ASSESMENT OF PHOSPHORUS LOADING INTO LAKE VICTORIA THROUGH RIVERS NZOIA, YALA, KISAT AND NYALENDA WASTE WATER TREATMENT PLANT IN KENYA

BY

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ABSTRACT

Lake Victoria is eutrophicated with *Myxophyceae* (blue green algae blooms), Vassia *cuspidate griff* (hippo grass) and *Eichhornia crassipers* (water hyacinth) being evident. Several problems have been identified that have arisen out of this eutrophication problem in the Lake, among them being but not limited to water quality. This research, therefore, endeavored to substantiate the source of the reported phosphates in Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plants in Kenya. This was achieved by assessing phosphate levels in water, sediments and air above the rivers both upstream and downstream. Sediment and water samples were collected using a grab sampler while air samples were collected using the atmospheric deposition sampling method. Sampling was done during the long wet and dry seasons. Water and atmospheric air samples were analyzed using UV-Visible spectrophotometer for total phosphates as sediments being analyzed for bio-available and exchangeable phosphates. Completely randomized design three factors was used, replicate of air, water and sediment from Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plants in Kenya. Analysis of variance (ANOVA) ($P \leq 0.05$) and Student T-Test ($P \leq 0.05$) ware used to check the variations. The results were subjected to MSTAT-C statistical analysis with analysis of variance being used to determine variations between parameters. The method used for analysis was spectrophotometric analysis. The results indicated that levels of phosphorus in sediment samples were higher than those of water and atmospheric samples in all the locations. Downstream samples recorded higher values than upstream samples in all the sample types and locations. Wet season samples recorded higher levels than the dry season samples in all the locations in sediments and water samples while in atmospheric air samples the total mean for dry season was higher than wet season. River Yala and Nzoia had the highest mean concentration of the phosphorus in all the sample types. Water and sediments from both rivers and effluent treatment points contained higher phosphorus levels than the recommended guideline for aquatic life indicating influence of anthropogenic sources. The atmospheric particulates around Rivers Nzoia, Yala, Kisat and Nyalenda Lagoons are significant source of phosphorus into water bodies. The findings could be used in formulating measures that can lead to reduction of eutrophication in Lake Victoria through proper land use, agriculture and domestic waste management as well as application in town planning programmes.

CHAPTER ONE

1.0: INTRODUCTION

Lake Victoria is the world's second largest freshwater lake by surface area, second to Lake Superior. The lake is shared among the three East African countries: Tanzania, Kenya and Uganda (LVEMP, 2002). It has a stretch of 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 and it covers a total volume of 2,760 $km^3$with average of minimum and maximum depths at 40 m and 80 m respectively (LVEMP, 2003). The lake covers a total surface area of 68,800 km^2 and has catchments total area of 193,000 km^2. 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 (LVEMP, 2003). Lake Victoria draws 20% of its water from the Kagera, Mara, Simiyu, Gurumeti, Nzoia, Yala, Kisat, Nyando, Migori, and Sondu-Miriu rivers and other smaller tributaries (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).

Lake Victoria is eutrophicated with algae blooms and water hyacinth being evident (COWI, 2002; LVEMP, 2002; 2003; Madadi *et al.*, 2007). Several problems have been identified that have arisen out of this eutrophication problem of Lake Victoria (LVEMP, 2002; 2003; Madadi *et al.,* 2007). Among the problems cited include but are not limited to rampant water borne diseases, reduced fish biodiversity, low dissolved oxygen, anoxia and increased disease vector habitats (Talling, 1965; 1966; Hecky, 1993; LVEMP, 2002; 2003; Madadi *et al.,* 2007). The nutrient elements limiting the primary production in freshwater is phosphorus (mainly phosphate) while that in the marine environments is nitrogen (mainly nitrate). Phosphorus loading into Lake Victoria has been identified to come from major rivers feeding it (Madadi *et al.,* 2007) and from atmospheric deposition (LVEMP, 2002). However, there exists a conflict between the major phosphate input into the lake with research in river and other land based pollution loading like effluent from waste water treatment plants, factory waste disposal among others indicating major loading activities (COWI, 2002; Madadi *et al.,* 2007). UNEP (2005) identifies anthropogenic activities like factory effluents, oils, grease and detergent spillage as well as sewage disposal as major sources of phosphates into the lake.

Research on the actual contribution of atmospheric deposition of phosphorus into Lake Victoria and subsequently rivers feeding the lake is scanty with most of the research attributing the pollution loading to mainly industrial, municipal and agricultural discharges into the aquatic systems (Madadi *et al.,* 2007). However, it is important to substantiate the fact that it is possible to have depositions from the atmosphere that may not necessarily be out of anthropogenic activities within the lake basin.

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 by 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 to distinguish as to whether atmospheric deposition is also a contributor to their loading amounts.

In addition, apart from the identification of loading amounts of phosphates by rivers into Lake Victoria as outlined by Madadi *et al.* (2007), it is important to authenticate the contribution as to whether if it is out of anthropogenic activities within the lake basin or by activities at the source of the river. Clearly defining the source of phosphates into Lake Victoria will go a long way in helping policy makers come up with policies that can help curb the problem of eutrophication in the lake.

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 (LVEMP, 2003; Madadi *et al.*

, 2007).

High phosphate concentrations in the aquatic systems stimulate the growth of plankton and aquatic plants that provide food for fish (LVEMP, 2003). 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 (LVEMP, 2001). 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 (LVEMP, 2002).

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; 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 (LVEMP, 2001). 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.

1.1: Background of the study

Phosphorus compounds find their way into a water body through both natural and anthropogenic deposition by surface run off of contaminated soil and other surface dumping of industrial and domestic waste. In the aquatic environment they distribute themselves in water but, since their solubility in water is low, most are found deposited in the sediments (LVEMP, 2003). Massive algal bloom is a major indicator of phosphorus and nitrogen in balance in aquatic environment as well as a source of excess nutrient exposure for the plant growth in water e.g. water hyacinth (LVEMP, 2002). The winds blowing over the lake region may also release their precipitates over the region during rainy seasons as particulates containing phosphorus. There is need to obtain data that pinpoints the sources of phosphorus found in the environment within the study area.

The area is surrounded with several agrochemical-based industries and agricultural activities. These industries are Nzoia Sugar Company, Mumias Sugar Company, United millers, Agrochemicals, and Kisumu molasses plant, which use sugar cane products as a raw material while Webuye Pan Paper uses wood and their factories discharge phosphate as effluents. (Afulo, 1995).

There is general fear that the industries in the catchment do not utilize their treatment works efficiently due to high cost of their maintenance. Mumias sugar factory discharges into Rivers Yala while Nzoia Sugar Company and Pan Paper mills discharge effluent into river Nzoia (LVEMP, 2003). Muhoroni agrochemical discharges into River Nyando while Kisumu molasses and United Millers discharge into Lake Victoria. The poor agricultural practices and deforestation leave bare land, which are exposed to wind, while industrial particulate as flux are released into the air within the Winam Gulf. The waste water contains higher levels of organic matter and detergents from domestic sources, which are believed to be sources of phosphorus compounds (Van den Bosh *et al.,* 1998). Kisumu City has two waste water treatment plants and collection points namely Nyalenda Lagoon and Kisat Conventional Treatment plant that are poorly maintained. Kisat releases wastewater with a BOD of 181 mg/L and often produces the smell of anaerobic process gases (LVEMP, 2003). This increases the nutrient load making the water aeration inadequate and lower oxygen levels. Many studies concerning nutrients that have been done have not combined the relation between the media of transport for the concerned pollutant. This study was to find the level of phosphorus compounds in air, water and sediments collected from the same sampling point within the Lake Victoria, Winam Gulf catchment area.

1.2: Statement of the Problem

There is lack of clarity as to whether the phosphates reported at the mouths of major rivers feeding Lake Victoria are out of anthropogenic activities within the river basin or activities upstream at the sources of the rivers.

It is also important to validate whether if the phosphates reported at the mouths of major rivers are from agricultural, industrial and/or municipal waste discharges or from atmospheric depositions, information on the loading could prove useful in coming up with mitigating factors that can help in controlling eutrophication in fresh water of Lakes Victoria.

1.3: Broad objective

The main aim of this research was to assess the contribution of phosphorus loading into Lake Victoria by rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant in Kenya.

1.3.1: Specific objectives

1. To determine and compare total phosphorus levels in air, water, exchangeable and bio-available phosphate levels in sediments both upstream and downstream of Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant in Kenya.

2. To determine any seasonal and site fluctuations of phosphorus levels in air, water and sediments of Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant in Kenya.

1.4: Null Hypotheses

1. Anthropogenic activities within basins of Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant in Kenya do not contribute to increased phosphate levels at their mouths in Lake Victoria.

2. There are no atmospheric phosphate depositions from the water, sediments and atmosphere to Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant in Kenya.

3. There are no seasonal variation in phosphorus levels within the basin of Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant in Kenya.

1.5: Justification of the study

Development within the northern catchments has increased greatly in recent years and Lake Victoria, Rivers Nzoia, Yala, Kisat, and Nyalenda waste water treatment plant have been subjected to ever increasing load of phosphorus and sediments resulting in decreased water quality. Increased phosphorus loading are most commonly due to excessive use of fertilizer, malfunctioning septic and sewerage systems, poor erosion control and improper waste disposal within the catchments watershed. As development continues to increase, the amount of total surface area also increases and the velocity of water moving through the watershed into the surface water is increased. This increased runoff erodes soil and transports organic materials and nutrients from surface soils, inorganic materials in the form of sand, silts and clay are also transported to receiving waters like Rivers Nzoia, Yala, Kisat, resulting in decreased water quality in Lake Victoria.

The LVEMP (2001 and 2002) estimated the nutrients input into the Lake Victoria 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 by 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 in Lake Victoria basin.

1.6: Significance of the study

The study uses data to identify the sources of phosphorus in the atmosphere, water and sediments that can facilitate a management strategy to significantly reduce phosphorus entry into the Lake Victoria and as a result ensure long term environmental sustainability of the lake ecosystem. The data generated will be useful in developing policies for environmental management of the lake and the Lake Basin catchment.

CHAPTER TWO

2.0: LITERATURE REVIEW

2.1: Introduction.

One of the sinks for many pollutants is a water body. Lake Victoria is one of such water bodies and also the second largest fresh water lake in the world with a surface area of 68,800 km^2. It has a volume of 2,760 km^3 and an average depth of 40 m while the maximum depth is 80m. It has a total catchment area of 19,400 km^2 of which the Kenyan side contributes 42,430 km^2. The Kenyan catchment is divided into two on the basis of rainfall distribution; the northern and southern catchment (Calamari *et al.*, 1995).

There are several rivers, which drain the entire Kenyan catchment and pour their water into Lake Victoria but from the northern catchments are rivers Nzoia and Yala (Calamari *et al.*, 1995). The annual rainfall in the northern catchment range between 900 mm and 2200 mm. River Nzoia transverses Trans-Nzoia, Uasin Gist, Bungoma and Busia District and has a total length of 334 km and dominates the northern half of the Lake basin with 24 sub-basins. Its catchment area covers 12,903 km^2 and has a mean discharge of 113 m^3/s. The area is surrounded with several agrochemical-based industries and agricultural activities. These industries are Nzoia Sugar Company, Mumias Sugar Company, United millers, Muhoroni Agrochemicals, and Kisumu molasses plant, which use sugar cane products as a raw material while Webuye Pan Paper uses wood and their factories discharge phosphate as effluents. The River Yala which transverses Kakamega and Siaya Districts has a total length of 219 km with a catchment area of 3,240 km^2 and a discharge of 27.4 m ^{3}/s (Chabeda, 1984).

The Nyalenda Lagoons were constructed in 1976/1977 to treat sewage from the south-east sector of Kisumu City. It has nine lagoons arranged in three rows. The lagoons were designed to treat 7000 m^3 wastewater/day. The effluent discharges into the Lake Victoria. Kisat waste water treatment plant is located off river Kisat and discharges its effluent into Lake Victoria through river Kisat. Kisat waste water treatment plant uses a trickling bio-filter system with a mechanized conventional treatment using cold sludge digesters and secondary and primary clarifiers. The plant has exhibited poor effectiveness as evident from the foul smelling water from river Kisat flowing into the lake. There is no published work on atmospheric phosphorus of Rivers Nzoia, Yala, Kisat and sediments of Nyalenda lagoons on the northern catchment of Winam Gulf.

Phosphorus (P), the 15th element on the periodic table with an atomic weight of 30.974, is an essential nutrient for all life forms. It plays a role in deoxyribonucleic acid (DNA), ribonucleic acid (RNA), adenosine di-phosphate (ADP), and adenosine tri-phosphate (ATP) (Denis, 1968). Phosphorus is required for these necessary components of life to occur. Phosphorus is the eleventh-most abundant mineral in the earth's crust and does not exist in a gaseous state. Natural inorganic phosphorus deposits occur primarily as phosphate in the mineral apatite. Apatite is defined as a natural, variously colored calcium fluoride phosphate [$Ca_5F(PO_4)_3$] with chlorine, hydroxyl, and carbonate sometimes replacing the fluoride. Apatite is found in igneous and metamorphic rocks, and sedimentary rocks (Smith, 1999). When released into the environment, phosphates will speculate as orthophosphate according to the pH of the surrounding soil. Phosphate is usually not readily available for uptake in soils. Phosphate is only freely soluble in acid solutions and under reducing conditions. In the soil it is rapidly immobilized as calcium or iron phosphates. Most of the phosphorus in soils is adsorbed to soil particles or incorporated into organic matter (Smith, 1999; Craig *et al.,* 1982; Holtan *et al.*, 1988).

Phosphorus in freshwater and marine systems exists in either a particulate phase or a dissolved phase. Particulate matter includes living and dead plankton, precipitates of phosphorus, phosphorus adsorbed to particulates, and amorphous phosphorus. The dissolved phase includes inorganic phosphorus (generally in the soluble orthophosphate form), organic phosphorus excreted by organisms, and macromolecular colloidal phosphorus (Craig *et al.,* 1982). The organic and inorganic particulate and soluble forms of phosphorus undergo continuous transformations. The dissolved phosphorus (usually as orthophosphate) is assimilated by phytoplankton and altered to organic phosphorus (Craig *et al.,* 1982; Holtan *et al.*, 1988).

The phytoplankton's are then ingested by detritivores or zooplankton. Over half of the organic phosphorus taken up by zooplankton is excreted as inorganic phosphorus. Continuing the cycle; the inorganic phosphorus is rapidly assimilated by phytoplankton (Smith, 1999; Holtan *et al.,* 1988). Lakes and reservoir sediments serve as phosphorus sinks. Phosphorus-containing particles settle to the substrate and are rapidly covered by sediment. Continuous accumulation of sediment will leave some phosphorus too deep within the substrate to be reintroduced to the water column. Thus, some phosphorus is removed permanently from bio-circulation (Smith, 1999; Holtan *et al.*, 1988).

2.2: Environmental problems of phosphorus

Phosphorus occurs in natural water and wastewaters almost solely as phosphates (LVEMP, 2001). 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 water treatment, whereas larger amounts are added to water during laundry or other cleaning processes because they form major constituents of many commercial cleaning preparations (LVEMP, 2003). Phosphates are used extensively in the treatment of boilers water (Metcalf and Eddy, 1991). 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 (Madadi *et al.,* 2007).

Phosphorus is essential to growth of organisms but can be the nutrient that limits the primary productivity of water body. 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 (Metcalf and Eddy, 1991). The sources, dispersion, transport and fate of phosphorus in the environment are highly complex due to the complexity of its forms and inter-conversions in the solid forms. Inorganic phosphate levels in ocean waters and aerobic land waters may be in the order of tens of micrograms of phosphorus per litre, whereas in anaerobic waters and sediments (or anaerobic bottom waters in the lakes) they can reach hundreds of micrograms of phosphorus per litre (Metcalf and Eddy, 1991).

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 plants and algal growth, microbial breakdown and other processes such as mineralization may transform organic and complexes phosphate forms through various steps into the readily available inorganic phosphate form (LVEMP, 2002). Processes such as runoff, stream - flow and ground water flow transport most of the total phosphorus. Moreover, wind may also transport some components of the total phosphorus around the landscape (Madadi *et al*., 2007)

High phosphate concentrations in the aquatic system stimulate the growth of plankton and aquatic plant that act as food for fish. This increased growth of planktons my cause an increase in the fish population and improve the overall water quality. However, as the excess of phosphate enters the water ways ,algae and aquatic plant grow wildly, choke up the waterway, and use up large amounts of oxygen (LVEMP, 2003). 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 (LVEMP, 2001).

The main issues in 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 water borne diseases and trans-boundary water management concerns (Hecky, 1993). Currently the lake is the final destination of factory effluents, oil and grease, and sewage from the urban centers as well as oil spillages from the extensive transport activities within the Gulf (UNEP, 2005). Other major challenges of concern include the unsustainable population pressure around Lake Victoria basin (which is currently estimated at 30 million people), poor 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 fisheries resources and introduction of aquatic invasive alien species (UNEP, 2005).

The use of agrochemicals is currently increasing in the basin in areas where large scale farming of tea, coffee, cotton, rice, 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 1960s when anoxia was localized and sporadic (Talling, 1965; Talling, 1966; Hecky, 1993; LVEMP, 2000; 2002, 2003). Algal concentrations were noted to be three to five-fold greater on the surface water today than in the 1960s reflecting higher rates of photosynthesis (Migiddle, 1993).

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 Biomphaloria snail, causing schitosomiasis, but also a home for the vector mosquito for malaria, a haven of snakes, at the expense of commercial fish species (LVEMP, 2003). The eutrophication process is likely to accelerate production of anoxins in the lake water.

The bloom - forming species of cyan bacteria can also produce potent hepato - (liver) toxins termed microcystins known for poisoning domestic livestock, wildlife, and susceptible humans (LVEMP, 2000).

It is clear that human activities are contributing to the environmental changes in the Lake Victoria ecosystem including deterioration of water quality, accumulation of toxic chemical and increase in load agrochemicals resulting into eutrophication and loss of biodiversity. Proper identifications of the sources of phosphorus and the contribution of land uses practices to the influx of phosphorus into the drainage systems will help in controlling eutrophication of the lake ecosystem (Madadi *et al*., 2007). The main factor for eutrophication into the Lake Victoria is possibly due to discharge of phosphorus. Dennis (1968) found a linear relationship between phosphorus and chlorophyll: $\log_{10}[\text{chil}] = 1.583\log_{10}[P]-1.134$. Calamari *et al.* (1995) also noted that phosphorus is the limiting factor for primary production in Lake Victoria.

2.3: Phosphorus in the atmosphere

Concern has been raised about the contribution of atmospheric deposition to the nutrient flux of Lake Victoria. A few studies on the atmospheric deposition over the African great lakes have shown that atmospheric deposition is a significant source of total nitrogen (TN) and total phosphorus (TP) in the lakes and in fact by far the highest contributor of nitrogen and phosphorus on the lake surface (LVEMP, 2003). This has been made worse by the large destruction of soil cover as a result of changes in the land use system, improper agricultural practices and transport from other regions through regional land global air circulation. It is estimated that dry and wet total phosphorus account for 50% and 55%, respectively (Parrish *et al*., 1988).

The LVEMP (2001; 2002) estimated that nutrients input into Lake Victoria including atmospheric deposition contributed 102,000t/y of total N and 24,00t/y of total P. These values indicate that atmospheric deposition is by 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 60% total nitrogen and total phosphorus loading, respectively however, some local scientists have strongly disputed the figures attributed to atmospheric deposition (LVEMP, 2001).

Similarly the biodiversity conservation study done on Lake Victoria on the Tanzania side confirmed that atmospheric particulates might be the significant source of phosphorus and nitrogen to the lake (Machiwa and Tungu, 2005). However, there is no reliable empirical data to confirm the assertions. Atmospheric sampling has been done for dry and wet atmospheric deposition; the deposition rate of phosphorus from wet deposition depends on the land use and place of sampling. Dry atmospheric deposition increased progressively due to seasonal change, for example, higher levels of phosphorus are deposited during long dry spells than during short dry spells in Uganda (Machiwa and Tungu, 2005).

The importance of atmospheric deposition as a phosphorus source to aquatic ecosystem has been well documented (Tamatamaha *et al.*, 2005). This is partly because important intersystem exchange of phosphorus via the atmosphere and partly because of human activities releases pollutants that are comparable to or even exceed the natural rate of mobilization. There is very little work that has been done on atmospheric deposition and it is, therefore, important to monitor phosphorus deposition from the atmospheric environment around Lake Victoria especially on the Kenyan side of Lake Victoria.

Wet and dry atmospheric flukes of total phosphorus (TP) and soluble reactive phosphorus (SRP) measured at four sites over twelve months period were used to estimate lake side atmospheric phosphorus deposition to Lake Victoria. The highest loading rate of 2.7 (TP) and 0.8 (SRP) kg/Ha^{-2}year^{-1} were measured at Mwanza compared to less than 1.9 (TP) and 0.65 (SRP) kg/Ha^{-2}year^{-1} measured in other sites. By applying these loading rates to the lake surface, it was estimated that 13.5 tones (13.5 x 10^{3} kg) of TP were deposited annually into the lake from the atmosphere (Rashid *et al.*, 2002).

Other studies done on other lakes showed that the atmosphere always contain some algae, viruses, bacteria, etc, which have been eroded or ejected into the atmosphere, as well as large amount of pollen during some seasons. The organisms and the pollen can be expected to have phosphorus concentration of about 0.2% (Maclntyre, 1968). Has shown that breaking bubbles at the surface of the ocean ejects materials from the uppermost layers into the atmosphere. Baylor *et al.* (1962) and Maclntyre *et al.* (1969) have shown that the spray is probably quite enriched in phosphorus. This would be an input which could correlate with the sea salt input from the atmosphere. If phosphorus containing particulates matter is enriched in the atmosphere several times before being permanently scavenged, this has serious implications on water bodies. This is because the surface of water bodies are sinks of particulate matters.

Reports from Murphy and Riley (1962) on phosphorus input from the atmosphere and their significant entry into oligotrophic lakes indicates that in Chicago the particulates in the atmosphere contains about 0.1% phosphorus. This particulate matter, when scavenged from the atmosphere by precipitation can be an important component of phosphorus budget of natural water bodies.

A number of investigators have attempted to assess the atmospheric contributions of phosphorus to water bodies. Cowen *et al.* (1976) conducted bioassays with *Selenastrum* on particulates from three samples of Madison. The total soluble Phosphorus concentrations were the same as the dissolved reactive Phosphorus level. Less than 25% of the particulate Phosphorus in these snow samples was available to *Selenastrum* in 18 days. Samples from various locations within New York State, contained small amounts of dissolved reactive phosphorus, compared to the total soluble phosphorus. Bioassays with *Selenastrum* on the total sample showed that in only three samples was the algal available phosphorus more than 10% of the total phosphorus concentration. In 12 of the samples, the percent algal available phosphorus was less than the percent dissolved reactive phosphorus.

Brezonik (1995) has reviewed the literature on atmospheric contributions of a variety of chemicals and found that ortho-phosphorus is typically in the order of 0-0.005 mg P/L, and total phosphorus in the order of 0.02-0.15 mg P/L. He also reported on the concentrations of phosphorus in rainwater collected from stations near Gainesville, Florida to have total phosphorus range from 0.02 to 0.65 mg P/L and ortho-Phosphorus from 0.004 to 0.043 mg P/L; soluble ortho-Phosphorus ranged from 7 to 66% of the total phosphorus.

Murphy and Doskey (1975) evaluated the phosphorus in rainwater collected from a top 10 m high building in a densely populated urban Chicago area. Air particulates were also collected using a high volume air sampling pump. The average concentrations of total Phosphorus in rainfall were found to be 0.034 mg P/L, and soluble orthophosphate was 0.012 mg P/L. Concentrations were found to be higher in lower volume rainfall events and lower in higher volume events. Concentration in eight snowfall samples ranged from 0.016 to 0.054 mg P/L, and 0.006 to 0.196 mg P/L for "orthophosphate" (assumed to be determined on unfiltered sample), with most concentrations in the 0.02 to 0.05 mg P/L range.

Peters (1977) collected eight rainwater samples, six samples of rainwater plus dust fall, and one snow sample from a pasture-forest area above the eastern shore of Lake Memphremagog, near Montreal, Canada. The samples were analyzed for total phosphorus (TP), soluble phosphorus (SP) and soluble reactive phosphorus (SRP). Although these samples were frozen prior to analysis, the author indicated that this type of preserving did not affect the integrity of Lake Memphremagog samples evaluated. He did not, however, evaluate the reliability of this preservation technique for their atmospheric samples. Using radiotracer techniques, Peters (1977) concluded that on the order of 38% of the atmospheric phosphorus was exchangeable, which he equated with being available for algal growth. A total of 188 precipitation samples were collected from six locations around Lake Michigan and analyzed for total Phosphorus by Murphy and Doskey (1975); 131 of these were also analyzed for dissolved reactive phosphate. Weighted (unclearly defined) average total phosphorus concentrations for the six stations ranged from 0.016 to 0.036 mg P/L; weighted average dissolved reactive phosphorus ranged from 0.006 to 0.014 mg P/L. The higher concentrations were typically found at the stations at the south end of the lake. On a station wide average, soluble orthophosphorus ranged from 30 to 56% of the total phosphorus concentration. A series of 23 rainfall samples was chemically fractionated further to determine the amount of hydrolyzable, organic and total reactive phosphorus in the samples.

The weighted average dissolved reactive phosphorus was 0.01 mg P/L; hydrolyzable (less dissolved reactive P), 0.0044 mg P/L; organic phosphorus, 0.009 mg P/L; and total reactive, 4.68 mg P/L. Twenty-two snow samples from four of the above cited locations were also analyzed by Murphy and Doskey (1975). Total phosphorus ranged from 0.07 to 0.058 mg P/L (mean 0.026 mg P/L) and dissolved reactive phosphorus from 0.002 to 0.024 mg P/L (mean 0.007 mg P/L). On a per sample basis, soluble reactive phosphorus was 39% of the total phosphorus. In a number of samples, the total reactive phosphorus concentration was considerably greater than the dissolved reactive phosphorus. Murphy and Doskey (1975) concluded that 50% of the total phosphorus present in precipitation is a reasonable estimate of the amount of phosphorus that will ultimately become available, although they did not conduct any bioassays to substantiate this conclusion.

From the above discussion it is clear that atmospheric deposition contribute phosphorus in the environment. It is therefore necessary to determine its contribution to the high levels of phosphates reported in Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant in Kenya.

2.4: Phosphorus in Water

Primarily biological processes contribute to formation of organic phosphates (Metcalf and Eddy, 1991). Polyphosphates enter sewage water through body wastes and food residues (Alloway, 1995b). They may also be formed from orthophosphates in biological treatment processes and receiving water organisms. Like polyphosphates, they are biologically transformed back to orthophosphates. Phosphates are typically present in raw waste water at concentrations of close to 10 mg/l as P (Free drinking water. com, 2009). During waste water treatment about 10-30% of the phosphates in raw waste water are utilized during secondary biological treatment for microbial cell synthesis and energy transport. Addition removal is required to achieve low effluent concentration levels from the waste water treatment processes. Effluent limits are usually from 0.1-2 mg/L of P, with many established at 0.8 mg/l (KEBS, 1996). Removal processes for phosphate from waste waters utilize incorporation into suspended solid and the subsequent removal of those solids (Free drinking water. com, 2009) which form sludge and finally biosolids.

There are higher loads of phosphorus in Kisumu region of Lake Victoria as compared to Uganda and Tanzania (Kayombo and Jorgensen, 2006). (Table 1). This is due to more industrialization around Winam Gulf, with large tea, rice and sugar farms (Oguttu *et al.*, 2008).

Table 1: Phosphorus loading into Lake Victoria due to waste water and runoff

Country	**T-P(t/y)**
Tanzania	292
Kenya	848
Uganda	484
Total	**1624**

Source: Kayombo and Jorgensen 2006

Rainfall can cause varying amount of phosphorus to wash off from farm soils into adjacent waterways. Phosphates will stimulate the growth of plankton and aquatic plants which acts as fish food. This may cause an increase in the fish population and improve the overall water quality. However, if an excess of phosphate enters the waterways; algal plants will grow wildly, choke up waterways and use up large amount of oxygen. This condition is known as eutrophication or over fertilization of receiving waters. This rapid growth of aquatic vegetation eventually dies and as it decays it uses up oxygen. This process in turn causes the death of aquatic life because of the lowering of dissolved oxygen levels (LVEMP, 2003).

The addition of phosphates through anthropogenic activities can accelerate the eutrophication process of nutrient enrichment that results in accelerated ecological aging of lakes and streams (LVEMP, 2003). Phosphorus, especially in inland waters, is often the nutrient that limits growth of aquatic plants. Critical levels of phosphorus in water above which eutrophication is likely to be triggered are approximately 0.03 mg/L of dissolved phosphorus and 0.1 mg/L of total phosphorus (USEPA, 1979). The discharge of raw or treated waste water, agricultural drainage, or certain industrial waste containing phosphate to a surface water body may result in a highly eutrophic state, in which the growth of photosynthetic aquatic micro and macro organisms are stimulated to nuisance levels (Free drinking water. com, 2009).

About 25% of the total phosphorus in settled sewage is present as orthophosphate such as PO_4^{3-} HPO_4^{2-}, $H_2PO_4^{2}$ which are available for immediate biological metabolism. Therefore, in terms of utilization both in the treatment plant and subsequently in the receiving waters, it is the organic phosphate concentration that is important rather than the total phosphorus concentration. After secondary treatment, about 80% of the total phosphorus in the final effluent is in the orthophosphate form. The average phosphorus concentration in sewage range from 5-20 mg/L as total phosphorus (Ramadori, 1987) of which 1-5 mg/L is of the organic fraction and the rest inorganic.

A previous study conducted by LVEMP to establish the levels of nutrients in the lake gave critical values with nutrient loading from the urban areas amounting to 6,955t BOD/y, 3028t total-N/y and 2686 t-Total P/y (LVEMP, 2001; 2002). However, this only included the pollution loading from the urban areas close to the lakeshore without consideration of 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 catchment areas to the lake contributing to more turbid and shallow points that are currently observable at their outlet than other parts of the lake (Madadi *et al.*, 2007). Municipal waste water consists of sewerage effluents, urban drainage and other collected wastewater. This usually contains high levels of organic matter and feacal material and depending on the treatment system; municipal waste water may contain various other organic and inorganic contaminants of industrial origin (Mason, 1981). In addition, garbage dumpsites contribute various pollutants into the surface and ground water.

Municipal point sources release higher organic and nutrients load than industries in the catchments. Kisumu Conventional Works can be considered as a hot spot with a mean final effluent BOD of 181 mg/L and final effluent of mean BOD 30 mg/L. Since most waste water facilities are in poor state the final effluent being discharged into the water does not meet effluent discharge guidelines (Abila *et al.*, 2005). Municipal waste water contains human excreta and detergent residues thus discharge of inadequately treated effluents into the lake introduces phosphorus into the water. It is estimated that 2 g of PO_4^{2-} in inorganic or organic form is excreted per person per day partially in urine and in feaces (Golterman, 1993). In urban centers each person contributes 2 g of tri-phosphate phosphorus from detergents per person per day which hydrolyses to PO^{4-} and becomes bio-available to plants (Van den Bosch *et al.*, 1998). The nutrient loading to the Winam Gulf was calculated and estimated using recorded amount of fertilizers used in the catchment areas, and decomposition of biomass (Van den Bosch *et al.,* 1998). The sugar based industries and pan paper mill off load their effluents into rivers and air within the catchments. The nutrient does not only come from the industries but also from municipal effluents and other agricultural activities like livestock farming in the catchment areas (Van den Bosch *et al.,* 1998).

Pulp and paper waste water contains both organic and inorganic nutrients. The organic nutrients include toxic substances such as phenols, resin and organic acids. Such substances act as biocides and are likely to adversely affect benthos and other aquatic organisms in the receiving stream. Pan paper's waste treatment facility has a mean BOD of 48 mg/L but realizes enormous quantity (mean of 35,000 m^3/day) that is high organic load with high COD load of 16291 kg/day (Abila *et al.*, 2005). This is indicative of a potential source of phosphorus as constituent of cells of plants. The wastes generated from sugar comprise bagasess, oil, mud, molasses and some sugar losses during production. Most of the factories in the catchments use waste sugar losses during production. Most of the factories in the catchments use water stabilization lagoons. Both Mumias and Webuye factories have aeration ponds. Sugar contains organic phosphates like glucose 6-phosphate, phospholipids and pigments.

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. While perennial horticultural areas are generally well managed with perennial cover and runoff control, many other areas with annual crops (e.g. maize) do not maintain ground cover throughout the year. Thus Majiwa e*t al.* (2001) reported that soil erosion losses are highest for annual crops and lowest for coffee and bananas. In addition cropping areas often extend down to stream and Lake Victoria edges, eliminating riparian buffering vegetation (wetlands) .Forested areas surrounding the lake and rivers have been cleared for settlements and agricultural activities (Majiwa e*t al.,* 2001). These poor land management practices have resulted in severe soil erosion (Scheren *et al.,* 2001) resulting in high impact on nutrients loading into the lake, thereby contributing to eutrophication. The annual increase in cultivated land is 2.2%, while overgrazing by 1.5 million cattle and 1.0 million goats exceeds the sustainable grazing rate by a factor of 5. The resulting influence of these factors on eutrophication of lake Victoria reveals itself through two main pathways; namely increasing soil erosion nutrient runoff and leakages to surface waters and increasing nutrient release to the atmosphere from animals and biomass burning and their consequent deposition to surface water. The phenomena not only cause the turbidity observed in Lake Victoria but also the transport of nutrient (e.g. phosphorus) and contaminants (e.g. agricultural chemicals) into the lake. Whereas high turbidity in Winam Gulf is caused primarily by increased siltation from rivers, the increasing turbidity in the main body of the lake is coused by high chlorophyll (a) concentration (Scheren *et al.,* 2001). The other source of nutrient loading comes from the use of fertilizers and the estimates using recorded amount of fertilizers used in the catchment area, calculated maximum nutrient loads in tons/year is 6018 due to phosphates (Table 2) (Jondiko, 2000)

Table 2: Estimated total nutrient load into water course of Winam Gulf - catchment area (tons/year) due to fertilizer use.

Nutrient	Maximum Recommended	Rectified Maximum	Rectified Minimum	Total
P_2O_5-input field	60,392	22,075	5,326	24,940
P_2O_5-input in Rivers	7,850	2,865	692	6,018

Source: Jondiko, 2000.

Several research works have been done on phosphorus in Lake Victoria. Madadi *et al.* (2007) indicates that the main sources of phosphorus load into the Kenyan part of Lake Victoria drainage system are water from both rivers and lake shores. Water from rivers, municipal waste, industries and lake do contain phosphorus levels higher than the recommended guidelines for aquatic life. The total seasonal averages of total phosphorus in the water are 4.61, 3.43, 2.45 and 2.30 mg/L for wet, short rain and dry season, respectively. Whereas the total reactive phosphate have means of 2.22, 2.08, 1.12 and 1.61 mg/L respectively in the same season (Madadi *et al.,* 2007), the project report on integrated water quality/limnology. The report did not handle course effect in the rivers as they flow into Lake Victoria (LVEMP, 2002) indicates that Kisumu bay of Winam Gulf and open Lake Victoria. Odada *et al.* (2004) indicates that the number of people without sewerage facilities in urban population is high and with an urban population growth rate of over 5-10% per year in larger cities Odada *et al.* (2004). The root causes of microbiological pollution is due to the treatment works in municipalities as they are either inadequate or are using old and absolute technology. Poor planning, lack of maintenance and inadequate investment in municipality waste water treatment systems have contributed to the increased untreated effluent discharge. Soaps and detergents that are being used within the basin are also contributing to eutrophication. Two surveys done in Lake Victoria basin revealed that deep and shallow areas of satellite lakes had varying nutrient levels. In deep waters PO_4^{3-} levels ranged between 0.171-0.225 mg/L, 0.067-0.364 mg/L and 0.043-0099 mg/L in Lake Victoria (Kulekana, 2004). A comparative limnological data since 1966 indicate data increase in phosphorus level (Table 3). This is apparently due to increased agricultural and industrial activities in the Kenyan gulf.

Table 3: Special comparative phosphorus of Winam Gulf.

Year/Nutrient	**1966**	**1977**	**1979**	**1990**	**1994**
PO_4^-P in mg/L	7-120	0.1-122	-	0.1-19	1-227.6
Kibos River mouth	10-120	0.5-122	0.16-18	1-30	0-2038.4
Nyando River	4.8	0.2-3	0.1-7.6	0.6-7.2	0-87.75

Source: Jondiko, 2000.

2.5: Phosphorus in sediments

Sedimentation is a major threat to surface water bodies such as lakes and rivers where the eroded soil from hill slopes are finally deposited. The nutrient loads transported by the rivers to Lake Victoria influenced by elevated human activities in the catchment drainage areas, and river discharges cannot be ignored any more. Suspended sediments act as a media of transport for nutrient accelerating the rate of nutrient accumulation on the surface (Chin gong and Michael, 2000). The phosphates that occur in the bottom sediments and biological sludge are precipitated into inorganic forms and incorporated into organic compounds. Phosphorus exists in sediments as a soluble anion (orthophosphate, PO_4^{3-}), a precipitated phosphate salt, or as part of a mineral or organic compound. Possible phosphate minerals in lake sediments include: stregnite [$FePO_4 \cdot 2H_2O$], vivianite [$Fe_3(PO_4)_2 \cdot 8H_2O$], hydroxyapatite [$Ca_5(PO_4)_3(OH)$], monelite [$CaHPO_4$], and variscite [$AlPO_4 \cdot 2H_2O$] (Bostrom, 1988; Sondergaard *et al.*, 2003; Christophoridis and Fyiantos, 2006). Internal loading occurs when conditions within sediments of a lake allow for P and N release into the water column, thereby increasing the TP (specifically available or reactive P (RP)) and TN of the water column, regardless of external loading. Penn *et al.* (2000) estimated internal loading can contribute up to 80% of the TP input of a lake under specific circumstances.

According to (Mwiriri *et al.*, 2005) the current annual sedimentation rate of Lake Victoria is the same order of magnitude as modeled for 1978, and comparison with calculated net deposition rate shows that 4% of phosphorus is permanently buried (COWI, 2002). However, (Swallow *et al.*, 2000) showed that settling rate at the river inlet in the catchment area was 1.0 cm/y, indicating a high accumulation of sediments of the lakeshore. A report by Gikuma *et al.* (2009) states that longitudinal gradients of sediment total phosphorus and its fractions in the Winam Gulf is result of high rates of terrigenous input and re suspension and transport of light phosphorus rich inorganic and organic matter towards the main lake. Total phosphorus in sediments range from 812.2 to 1.738 mg/kg dry weight and is highest in Rusinga channel. According to Tamatamaha *et al.* (2004) rivers Simiyu and Kagera released 28.65 + 0.89 and 66 tons of SRP, respectively to Lake Victoria. Studies done by Madadi *et al.* (2007) indicate that sediments of rivers from the southern catchment of Lake Victoria had high levels of phosphorus concentration. The highest bio available phosphates detected in rivers during the rainy season was 28.94 followed by 27.76 and 26.69 and 24.43 mg/kg detected in samples from Rivers Nzoia, Yala, Mugruk and Kuja respectively.

The levels of phosphorus collected from the lake samples were higher than those detected in river samples. With the highest of 56.61, 52.83 and 24.24 mg/kg detected in sample from Sio Port Victoria and Usenge, respectively. This showed that the levels of phosphate detected in the lake samples were higher than those of river samples. Excess phosphorus can be buried into the sediments of a certain extent before significant eutrophication occurs. Typical over 50% of external phosphorus lead to water bodies retained by the sediment. This varies widely with the characteristics of the water shade and receiving lake but can be up to 90% retained by the sediment (Lijklema, 1986). Sonzogni *et al.* (1982) defined biological available phosphorus as the amount of inorganic phosphorus phosphorus – deficient algal community can utilize in a time period exceeding 24 hours.

Phosphorus is then excreted as fecal pellets waste by primary and secondary consumers. Primary and all secondary contribute to phosphorus flow when they die and settle on the bottom and undergo decomposition. This indicates that sediments might be acting as sinks for the phosphorus load from the catchment area. However, there is very little work done on the contribution of the phosphates settled in sediments and their possible mobility from upstream to Lake Victoria in Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plants in Kenya. The fairly upper catchment of Winam Gulf rivers add to erodability. Chakela and stocking (1988), observed that the slops and rainfall are the dominant factors that largely explain the variation of soil erosion.

Destruction of soil cover in the catchment adds to this problem. Lamb (1999) reported that some fertilizers applied to agricultural lands is transported into streams by runoffs and sometimes represent up to about 80%. Mason (1981) showed that the loss of phosphates by leaching from agricultural land is very small, so the input into rivers is largely by erosion. Aquatic organisms are comprised of phosphorus containing macromolecules such as nucleic acids (DNA and RNA), phospholipids membranes, and phosphate monoesters which enter the organic phosphorus pool upon death of the organism (Wetzel, 1999). Studies have shown that total organic Phosphorus constitutes about 1/3 of the TP in lake sediments (Wetzel, 1999; Williams and Mayer, 1972; Bostrom *et al.,* 1982). However, the content varies among sediments according to the lakes morphology, hydraulic loadings, hydrodynamics, trophic state, and other factors (Wetzel, 1999).

When assessing nutrient availability within natural systems, organic forms of phosphorus, such as inositol phosphates, are often considered immobile, refractory, or bio-unavailable. This is mainly because they do not react with molybdate, used in a colorimetric test that determines the concentration of bio-available Phosphorus, or soluble reactive Phosphorus (McKelvie, 2007). However, sediment bacteria and micro algae enzymatically hydrolyze terminal phosphate groups of exogenous compounds such as glycerol-phosphate, adenosine $5^{“}$-monophosphate (AMP), guanosine $5^{“}$-monophosphate (GMP), adenylic acids, phosphonate compounds, and others (Wetzel, 1999; Cambella *et al.*, 1984a). This mineralization process involving different phosphate compounds, and the resulting release of inorganic phosphate plays an important role in the Phosphorus cycle by contributing to the bio-available Phosphorus pool; an aspect that is not well characterized in lake sediments. Additionally, bacteria and algae are able to directly utilize dissolved (Bentzen *et al.,* 1992; Cotner and Wetzel, 1992). The bioavailability of organophosphates or the potential for organophosphates to be transformed into more bio-available forms is dependent on biogeochemical reactions, mobility, and speciation within the sediment; all of which may be different in comparison to orthophosphate mobility and bio-availability.

Of the three primary nutrients (P, N and C), phosphorus is the scarcest in natural environments. Weathering of phosphorus-containing rocks, agricultural and urban drainage, decomposition of organic matter and atmospheric dust are the principal mechanisms for phosphorus to reach aquatic environments (Cotner and Wetzel, 1992). There are several mechanisms that transfer phosphorus from water to the sediments: sedimentation of suspended particles brought by water feeding the pond, sedimentation with allochthous or autochthonous organic material, assimilation of phosphorus in the water column by plankton or other biota, sedimentation of dead organisms and direct adsorption from sediments (Knud-Hansen, 2002).

The organic form of Phosphorus consists of dissolved organic molecules such as polypeptides, enzymes, adenosine tri-phosphate and organophosphates released into the water through decomposition, excretions and form of secretions from algae and the rest of the aquatic community. Inorganic phosphorous in mud occurs as calcium, iron and aluminium phosphates. In acidic soils, aluminium ions occur in fairly high concentrations and react with phosphates. At the same pH, there are several orders of magnitude more aluminium than ferric ion in aerobic mud. Therefore, phosphate first reacts with aluminium, but the existence of iron phosphate in the mud suggests that some aluminium phosphate is transformed to iron phosphate (Knud-Hansen, 2002).

Phosphorus present in pore water is termed inerstol phosphorus, and phosphorous absorbed to the particles is particulate phosphorus. Distinction between the two is arbitrary and is made by filtration through a membrane of 0.45- μm pore size. The filterable material is defined as dissolved and the retained material as particulate. Phosphorus is soluble and is the most reactive species of phosphorus in sediments. The portion of soluble phosphorus in pore water is small; estimated to be 1% compared to particulate phosphorus and is about 5 to 20 times more concentrated than in pond water (Delince, 2000). The concentration of interstitial phosphorus is sensitive to changes in the environment and changes during the year. Highest concentrations are recorded when sediments are oxygenated and occur in the soil are as a result of microbial activity, reacting to changes in the availability of organic matter. Orthophosphate is the dominant form of phosphorus in the upper layer of sediments, while in deeper layers, has phosphorus bound in various chemical compounds (Delince, 2000).

The largest portion of phosphate in soil originates from decomposition of organic matter and from fertilisation of the pond. The contribution of phytoplankton to organic loading depends on the natural productivity of the pond, and on the amount of grazing upon phytoplankton.

Decomposition and release of phosphate from organic matter is a function of temperature and activity of micro organisms (Delince, 2000). Immobilization of phosphorus in soil is the result of sorption. Sorption is the removal from solution to a solid phase and involves binding at fixation sites on the surface of colloids. Decomposition of organic matter releases carbon dioxide and phosphate, which raises the concentration of free phosphate and increases the concentration of phosphate absorbed. As a result of sorption onto sediments, phosphorus accumulates and is trapped in the soil (Delince, 2000). Phosphorus is immobilized in sediments because surface sediments act as a barrier to exchange between water and sediments.

The transformation of organic matter in sediments results in a transfer of detrital phosphorus, via living biomass to the pool of interstitial or labile phosphorus. The effects of the mobilization process on phosphorus depend on the state of organic matter sedimenting on sediments and the prevailing type of transformation, the initial content of the organic matter and the C/N ratio of the settling organic matter, the concentration of interstitial phosphorus and the saturation percentage of sediments with regard to phosphorus, the sedimentation rate of phosphorus and environmental conditions such as temperature, redox potential and dissolved oxygen concentration (Delince, 2000). The amount of phosphorous entering ponds from natural sources, including release from the pond sediments, is usually small even in highly productive ponds. Phosphorous in manure is released when bacteria degrade manure (Delince, 2000).

Movement of groundwater promotes the diffusion of phosphate. Sediments release phosphate when the movement of water is either upward or downward. Benthic organisms also transport phosphorus. When sorbed to detritus, phosphorous is temporarily immobilized. Consumption of detritus by detritivorous organisms results in its exportation from the sediments. Part of the phosphorus ingested by these organisms is assimilated and the other part is excreted. This bio-detritic phosphorous is therefore more mobile than when sorbed in colloids. When large amount of phosphorus are immobilized in the soil, the ability of the sediment to remove inorganic phosphorus from the water is decreased and each addition of phosphorus through fertilization is more available for production (Delince, 2000).

Much emphasis has been placed on the quantification of phosphorus in water due to its fundamental importance as a plant nutrient and major cellular constituent (McKelvie *et al.*, 1995). The speciation of Phosphorus is quite complex, and for analytical purposes, four operational categories are commonly used to characterize phosphorus (Anderson *et al.*, 2002). These are: dissolved reactive Phosphorus (DRP), dissolved non-reactive Phosphorus, particulate reactive

Phosphorus, and particulate non-reactive Phosphorus. These fractions are partitioned with dissolved Phosphorus passing through a 0.45 µm filter, and reactive Phosphorus determined via a colorimetric reaction with acid-molybdate. (Anderson *et al.*, 2002). But this classification scheme does not necessarily correspond to the role these forms play in the biotic cycling and utilization of Phosphorus (Anderson *et al.*, 2002).

The use of chemical approaches to estimate eutrophication risk is problematic for management purposes as this approach does not actually estimate the amount of Phosphorus that is biologically available to support phytoplankton and bacteria growth (Ekholm and Krogerus, 1998; Gerdes and Kunst, 1998). Bio-available Phosphorus (BAP) is the component of total phosphorus which supports the growth of algae or other organisms (Bostrom *et al.*, 1988). Previous studies have indicated that BAP rather than TP or DRP provides the most accurate measure of water quality conditions in lake systems (Butkus *et al.,* 1988; Gerdes and Kunst, 1998). Numerous approaches have been applied to estimate BAP, including bioassays (Bostrom *et al.,* 1988; Abrama and Jarrells, 1992), ion-exchange resin-impregnated membranes and NaOH and NH_4F based chemical extractions (Sharpley, 1993a).

Previous studies have shown that algal bioassays are the most reliable technique for quantifying BAP (Twinch and Breen, 1982; Ekholm and Krogerus, 2003). In batch assays, algae and the sample are directly mixed, thus allowing the activity of surface-bound algal enzymes to release particulate organic phosphorus (Reynold and Davies 2001). Many studies suggest that Phosphorus availability may vary between different sources of waters as a function of their physical, chemical and biological conditions (*Morse et al.,* 1998; Christen, 2007). Because of concern for the eutrophication problems caused by wastewater discharges (Morse *et al.*, 1998), considerable effort is now being devoted at the national scale towards advanced Phosphorus removal one of the most important questions associated with these efforts is how these advanced nutrient removal processes affect the speciation and in particular the bioavailability of Phosphorus for phytoplankton and planktonic bacteria (Neethling *et al.*, 2010). Understanding of these questions is critical to ongoing efforts to control the negative consequences of widespread eutrophication on surface water bodies.

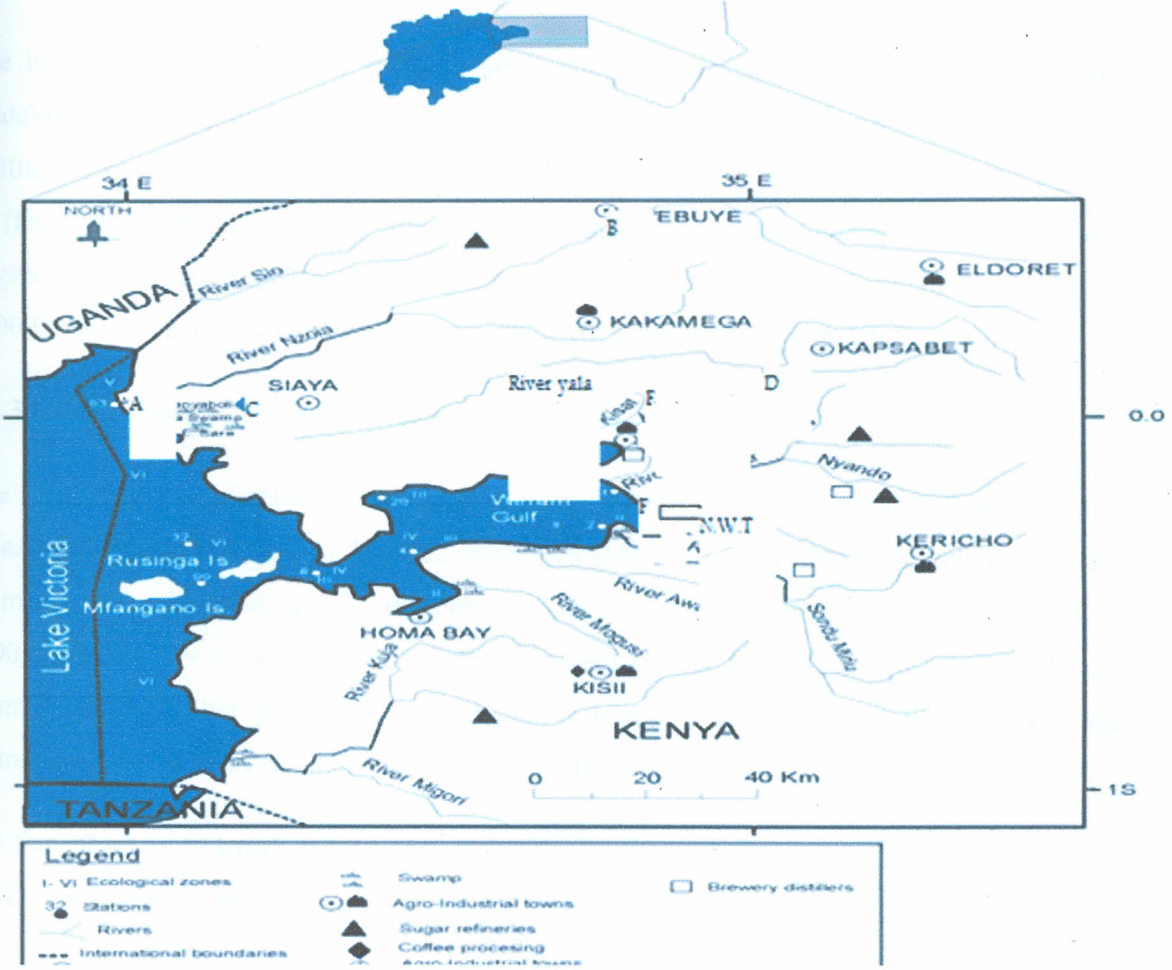
CHAPTER THREE

3.0: METHODOLOGY

3.1: Sampling Sites.

The study area comprised of downstream and upstream of Rivers Nzoia, Yala, Kisat and Nyalenda lagoons (Figure 1). The selected areas have farming activities, waste water treatment plants and factory activities which are likely to generate high level of phosphorus in the surrounding waters.

Figure 1: Map of Winam Gulf showing Rivers Nzoia, Yala, Kisat and Nyalenda Lagoons



A = River Nzoia downstream
B = River Nzoia upstream

C = River Yala downstream
D = River Yala upstream
E = River Kisat downstream
F = River Kisat upstream
G = in let Nyalenda Lagoon
H = out let Nyalenda Lagoon

Source: School of Environmental and Earth Sciences, Maseno University, Kenya.

3.2: Materials and Methods.

3.2. 1: Chemicals.

The chemical used were purchased from Kobian Kenya LTD, the analytical grades were concentrated 98% sulphuric acid H_2SO_4, 98% nitric acid HNO_3, ammonium persulphate $(NH_4)_2S_2O_8)$, 98% potassium persulphate $K_2S_2O_8$, 99% sodium hydroxide NaOH, 32% hydrochloric acid HCl, 98% sodium chloride NaCL, 98% magnesium chloride $MgCl_2$, enophothalin indicator $C_{20}H_{14}O_4$, ammonium Molybdate $(NH_4)_2MoO_4)$, 99% ammonium vanadate($NH_4)_3VO_4$.

3.2.2: Instruments.

The instruments used include: sediment grab sampler, undersurface water sampler (locally made) (Bowa, 2008), buckets for air sampling (localy made) (Machiwa and Tungu, 2005). (SF-C 30K W) Sanyo deep freezer, China; UNB 200,Germany,Memmert oven, analytical balance PI (fisher scientific A-16, USA) micro-Kjeldahl flask, Spectrophotometer CE 393, England, Digital Grating spectrophotometer (690 nm), H400-HS Hot plate, Lab depot Inc-USA, BT 3000 Orbital shaker Lab depot inc - USA, 18020AQ.Analog water bath, USA.

3.2.3 Glass wires and other Materials.

The glass wire used included: Erlenmeyer flask 125 mL, 250 mL, conical flask 125 mL, Measuring cylinders 10 mL to 200 mL, Micro-Kjeldahl flask, digesting rack, volumetric flask 10 mL to 200 mL, glass scoop, and pipette bulb, 2 L amber glass bottle, beakers 50 mL to 1000 mL and other materials included :Safety shield, Safety goggles, stilled water, 0.45- µm membrane filter, filter photometer, watch clock, labels, poles, ice –cold box, a pistol and motor, 45- µm mesh sieve, aluminum foil and writing materials.

3.3: Sampling and sample treatment.

3.3.1: Atmospheric Sampling

Sampling was done for wet and dry atmospheric deposition. Dry atmospheric deposition sampling was done during dry season (August – September 2008) and wet atmospheric deposition sampling during wet season (March - May 2009). Two buckets each measuring (30 cm diameter and 33 cm height) were cleaned with hydrochloric acid. Each of the buckets was placed on 1.5 m high flat surface supported by a pole and left for 24 hours. For wet deposition the volume of water collected was measured and recorded. The sample was poured into acid rinsed amber-glass of bottles 2 L capacity preserved with hydrochloric acid and labeled (ALPHA, 1995). For dry atmospheric deposition sampling, watman filter paper No. 42 was placed in the bucket with 1 L of water as an adsorbent and after sampling distilled water was added to restore the volume lost as a result of evaporation. Each sample was put in acid rinsed amber bottle of 2 L and preserved with nitric acid, labeled and transported to the laboratory for analysis.

3.3.2: Water Sampling

Replicates of 1 L water samples were collected from one meter depths using weighed clean amber-glass bottles 3 L capacity with small mouth (2-3 cm inside diameter). To each of the 1 L of water sampled 1 mL of HCL acid was immediately added and the bottle capped, labeled and stored in ice-cold box before being transported for refrigeration at 4°C (Nichole and Mason, 2001).

3.3.3: Sediment Sampling

Replicates of surface sediment samples were collected from both upstream and downstream of Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant in Kenya using a grab sampler from 5 cm bellow sediment surface respectively and dried at room temperature then ground by a pestle and motor in order to normalize for variations in grain size distribution according to procedures of Bowa (2008). It was then sieved through a 45μm mesh sieve, stored in aluminum foil sprinkled with hydrochloric acid solution 1:1 and frozen ready for digestion.

3.4: Determination of total phosphorus in atmosphere.

Digestion of total phosphorus in atmosphere was conducted using per sulphate (ALPHA, 1995; Madadi *et al.,* 2007). To 50 mL of sample were added 0.05mL phenolphthalein indicator and the red color discharge 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 per sulphates and boiled on a hot plate for 90 minutes. The digest was treated with 6 N sodium hydroxide solution until faint pink color was observed and then discharge by adding drops of 1:1 hydrochloric acid solution before dilution to 100 mL. One milliliter of 1:1 hydrochloric acid solution with deionized water was added to all the samples and total phosphorus determination conducted using the stannous chloride method. Absorbance was quickly read at 690 nm against a blank reading of distilled water in a CE 393 Digital Grating spectrophotometer. The total phosphorus was calculated at 690 nm (ALPHA, 1995)

3.5: Determination of total phosphorus in water.

Water sample digestion was carried out according to the procedures described in Anill's book for total phosphorus (Anil, 1994). Under this method, a volume of 100 mL of water sample in a beaker was digested at 150 ^{O}C with 1 mL concentrated sulfuric acid (H_2SO_4) + 5 mL concentrated nitric acid (HNO_3) and evaporated to dryness. The residues ware leached with 5mL 1 N nitric acid and transferred into to a 50 mL volumetric flask. Five milliliter of 10% ammonium molybdate was added and then 5ml of 0.25% ammonium vanadate in 6 N hydrochloric acid added. The mixture was diluted to the mark with distilled water and left to cool for 10 minutes. Absorbance was measured using an ultra violet spectroscopy (UV-1650 PC-UV-vis spectrophotometer Shimadzu) machine of yellow reaction product, vanadomolybdophosphate at 460 nm. Absorbance of a blank and standards (prepared from a solution of phosphate 220 g KH_2PO_4/L) (1 mL = 50 μgPO_4) carried out through the sample steps were measured. A calibration curve was prepared and total phosphorus concentration deduced directly from the machine.

3.6: Determination of total phosphorus in sediments

3.6.1: Sediment exchangeable phosphorus

Sediment exchangeable phosphorus was determined using the method by (Haggard *et al.*, 1998; Madadi *et al.,* 2007). Approximately 10-30 g of pre-sieved (45 μm mesh) sediment 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. A volume of 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 to the mark with distilled water in the volumetric flask. Absorbance measurements were taken after 15 minutes at 470 nm for sediment exchangeable phosphate determination.

3.6.2: Sediment bio-available phosphorus

Sediment bio-available phosphorus was determined using Sonzogni *et al.* (1982) method. Wet sediment was dried and seived using 45 μm mesh. 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 orbital shaker for 1 hour. Incubation was done as per (Butkus *et al.,* 1988;

Dorich *et al.,* 1980). Samples were incubated at 24±2^{O}C under continuous fluoresent lighting of 4300l m±10% in a horizontal shaker at 110 rpm for 14 days. The 14 days incubation period is based upon the maximum growth potential for the study of algae in Laboratory conditions (APHA, 1998). 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 to the mark with distilled water. Absorbance measurements were taken after 15 minutes at 470 nm for sediment bio-available phosphate determination and concentration of phosphate detarmined.

3.7: Statistical analysis

Measures of central tendency were determined using the MSTAT-C program. Completely randomized design three factor and Student t-test methods were used to determine the least significant difference.

CHAPTER FOUR

4.0: RESULTS AND DISCUSSION

4.1: Total phosphorus in atmospheric air

Dry and wet atmospheric depositions collected in the year were used to test for the null hypothesis. The result for atmospheric air samples shows that River Nzoia had the highest mean location while River Kisat had the lowest mean location of total phosphorus concentration (Table 4). There was significant difference $P \leq 0.05$ in the locations. The downstream river course atmospheric air had higher levels of total phosphorus concentrations compared to the upstream. Dry season phosphorus level was higher than wet in all the locations (Table 4). This result is attributed to the wind blowing over the lake region which may release their particulates over the region during the wet and dry season's particulates which contain more phosphorus. There were significant interactions suggesting no uniform response patterns for all locations, course and seasons. Thus the total phosphorus concentration in atmospheric air in all the locations at different courses and season did not occur in the same pattern. Similarly air particulates results demonstrate that atmospheric air in the region contributes phosphorus to the water bodies.

Table 4: Total Phosphorus mean concentration in atmospheric air (mg/L) at difference Location, Course and season

Location	Course		Season		Mean Location
	Upstream	Downstream	Wet	Dry	
River Nzoia	0.029	0.04	0.032	0.037	0.035
River Yala	0.028	0.022	0.024	0.026	0.025
River Kisat	0.012	0.016	0.003	0.025	0.014
Nyalenda Lagoon	0.029	0.029	0.011	0.048	0.03
Mean course/season	0.025	0.027	0.018	0.034	
LSD ($P \leq 0.05$)	NS		NS		0.0061
CV%	26.04				
Interactions (S×C)	0.006				
Interactions (S×L)	0.008				
Interactions (C×L)	0.008				
Interactions (SXCXL)	0.011				

S × C = season and course, S × L = season and Location, C × L= course and Location,

S × C × L= Season, course and Location.

The phosphorus conveyed through the atmosphere may originate from either distant or local sources. Major phosphorus sources for long range atmospheric transport are soil derived dust from arid and desert regions, volcanic activities, marine aerosols combustion sources and burning, agriculture and industry (Graham and Duce, 1979; Mahowald *et al.,* 2008). Pollen, plants fragments and primary biogenic aerosols e.g. (bacteria, detritus) are usually local phosphorus sources and significantly contribute to or even dominate the total atmospheric phosphorus input to surface water in forested areas away from desert regions (Psenner, 1984, Cole *et al*., 1990; Mahowald *et al*., 2008).

Very few studies have been carried out on atmospheric air around Lake Victoria (Machiwa and Tungu, 2005; Rashid *et al*., 2002; LVEMP, 2001 and 2002). A comparison of results on atmospheric air around Lake Victoria and other parts of the world is presented in Table 5. Result shows that the atmosphere of the northern catchment of Winam Gulf is 0.017 mg/L for both wet and 0.034 mg/L dry season (Table 4 and 5). Thus there was no seasonal variation in the atmospheric samples analyzed and this could be attributed to uniform and change of wind patterns in the region due to the re-aforestation under climate change programs which are currently going on in the country (Kenya), which is part of the Millennium declaration which was adopted in the year 2000 in the United Nation General Assembly. In all the season, location and course total phosphorus concentration in air samples was bellow the international standards of 0.100 mg/L (EMCA, 2006) for atmospheric air.

Table 5: Comparison with other atmospheric air results of total phosphorus.

Region	Source	Season	
		Wet (P in mg/L)	Dry (P in mg/L)
Canada	Peters, 1977	0.016	0.054
Chicago	Murphy, 1975	0.034	0.02
Florida	Brezonik, 1995	0.65	0.02
Tanzania	Rashid, 2002	0.8	0.65
Kenya	This study	0.018	0.034

The atmospheric air results from other regions are also below the international standards of 0.100 mg/L (EMCA, 2006). The results are in agreement with earlier results from other regions that wet season contains higher levels of total phosphorus concentration than the dry season (Murphy and Doskey, 1975; Brezonik, 1997; Rashid *et al*., 2002).

This could be attributed to the large distraction of soil cover as a result of change in Land use systems, improper agricultural practices and transport from regions through regional land global air circulation. The study reveals empirical data that atmospheric deposition from rivers

Nzoia, Yala, Kisat and Nyalenda waste water treatment plant contribute to phosphorus levels into Lake Victoria. This confirms that atmospheric particulates are significant sources of phosphorus into water bodies.

4.2: Total phosphorus concentration in water

Measured total phosphorus concentration in waters of River Nzoia, Yala, Kisat and Nyalenda waste water treatment plant was analyzed (Table 6) to determine whether their contribution to the lake pollution was significant or not.

Table 6: Total Phosphorus mean concentration in water (mg/L) at difference location, Course and season.

Location	Course		Season		Mean Location
	Upstream	Downstream	Wet	Dry	
River Nzoia	1.31	6.15	2.36	5.10	3.73
River Yala	30.83	27.67	31.17	27.33	29.25
River Kisat	2.43	12.88	8.57	6.75	7.66
Nyalenda Lagoon	1.57	6.00	2.58	4.98	3.78
Mean Course/Season	9.04	13.18	11.17	11.04	
LSD ($P \leq 0.05$)	0.65		1.00		0.76
CV%	7.27				
Interactions (S×C)	0.804				
Interactions (S×L)	1.036				
Interactions (C×L)	1.013				
Interactions (S×C×L)	1.410				

S × C = season and course, S × L = season and Location, C × L = course and Location,

S × C × L = Season, course and Location.

4.2.1: Course and Location variation of total phosphorus in water

Total phosphorus concentration in most of the water samples collected in all the stations was considerably higher than the recommended guideline of aquatic life. River Yala water was found to contain highest phosphorus levels, followed by River Kisat and River Nzoia had the lowest levels (Table 6). This was mainly attributed to heavy agricultural activities practiced around the rivers ranging from cultivation of maize, rice sugarcane and yams. In addition River Yala is very close to the Dominion farms which is a large agricultural farm in the downstream, comprising of sugarcane, rice plantations and is characterized by extensive soil erosion.

There was significant difference in course of water samples collected in all the locations. The downstream of rivers generally had the highest total phosphorus levels which indicated that there are more activities along the river as it flows downstream; however, River Yala recorded the opposite of this (Table 6). The two course showed significant difference with their LSD testing relevant significant variation between downstream and upstream concentration at P=0.065. The sugarcane - based and agro - based industries offload their effluent into Rivers Yala and Nzoia. This also collaborates the relatively high phosphorus levels found in the waters at the downstream of the rivers (Table 6). Phosphorus does not only come from industries but also from the municipal effluents. This is collaborated by the phosphorus levels at the Nyalenda Lagoons and River Kisat. In urban areas, there is a tendency for the slums such as Nyalenda, Obunga and Manyatta, to drain there domestic waste into Nyalenda Lagoons and River Kisat. Besides this, livestock in catchments areas of the studied areas also can be contributing to this phosphorus load. Although data on this has not been collected.

4.2.2: Seasonal variation of total phosphorus in water

The wet season had higher values than the dry season. The finding clearly represents the impact of rains as agent of transport of Total Phosphorus. During rainy season runoffs from agricultural and domestic which contain fertilizers, detergent are drained into the rivers and waste water system hence higher mean levels of total phosphorus during the wet season were recorded (Table 6). During the rainy season, the high level of phosphorus may also be as a result of leaching from farm land and rain. High soluble reactive phosphorus and insoluble phosphates is probably absorbed in water during the anoxic period hence high concentration of phosphorus. Total phosphorus concentration in water sample showed significant variation among seasons ($P \leq 0.05$) wet season was higher than dry season (Table 6). There were significant interactions suggesting no uniform response patterns for all locations, course and seasons. Thus the total phosphorus concentration in water in all the locations at different courses and season did not occur in the same pattern.

4.2.3: Comparison of water results with others

Several studies have been done on phosphorus in Lake Victoria water using different methods. Studies by Madadi *et al.* (2007) show that wet season have higher levels than dry season. Wet season had a mean of 4.61 mg/L and dry season 2.30 mg/L for water from rivers and lake shores, these rivers include Awach, Nzoia, Kuja, Migori, Yala, etc. Koyambo *et al.* (2006) studied pollution loading into Lake Victoria due to urban waste water runoff (Table 1). The result showed that Winam Gulf had higher phosphorus level as compared to Uganda and Tanzania LVEMP (2002) indicated that Kisumu bay, Winam Gulf and open lake waters had total phosphorus of 0.054, 0.022 and 0.052 mg/L, respectively. Homa bay and Nyalenda lagoon had 3.38 and 2.27 mg/L, respectively.

Table 7: Comparison of seasonal variation with other water results of total phosphorus.

Source	**Season**	
	Wet (P in mg/L)	Dry (P in mg/L)
Ramdori (1987)	5.20	1.50
Kulekana (2004)	0.36	0.07
Madadi *et al.* (2007)	4.61	2.63
This study	11.17	11.04

The results suggest that indeed significant levels of phosphorus in water samples, has been recorded as observed in earlier studies by (Madadi *et al.,* 2007; Kulekana, 2004). Total phosphorus samples in the entire four sites had levels above the international standards of 2.00 mg/L (EMCA, 2006) but beyond 0.100 mg/L (USEPA, 1979). There were significant ($P \leq 0.05$) interaction effect between season, course and Location (Table 6) suggesting that phosphorus concentration responses did not occur in similar pattern. Water from Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant contain higher levels of phosphorus above the Local and international standards of 2.00 mg/L (EMCA, 2006) but beyond 0.100 mg/L (USEPA, 1979).

4.3: Sediment.

4.3.1: Exchangeable Phosphorus in sediments.

Phosphorus concentration in sediment was determined in the form of exchangeable phosphorus, which is magnesium chloride extract and bio-available phosphorus, which is sodium hydroxide extract. Measured total phosphorus concentration in sediments of Rivers Nzoia,Yala, Kisat and Nyalenda waste water treatment plant are presented in Table 8 and 9.

Table 8: Total Phosphorus mean concentration in exchangeable sediments (mg/kg) at difference location, Course and season.

Location	Course		Season		Mean Location
	Upstream	Downstream	Wet	Dry	
River Nzoia	2.11	4.64	3.86	2.90	3.38
River Yala	19.10	18.14	18.12	18.63	18.62
River Kisat	2.57	7.09	7.39	2.28	4.83
Nyalenda Lagoon	2.53	6.44	6.19	2.78	4.49
Mean Course/Season	6.58	9.08	9.01	6.64	
LSD ($P \leq 0.05$)	0.99		1.54		1.16
CV%	15.84				
Interactions (S×C)	1.24				
Interactions (S×L)	1.59				
Interactions (C×L)	1.55				
Interactions (S×C×L)	2.17				

S × C = season and course, S × L = season and Location, C × L = course and Location,

S × C × L = Season, course and Location.

4.3.2: Course and Location variation of sediment exchangeable phosphorus

The highest sediment exchangeable phosphorus was detected in samples from Rivers Yala while River Nzoia had the lowest mean concentration (Table 8). Sediment exchangeable phosphorus samples in the entire four sites had levels above the international standards of 2.00 mg/L (EMCA, 2006) but beyond 0.100 mg/L (USEPA, 1979). Most of the locations considered for instance were higher in Rivers Yala and Nzoia where land use was mostly under agriculture and sub urban settlement as compared to River Kisat and Nyalenda Lagoons where most land is under urban settlement and industrial use. The spatial difference in mean season along the rivers reflected human activities in the vicinity of the sampling locations. The low total phosphorus concentration at the Nyalenda Lagoons can be attributed to less Industrial and agricultural activities before the stations. High values of total phosphorus of River Kisat can be attributed to sediments from Obunga slums, associated activities like brewing, deposition of domestic waste, raw sewage effluent and industrial waste. While the high values from water (Table 6) and sediments were recorded along Rivers Yala and Nzoia. These high levels might have originated from washing and leaching of phosphate fertilizer used on riparian zones. On the other hand the high levels of total phosphorus concentration might have been from direct washing of animals in the river and grazing also affecting water quality. There was significant difference in all the locations ($P \leq 0.05$).

Downstream of the rivers had high levels of total phosphorus concentration than the upstream in all the locations and sample types. Land use practices along the rivers, human settlement, industrial and municipal discharges were the major factors that May have influenced phosphorus levels in water and sediment samples. There was significant difference between downstream and upstream in water samples.

4.3.3: Seasonal Variation in Sediment exchangeable phosphorus

The highest levels of sediment exchangeable phosphorus in the northern gulf of lake Victoria were detected in sediment samples collected during wet season (Table 8). This could be attributed to the samples collected two weeks after the heavy rainy season and most of the sediments had been washed into the rivers. Seasonal variation was experienced in all the locations and sample type. Wet season had the highest levels in all the location and sample types and this clearly represent the impact of rains as agent of transport of total phosphorus and also the impact of runoffs from agricultural and domestic origin which contain fertilizers, detergents and drained to the rivers and waste water systems hence higher levels of total phosphorus during rainy season. There were significant ($P \leq 0.05$) interaction effect between season, course and location (Table 8) suggesting that phosphorus concentration responses did not occur in similar patterns.

Table 9: Comparison of seasonal variation with other Exchangeable phosphorus sediments.

Source	Season	
	Wet (P in mg/kg)	Dry (P in mg/kg)
Kulekana (2004)	2.70	1.90
Madadi *et a l.* (2007)	12.31	9.01
This study	4.13	6.64

The results from table 9 suggest that indeed significant levels of exchangeable phosphorus in sediments and water samples, has been recorded as observed in earlier studies by (Madadi *et al.*, 2007; Kulekana, 2004) and this can be attributed to the fact that most common type of land cover in the northern catchments of Lake Victoria is defined as agricultural area covering approximately 40% of the region. It comprises various forms of agriculture and a varying degree of agricultural intensity. Hence agricultural nutrient leaching is widely experienced.

Eutrophication is a problem of current interest, and agriculture the major anthropogenic source of phosphorus pollution (EPA, 1990). Agriculture contributes to degradation of the environment in a few major forms comprising irrigation, fertilizer application and use of pesticides, as well as deforestation, in order to expand agricultural areas. Irrigation is still less common in the northern catchment of Winam Gulf in general; only about 7 – 10% of the cultivated areas of the northern catchment are irrigated. Irrigation is, however, increasing and a major development of irrigation facilities has recently taken place, for example, along River Yala and Nzoia. Irrigation has changed the natural water regime and possibly increased movement of phosphorus and leaching in the downstream of the Rivers Yala and Nzoia.

Fertilizer use has probably increased in the northern catchment as crop production needs to meet the demands of a growing population hence mismanagement of fertilizers which leads to severe negative impacts on the surrounding watershed, and will be a growing concern as fertilizer use increases. In some areas of northern catchment of Winam Gulf, farmers already apply about 50 - 60% more fertilizer than the crop needs for growth (LVEMP, 2003) due to poor crop management and/or lack of knowledge in application of fertilizer. Thus high fertilizer use causes nutrient imbalances on the field and negative impacts downstream due to nutrient leaching and erosion (Lefroy and Craswell, 1997).

4.4: Bio-available phosphorus in Sediment.

Bio-available phosphorus in sediments is the sum of immediately available phosphorus and the phosphates that can be transformed into an available form by naturally occurring process (Bostrom *et al.,* 1988).

Table 10: Total Phosphorus mean concentration in Bio-available sediments (mg/kg) at difference location, course and season.

Location	Course		Season		Mean Location
	Upstream	Downstream	Wet	Dry	
River Nzoia	6.07	27.20	16.24	17.23	16.63
River Yala	115.99	105.01	130.88	90.13	110.5
River Kisat	5.12	67.97	39.75	33.34	36.54
Nyalenda Lagoon	5.82	29.50	16.91	18.41	17.66
Mean Course/Season	33.25	57.42	50.94	39.73	
LSD ($P \leq 0.05$)	3.34		5.17		3.92
CV%	9.21				
Interactions (S×C)	4.16				
Interactions (S×L)	5.35				
Interactions (C×L)	5.23				
Interactions (S×C×L)	7.29				

S × C = season and course, S × L = season and Location, C × L= course and Location, S × C × L= Season, course and Location.

4.4.1: Course and location variation of bio-available phosphorus in sediments

High sediment bio-available phosphorus in sediments detected in samples from Rivers Yala, Kisat, Nzoia, and Nyalenda Lagoon. River Yala had the highest phosphorus bio-available sediment (Table 10). Similarly in this station, washing, leaching in phosphates fertilizers used on the riparian zone and other agricultural activities was a major source of phosphorus as opposed to domestic and municipal discharge. River Kisat also recorded high values of bio – available phosphorus sediments (Table 10), which could be attributed to sediments from the Obunga slums in Kisumu city and associated activities like brewing, deposition of domestic waste, raw sewage effluent and industrial waste deposition in the river. River Nzoia is quite fast and hence the settling time for the sediments is quite long and as a result phosphorus residues would be carried in form of suspended particles and discharged into Lake Victoria. High concentration of phosphate indicates organic pollution and this was in the case of the study area as significant values of total phosphorus were recorded in all the stations.

Sediment bio-available phosphorus samples in the entire four sites had levels above the international standard of 2.00 mg/L (EMCA, 2006) but beyond 0.100 mg/L (USEPA, 1979; USEPA, 1986). Indeed there were significant ($P \leq 0.05$) interaction effect between season, course and location (Table 10) suggesting that phosphorus concentration responses did not occur in similar pattern. This could be due to several factors including rainfall distribution, and altitude differences. Although these factors were not monitored in the present study the extent of their variation may be large in the various geographical locations. The results also demonstrate that wet season had high phosphorus concentration irrespective of location and course (Table 10). These results are in agreement with the earlier results (Table 11), (Tamatamaha, 2004; Madadi *et al.*, 2007; Gikuma *et al.*, 2009) which indicates that bio available phosphorus levels in wet season is higher than in dry season. The levels of bio-available phosphorus in the rivers were higher than those detected in exchangeable phosphorus. This is attributed to the fact that bio-available phosphorus fraction also contains phosphate bound to metal like iron, aluminum and calcium which is not incorporated in the exchangeable phosphorus fractions.

4.4.2: Seasonal variation in bio-available sediments.

There were significant differences in season of bio-available sediments in all the locations sampled ($P \leq 0.05$). Wet mean season concentration for sediment bio-available phosphorus had the highest levels (Table 10). This could be attributed to the samples collected after heavy rainy season and most of the sediments had been washed into the rivers.

Table 11: Comparison of seasonal variation with other bio-available phosphorus in sediments results.

Source	Season	
	Wet (P in mg/kg)	Dry (P in mg/kg)
Tamatamaha (2004)	66.00	28.65
Madadi *et al* .(2007)	24.87	8.22
Gikuma *et al.* (2009)	81.2	1.74
This study	50.94	39.73

Most researchers have reported that about 0.80 mg/kg PO^{-}_4 (UNEP, 1995) is present in African Rivers such as Nyando, Sondu Miriu, Simiyu, Kagera and Mara. This coordinates the finding on Rivers Nzoia, Yala, Kisat and Nyalenda Lagoons as sources of pollution of Lake Victoria (Table 10).

CHAPTER FIVE

5.0: Conclusion, Recommendations and Further Research

5.1: Summary

The study was carried out in the northern catchment of Lake Victoria Basin in Kenya with the purpose of assess in the contribution of phosphorus loading into Lake Victoria by Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plants in Kenya. The matrices were sampled using randomized sampling method, to determine sampling location and seasonal variations. Air, water and sediment samples were collected from up and down streams of Rivers Yala, Nzoia and Kisat and Nyalenda lagoon during wet and dry seasons. This study has detected phosphorus and determined the extent of pollution of the catchment area by this contaminant, considering the data presented elsewhere in this literature, the conclusion drawn in this study can be summarized below.

The total phosphorus concentration in water and sediment with exception of atmospheric air were above the international standards (USEPA, 1979; WHO, 1987; EPA, 1990, EMCA, 1979) which contribute heavily to total phosphorus in Winam Gulf were the waters and sediments of Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant. This could be attributed to activities from possibly agriculture, pan-paper processing, and sugar factory activities. There was a general increasing concentration of phosphorus trend downstream of all the river mouths. Total phosphorus concentration was relatively high and generally uniform downstream in both water and sediment. The increase trend of phosphorus indicates a continued input along the rivers likely from agricultural phosphate fertilizers, runoff or it could be a combination of point sources from municipal waste and the sugar factories (Nzoia and Mumias). Others maybe from diffused sources from maize, sugarcane, rice and coffee plantations in the catchment. Thus agriculture, municipal and industrial activities upstream seem to contribute remarkably to phosphorus concentration in Rivers Nzoia, Kisat, Yala and Nyalenda waste water treatment plant.

In general, more of the phosphorus was in the water and sediments than in the atmosphere, which is likely to show that they could be transported from the entire catchment towards the rivers by runoffs during wet season and that sediments are sinks of phosphorus. Phosphorus contribution from the atmosphere into the Lake Victoria from the northern catchment is very minimal but significant. There were no significant interactions suggesting uniform response patterns for all locations, course and seasons. Thus the total phosphorus concentration in atmospheric air in all the locations at different courses and season occurred in the same pattern. Similarly air particulates results demonstrate that atmospheric air in the region contributes phosphorus to the water bodies.

The results from the study validate that anthropogenic activities within basins of Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plant in Kenya contribute to the phosphate levels reported at their mouths in Lake Victoria. The study also shows that there are phosphate depositions from the water, sediments and atmosphere to Rivers Nzoia, Yala, Kisat and Nyalenda waste water treatment plants in Kenya.

5.2: CONCLUSION

1. Change in course was found to be the major variation in total phosphorus concentration The change in course was attributed to farming activities in the streams as was clearly seen from their difference in downstream and upstream concentration each sample type and location.

2. Seasonal variation was recorded in all the sample type in each location. Wet season showed higher means exchangeable phosphorus, bio-available phosphorus and total phosphorus concentration than dry season samples in all the sampled locations.

3. The atmosphere of the northern catchment of Winam Gulf contains a small but relevantly constant amount of total phosphorus concentration. This indicated that atmospheric air is a contributor of phosphorus in Lake Victoria.

4. The sinks of phosphorus in the northern catchment area are water and sediments, most water and sediment samples were above the international set standards.

5.3: RECOMMENDATIONS

The recommendation is divided into two namely environmental management and further research.

A) Environmental management

1. Monitoring of the lake region should continue with special emphasis on phosphorus in atmosphere, water and sediments in areas that have not been covered.
2. Adoption of polluter pays principle.
3. The Kisumu water and Sewerage Company, Dominion farms, Mumias sugar and Pan Paper mills should consider improving treatment of waste water before discharge to the water bodies, currently River Kisat more or less discharges raw sewage into the waters of Winam Gulf based on BOD results and foul smell.
4. The Kisumu water and Sewerage Company, Mumias sugar and Pan Paper mills should consider treatment of sewage using wet land before discharge to the water bodies.
5. It is recommended that more hippo grass be planted on the shores of Lake Victoria and other water bodies to buffer against erosion and wash off into the lake.

B) Further research

1. Further research should be done on atmospheric phosphorus in other catchment of Winam Gulf.
2. Research on domestic soot should be done to determine the extent of pollution due to atmospheric phosphorus emerging through soot.
3. Research on the amount of particulate phosphorus in algae, virus and bacteria which are ejected from the atmosphere into Lake Victoria.

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