 ml volumetric flask, 35 ml of the filtrate was added, then 10 ml of Vanadate-molybdate reagent and topped to the mark with distilled water. Absorbance measurements were taken after 15 minutes at 470 nm for available phosphate determination.

3) Sediment exchangeable phosphorus

Sediment exchangeable phosphorus was determined using the method by Haggard et al. (1999). Approximately 10-30 g of pre-sieved sediments was placed in a 250 ml Erlenmeyer flask, and mixed with 100 ml of 1 M MgCl_2 solution. The samples were shaken for 1 hour on the orbital shaker. 50 ml of the supernatant was diluted to 100 ml and pH adjusted to acidic using 1:1 hydrochloric acid. 0.2 g activated carbon was added and shaken for fifteen minutes. The sample was then filtered through double Whatman filter paper number 42. To 35 ml of the filtrate, 10 ml of Vanado-molybdate reagent was added and topped to the mark with distilled water. Absorbance measurements were taken after 15 minutes at 470 nm for sediment exchangeable phosphate determination.

4) Sediment bio-available phosphorus

Sediment bio-available phosphorus was determined by Sonzogni et al. (1982) method. Approximately 20-30 g sieved wet sediments was extracted with 100 ml 0.1 N NaOH solution in 250 ml flask. The samples were mixed on the shaker for 1 hour. After incubation, 35 ml sample aliquots were taken and filtered through into a pre-labeled 50 ml volumetric flask. To this 35 ml of the filtrate, 10 ml of Vanado-molybdate reagent was added and topped to the mark with distilled water. Absorbance measurements were taken after 15 minutes at 470 nm for sediment bio-available phosphate determination.

5) Statistical analysis

Statistical analysis was applied to determine the correlation coefficients between the seasonal variations and the levels of sediment exchangeable phosphorus concentrations (EPCo), sediment bio-available phosphorus (SBAP), soil available phosphorus (EXP), total reactive phosphorus (SRP), total hydrolysable phosphorus (THP) and total phosphorus (TP) in water samples.

Results and discussion

Speciation of phosphates in water from Lake Victoria catchments

The phosphate levels analyzed in water samples were categorized into total reactive phosphates (TRP), total hydrolysable phosphates (THP) and total phosphate (TP). The levels of total phosphates were the highest in all the seasons followed by reactive phosphates and lastly the total hydrolysable phosphates. Effluents from the water treatment plants were found to contain the highest phosphate levels compared to the rivers and municipalities located along the lakeshore. Among the effluent sample sites, Homa Bay wastewater treatment effluent was found to contain the highest phosphate concentration for all the three phosphate categories analyzed in all the four seasons, and in some cases with magnitudes as high as ten times compared to the other sampling points investigated.

Phosphate levels in water during wet season

Total reactive Phosphates in water during wet season

Phosphate concentrations in most of the water samples collected in all seasons were considerably higher than the recommended guideline for aquatic life. Homa Bay sewage effluent was found to contain the highest phosphates levels with concentration of 17.04 mg/l, followed by Kisati sewage effluent with concentration of 5.24 mg/l. Among the rivers, River Awachi Seme, Nyando, Sondu Miriu, Awachi and Yala had the leading concentrations varying between 2.2 and 1.6 mg/l. Water samples from the key towns along the lake indicated levels comparable with those detected in the river samples. Kusa Beach had highest concentration of phosphate with concentration of 3.17 mg/l (Figure 2). This was mainly attributed to the heavy agricultural activities practised around the beach ranging from the cultivation of maize, sugarcane, yams and rice. In addition, this beach is very close to the mouth of River Nyando, which is likely to be contributing to the high levels of phosphate load. The river traverses heavy large agricultural farms in the upstream comprising of coffee, tea, sugarcane, and rice plantations and is characterised by extensive soil erosion.

Total hydrolysable phosphates in water during wet season

The concentration of hydrolysable phosphates ranged between 3.37 mg/l to below detection limit during the wet season. The highest concentration was detected in the samples from Homa Bay sewage effluent followed by Nyalenda effluent and River Sio with mean concentrations of 3.38, 2.27 and 1.97 mg/l respectively. All the samples collected from the lakeshores contained levels of hydrolysable phosphates below 1 mg/l with majority of the points having hydrolysable phosphates below detection limit (Figure 2). Similarly, five out of the eleven rivers covered under this study had hydrolysable phosphate below detection limit.

Total phosphates in water during wet season

Like in the case of total reactive phosphates, most of the samples analysed had high levels of total phosphates. This could be attributed to the fact that total phosphate accounts for all the total reactive phosphate, the hydrolysable phosphates and the organically bound phosphates in the water. The concentration of total phosphate in effluents from the water treatment sites ranged between 1.59 and 21.51 mg/l. The levels detected in the river samples were considerably lower with detected concentrations between 0.45 to 6.51 mg/l. Total phosphate levels in samples from the municipalities along the shorelines ranged between 7.0 and 1.41 mg/l (Figure 2).

Phosphate levels in water during dry season

Total reactive Phosphates in water during dry season

High levels of reactive phosphates were detected in effluents compared to rivers and lake samples. Homa Bay effluent, Kisati, Saka and Homa Bay discharge effluents were the leading in reactive phosphate concentrations. Samples from the rivers and municipalities had comparable levels of reactive phosphates varying from 0.8 mg/l to below detection limit (Figure 3).

Total hydrolysable phosphates in water during dry season

Hydrolysable phosphate concentration in the dry season ranged between 3.83 mg/l to below detection limit. Effluents from direct discharge points and the water treatment plants had the highest concentration with 3.83 mg/l detected in samples from Homa Bay sewage. This was over three times higher than the levels found in the rivers and lake samples (Figure 3).

Total phosphates in water during dry season

The highest concentration registered during this season was 21.37 mg/l whereas the lowest was 0.78 mg/l. The levels detected in the effluents discharged into the lake were still higher than those detected in the rivers and lake samples. Homa Bay water treatment effluents had the highest concentration detected with 21.37 mg/l followed by Kisati with 12.41 mg/l. The rivers samples had total phosphate concentration ranging between 1.89 and 0.78 mg/l detected in samples from River Sondu Miriu and River Nyamasaria respectively. The levels in samples from the lakeshores varied between 1.72 and 0.95 mg/l detected in samples from Kendu Bay and Muhuru Bay respectively (Figure 3).

Phosphate levels in water during short rain season

Total reactive Phosphates in water during short season

Total reactive phosphate in the samples collected during the short rain season ranged between 20.05 and 0.84 mg/l in effluents discharged into the lake. The highest levels were in effluent samples from Homa Bay wastewater treatment plant followed by Saka, Kisati, Homa Bay open discharge, Nyalenda and KWASCO. Total reactive phosphate in river samples ranged between 2.21 and 0.84 mg/l with the highest concentration found in samples from River Sondu Miriu and Nyando. Reactive phosphate in lake water samples varied between 2.0 mg/l and 0.94 mg/l detected in samples from Mbita and Sio Port respectively (Figure 4).

Total hydrolysable phosphates in water during short rain season

Very high levels of hydrolysable phosphate were detected in samples from Homa Bay wastewater treatment plant with concentration of 7.71 mg/l. The rest of the samples analysed for this parameter were much lower with average concentrations varying between 0.88 to below detection limit. The levels in lake water ranged between 0.63 mg/l to below detection limit whereas the river water had concentrations between 0.88 mg/l to below detection limit (Figure 4).

Total phosphates in water during short rain season

Total phosphate levels in the short rain season were higher compared to the previous two seasons (wet and dry season). However, like in the past two cases, Homa Bay water treatment effluent contained the highest total phosphate levels during the short rain season with mean concentration of 33.03 mg/l. Other effluents with high total phosphate concentrations were Kisati, Saka and Homa Bay open discharge with concentrations of 6.28, 5.66 and 3.02 mg/l respectively. The levels of total phosphates detected in the river samples during the short rain season varied between 4.49 and 1.35 mg/l. The highest concentration was detected in samples from River Awachi and this could be attributed to farming activities taking place upriver and drainage of municipality wastes within the river catchment. The lake water samples had concentrations between 4.66 and 1.35 mg/l with the highest concentration detected in samples from Mbita Winam Gulf (Figure 4). In general the levels of total phosphate in the lake and river waters were in comparable range.

Phosphate levels in water during dry season2

Total reactive Phosphates in water during dry season2

The samples collected during the dry season 2 in March 2007 had total reactive phosphate ranging between 19.62 mg/l and 0.71 mg/l. In general, samples from effluent discharge points still contained the highest amounts of total reactive phosphate in this season with the highest of 19.62 mg/l detected in samples from Homa Bay wastewater. Other points in this category had concentrations ranging between 1.51 and 0.71 mg/l. River water samples had total reactive phosphate concentration between 1.94 and 0.74 mg/l. The river with the highest reactive phosphate during this season was Awachi Seme followed by Rivers Sondu Miriu, Nyando and Nyamasaria had equal concentrations of 1.07 mg/l. The lake water collected during this season had reactive phosphate concentrations close to that detected in the river water samples, with the highest concentration of 1.22 mg/l and the lowest of 0.78 mg/l (Figure 5).

Total hydrolysable phosphates in water during dry season2

Total hydrolysable phosphate varied between 5.58 mg/l and below detection limit. Homa Bay water treatment effluent had the highest concentration detected followed by Mbita main lake, KWASCO and Sondo Miriu sampling points, with concentrations of 5.48, 0.88, 0.60 and 0.55 mg/l respectively. In general, total hydrolysable phosphates were the lowest detected at all the samples except at Homa Bay open discharge where it was higher than the reactive phosphate

concentration (Figure 5). Most of the river water samples and the lake water samples had most of the points with hydrolysable phosphate below detection limit.

Total phosphates in water during dry season2

Total phosphate concentration in the dry season2 varied between 20.28 and 0.94 mg/l with the highest detected in effluents from Homa Bay wastewater treatment plant. Samples from effluents discharge points into the lake were characteristically higher compared to most of the samples collected from the rivers and the lake. Homa Bay wastewater treatment plant effluents had concentration of 20.28 mg/l followed by Homa Bay open discharge, KWASCO, Nyalenda, Saka and Kisati (Figure 5). All samples from the rivers had total phosphate concentration below 2 mg/l with the highest phosphate concentration from Rivers Awachi Seme, Nyando and Kuja having concentrations of 1.97, 1.69 and 1.46 mg/l respectively. The lake water samples had concentrations between 2.04 and 0.94 mg/l. The highest concentrations of total phosphate in this category were detected in samples from Kendu Bay, Kisumu Car wash and Mbita Winam Gulf, with mean concentrations of 2.02, 1.74 and 1.65 mg/l respectively.

Seasonal variations of phosphates in water samples

Seasonal variation of the phosphate levels in the water samples indicated that the wet season and the short rain seasons were leading in the concentrations of total reactive phosphates, followed by the dry season2 and lastly the dry season1 for both river and lake water samples. The effect of seasonal variations on the level of total reactive phosphates was not very well demarcated in the case of effluent discharges into the lake. This could be attributed to the fact that most of the wastewater treatment systems in the region are either not properly functioning or they are overloaded beyond their designed capacity especially during the wet season and short rain season when the runoffs affect the performance of the systems. All the river and lake samples collected over all the four seasons had total reactive phosphate below 4 mg/l (Figure 6).

For the river and lake samples total hydrolysable phosphates were high in the wet season and the dry season1. The levels of hydrolysable samples in the lake and river samples were below 2 mg/l, whereas the effluent discharge points had hydrolysable phosphate between 7.71 and below the detection limit. There was no clear demarcation between the seasonal variations and the concentrations of hydrolysable phosphates in the effluents discharged into the lake (Figure 7).

The levels of total phosphates in the lake and river water samples seem to be influenced by the seasonal variations. The phosphate levels decreased from the wet, short rain, dry season 2 and dry season 1 in over 90% of the samples. However, similar trend was not observed in the case of the samples collected from the effluent discharge points (Figure 8).

Phosphate levels in sediments collected from Lake Victoria drainage Basin

Phosphate concentration in sediment samples was determined in the form of exchangeable phosphate, which is the magnesium chloride extract, and the bio-available phosphate, which is the sodium hydroxide extract.

Sediment exchangeable phosphate in Lake Victoria drainage basin

The highest levels of sediment exchangeable phosphate in Lake Victoria drainage basin were detected in samples collected during the dry season₂ (March 2007) followed by the dry season₁ (August 2006). There was no clear trend between the levels detected during the wet season and the short rain season since the concentrations were high and low at different points in both cases (Figure 9). The highest amount of sediment exchangeable phosphates in river samples collected during the dry season₂ were in samples from River Sio, River Awachi, Nzoia and Kuja with concentration of 12.35, 12.24, 9.28 and 9.23 mg/kg respectively. The highest sediment exchangeable concentrations in lake samples collected during the dry season₂ were detected in samples from Misori, Port Victoria, Muhuru Bay, Luanda and Sio Port with concentrations of 13.60, 11.60, 11.16, 10.94 and 10.92 mg/kg respectively. Sediment exchangeable concentration in the dry season₁ varied between 8.01 and below detection limit. The highest concentration in the river sediments were detected in samples from Rivers Yala, Awachi, Mugruk, Awachi seme, Kuja and Nzoia with concentrations of 5.51, 4.33, 4.2, 4.08, 3.42, and 3.21 mg/kg respectively. The levels detected in the lake sediments in this season were slightly higher than those detected in the river sediments. This could be attributed to the fact that these samples were collected after the heavy rain season and most of the sediment in the river samples had been washed into the lake. The highest sediment exchangeable phosphates were detected in samples from Luanda, Hippo point, Misori and Muhuru Bay with concentrations of 8.02, 6.44, 5.44 and 5.35 mg/kg. The highest concentrations of exchangeable phosphates in sediments collected in the wet season from the direct discharge points were 12.23, 3.89 and 2.16 mg/kg in samples from Nyalenda, KWASCO and Saka respectively. Samples from the river contained concentrations between 4.13 and below detection limit. The samples from lake points had concentrations 7.29 mg/kg and below detection limit. The highest concentration detected was 7.29 detected in samples from Sori (Figure 9). Samples collected in the short rain season had concentrations between 6.4 mg/kg and below detection limit. The highest levels in this season were detected in samples from Kisati, River Nyando, KWASCO and Kendu Bay, with concentrations of 6.4, 5.52, 5.2 and 5.05 mg/l respectively.

Sediment bio-available phosphate in Lake Victoria drainage basin

The levels of sediment bio-available phosphate in the drainage system were higher than those detected for exchangeable phosphates. This could be attributed to the fact that bio-available phosphate fraction also contains phosphate bound to metal ions like iron, aluminium and calcium which is not incorporated in the exchangeable fractions. The highest concentration of bio-available phosphate was detected in the dry season₂. However, there was no clear demarcation of trends with respect to this fraction in the sediments since high and low levels were observed in various samples collected at different times. Samples collected in the wet season had average concentration of 23 mg/kg with the general concentrations ranging between 59.79 mg/kg and below detection limit. The highest bio-available phosphate detected in river during the rain season was 28.94, followed by 27.76, 26.69 and 24.43 mg/kg detected in samples from River Nzoia, Yala, Mugruk and Kuja respectively. The levels detected in the lake samples were slightly higher than those detected in the river samples, with the highest of 56.61, 52.83, and 24.24 mg/kg detected in the samples from Sio Port, Port Victoria and Usenge respectively. This shows that the levels of bio-available phosphate detected in the lake samples were higher than those in the river samples indicating that lake sediments might be acting as sink for the

phosphate load from the catchments. However, the sediments retained phosphate that may later be recharged through microbial activity to the water column during the up-welling processes and hence influence the cycling of the phosphate load in the lake. The highest levels of bio-available phosphate in effluent discharge systems were detected in samples from Kisati followed by Saka and Nyalenda (Figure 10). The concentrations detected in this category of sampling points were slightly higher than those detected in the lake and river samples and this could be attributed to high amounts of biological wastes associated to these types of sources. In the samples collected during dry season1, bio-available phosphate levels were found to be lower than those detected in the wet season. Higher amounts were detected in the lake samples compared to the river samples, and this could be attributed to the fact that this season follows immediately after the heavy rain season and most of the sediments from the rivers and discharge points have been washed into the lake. The average concentration of bio-available phosphate detected during this season was 19.74 mg/kg with the highest concentrations of 51.42, 33.83 and 31.08 mg/kg detected in samples from Usenge, Sio Port and Hippo Point respectively, all from the lake sampling stations. The mean bio-available phosphate concentration in samples collected during the short rain season was 14.25 mg/kg, with the highest concentration of 27.92 mg/kg detected in samples from Sio Port followed by 27.70 mg/kg in samples from Port Victoria.

Similar to the case observed in the wet and dry season, the highest concentrations of bio-available phosphate concentrations were detected in the lake sediments compared to the river samples and could be attributed to the influence of the rain on transport of sediment phosphates into the lake. The lake sediment samples had concentrations between 27.92 and 5.75 mg/kg, whereas river samples varied between 7.53 and 16.87 mg/kg. The highest levels in the river samples were detected in samples from Rivers Kisian, Awachi Seme, Awachi and Yala. Except River Yala, the rest of rivers found to have the highest bio-available sediment concentrations are smaller and slow flowing and this could have contributed to the high levels of bio-available phosphates detected. In contrast, the major rivers like Nzoia, Nyando and Kuja are quite fast and hence the settling time for sediments is quit long and as a result phosphate residues would be carried in form of suspended particles and discharged into the lake. The samples from discharge points had phosphate levels between 20.65 and 19.69 mg/kg.

In the dry season2, average concentration of bio-available phosphate was 24.45 mg/kg. The highest concentration detected in this season was 82.6 mg/kg detected in samples from Port Victoria. In general bio-available sediment concentration in the lake sediment varied between 82.6 and 5.1 mg/kg with key points being Port Victoria, Usenge, Kisumu Railways (Car wash), Sio Port, Dunga Beach, Kusa and Muhuru Bay with mean concentrations of 82.60, 42.31, 34.12, 31.56, 30.96, 26.92 and 20.14 mg/kg respectively (Figure 10). River sediment samples had bio-available phosphates between 27.71 and 8.03 mg/kg with the highest concentration detected in samples from rivers Yala, Nzoia, Kisian and Sondu Miriu (Figure 10). Sites located along the effluent discharge points to the lake had concentration between 74.71 and 11.95 mg/kg with the highest levels detected in sediments from Kisati, Saka and KWASCO.

Soil available phosphate in Lake Victoria drainage basin

The average soil available phosphate was highest in the dry season2 followed by the short rain and the dry season1. The average soil available phosphate concentration in the dry season1 was 566 mg/kg with the mean concentrations ranging from 2,643 to 76.9 mg/kg. Soils collected from

the farms close to towns along the lakeshore were found to contain higher available phosphate levels compared to those collected from farms close to the river mouths and effluent discharge points. Soils from farms around Misori, Sori and Mbita main lake had the highest available phosphate in the dry season¹ among the points close to the towns along the lakeshore. Soils from the farms close to the river mouths had mean available phosphate concentrations between 265 and 93 mg/kg with the highest concentration detected in the samples from farms around rivers Nzoia and Yala, whereas the highest concentration in samples from farms close to the effluents discharges was 233 mg/kg detected in samples from farms around Kisati.

Samples collected during the short rain season had mean concentration of 639 mg/kg and the highest concentration was 2,853 mg/kg detected in samples from farms around Mbita main lake. Samples from farms close to the towns along the shoreline of the lake were found to contain higher available phosphates compared to those close to the sampling points located at the river mouths. The levels of soil available phosphates in the samples from lakeshore varied between 2,853 and 128 mg/kg, whereas those from the farms close to the river mouths ranged from 106 and 338 mg/kg.

The mean concentration of soil available phosphorus in samples collected during the dry season² was 1,076 mg/kg with the highest detected in soils from the farms located close to the towns along the lakeshores. In this season, soils from Homa Bay and Misori were the leading in available phosphate concentration followed by Sori and Kusa with mean concentrations of 5,232, 4,885, 3,415 and 3,267 mg/kg respectively (Figure 11). On the contrary the soils collected from the river farms in the same season had mean available phosphate concentrations ranging between 76 mg/kg and 538 mg/kg, which were almost ten to one hundred times lower than the former. The highest concentration in river soil was 538 mg/kg detected in samples from River Nyando. Similar to the river samples, soils collected from the areas close to the effluent discharges had low soil available phosphate levels with mean concentrations ranging between 531 and 199 mg/kg. The highest concentration was detected in soils from farms around Sake effluent discharge.

Statistical analysis of the data indicated strong positive Pearson correlation between phosphate levels in the four seasons with values between 0.873 and 0.97 indicating the likelihood of accumulation of phosphate in the lake Victoria drainage basin with time. This has challenging implication on the management of the catchment and the lake. There is there is need for the government of Kenya together with institutions involved in the management of the catchment to evaluate regulatory regimes to discourage unsustainable land use practices.

Conclusion

- 1) Seasonal variations in lake Victoria catchments are influencing phosphate levels in the lake water.
- 2) The human activities along the Lake Victoria shorelines are contributing to the accumulation of phosphates and therefore influencing phosphate load into the lake.
- 3) The Lake Victoria sediment is acting as a sink for phosphate coming from the catchments' rivers and runoffs from the farms around the shoreline.
- 4) The concentration of phosphates in the effluents discharged into Lake Victoria is higher than the recommended effluent limits and therefore contributing to the phosphate load into the lake.
- 5) The rivers draining into Lake Victoria have high phosphate levels and leading to the algal and macrophyte blooms in Lake Victoria. This is also corroborated by high load of water hyacinth in hot spots like Homa Bay beach.
- 6) The phosphate levels in the soils along the shorelines are acting as source of phosphate load into the Lake Victoria.
- 7) The water bodies in the Lake Victoria catchments have high phosphate levels and likely to suffer eutrophication.

Recommendations

- 1) The seasonal impact on the influx of phosphates into the Lake Victoria can be controlled by improving the current practices in the catchments. These include farming and waste disposal practices. The government of Kenya should evaluate regulatory regimes to discourage the practices.
- 2) There is need to effect stringent rules on the discharge of effluents into the lake to ensure that the lake is not used as a dumping site for poorly treated or untreated effluents.
- 3) Farming activities along the lakeshore should be discouraged and a minimum distance to the lake should be set beyond which no farming should be allowed.
- 4) Education of the small-scale farmers should be enforced in the catchments to ensure that they are able to practice sustainable and environmentally friendly agriculture.
- 5) There is need to develop a databank of water quality of the Lake Victoria catchments to help to track environmental changes facing the lake.

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Figure 1: Map of the Kenyan part of Lake Victoria Drainage Basin

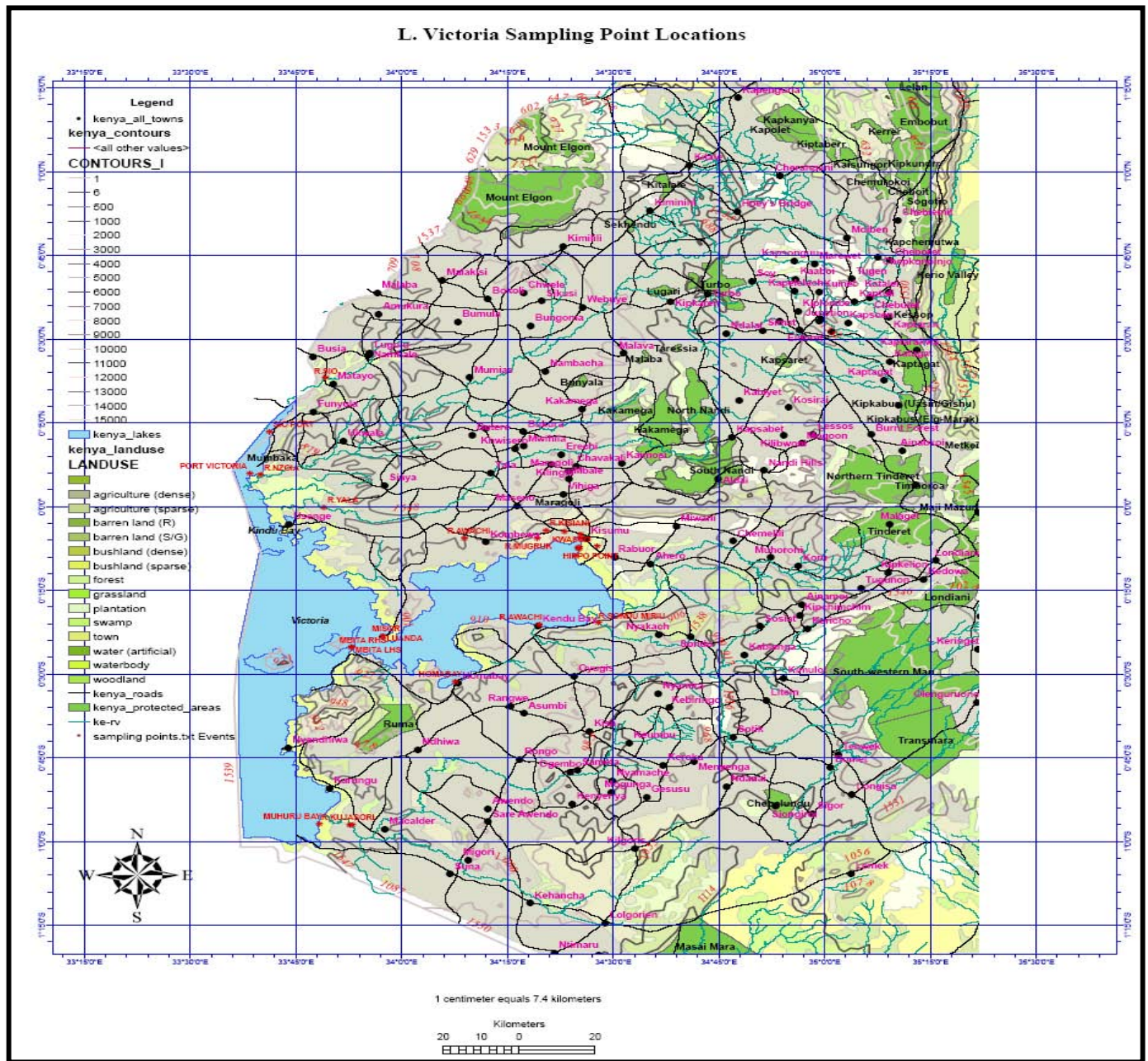


Figure 2: Phosphates in water during wet season

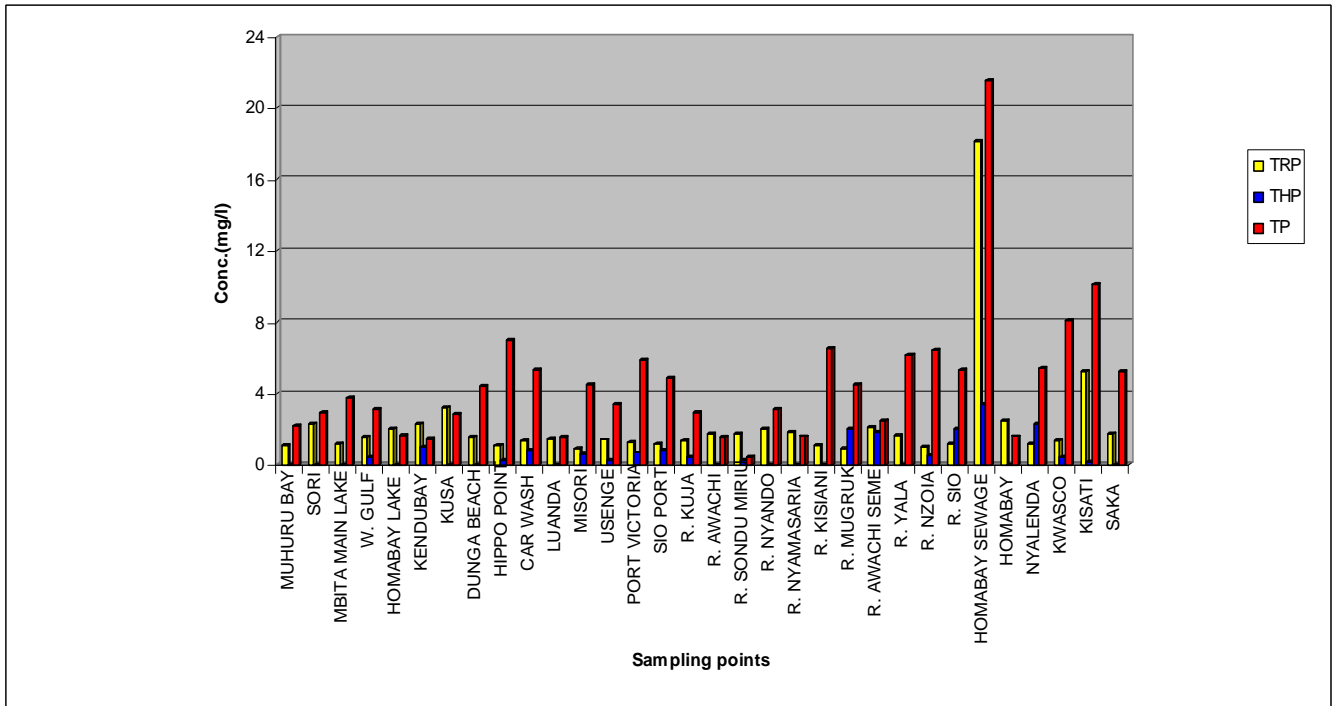


Figure 3: Phosphates in water during dry season 1

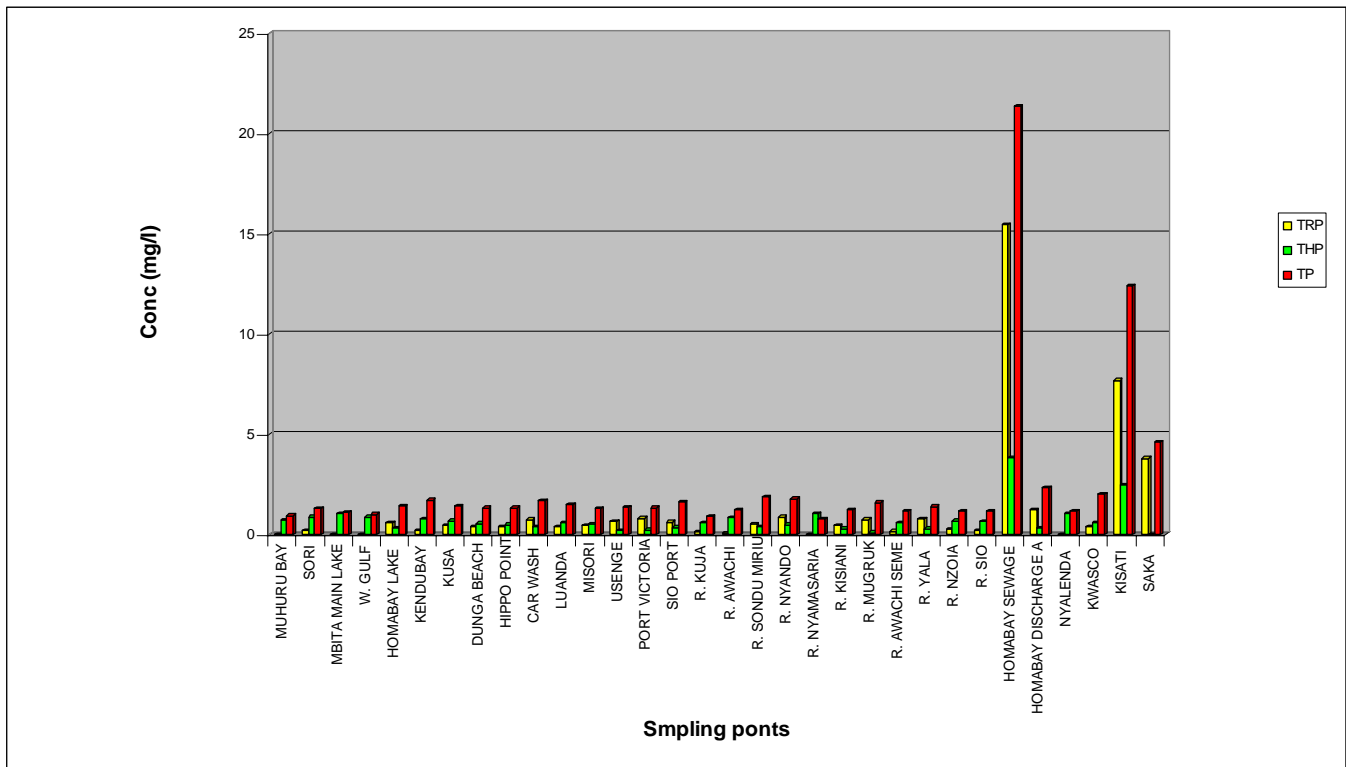


Figure 4: Phosphates in water during short rain season

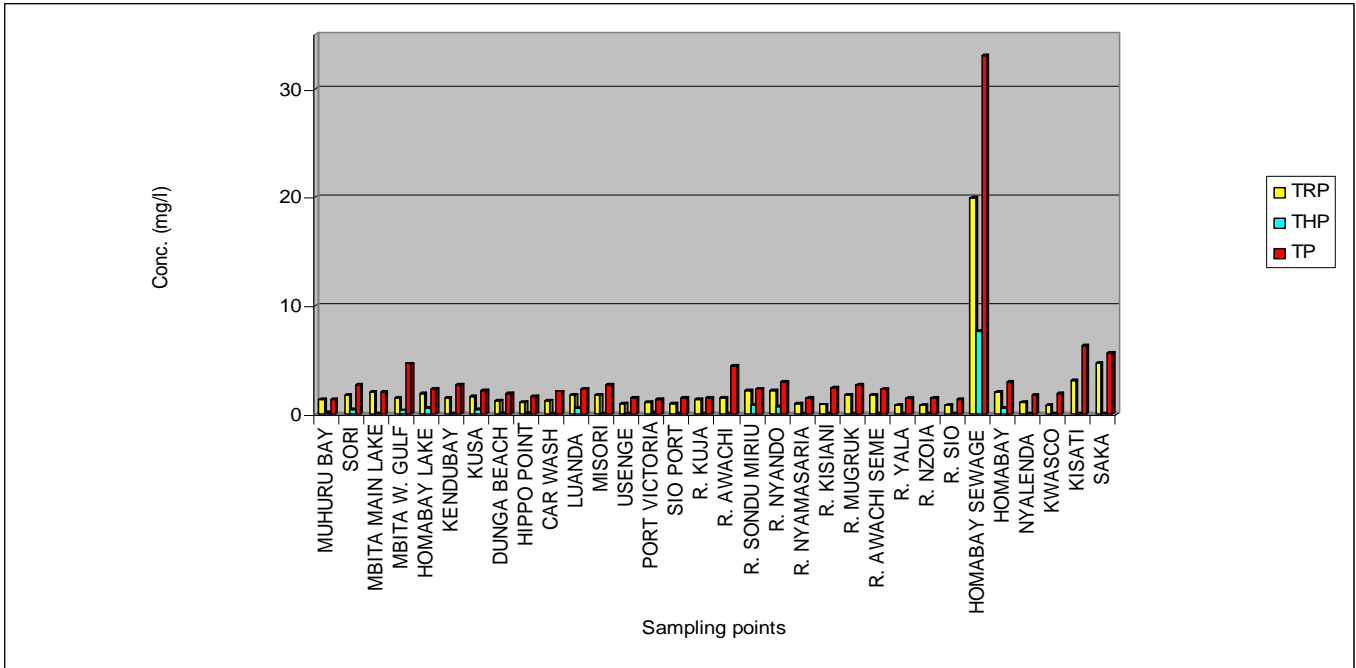


Figure 5: Phosphates in water during dry season2

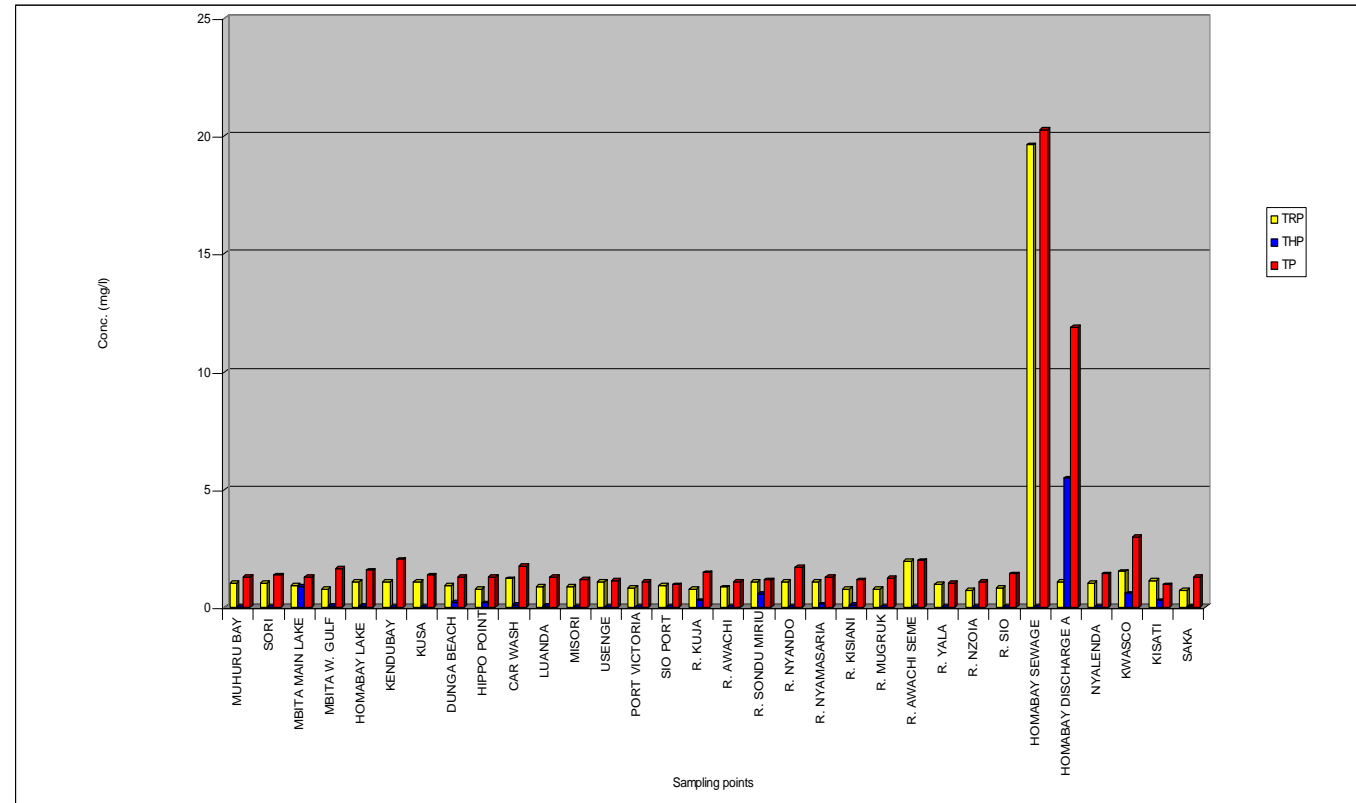


Figure 6: Seasonal variations of reactive phosphates in water

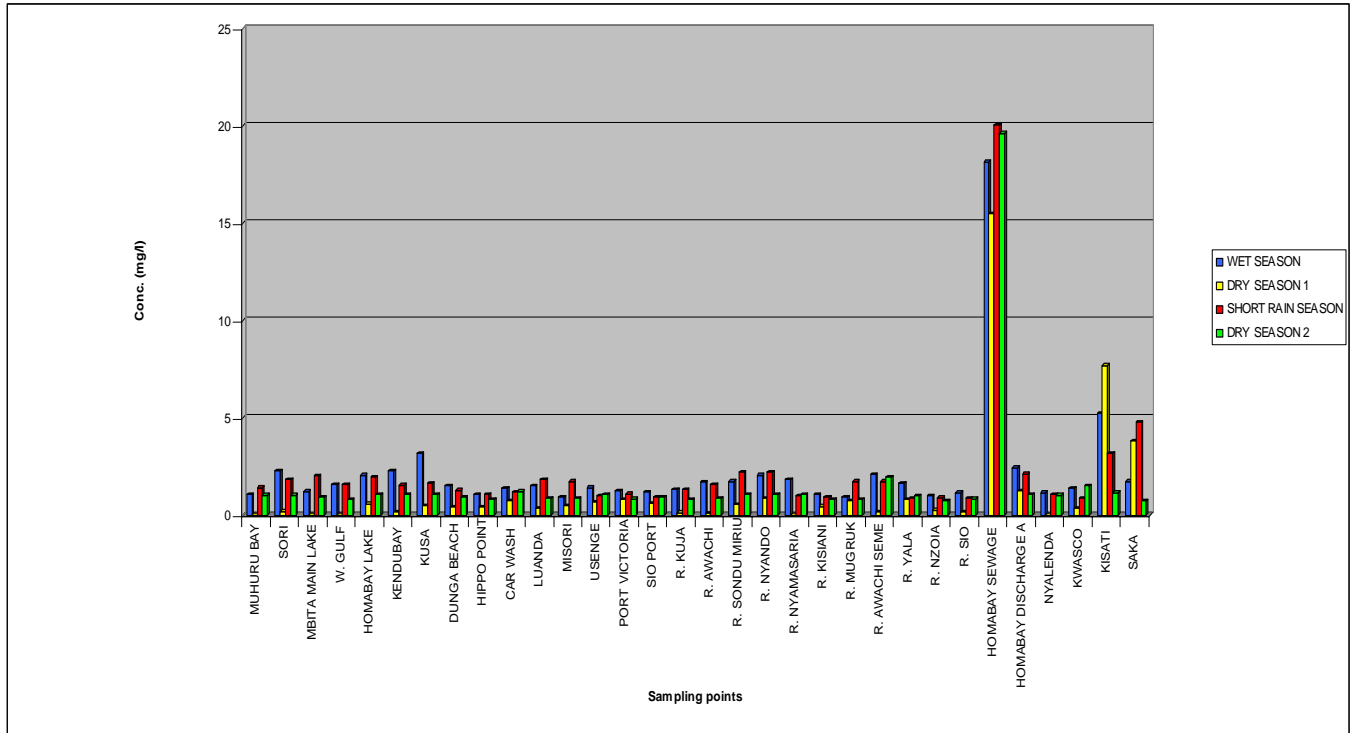


Figure 7: Seasonal variations of hydrolysable phosphates in water

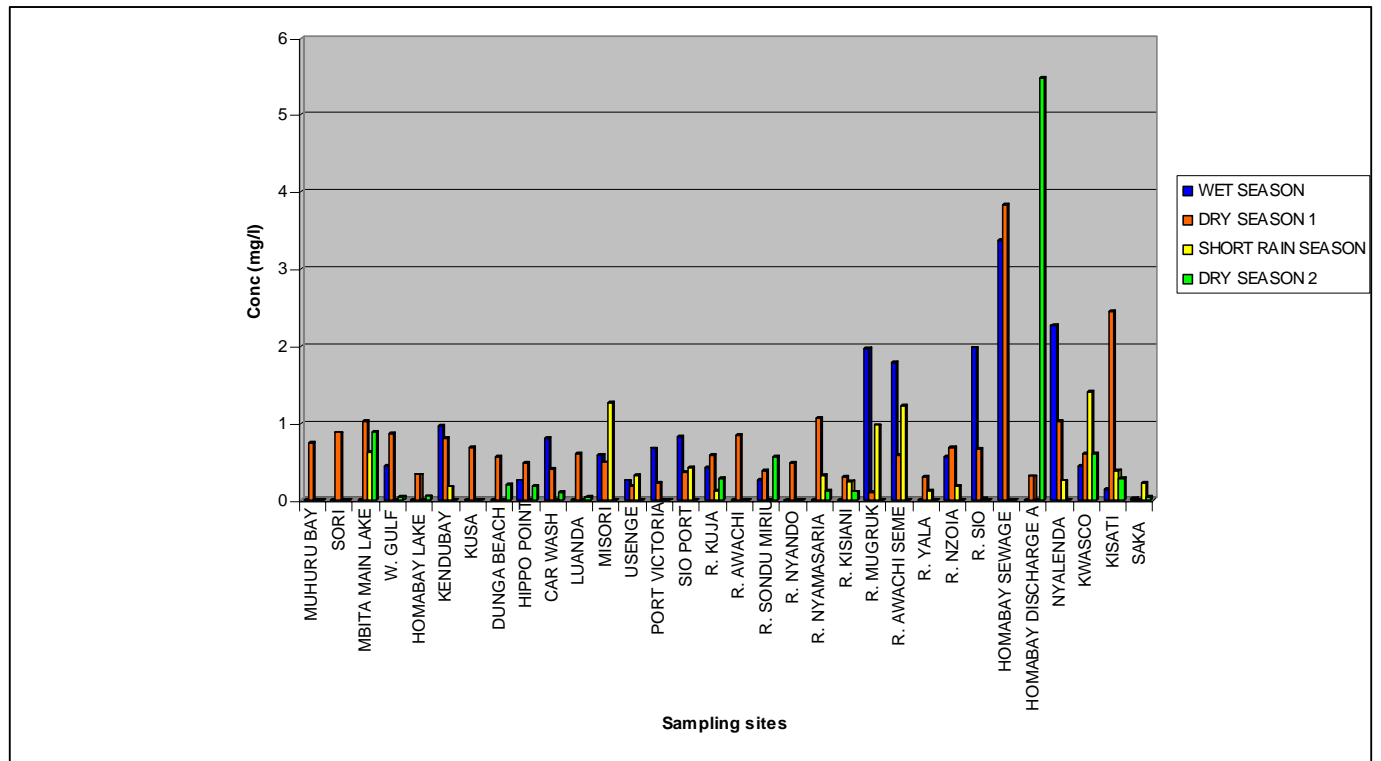


Figure 8: Seasonal variations of total phosphates in water

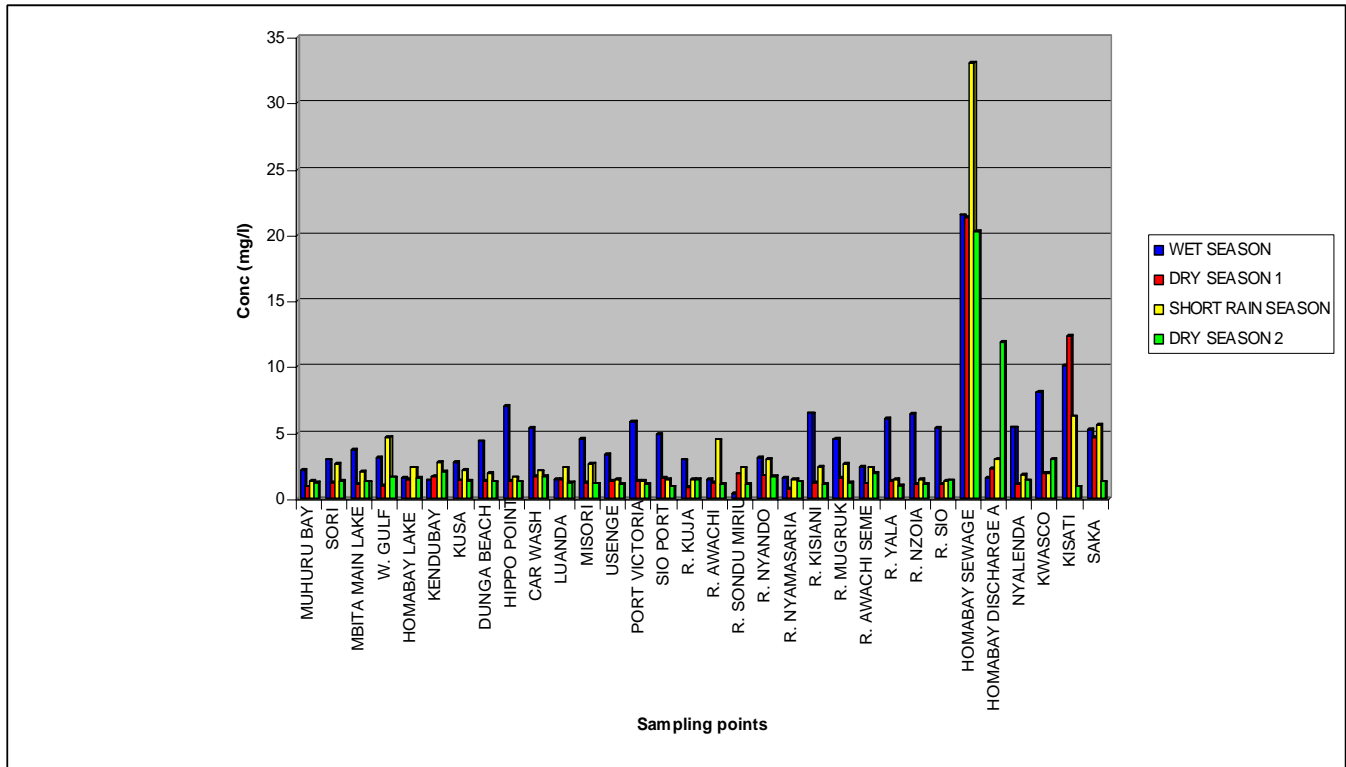


Figure 9: Seasonal variations of exchangeable phosphates in sediments from Lake Victoria catchments

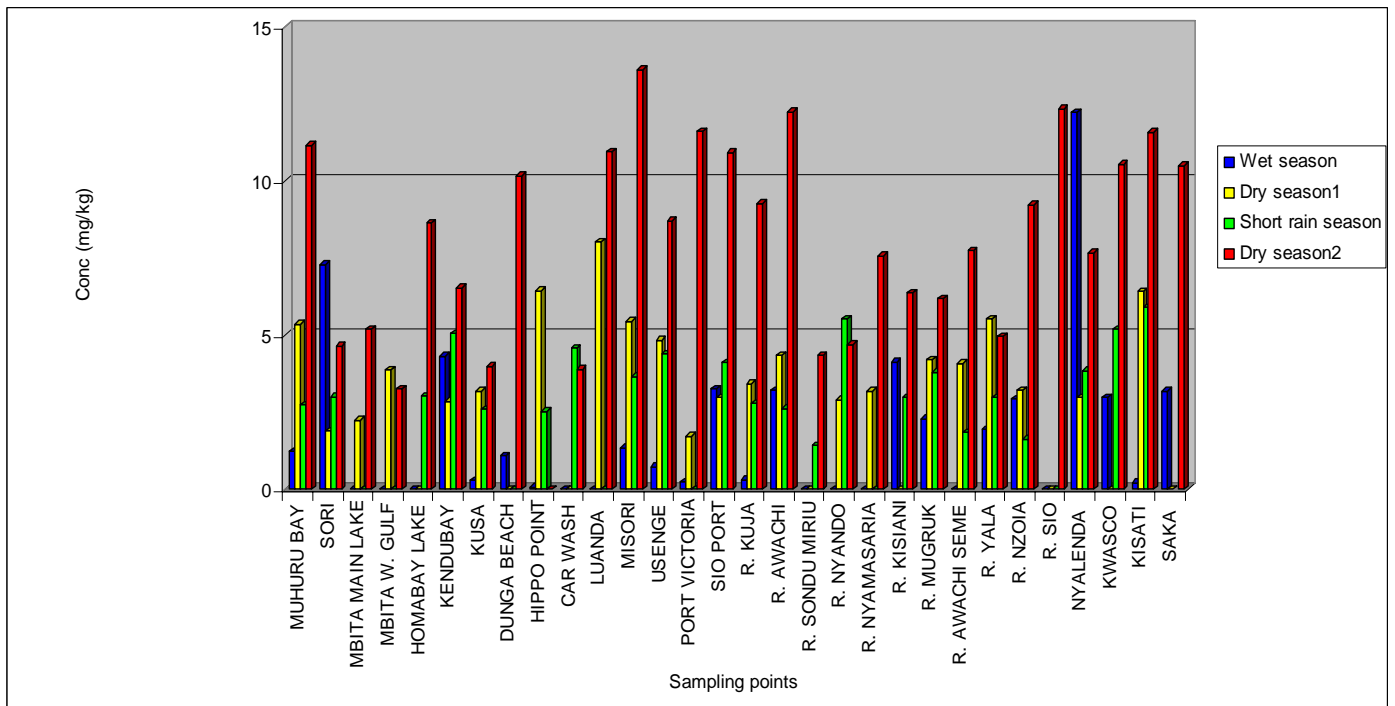


Figure 10: Seasonal variations of sediments bio-available phosphates in Lake Victoria catchments

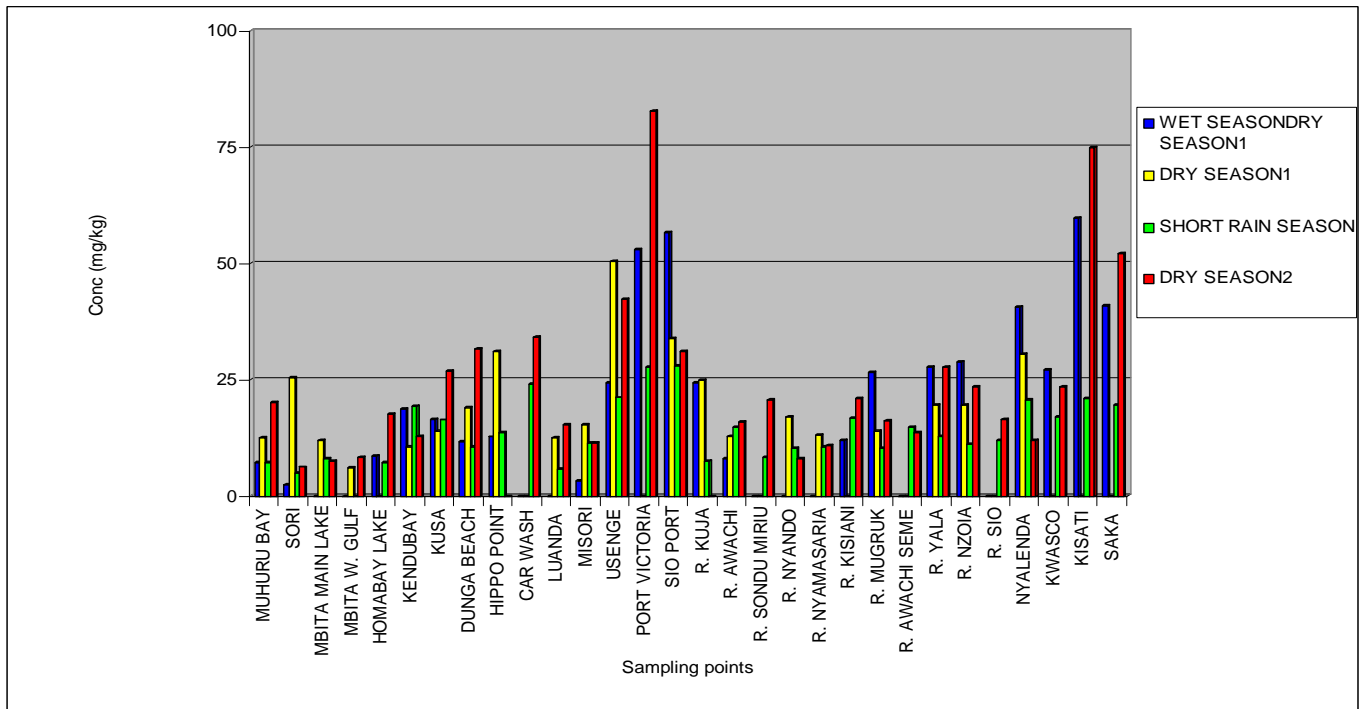


Figure 11: Seasonal variation of available phosphates in soils from Lake Victoria catchments

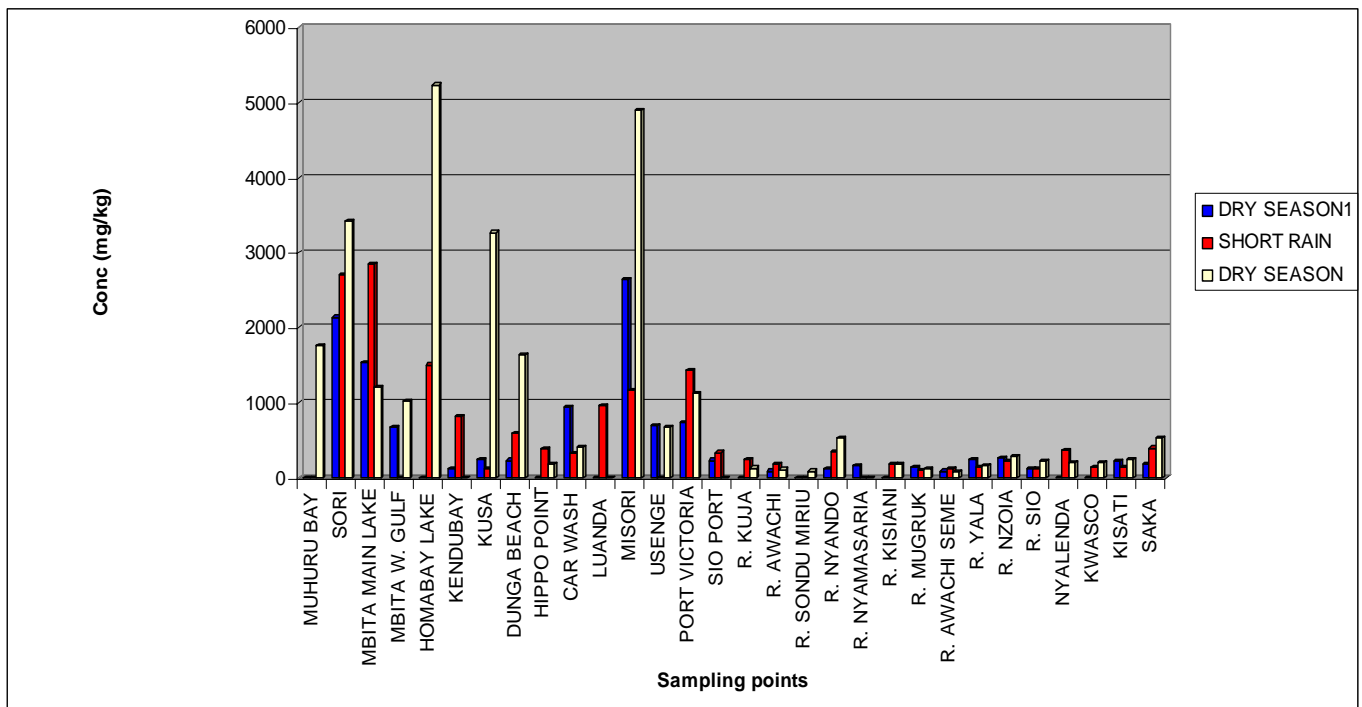


Table 1: GPS Locations of the sampling points

No.	SAMPLING POINT	LATITUDES	LONGITUDES	ALTITUDE (m)
1	MUHURU BAY	005654S	0340753E	1127
2	SORI	005657S	0341231E	1129
3	MBITA WINAM GULF	002511S	0341229E	1139
4	MBITA MAIN LAKE	002514S	0341227E	1134
5	HOMABAY	003120S	0342712E	1137
6	KENDUBAY	002057S	0343924E	1135
7	KUSA	001834S	0345054E	1170
8	DUNGA BEACH	000847S	0344412E	1139
9	HIPPO POINT	000729S	0344433E	1145
10	CAR WASH	000542S	0344458E	1126
11	LUANDA	002313S	0341653E	1123
12	MISORI	002308S	0341655E	1125
13	USENGE	000421S	093450E	1198
14	PORT VICTORIA	000555N	0335802E	1138
15	SIO PORT	001326N	0340049E	1142
16	R. KUJA	005701S	0341235E	1136
17	R. AWACHI	002106S	0343906E	1150
18	R. SONDU MIRIU	002052S	0344728E	1140
19	R. NYANDO	011450S	0364642E	1730
20	R. NYAMASARIA	000705S	0344718E	1136
21	R. KISIANI	000416S	0344002E	1160
22	R. MUGRUK	000542S	0343847E	1178
23	R. AWACHI SEME	000545S	0342829E	1191
24	R. YALA	000006S	0340831E	1166
25	R. NZOIA	000540N	0335931E	1153
26	R. SIO	002302N	0340846E	1157
29	NYALENDA DISCHAGE	000732S	0344443E	1140
30	KWASCO	000717S	0344443E	1127
31	KISATI	000458S	0344456E	1179
32	SAKA	000431S	0344238E	1176

Table 2: Pearson Correlation analysis for phosphates in water

Correlations

		WET SEASON	DRY SEASON1	SHORT RAIN	DRY SEASON2
WET SEASON	Pearson Correlation	1.000	.938**	.966**	.966**
	Sig. (2-tailed)	.	.000	.000	.000
	N	32	32	32	32
DRY SEASON1	Pearson Correlation	.938**	1.000	.926**	.873**
	Sig. (2-tailed)	.000	.	.000	.000
	N	32	32	32	32
SHORT RAIN	Pearson Correlation	.966**	.926**	1.000	.969**
	Sig. (2-tailed)	.000	.000	.	.000
	N	32	32	32	32
DRY SEASON2	Pearson Correlation	.966**	.873**	.969**	1.000
	Sig. (2-tailed)	.000	.000	.000	.
	N	32	32	32	32

** . Correlation is significant at the 0.01 level (2-tailed).