MODELING NON-POINT SOURCE POLLUTION IN LAKE VICTORIA

A CASE OF GABA LANDING SITE

BY

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DECLARATION

I, **Bongomin Joachim** declare that this research project is my original work and has never been presented to this University or any other University or Institution of higher learning for the award of degree or any other award.

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DEDICATION

This book is dedicated to my beloved parents, brother and his family, and sisters who made important contributions towards my study. To all my friends who inspired me to undertake postgraduate studies and supported me with their brilliant ideas to finish this research project in time. Thanks a lot and may the good Lord bless you all.

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May God bless you abundantly.

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ACRONYMS

ANOVA:	Analysis of Variance
DO:	Dissolved Oxygen.
DWD:	Directorate of Water Development
EC:	Electrical Conductivity.
FAO:	Food and Agriculture Organization
GIS:	Geographical Information System
GPS:	Global Positioning System
Hotspot:	Point where surface runoff concentrates and enters the lake.
KCC:	Kampala City Council
LSD:	Least Squared Difference
LVEMP:	Lake Victoria Environment Management Project.
MP:	Management Practice
MUIENR:	Makerere University Institute of Environment and Natural Resources.
MWLE:	Ministry of Water Lands and Environment.
NARO:	National Agricultural Research Organization
NEMA:	National Environment Management Authority
NPS:	Non Point Source.
Nutrients:	Refers to ammonia-N, nitrite-N, nitrate-N and ortho-phosphate
NWSC:	National Water and Sewarage Corporation
PS:	Point Source
TDS:	Total Dissolved Solids.
TSS:	Total Suspended Solids
U.S.A:	United States of America.
UBOS:	Uganda Bureau of Statistics.
USEPA:	United States Environmental Protection Agency.
USGS:	United States Geological Survey

ABSTRACT

Lake Victoria is one of the largest fresh water bodies in the world. Currently it is being threatened by various types of pollutants originating from different land uses-both point and non-point sources. The objectives of this study were; to identify and characterize different land-use activities, and locate NPS pollution hot spots, quantify pollutant and sediment loads, assess pollutant dispersion following discharges into the Lake, develop a one-dimensional mathematical model for nutrients discharged and recommend ways of managing such flows.

Characterization of land use was achieved using GIS and remote sensing techniques. Within the lake, samples were taken both in the vertical and horizontal direction using hand driven pump and hand held GPS. Physico-chemical parameter concentration was determined using digital hand held meters and for nutrients, photometric method was used using Photometer 7100. TSS was analyzed using gravimetric method. The model was developed basing on the fundamental principle of conservation of mass for managing surface water quality.

Gaba fish landing site was identified as a NPS pollution hotspot and runoff from this site conveys sediments and nutrients that are contributing significantly to lake Victoria pollution. Comparison between dry and rainy season pollution concentrations revealed that Ammonia-N, Nitrite-N and Ortho-Phosphate had higher pollution concentrations during the rainy season unlike Nitrate-N which had a higher concentration during dry season. The latter was attributed to sustained input of surface runoffs while the former was attributable to the nitrification processes These concentrations of Ammonia-N and Nitrite-N are similar to those that have been found by earlier studies to be toxic for the fish within the lake. Associated increase in physico-chemical parameter concentration was likely to affect fish availability and assemblage in areas close to shore settlements.

The respective distances traversed by these nutrients were found to be 38meters for ammonia-N, 45meters for nitrite-N, and 34meters for both nitrate-N and ortho-phosphate. The respective model concentrations of these pollutants compared well with measured concentration at the traversed distances. A number of management measures were suggested to improve on water quality.

CHAPTER ONE

INTRODUCTION

Lake Victoria is one of the largest fresh water bodies of the world and is bordered by Kenya, Tanzania and Uganda, with streams and rivers stretching as far as Burundi and Rwanda also feeding into it (Rizzolio, 2000). Being the source of the Nile, its waters are greatly committed downstream. The Lake is not only a source of food, water , employment, transport, hydroelectric power, and recreation, but is also now used as dumping ground for various types of wastes (Chege, 1995; Matagi, 2002; MWLE, 2006). According to Kyomuhendo (2002), the once clear, life-filled Lake Victoria is murky and smelly. Furthermore these days the pollution impact by municipal and industrial discharges is visible in some of the rivers feeding the Lake and along the shoreline, such as shallow Winam Gulf in Kisumu (Kenya) and near Mwanza (Tanzania) and Inner Murchison Bay (Kampala). The ecological health of Lake Victoria has been affected profoundly as a result of rapid increasing human population due to migration to the area by plantation workers, clearance of natural vegetation along the shores to establish plantations of coffee, tea and sugar (Nkonya et al., 2002; MWLE, 2006), prolific growth of algae (Kyomuhendo, 2002; Larsson, 2002) and dumping of untreated effluent by several industries (Matagi, 2002). As a result, the treatment cost of potable water has increased (Banadda et al., 2006).

1.1 Research Problem

Lake Victoria is a key strategic resource vital for sustaining livelihoods of over 33 million people within its basin, promoting development, and sustaining the environment. Rapid population growth, increased agriculture, urbanization, industrial activities, poverty in rural and peri-urban areas, and uncontrolled dumping of waste is causing degradation of the available water resources. Forests are being cut down, soils are eroded, wetlands are drained, channels are silted, and the lake water is being polluted partly as NPS pollutants and the trend of lake pollution is on the increase. The consequence of this is algae blooms, insurgency of water weeds (such as water hyacinth), and water borne diseases. Little work has been done to quantify NPS impact on the

Lake, biodiversity therein, and the livelihoods depending on the Lake. Identification and quantification of the NPS will contribute to controlling the impacts related to the same.

1.2 Objectives

1.2.1 General Objective

The overall objective of the research is to develop management strategies, both structural and non-structural, which address pollutant flows into the lake that originates from non-point sources (NPS).

1.2.2 Specific Objectives

The specific objectives of the study are;

1. Identification and characterization of different land-use activities, and location of non-point source pollution hot spots.
2. Quantification of pollutant and sediment loads.
3. Assessment of the dispersion of the pollutants following discharges into the Lake.
4. Development of a one-dimensional mathematical model for nutrients discharged into the Lake.

1.3 Hypothesis

Null Hypothesis

Non-point source pollution does not contribute significantly to Lake Victoria's pollution by introducing nutrients in form of ammonia-N, nitrite-N, nitrate-N, and ortho-phosphate through surface runoffs.

1.4 Justification

Pollutant characteristics, which include the type, quantity, mode of transportation, final deposition points, locations and sources in Kampala, are largely unknown. Moreover, there is no mechanism for assessing the impact of the resultant loads on the surface and subsurface water in the study areas. Efforts to mitigate the impacts of this type of pollution by policy makers are limited due to financial constraints, land ownership issues, and non implementation of mitigation measures by local communities. Encroachment on wetlands has degraded the swamps which otherwise would act as filters to the surface runoff water. Continuous deposition of contaminated water if not stopped may lead to growth of planktons in Lake Victoria and suffocating aquatic life. Indeed, the current green water in the lake may bear links to contaminated water within the study area.

Against this background, there is therefore a need to undertake a research directed towards addressing this situation.

This research will contribute towards development of policies which conserve the environment and improvement of water quality when management measures are implemented. The modeling approach used was based on the fundamental principle of conservation of mass when managing surface water quality. A number of mathematical models have been applied in water resources, e.g. ecological model, estuary model, in linear and dynamic programming, to maximize or minimize certain parameters, basing on the modeling objectives at hand. The principle of conservation of mass is another widely applied technique in the treatment of waste water, leading to partial differential equations. The solution of such partial differential equations, subject to the appropriate initial and boundary conditions, represents the temporal and longitudinal distribution of the materials of interest along a water course. In the present case, the principle of conservation of mass was found more appropriate and provided a more accurate approximation, in comparison with other mathematical models.

As a result of the ever increasing pollution problem within Lake Victoria, the model can be used for zoning of polluted shore areas into Lake Victoria where water quality has been degraded and is viewed as unfit for human use and other purposes

1.5 Conceptual Framework on the Problem

For any precipitation, sediments are always generated due rain drop impact on the soil. Detachment magnitude depends on the nature of land surface cover. Part of the precipitation infiltrates into the ground while some fraction is conveyed as surface runoff. On the other hand, due to various land use forms, waste is generated and the surface runoff transports these sediments and pollutant loads into water body where they lead to deterioration in water quality. Therefore structural and non-structural management measures were suggested to manage such flows. Figure 1.1 shows the conceptual framework

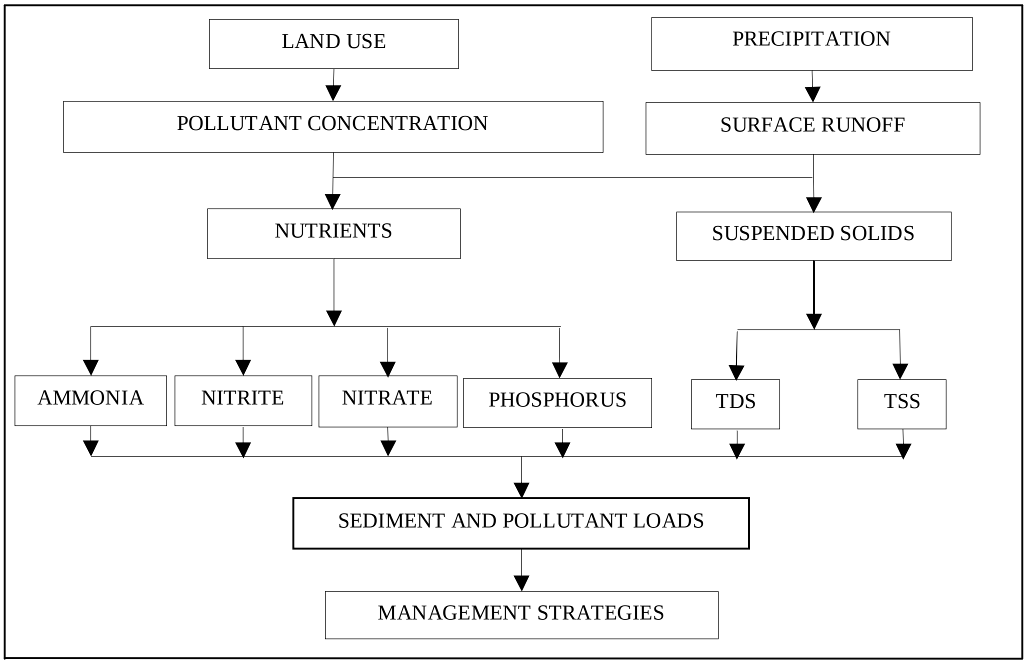

Figure 1.1: Shows the Conceptual Framework

1.6 Description of Study Area

The study site is Gaba, located in Makindye Division of Kampala City (Figure 1.2). Its relief consists of undulating terrain both hills and valleys. The lands from hill-top to valleys are used for human settlements, yet the valleys are wetlands in most cases.

Gaba is a landing site for fishing boats, and National Water and Sewerage Corporation's water treatment/pumping station, which supplies water to Kampala City areas.

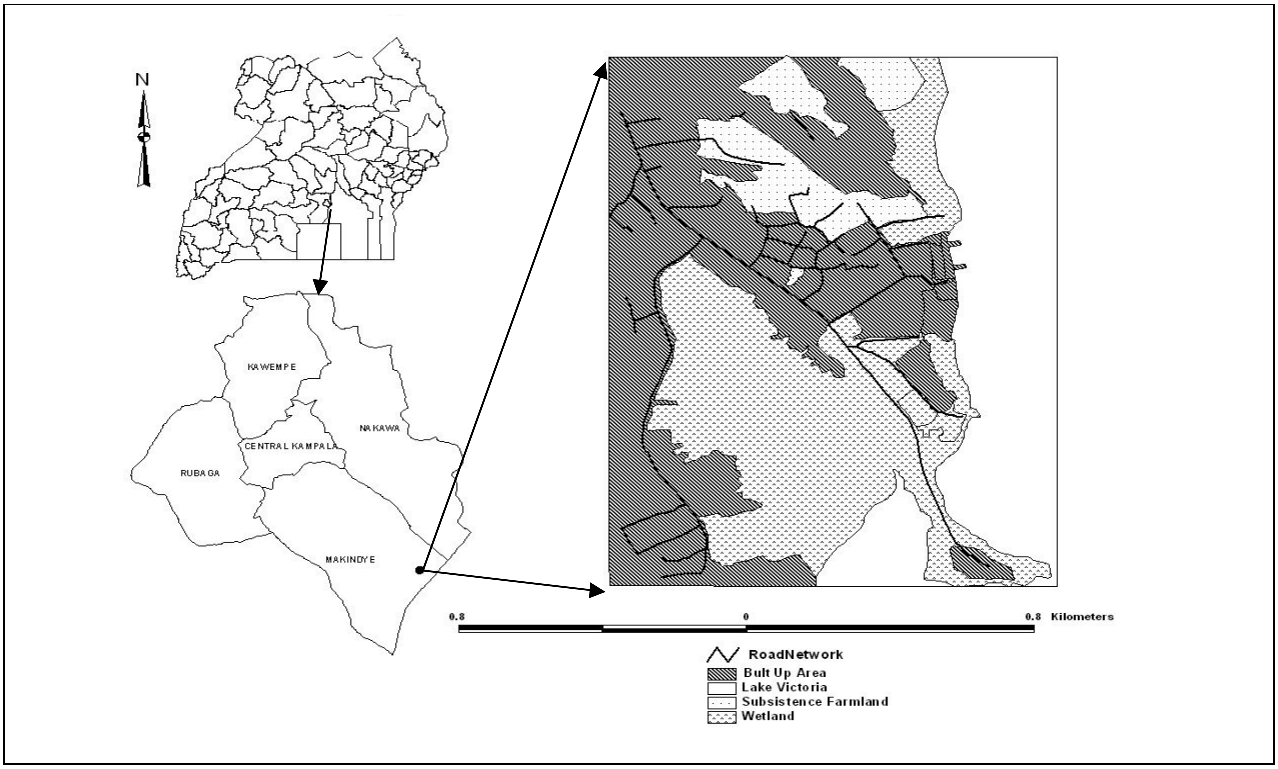

Figure 1.2: Shows the coverage of the location of the study area

Gaba being just adjacent to the lake Victoria with high levels of activity, it is anticipated that a big portion of surface runoffs find their ways into the lake without any form of treatment. It has been observed that the shore lake water always changes to brownish colour when it rains and this colour returns to normal after some time. Runoffs originating from far inland sources also converge close to this area, but because they pass through swamps(a treatment facility), their pollutant concentrations were considered to be lower than that of the landing site, where no solution exist to control such pollutant flows, thus the choice to carry out the study at the site.

Furthermore, the site is a market place with bare soil surfaces, and high volume of solid waste are always generated which are dumped directly into the lake, though attempts have always been made to collect them.

1.6.1 Climate and Rainfall

The micro-catchment experiences two rainy seasons per year with an annual average estimated to be over 1000mm. The first rainy season is from mid February to end of May, and the second rain season is from mid August to end of December. Two dry spells separate the rain seasons.

The first dry season is from June to mid August and is followed by the second which is of a short spell between January and February. Temperatures in Kampala range from 15°C to 30°C most of the year (NEMA Environment report, 2006/2007).

1.7 Scope of the Research

The research activities were restricted to:

1. Identification and characterization of land use activities, location of non-point source pollution hotspots using GIS and remote sensing techniques.

2. Quantification of pollutant and sediment loads (Total Dissolved Solid, Total Suspended Solids, ammonia-N, nitrate-N, nitrite-N, and ortho-phosphate).

3. Assessment of the variation of physico-chemical parameters, namely Temperature, dissolved oxygen (DO), Electrical Conductivity (EC), and pH.

4. Development of a model that can be used to predict the distance from shore, which the nutrients carried by runoffs traverse, following discharges into the Lake waters

CHAPTER TWO

LITERATURE REVIEW

2.1 Land Degradation in Uganda

The awareness of the occurrence of land degradation and its consequences on water resources development is manifested in various national agenda and policies, and signatories to major international agreements regarding water resources e.g. The National Water Policy (1999), National Environment Management Act (1995), Water Action Plan (1993) as emanated from the Dublin and Rio de Janeiro United Nations Commission on Economics and Development (UNCED) process (1992) on fresh water resources. Emphasis is placed on the integration of water and land use. Land degradation in Uganda has attracted debates and concerns and received widespread public recognition. This has resulted into the development of various policies seeking to address issues related to the sustainable use of land resources. Land use change, enhanced by population increase, has been associated with land degradation, especially soil erosion and depletion of nutrients. Lake Victoria catchment is a prime agricultural area that has experienced land use changes which are believed to have contributed to the siltation and eutrophication of Lake Victoria through soil erosion (Isabirye et al., 2005). In Mayuge, most of the land is allocated to sugarcane. Farmers use steep slopes for cultivation of food crops. Thickets have been cleared selectively to give way to farmlands with indigenous trees and forest reserve periodically encroached on for maize cultivation (Isabirye et al., 2001). United States Geological Survey (2008) reported that clearing of forest enhanced surface run-off loaded with suspended sediments into water bodies. The problem associated with sediment transport is that it acts as a carrier for nutrients (especially phosphate), heavy metals and pesticides that adversely affect water quality. Nyangababo (1987) demonstrated the presence of pollutants-lead, in streams feeding into Lake Victoria and concluded that their sources followed a pattern corresponding to Kampala City road networks

2.2 Effects of Urbanization on Water Quality

In Uganda, increased urbanization and industrialization in recent years, especially in the city of Kampala, has led to an increase in the city's population and development of informal settlements. The resident population of Kampala city is 1.2 million people with an annual growth rate of 3.8% (UBOS, 2002). The level of urbanization in 2000 was 14.2% and with an urban growth rate of 5.2%. It is projected to increase to 20.7% by 2015 (Mukwaya, 2004). This population size almost doubles during the day since the city serves as a workplace for residents of several nearby areas, but who go back home in the evening. In Kampala, about 900 tones of solid waste are generated daily, of which only about 40% is collected and disposed off by Kampala City Council (KCC), while the rest is indiscriminately disposed off. Of the total effluent from industrial and domestic sources in the city, 10% is treated and the rest is discharged untreated (Kulabako, 2004).

The informal peri-urban settlements have a high population density, are located in valleys and wetlands with a high water table, are predominantly inhabited by the urban poor and have inadequate basic services such as water supply and sanitation (excreta, solid waste, sullage and storm water management). Environmental conditions in many urban areas within Kampala City are appalling. With increased impervious surfaces, these wastes find their way into streams, swamps and lowland areas as runoff when it rains. Accessibility to environmental services ranges from total inadequacy to non-existence in most of these peri-urban settlements. Inadequate planning or lack of it in some areas and the resultant development in inappropriate areas such as open spaces, swamps, and steep slopes is causing serious environmental problems such as water pollution, disease outbreaks etc. Environmental components in and around Kampala City are very much at risk due to a variety of activities associated with uncontrolled urbanization process (Mukwaya, 2004).

In the informal settlements where a great majority uses shallow water, its quality has become a widespread concern. Recent studies carried out in these areas suggest a link between the incidence of cholera, acute diarrohea and use of contaminated protected springs (Howard et al., 2000). In addition, due to poor sanitation, disease outbreaks (malaria, cholera, typhoid) are prevalent, especially during rainy seasons as a result of flooding. In general the microbiological quality of springs in Kampala is found to be poor. The study showed pronounced seasonality with significant increases in contamination noted in wet periods and more recent studies have shown very rapid response to rainfall events (Howard et al., 2000). Dougherty (2004) defined NPS pollution as originating from urban runoff, construction, hydrologic modification, silviculture, mining, agriculture, irrigation return flows, solid waste disposal, atmospheric deposition, stream bank erosion, and individual sewage disposal. The major sources of pollutants in a watershed especially in Kampala are typically storm water runoff pollution from urban settlements and agricultural areas without sewer lines. Storm water runoff pollution discharges into streams and lakes, and from shore settlements at many dispersed points and poses substantial health risk (Tonderski, 1996). The study by Dougherty (2004) revealed extensive water quality impacts resulting from storm water runoff pollution, especially nutrients and suspended solids and showed a link between urban runoff and NPS pollution. Corresponding links between land use and NPS pollutant delivery has been investigated at a variety of temporal and spatial scales. Rapid urbanization, with its associated land clearing and paving of pervious area, has accelerated the problem of water pollution. While runoff from rainfall is a natural occurrence, the problem lies in the nature of the land on which rain falls. As the amount of paved impervious surface area increases, the volume and rate of runoff (as well as the accompanying pollutant loads) increases. Storm water flowing over roofs, streets, lawns, commercial sites, industrial areas, and other permeable and impermeable surfaces transports many pollutants into surface and ground waters. Rain washes sediments and nutrients from bare soil into receiving waters (Livingston, 1985).

Conservation of water resources and the assurance of a high quality of life are intimately associated with a region's land use. As land is changed from its original state to more intensive uses, water quality tends to deteriorate. Transition periods between different uses (e.g. construction) are especially critical. Each progression towards more intensive land use disrupts the natural processes which protect and preserve water quality. While not all urban centers are predestined to poor water quality, as the intensity of land use increases, it becomes more important to manage water resources effectively. Currently, the capacity of the municipal authorities to provide basic services to meet the sanitary needs of the increasing population is limited.

2.3 Effects of Shoreline Activities and Pollutant Load on Lake Victoria

Farmers who double as fishermen blame the low fish catch on the increased numbers of landing sites (number of fishermen) and poor fishing methods like use of small sized nets. Whereas the farmers' observations are true, it has been established that the pollution of Lake Victoria is due to human pressure on forest resources and is also a major cause of reduced fish harvests. Developing lakeside land therefore decreases the density of trees around the shoreline, which subsequently decreases the growth of other vegetation in this zone reducing potential terrestrial subsidies and complex habitats for fish (Elizabeth et al., 2008). Fish growth decreases with intensity of lake shore development as a result of littoral zone degradation. Such shoreline changes also affect water quality by altering terrestrial runoff patterns and increasing water temperatures because of loss of shade. Fish caught especially Nile perch requires a lot of firewood to smoke. This activity has also enhanced the excessive cutting of trees in the neighborhood of shoreline settlements and landing sites. A rapid rural appraisal report in Rakai (Ssenteza et al., 1998) also indicated that population pressure has led to deforestation which has surpassed the tree planting and forest recovery process, leading to environment degradation, decreased supplies of fuel-wood and land productivity.

Nutrients and sediments from far inland enter the lake directly without being filtered as a result of clearing of vegetation surrounding the Lake. Tonderiski (1996) noted that fishing shoreline settlements have less that 20% of pit latrines coverage thus most human waste is discharged directly into Lake Victoria. Pollution is viewed as a serious threat to water quality for its direct and indirect impacts on lake communities (Aaike et al., 2008).

Although (ILEC, 2001) reported that siltation is not a serious issue with average sedimentation rate ranging from 8.5 - 17 tons/ha/year, eutrophication is serious and has resulted in unusual algal bloom prompting Kyomuhendo (2002) to comment that the Lake is now murky and smelly. Eutrophication is confined to major urban areas around the Lake shore. The key area is Winam Gulf near Kisumu in Kenya (Ojok, 2002). The main body of the Lake is mesotrophic. Although nutrient loads to the Lake are not known, LVEMP (2004b) observed that near shore areas may be highly affected by eutrophication, especially the hot-spot areas such as Winam Gulf-Kenya, Murchison Bay-Uganda, Napoleon Gulf-Uganda, and Mwanza Gulf-Tanzania. In these areas chlorophyll-a concentrations today rise far beyond what has been measured previously. These hot-spots are mainly point sources in nature although for most of these hotspots, including Murchison Bay, it is a mixture of both PS and NPS and no attempt has been made to quantify NPS alone.

2.4 Source of Nutrients in Lake Victoria

Eutrophication of Lake Victoria, among others, has been identified as a major issue contributing to lower lake ecosystem productivity (LVEMP, 2004b; ILEC, 2001). Whereas the impact of eutrophication on various lake ecosystem functions and productivity has been quantified and well documented, the source of nutrient load remains a controversial issue. Recent findings show that eutrophication is widespread and emphasis has been on identification of possible sources of nutrients, especially phosphorus-P. Recent and paleo-limnological investigations have been used to try and identify sources of nutrients causing eutrophication in Lake Victoria with most paleo-limnological studies concluding that soil sediments from agricultural fields are major sources of P that ends up in the lake. A study on lake sediments by (Hecky et al., 2000b) reported a 2-3 fold increase in P loading over the past 50 years with changes in the lake ecosystem beginning even earlier in the century. These paleo-limnological studies clearly indicate that sediment loads as a result of increased agricultural activities due to population increase are a major source of nutrients that have caused eutrophication of Lake Victoria. However, there are contradicting paleo-limnological studies suggesting that sediments and therefore agricultural land are not the major sources of P but that the P loading to the lake may be primarily external rather than from the sediments. As for paleo-limnological studies, recent studies on sources of nutrients causing lake eutrophication show that inappropriate agricultural practices have favoured sediment loss that has ended into the lake.

2.5 Land Use Mapping in Water Resources Planning and Management

The knowledge of land use and land cover is important for many planning and management activities and is considered an essential element of modeling and understanding the earth as a system (Lillesand et al., 2000). Land use and management have been shown to influence the quality and quantity of storm water runoff (Graves et al., 2004). Zampella et al., (2007) in their assessment of watershed disturbances reported significant effect on water chemistry of streams resulting from land-use-related watershed disturbances. In urban areas, water quality degradation may be associated with the extent of impervious area. Land use/cover change has profound effects on regional climate, soil, rainfall, and water quality by affecting regional material cycling and energy flows (Liang et al., 2004). An understanding of the influences of land use/cover change on a regional environment, especially the processes and flux of nutrients at the catchment scale, is needed to develop land use policies in accordance with sustainable development strategies (Ackerman et al., 2008). The primary way land use/cover change affects element transportation is by NPS. Rainstorm runoff plays an essential role in NPS pollution, and most nutrient export happens during heavy rainstorms.

The term land cover relates to the type of features present on the surface of the earth, and land use relates to the human activity or economic function associated with a specific piece of land. Small scale aerial photography and satellite images have been utilized for land use/land cover mapping, water pollution detection, and eutrophication studies. Depending on the level of mapping details, land use can be described as urban use, residential use, or single family residential use. The same tract of land would have a land cover consisting of roofs, pavement, grass and trees. For a hydrologic study of rainfall runoff characteristics, it is important to know the amount and distribution of roofs, pavements, grass, and trees in this tract.

The USGS (2008) derived a land use and land cover classification system for use with remote sensing data. While land cover information can be directly interpreted from appropriate remote sensing images, information about human activities on the land cannot always be inferred directly from land cover. Thus additional information sources are needed to supplement the land cover data. Supplemental information (ground truthing) is also necessary for determining the use of such land as residential areas, rangelands, swamps, water bodies etc.

2.6 Nutrient Dispersion and Lake Mixing

Temperature stratification and vertical mixing are important physical processes in lakes. In a shallow lake, vertical mixing is driven by wind-induced forced convection or buoyancy-induced natural convection (Herb et al., 2005; Ivey and Patterson, 1984). The magnitude of vertical mixing controls the temperature profile and the distribution of materials such as dissolved oxygen and nutrients in the water column. Thus, models for temperature stratification and mixing are a basic component of lake water quality models. Shallow lakes have unique physical and biological characteristics that require additional considerations for water quality models. Wind shear provides kinetic energy for vertical mixing at the water surface, which is transmitted down via mean flow and turbulent diffusion to establish the surface mixed layer (Ilker et al., 2002). During periods of positive surface heat flux surface heating, stable density gradients and stratification act as a potential energy barrier to turbulent diffusion, and reduce the mixed layer depth. During periods of negative heat flux and surface cooling, an unstable density stratification is produced in the water column, resulting in penetrative convection, additional production of turbulent kinetic energy and continuous deepening of the mixed layer. The surface mixed layer depth is determined primarily by the duration of the cooling process and is enhanced by wind. The surface mixed layer depth and its rate of change have been related to the Richardson number, a measure of the relative rates of turbulent kinetic energy production by shear and change of potential energy due to lifting work against density stratification. In a deep lake, the long time constant of mixed layer depth development combined with transient meteorological conditions prevent the mixed layer depth from reaching equilibrium, so that the instantaneous mixed layer depth depends on the time history rather than the current values of meteorological conditions. In general, kinetic energy for mixing is transferred from the atmosphere to the water column as drift mean flow, waves and turbulence. Mean flow then produces additional turbulent kinetic energy via shear production.

In spite of the enormous attention that has been accorded in tackling the pollution problem during the last decades, it has persisted though *PS* has mainly been the focus. Although NPS often impacts at a large scale and some authors such as Makundi (2001) reported it in lake Victoria, the state of the art literature indicates that *few studies* aimed at predicting such type of pollution have been carried out in the basin. Currently there are limited data and analysis of available information. The seriousness of NPS pollutants is likely to increase because of inadequate laws and history to mitigate its effects. Our knowledge of the process of lake system degradation is still little and limited to identifying human impacts. The point in the catchment development process when impacts are evident in lakes and the extent these effects can spread within the lake is also limited. Yet the shallow water near shore provides the most important feeding and breeding habitat for organisms, particularly fish and amphibians. In addition to altering food availability, pollution may affect reproductive habitat for the many fish and other organisms that require shallow water for breeding. It is therefore necessary to examine the contribution of surface runoff from the study area to the pollution of Lake Victoria and their spread within the lake as well as their effects on the lake ecosystem.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Land Use Activities and Location of NPS Hotspots

Google earth picture combined with Arc View GIS 3.3 were used to identify and characterize different land uses within the study area basing on observed variations in the picture, each with different potential for causing water pollution as non-point sources. The accuracy of identified land uses were improved using topographic sheets obtained from NARO-Kawanda. The classification system used to name the land uses was Biomass Uganda. This classification system is more suitable to Ugandan situation and for this study than other systems developed by FAO or USA which are different and more general from our current situation

3.2 Data Collection Period

Two rain seasons in a year were used for data collection and one dry season was used for purposes of comparing the levels of lake pollution between dry and rain seasons. 68 lake water samples for each rain season and 64 lake water samples for dry season were collected and analyzed. Runoff data used for model validation was collected separately during the second rain season. A total of 204 samples were collected. Data collection during first rain season started from mid August, 2008 to mid November, 2008. Second rain season data collection was in April, 2009. For dry season, data was collected from mid February, 2009 to late March, 2009. To ensure that samples were always taken from the same spot within the Lake, mapping of the sampling points were done using a hand held GPS and a boat. The sampling coordinates were stored in a GPS and later traced during subsequent sampling. The mapping was done after rain event in order to locate the path/areas these runoff normally follow when released into the Lake.

3.3 Sampling Plan

Samples of runoff from the study site were taken using grab sampling just before they mix with the lake water and analyzed for nutrients and physico-chemical parameters. While within the lake for a horizontal transect, samples were taken at horizontal distances of 10m interval over a distance of 50m starting from the shore, where the surface runoff was released. For the same sampling points within the lake, samples were drawn at vertical distances of 0.5m, 1.0m and 1.5m from water surface, using a hand pump with graduated delivery pipe so as to take samples at the required vertical distances. Practical measurement using measuring meters were used to supplement the GPS accuracy on days where reception was not very good. Data collection was done during months when the lake is calm. The risky months of June and July when the lake is rough due to strong wind was avoided. Also, field observation showed that lake water remains calm during rainfall event and data collection targeted such calm and less risky periods.

3.3.1 Sample Treatment

The sample bottles were rinsed thoroughly with the samples to be analyzed and then lake water samples were pumped into them. These samples were then stored in a cooler and transported within less than two hours to Makerere University Institute of Environment and Natural Resources (MUIENR) wet laboratory where they were analyzed immediately for the nutrients (Ammonia, Nitrite, Nitrate, and Phosphate). Conductivity/TDS/T, and HQ10LDO meters were used to measure pH, EC, TDS, T, and DO instantly from the field. The photometric method was used to measure nutrients while in laboratory, using Wagtech Photometer 7100.

TSS was measured using gravimetric method (Adong, 2001). In this method, the initial weight of 0.47μm pore size membrane filter paper was recorded. 100ml of the sample was then filtered through it using a filtration unit. The filter paper containing the suspended solid was wrapped in Aluminum foil and oven-dried at 105^{o}C for one hour. The final weigh of the filter paper was recorded. The change in weight of the filter paper represented the concentration in mg/liter of TSS.

A one-sample t-test/Upper-tailed test was used to test for the hypothesis using XLSTAT on the basis that the observed mean was greater than the theoretical mean. A one way ANOVA test was performed using SPSS Version 16 to establish any variability in the data collected both horizontally from shore into the lake and vertically downwards from water surface for both dry and rain season. Multiple comparison, (LSD) test was performed for any variation seen to be significantly different at α=0.05 from result of ANOVA

3.4 Modeling Approach

The modeling approach employed invoked the fundamental principle of conservation of mass for management of surface water quality (Biswas, 1976), stated by the equation

$$\frac{1}{A}\left\{\frac{\partial}{\partial x}\left[\varphi(x)A(x)\frac{\partial C(x,t)}{\partial x}\right]-\frac{\partial}{\partial x}\left[Q(x,t).\,C(x,t)\right]\right\}+\vartheta(x,t)=\frac{\partial C(x,t)}{\partial t} \tag{3.1}$$

Where t is time, x is the coordinate of a point on the water body, $A(x)$ is the cross sectional area at the point x, $\varphi(x)$ is the longitudinal dispersion coefficient at the point x, $C(x,t)$ is the concentration of nutrient of interest at x and time t, $Q(x,t)$ is the flow rate at the point x and time t, and $\varphi(x,t)$ is the net rate of change of nutrients due to sources and sinks at x and t.

Due to the shallow depth of measurement in the vertical direction, which provides a basis for uniform mixing (Herb et al., 2005), the variation in dispersion is found to exist only in the longitudinal direction relative to the lake shore where runoff discharges into the lake. In addition, the waste water flow within a prescribed time interval was considered constant in view of the assumption that the parameters for dispersion, $\varphi(x)$, flow $Q(x)$ and area $A(x)$ were constant for all the points x within a range of distance along the water course. Under these conditions, Equation 3.1 takes on the form of the steady state equation, given by

$$\varphi\frac{d^2C(x)}{dx^2}-\frac{Q}{A}\frac{dC(x)}{dx}+\vartheta(x)=0 \tag{3.2}$$

Thus the concentration of materials of interest at the various locations along the water course is only a function of distance.

Integrating Equation 3.2 gives the residual concentration of a pollutant at any distance or point x due to the steady discharge at another point x (equation 3.3).

$$C_{i,x}=\alpha C_i \tag{3.3}$$

Where $C_{i,x}$ is the concentration of pollutant at site x resulting from the discharge of pollutant from site i.

3.4.1 Data Modeling Process and Application of the Model

The data was first screened to eliminate outliers. Median values for the screened samples collected was used to generate the measured trend to be modeled. The coefficient of dispersion was solved for basing on Equation 3.3 and then plotted (dispersion coefficient against horizontal distance). The equation for the plot represented the dispersion coefficient. The equation was then used to generate the pollutant concentrations at the various sampling points when applied successively between the various point as one moves from shore into the lake.

3.4.2 Model Calibration and Validation

Model concentrations and field measured values vere plotted on the same axis against horizontal distance. It was observed that the model over estimated the pollutant concentration and calibration was done by introducing a term that would subtract from the model the difference between the model and measured concentration. This difference was found to behave in the same way represented by the model equation 3.3. Therefore, its separate calibration dispersion coefficient was generated and subtracted from the model concentration. Validation was carried out using four separate set of data collected during second rain season and the model equation generated. Respective equations for the nutrients were applied successively between two measurement points to yield concentrations from point of discharge into the lake. The generated concentration when plotted against horizontal distance will yield a horizontal distance for which the model concentration equals to the lake pollution level. This horizontal distance is then taken to be the distance to which nutrients conveyed by surface runoff disperses when discharged into the lake for any rain event

3.4.3 Model Validation

To validate the model, concentrations of nutrients before mixing with the lake water was used to generate the dispersion trend using the calibrated model. The nutrient concentrations generated using the calibrated and validated model were plotted on x-y axis and a perfect correlation was observed as indicated by their R^2 values

CHAPTER FOUR

RESULTS

4.1 Characterization of Land Use Activities in the Study Area

Gaba is located in Makindye Division of Kampala District, the Capital City of Uganda. The site borders Lake Victoria and consists of various land use types (Figure 4.1and Table 4.1).Within this area is Gaba fish landing site, a shore settlement and market place. Preliminary studies carried out on this shore settlement suggested that this site is a pollution hotspots by the nature of land uses in the area and non existent surface water treatment facility existing in the place when it rains. By virtue of proximity to the lake, pollutants originating from the landing site and possibly the neighboring areas enter directly into the lake water without any treatment and may lead to the lowering of water quality and yet this area happens to have a high population whose lives depend on the lake. Observed variation in the picture from google earth was delineated in Arc View GIS 3.3 giving rise to different land use types. Correction was then made on the land uses using topographic sheet of the study area.

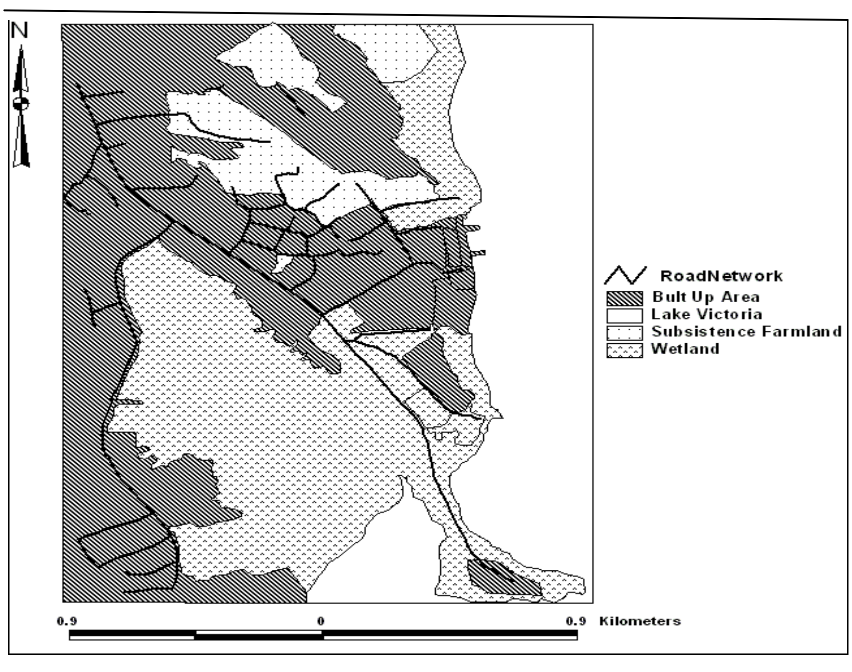

Figure 4.1: Land Use Activities in Gaba

Land Use Types	Km^2	Percentage Coverage
Bult Up Areas	0.13	36.1
Wetland	0.11	30.6
Lake Victoria	0.09	25.0
Subsistence Farmland	0.03	8.3

Table 4.1: Shows Representation of Each Land Use Type

4.2 Land Uses within the Study Area

The study area has several land uses which include Built up areas, Wetland, lake Victoria and Subsistence farmland. A brief description of these follow

4.2.1 Wetland

Wetlands are facilities used for treatment of waste water by vegetation uptake of the nutrients. The dominant vegetation within the wetland are *Cyperus* and *Vossia Cuspidata.* As a result of the ever increasing population, the wetlands are slowly being depleted and some of the land uses such as subsistence farmland are actually depleted wetlands now used for growing food crops. When it rains these areas are the pathways for surface runoff into the lake. Encroachment into these areas has increased lake pollution as the dominant vegetation gets destroyed. The percentage representation of wetland in the study area is 30.6%

4.2.2 Built Up Areas

Built up area constitute 36.1% and consists of paved rooftops used for human settlements. These areas lack enough facilities to collect domestic waste. Solid wastes are dumped indiscriminately including dumping into the poorly maintained drainage channels. Soil surfaces in these areas are bare and always covered with litter. As a result, there is poor environmental and sanitation situation in these areas. When it rains, because of poor drainage channels, waste water creates its own path to low land areas and degraded wetlands which ultimately ends up into Lake Victoria where they lead to lowering of water quality. Also within this study area is Gaba fish landing site with fish vending as the major activity. The area is also a residential and commercial place, with daily marketing activities. Generally, the landing site is closely associated with activities characterizing peri-urban settlements. Surface runoffs originating from these areas are discharged directly into the lake. For any rain event, runoff discharged into the lake causes the colour of the water to change to brown as much silt is carried within the waste water. Lake siltation was evident since close to the shore vertical depth of water kept on reducing and samples could not be obtained. Adjacent to it are beaches and NWSC pumping/treatment facility which supplies water to Kampala City. The station has already experienced increases in water treatment cost due to increased pollution of lake Victoria.

4.2.3 Subsistence Farmland

Occupy 8.3% of the total land use in the area. Most of the farming practiced in this area are for food crops and some for market sale. They are mainly practiced in lowland areas and swamps.

4.3 Contribution of Nutrients from Land Use to Lake Victoria Pollution

Measured concentration of nutrients in surface runoff discharged into Lake Victoria was tested against established benchmarks (Table 4.2) to determine whether their contribution to lake pollution was significant or not. This evolved as a result of deteriorating water quality of lake Victoria. It was therefore necessary to assess the contribution of surface runoff to water pollution being discharged into the lake as non point sources. Eight data sets collected over two rain seasons in a year were used to test for the hypothesis as shown in the summary statistics for each nutrient (Tables 4.3 to 4.10).

Table 4.2: DWD Benchmark Concentrations of Nutrients in Waste Water

Nutrients	*Ammonia*	*Nitrite*	*Nitrate*	*Phosphate*	*TDS*	*EC*	*pH*	*DO*
Standard (mg/l)	< 7.5	0.1	10	5	500	1000	6.8 - 8.4	>5.0

Table 4.3: Summary Statistics for Ammonia-N

Variable	*Observations*	*Missing data*	*Without missing data*	*Min.*	*Max.*	*Mean*	*Std.*
Ammonia – N	8	0	8	2.340	16.340	8.850	6.482

Table 4.4: One-Sample t-Test/Upper-Tailed Test for Ammonia-N

Difference	1.350
t (Observed value)	0.589
t (Critical value)	1.895
DF	7
p-value (one-tailed)	0.287
Alpha	0.05

Table 4.5: Summary Statistics for Nitrite-N)

Variable	Observations	Missing data	without missing data	Min.	Max.	Mean	Std.
(NO_2 – N)	8	0	8	0.070	0.900	0.315	0.329

Table 4.6: One-Sample t-Test/Upper-Tailed Test for Nitrite-N

Difference	0.215
t (Observed value)	1.845
t (Critical value)	1.895
DF	7
p-value (one-tailed)	0.054
Alpha	0.05

Table 4.7: Summary Statistics for Nitrate (NO_3 – N)

Variable	*Observations*	*missing data*	*without missing data*	*Min.*	*Max.*	*Mean*	*Std.*
(NO_3 – N)	8	0	8	0.224	1.918	0.561	0.571

Table 4.8: One-Sample t-Test/Upper-Tailed Test for Nitrate-N

Difference	-9.439
t (Observed value)	-46.729
t (Critical value)	1.895
DF	7
p-value (one-tailed)	1.000
Alpha	0.05

Table 4.9: Summary Statistics for ortho-phosphate

Variable	*Observations*	*missing data*	*Without missing data*	*Min.*	*Max.*	*Mean*	*Std.*
(PO_4-P)	8	0	8	1.72	26.1	6.799	8.066

Table 4.10: One-Sample t-Test/Upper-Tailed Test for ortho-phosphate

Difference	1.799
t (Observed value)	0.631
t (Critical value)	1.895
DF	7
p-value (one-tailed)	0.274
alpha	0.05

The average concentrations of nutrients discharged into lake Victoria were 8.47±0.18mg/l for ammonia-N, 0.4±0.02mg/l for nitrite-N, 0.56±0.04mg/l for nitrate-N, and 6.8±3.20mg/l for PO_4-P. The contributions of ammonia-N, nitrite-N, and PO_4-P were found to be significant at 5% significance level (p = 0.287, 0.054 and 0.274 respectively). Nitrate-N contribution was not significant (p = 1.000).

4.4 Lake Concentrations of Physico-chemical Parameters at Gaba Landing Site

Measurement of both physico-chemical parameters and pollutant loads were done for two rain season and one dry season. The aim was to determine the changes in concentrations of the measured parameters as a result of surface runoff discharges into Lake Victoria, and its bearing on water quality (Table 4.11 and Table 4.12). Dry season concentrations would aid comparison when there is no input of surface runoff. 136 samples were collected for very heavy rainfall event and 64 samples were collected in dry season. In each rain season, 4 samples were taken from each sampling point and measured for the parameters. A total of 8 samples were collected from each point for the two rain seasons. For dry season, 4 samples were used.

Sediment loads were quantified using gravimetric method, nutrients using photometric method and physico-chemical parameters using hand held meters that gave instant concentrations for the measured parameter.

Table 4.11: Average Concentrations of Physico-chemical Parameters over two Rain Seasons

	Horizontal distance (m)						
Vertical depth (m)	**Runoff**	**0**	**10**	**20**	**30**	**40**	**50**
DO (mg/l)							
0.5	16.70±0.04	9.92±0.01	8.36±1.08	7.47±1.13	7.86±1.20	7.75±1.36	7.42±0.94
1.0			6.2±0.09	6.65±1.24	6.71±1.22	8.00±1.19	6.68±1.08
1.5				5.78±0.60	6.43±0.99	6.26±1.01	6.32±0.91
TDS (mg/l)							
0.5	300.00±8.73	157.65±6.40	66.96±5.51	64.86±5.43	64.29±4.84	64.21±4.75	64.74±5.40
1.0			65.03±5.90	65.86±5.38	65.40±4.31	64.60±4.18	64.24±4.41
1.5				62.85±5.64	65.10±5.76	65.50±4.76	65.14±4.61
TSS (mg/l)							
0.5	50.2±2.61	32.6±2.04	19.4±1.93	15.0±1.34	8.0±1.92	6.0±1.66	8.0±1.69
1.0			15.0±1.86	10.0±1.32	10.0±1.84	8.0±1.39	2.0±1.77
1.5				8.9±1.50	13.0±1.98	10.0±1.74	10.0±1.90
pH							
0.5	7.02±0.39	6.63±0.46	7.30±0.46	7.67±0.49	7.29±0.61	7.25±0.58	7.11±0.71
1.0			7.19±0.15	7.61±0.62	7.59±0.54	7.15±0.58	7.26±0.61
1.5				7.33±0.64	7.69±0.51	7.09±0.60	7.69±0.43
T (^oC)							
0.5	24.35±1.21	24.61±1.38	24.56±1.35	24.64±1.34	24.63±1.31	24.81±1.33	25.30±1.95
1.0			24.64±1.10	24.34±1.23	24.34±1.30	24.45±1.31	24.52±1.30
1.5				24.95±1.02	24.32±1.33	24.52±1.34	24.55±1.32
EC (µS/cm)							
0.5	431.50±26.14	313.00±64.02	160.49±61.26	107.10±23.9	104.44±22.15	104.98±21.45	105.83±23.13
1.0			121.83±25.40	112.44±22.03	104.47±23.04	103.89±22.42	105.12±21.84
1.5				105.86±25.13	106.24±24.34	105.50±23.58	105.31±23.21

Key: (a) Runoff refers to rain water just before discharge into the lake after a rain event
(b) Horizontal distances are the sampling points within the lake after rainfall event (0, 10, 20, 30, 40, 50)
(c) Vertical depth is the depth below Lake water surface where samples were drawn for respective horizontal distance
(d) Blank concentrations at vertical depth 1.0m and 1.5m refer to shallow depth at such horizontal distances.

Table 4.12: Average Concentrations of Physico-Chemical Parameters in Dry season

	Horizontal distance (m)					
Vertical depth (m)	**0**	**10**	**20**	**30**	**40**	**50**
DO (mg/l)						
0.5	3.60±0.60	4.80±0.58	5.70±0.30	6.40±0.26	7.20±0.19	7.60±0.27
1.0			4.90±0.31	6.00±0.24	7.20±0.94	7.50±0.22
1.5				5.90±0.27	6.10±0.32	6.60±0.33
TDS (mg/l)						
0.5	170.00±1.80	94.80±1.78	70.00±2.74	48.20±0.80	88.50±1.61	40.80±1.47
1.0			58.00±1.63	43.00±1.33	47.00±1.48	41.10±0.17
1.5			47.90±1.61	45.40±0.72	44.00±1.15	41.20±0.42
EC (µS/cm)						
0.5	368.60±23.90	100.94±21.30	106.32±29.6	100.40±31.67	99.38±32.20	102.66±31.83
1.0			103.54±31.02	99.88±32.19	102.96±31.38	101.74±31.63
1.5			91.20±28.6	99.60±32.51	103.66±30.71	100.46±30.52
pH						
0.5	7.02±0.72	7.71±0.68	8.13±0.50	8.54±0.38	8.89±0.74	8.98±0.69
1.0			8.10±0.21	8.61±0.47	8.92±0.71	8.97±0.73
1.5			7.78±0.30	8.69±0.60	8.92±0.79	8.74±0.50
T (^{o}C)						
0.5	25.86±1.02	26.18±1.05	26.30±1.07	26.04±0.98	26.28±0.89	26.14±0.85
1.0			26.10±1.06	26.02±0.88	26.20±0.99	25.96±0.91
1.5			26.70±1.07	25.96±1.07	25.96±0.82	26.28±0.83

Key: (a) Horizontal distances are the sampling points within the lake after rainfall event (0, 10, 20, 30, 40, 50)
(b) Vertical depth is the depth below Lake water surface where samples were drawn for respective horizontal distance (0.5, 1.0, 1.5)
(c) Blank concentrations at vertical depth 1.0m and 1.5m refers to shallow depth at such horizontal distances.

4.4.1 Variation in Dissolved Oxygen Concentration

The DO concentration in surface runoff was 16.7±0.04mg/l. In Lake water, its concentration ranged between 9.92±0.01mg/l to 5.78±0.60mg/l (Table 4.11). In dry season (Table 4.12), the DO range was between 3.60±0.60mg/l to 7.60±0.27mg/l.

The DO level decreased from shore into the lake in rainy season and increased from shore into the lake for dry season. There was slight drop in DO concentration from the water surface vertically downwards with an exponential decrease from point of surface runoff discharge into the lake. Overall its concentrations both in dry and rain seasons within the Lake were still higher than the recommended minimum of 5.0mg/l (Figure 4.2).

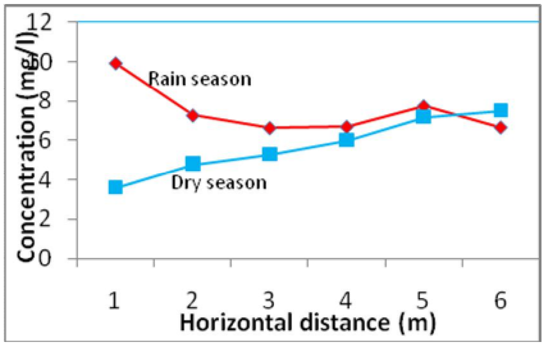

Figure 4.2: Overall Variation in DO Concentration between Dry and Rain Season

(a) Dissolved Oxygen Variation within Season

ANOVA revealed variation in the horizontal direction between groups at 10m horizontal distance (p=0.006) and 40m distance (p=0.016). LSD test for Horizontal distance ten was not performed due to shallow depth which did not allow sampling at 1.0m and 1.5m to be made. LSD test also revealed that at horizontal distance of 20m, nutrient concentration at 0.5m depth was significantly different from the one at 1.5m depth (p=.040) but not significantly different from concentration at vertical depth 1.0m (p=.384). At horizontal distance fourty, the concentration at 0.5m was significantly different from the one at 1.0m (p=.029) and no difference existed at 1.0m depth with 1.5m (p=.460).

In the vertical direction, ANOVA showed significant difference between groups at 0.5m depth (p=0.000) and 1.0m depth (p=0.006). LSD test showed at 0.5m, concentration at 0m horizontal distance was significantly different from concentrations at horizontal distances from 10m to 50m (p=.001, .000, .000, .000, .000 respectively). There was no variation in dry season DO concentration

(b) Seasonal Variation in Dissolved Oxygen Concentrations

DO concentration showed significant variation among the seasons (p=.035). First rain season showed no significant difference with the second season (p=.151) and dry season (p=.076). However second rain season was significantly different from dry season concentrations (p=.010). In vertical direction variation in DO concentration was not significant (p=0.056). However LSD test revealed significant variation between second rain season and dry season concentrations (p=.018)

4.4.2 Total Dissolved Solid (TDS) Variation

Total Dissolved Solids (TDS) concentration in surface runoff was 300±8.73mg/l, lower than the maximum recommended concentration of 500mg/l. In lake water its average concentration ranges from 157.65±6.40mg/l at the shore to 62.85±5.64mg/l. In dry season, its concentration ranged between 170.0±1.80mg/l to 40.8±1.47mg/l and showed a slight decrease from water surface vertically downwards and an exponential decrease from shore into the lake. There was slight increase in concentration in the vertical direction for rain season. The concentrations in rainy seasons were higher than its corresponding dry seasons.

There was no variation in TDS concentration within the seasons both in the horizontal and vertical direction (p=.559)

(a) Within Season Variation in TDS Concentrations

In the vertical direction at 0.5m depth there was significant variation between the groups (p=.000). At this depth-0.5m, the concentration at 0m horizontal distance was significantly different from the rest of the horizontal distances (p=.000 for all horizontal distances. horizontal distances in dry season showed no significant variation (p>.05).

(b) Seasonal Variation in TDS concentration

Although there was variation in TDS concentration between first and second rain season, one way ANOVA revealed that the variation was not significant within all the seasons (p=.559). In the vertical direction, TDS concentrations were not significant (p=.559)

4.4.3 Variation in Total Suspended Solids (TSS) Concentration

TSS concentration in surface runoff was 50.2±2.61. Within the Lake, its concentration ranged between 32.6±2.04mg/l to 2±1.77mg/l. TSS decreased from shore into the lake but in the vertical direction, the concentration increased from water surface inwards into the lake (Figure 4.3). Close to the Lake bottom at 1.5m vertical depth, the concentration was almost constant. In dry season, concentrations were undetectable and most of the concentrations were zero

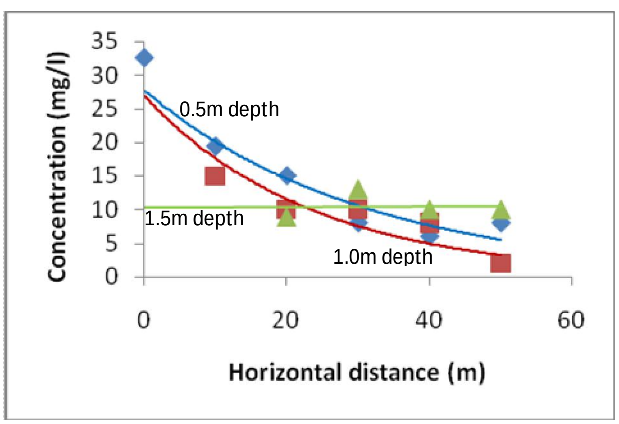

Figure 4.3: Variation in TSS concentrations

(a) Within season variation in Total Suspended Solids (TSS)

using one way ANOVA, there was significant difference in concentration for horizontal direction ($p=0.00$). Concentration at horizontal distances from shore to 30 were significantly different from concentrations at all horizontal distances. At 40m horizontal distance, analysis revealed varying trend which is not clearly marked. TSS therefore dispersed to about 40m and beyond this point the concentration reduced to lake concentration. In the vertical direction, there was also significant difference ($p=0.04$). Concentration at 0.5m was significantly different from concentration at 1.0m ($p=0.015$). However concentration at 1.0m was not significantly different ($p=0.084$). There was no variation in TSS concentration between first and second rain season. Dry season concentration were zero.

4.4.4 Variation in Electrical Conductivity

Electrical Conductivity (EC) value in runoff was 431.5±26.14µS/cm. The values ranged from 313.0±64.02µS/cm to 103.89±22.42µS/cm. This showed an increase in EC concentrations during rain seasons than in dry season (Table 4.11 and Table 4.12) but in the horizontal direction, an exponential decrease was observed. With continuous deposition of surface runoff into the lake, there may be further deterioration in lake water quality though the level is still lower than the recommended of 1000µS/cm

(a) Within Seasonal Variation in Electrical Conductivity

During the rain season, there was no significant difference in EC in the horizontal direction ($p>0.05$). In the vertical direction, significant variation were manifested at 0.5m depth between groups ($p=.005$). LSD test revealed that at 0.5m, the concentration at 0m was different from the rest of the horizontal distances ($p=.003$ for 10m, .001 for 20m to 50m each). However 0m had fewer groups for comparison to be made.

Dry season ANOVA revealed no significant difference in the horizontal direction ($p>0.05$). In vertical direction, there was significant variation between groups at 0.5m depth. The LSD test revealed that the 0m concentration was significantly different from concentrations for the entire horizontal distances ($p=.000$ each) *(b) Seasonal Variations in Electrical Conductivity*

From ANOVA, EC variation among the various seasons was not significant (p=.470) though their means were different. Also in the vertical direction, variation was not significant (p=.350)

4.4.5 Variation in pH

The pH of runoff was very close to neutral (7.02±0.39). Within the Lake, pH had a range of between 6.63±0.46 to 7.69±0.43 for rainy season and 7.02±0.72 to 8.98±0.69 for dry season, with no clearly marked variation in the vertical direction. A comparison between dry and rainy season values however revealed that the pH level in dry season was higher than its corresponding rain seasons values (Figure 4.4), and some of the concentrations lied above the recommended range of between 6.8 to 8.4 suggesting impairment in water quality and lake ecosystem productivity (Gordon et al., 1968).

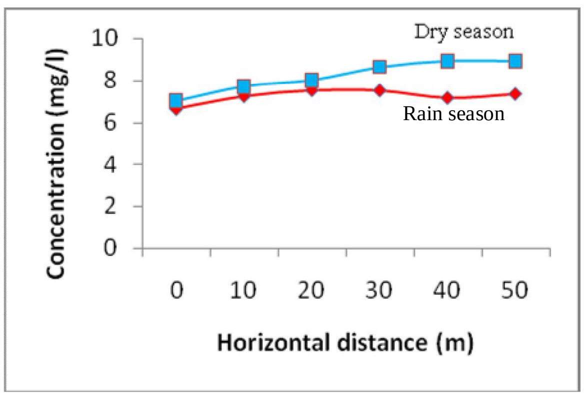

Figure 4.4: Overall Seasonal Variation in pH

In horizontal direction, pH variation was significant (p=.000). LSD test revealed no variation in pH between first and second rain season (p=.249) but variation existed between first season and dry season (p=.000). Also second rain season value was significantly different with dry season one (p=.000). In vertical direction, pH showed significant variation (p=.000). First and second rain season showed no variation between them but first season showed significant variation with dry season (p=.000). Also second rain season showed significant variation with dry season (p=.000)

4.4.6 Variation in Temperature

The runoff temperature was 24.35±1.21^{o}C and ranged between 24.32±1.33^{o}C to 25.30±1.95^{o}C in rain season and 25.86±1.02 to 26.70±1.07 in dry season and water temperature was higher in dry season than its rain season values.

(a) Within Seasonal Variation in Temperature

There was no significant variation in temperature (p>.05) in both horizontal and vertical direction. Also in dry season, both in vertical and horizontal direction there was no significant difference (p>.05)

(b) Seasonal Variations in Temperature

Temperature variation among seasons were significant (p=.000). LSD test revealed that first rain season temperatures were different from second rain season (p=.005) and dry season (p=.000). Second rain season showed no variation with dry season (p=.108). In vertical direction, temperature variation was significant (.000) with first rain season being significantly different from second season (p=.005) and dry season (p=.000)

4.5 Nutrients Concentration within Lake Victoria at Gaba Landing Site

Nutrient input into Lake Victoria is one of the causes of low ecosystem productivity within Lake Victoria. Some of the sources are believed to come from the various land use activities. This land uses contribute nutrients to the Lake in form of surface runoff where they lead to deterioration in water quality and eutrophication. The study aim was to assess nutrient dispersion into the Lake after it has been released both horizontally and vertically and to determine the variation in their concentrations as they disperse within the lake (Table 4.13 and Table 4.14)

Table 4.13: Average Concentrations of Nutrients over two Rainy Seasons

Vertical depth (m)	Horizontal distance (m)						
	Runoff	0	10	20	30	40	50
Ammonia - N (mg/l)							
0.5	8.47±0.18	0.82±0.16	0.33±0.15	0.18±0.09	0.16±0.06	0.17±0.13	0.13±0.07
1.0			0.27±0.21	0.21±0.11	0.16±0.05	0.15±0.05	0.13±0.05
1.5				0.18±0.07	0.20±0.16	0.16±0.05	0.15±0.08
Nitrite - N (mg/l)							
0.5	0.40±0.02	0.06±0.01	0.03±0.02	0.02±0.005	0.018±0.006	0.02±0.005	0.02±0.005
1.0				0.02±0.006	0.016±0.006	0.02±0.007	0.02±0.007
1.5				0.02±0.006	0.018±0.006	0.02±0.009	0.02±0.009
Nitrate - N (mg/l)							
0.5	0.56±0.04	0.13±0.05	0.10±0.05	0.08±0.03	0.08±0.02	0.07±0.02	0.08±0.02
1.0			0.04±0.03	0.09±0.02	0.07±0.02	0.08±0.02	0.08±0.02
1.5				0.09±0.01	0.07±0.02	0.08±0.02	0.09±0.03
PO_4-P (mg/l)							
0.5	6.80±3.20	0.66±2.97	0.25±3.45	0.26±0.18	0.26±0.12	0.18±0.08	0.31±0.58
1.0			0.08±3.59	0.26±0.17	0.39±0.39	0.22±0.13	0.22±0.14
1.5				0.20±0.11	0.23±0.17	0.26±0.23	0.26±0.15

Key: (a) Runoff refers to rain water just before discharge into the lake after a rain event;
(b) Horizontal distances are the sampling points within the lake after rainfall event (0, 10, 20, 30, 40, 50)
(c) Vertical depth is the depth below Lake water surface where samples were drawn for respective horizontal distances
(d) Blank concentrations at vertical depth 1.0m and 1.5m refer to shallow depth at such horizontal distances.

Table 4.14: Average Concentrations of Nutrients in Dry Season

Vertical depth (m)	Horizontal distance (m)					
	0	10	20	30	40	50
Ammonia – N (mg/l)						
0.5	0.04	-	-	-	-	0.03
1.0			-	-	-	-
1.5			-	-	-	-
Nitrite – N (mg/l)						
0.5	0.10±0.011	0.02±0.01	0.02±0.011	0.01±0.009	0.01±0.008	0.01±0.009
1.0			0.02±0.011	0.02±0.008	0.02±0.009	0.02±0.009
1.5			0.02±0.010	0.02±0.009	0.02±0.008	0.01±0.008
Nitrate – N (mg/l)						
0.5	0.18±0.060	0.1016±0.041	0.10±0.079	0.09±0.063	0.10±0.066	0.08±0.050
1.0			0.10±0.061	0.09±0.054	0.09±0.054	0.09±0.061
1.5			0.11±0.052	0.08±0.049	0.08±0.044	0.07±0.053
PO_4-P (mg/l)						
0.5	2.46±0.11	0.28±0.16	0.21±0.19	0.16±0.12	0.18±0.11	0.17±0.12
1.0			0.14±0.07	0.18±0.10	0.18±0.11	0.13±0.10
1.5			0.23±0.09	0.15±0.09	0.18±0.10	0.12±0.08

Key: (a) Horizontal distances are the sampling points within the lake after rainfall event (0, 10, 20, 30, 40, and 50)
(b) Vertical depth is the depth below Lake water surface where samples were drawn for respective horizontal distances
(c) Concentration for ammonia refers to concentration being undetectable in that season
(d) Blank concentrations at vertical depth 1.0m and 1.5m refers to shallow depth at such horizontal distances.

4.5.1 Variation in Ammonia-N Concentration

Over the two rain seasons, average concentration of ammonia-N in surface runoffs was 8.47±0.18mg/l. From the Lake shore to the 50m mark, its concentration ranged between 0.82±0.16mg/l to 0.13±0.07mg/l (Table 4.13). During dry seasons, ammonia-N concentrations were undetectable and is indicated as a dash on Table 4.14

(a) Within Season Variation in Ammonia-N Concentration

Ammonia-N showed no significant difference for all the horizontal distances ($p>0.05$). Analysis for horizontal distances ten and zero was not performed because of inadequate data (less than two groups for comparison to be performed.

In the vertical direction, there was a significant difference at 0.5m depth ($p=0.002$). Multiple comparison using LSD revealed that at vertical depth of 0.5m, the concentrations at zero horizontal distance was significantly different from all the horizontal distances. Comparison for zero horizontal distance was not performed because of few data groups required for comparison.

(b) Seasonal Variation in Ammonia-N Concentrations

In vertical direction there was no significant variation between first and second rain season ($p=.826$). Comparison could not be made with dry season because ammonia-N concentrations because ammonia-N concentrations were below detectable limit and could not be measured. In horizontal direction, there was no significant variation ($p=.288$)

4.5.2 Variation in Nitrite-N Concentration

Nitrite-N concentration in surface runoff was 0.40±0.02mg/l and ranged between 0.06±0.01mg/l to 0.016±0.006mg/l within the lake. In dry season, Lake concentration ranged between 0.10±0.011mg/l to 0.01±0.008mg/l. This concentration is higher than its corresponding dry season (Figure 4.5)

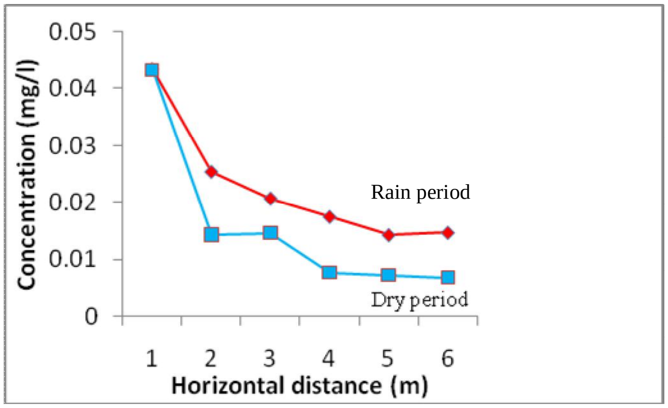

Figure 4.5: Comparison between Rain and Dry Period Nitrite-N Concentration

(a) Within Season variation in Nitrite-N

Analysis of nitrite-N concentration using one way ANOVA showed no significant variation in the concentration for horizontal direction ($p>0.05$). in the vertical direction at 0.5m there was significant difference between the groups ($p=0.000$). LSD test indicated that the concentration at 0m distance was significantly different from the rest of horizontal distances from 10m to 50m

For dry season, in vertical direction, there was significant difference at 0.5m depth ($p=0.044$) between the groups and in horizontal direction there was no significant difference. In horizontal direction, there was no significant difference.

(b) Seasonal Variation in Nitrite-N Concentration

In both vertical and horizontal direction, variation in mean concentration were not significant ($p=.943$, and .936 respectively).

4.5.3 Variation in Nitrate-N Concentration

Nitrate-N concentration in surface runoff was 0.56±0.04mg/l and had lake concentration range between 0.13±0.05mg/l to 0.04±0.03mg/l. Its Lake concentrations in dry season ranged between 0.18±0.06mg/l to 0.07±0.053mg/l and these concentrations were higher than the corresponding rain season (Figure 4.6).

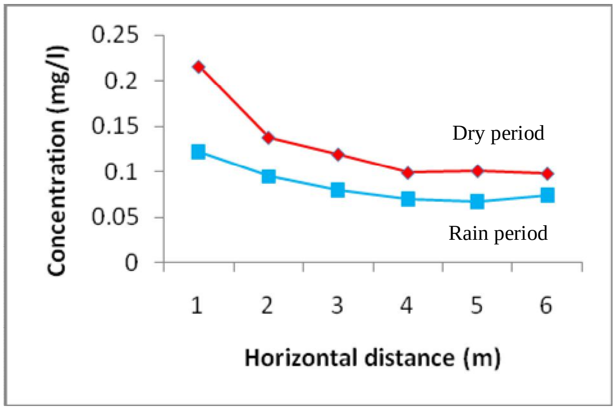

Figure 4.6: Comparison between Rain and Dry Period Nitrate-N Concentration

(a) Within Season Variation in Nitrate-N Concentration

In rain season, nitrate showed no significant difference (p>0.05) in horizontal direction. In the vertical direction, the variation was at 0.5m depth between groups and the variation was for all the horizontal distance from 10m to 50m. Also variation existed at 10m at 0m horizontal distance (shore)

For dry season, there was no significant difference in both horizontal and vertical direction (p>0.05). In vertical direction, there was also no significant variation (P>0.05)

(b) Seasonal Variation in Nitrate-N Concentration

Nitrate-N concentration was significant in the vertical direction from ANOVA (p=.010). first rain season was significantly different from second rain season (p=.019) and significantly different from dry season (p=.004). Second season was not significantly different from dry season concentration (p=.843). in the horizontal direction, nitrate concentration was significant (p=.010). first season was different from second season (p=.019) and also dry season (p=.004). second season variation with dry season was not significant (p=.843)

4.5.4 Variation in Ortho-phosphate Concentration

Ortho-phosphate had a concentration of 6.80±3.20mg/l in surface runoff and range of 0.66±2.97mg/l to 0.08±3.59mg/l within the lake. In dry season, lake concentration of phosphate ranged between 2.46±0.11mg/l to 0.12±0.08mg/l and the dry season concentration was lower than for its corresponding rain season (Figure 4.7)

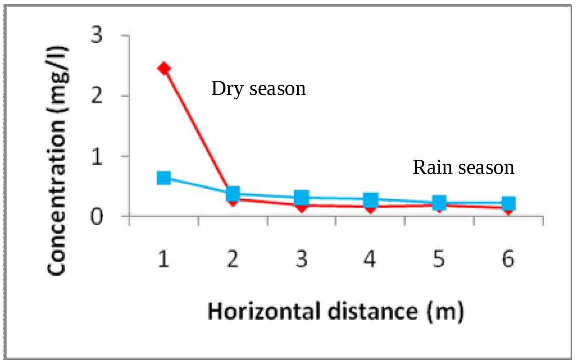

Figure 4.7: Comparison between Rain and Dry Season ortho-phosphate Concentration

(a) Within Season Variation in Ortho-phosphate Concentration

In the horizontal direction, there was no variation (p>0.05) and in the vertical direction, there was variation between groups at 0.5m vertical depth. Multiple comparison using LSD showed significant difference in the horizontal direction from 10m to 50m at 0.5m vertical depth. Variation at zero horizontal distance should be ignored because there was no enough group of data for comparison

There was no significant difference in the horizontal direction for phosphate (P>0.05). in vertical direction at 0.5m depth, there was significant variation between groups (p=0.00), and multiple comparison using LSD showed variation with horizontal distance from 10m to 50m. The significant variation at zero horizontal distances should be ignored because of less than two data comparison to be made due to change in lake profile as one moves from shore into the lake, the lake becomes deeper.

(b) Seasonal Variation in Ortho-phosphate Concentration

Concentration of ortho-phosphate was not significant (p=.114) in the vertical direction. In horizontal direction, mean concentration was not significant (p=.114)

4.6 Model Generation Process for Nutrient Dispersion Coefficients

Modeling the data was performed by means of equation (3.3) to facilitate prediction of dispersion distances traversed by nutrients carried in the surface runoffs. From the equation, the dispersion coefficients were determined and then plotted. These plots represented the rate at which nutrients were being dispersed within the Lake

4.6.1 Dispersion Coefficient for Ammonia-N

Figure 4.8 below is the graph of the variation of dispersion coefficients versus the horizontal distance traversed by ammonia-N

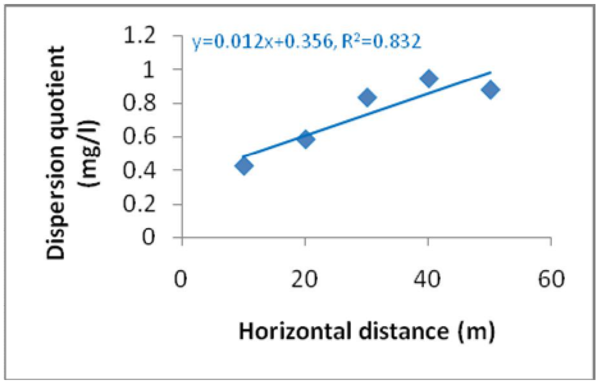

Figure 4.8: Dispersion Coefficient for Ammonia-N

4.6.2 Dispersion Coefficient for Nitrite-N

Figure 4.9 below is the graph of the variation of dispersion coefficients versus the horizontal distance traversed by Nitrite-N

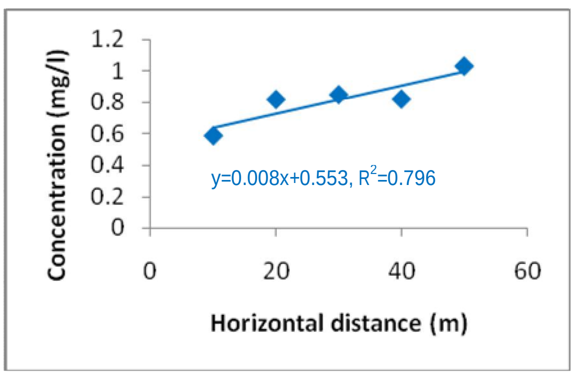

Figure 4.9: Dispersion Coefficient for Nitrite-N

4.6.3 Dispersion Coefficient for Nitrate-N

Figure 4.10 below is the graph of the variation of dispersion coefficients versus the horizontal distance traversed by Nitrate-N

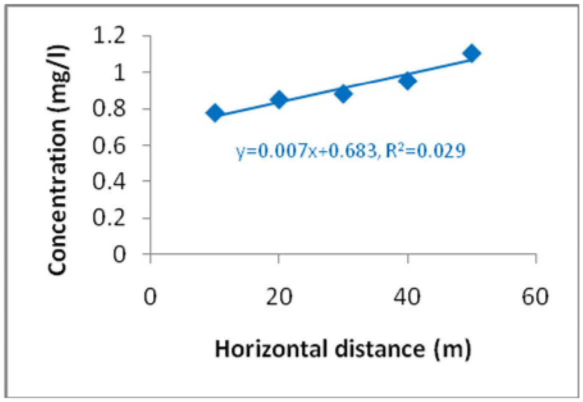

Figure 4.10: Dispersion Coefficient for Nitrate-N

4.6.4 Dispersion Coefficient for ortho-phosphate

Figure 4.11 below is the graph of the variation of dispersion coefficients versus the horizontal distance traversed by ortho-phosphate

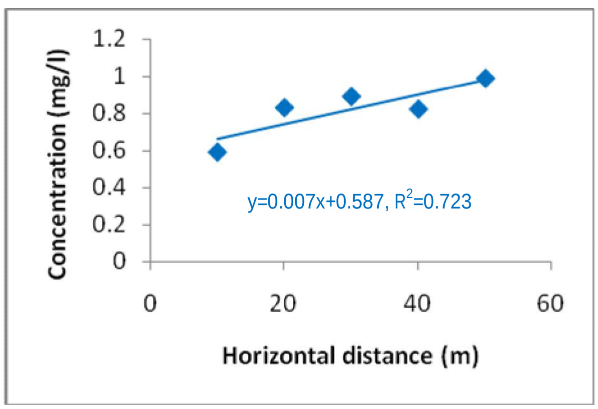

Figure 4.11: Dispersion Coefficient for ortho-phosphate

4.7 Verification of Model Output

Using the dispersion coefficient generated, model concentration output for the various nutrients were generated and plotted against the practically measured trend to determine whether the model prediction were in agreement with measured dispersion trends. The plot revealed that the models over estimated nutrient concentrations as shown in Figures 4.12 to 4.15 below

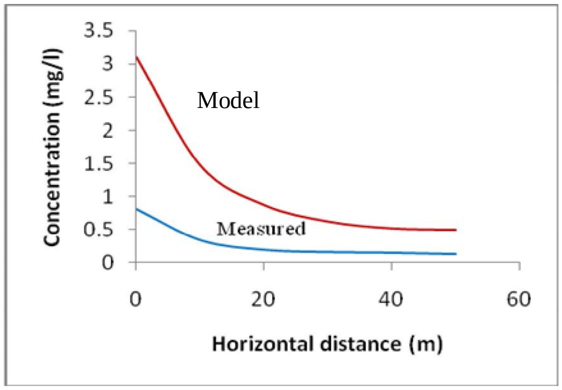

Figure 4.12: Comparison between Model and Measured Ammonia-N Concentration

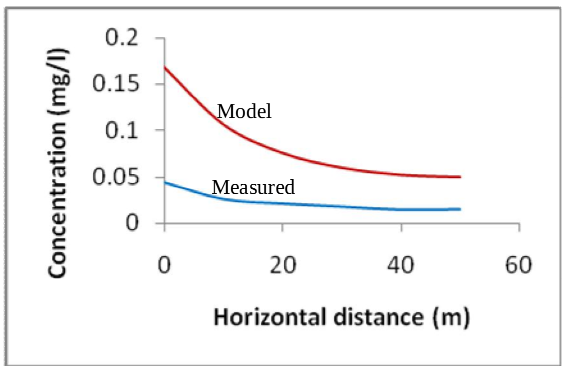

Figure 4.13: Comparison between Model and Measured Nitrite-N Concentration

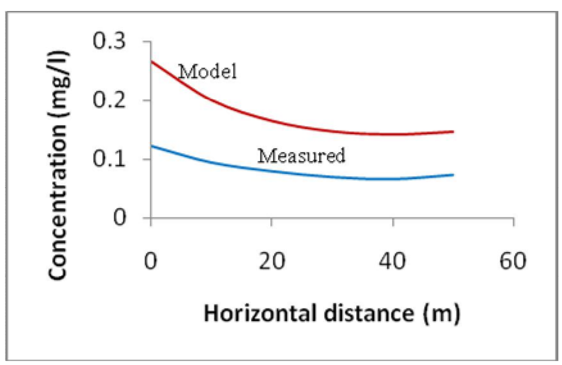

Figure 4.14: Comparison between Model and Measured Nitrate-N Concentration

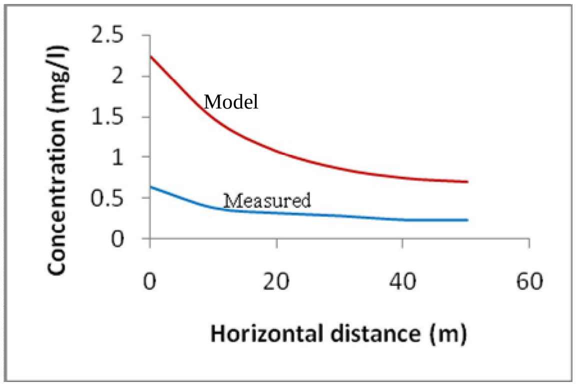

Figure 4.15: Comparison between Model and Measured ortho-phosphate concentration

4.8 Model Calibration

Stemming from the over estimation of the model, calibration was necessary. This was performed by establishing a calibration function that would adjust the model concentration to measured Lake concentration.

4.8.1 Obtaining the Calibrating Function

The difference in concentration between the model and measurement was obtained and plotted which gave an exponential trend (Figures 4.16, 4.18, 4.20 and 4.22). This difference was represented in terms of dispersion coefficient (Figures 4.17, 4.19, 4.21 and 4.23) below.

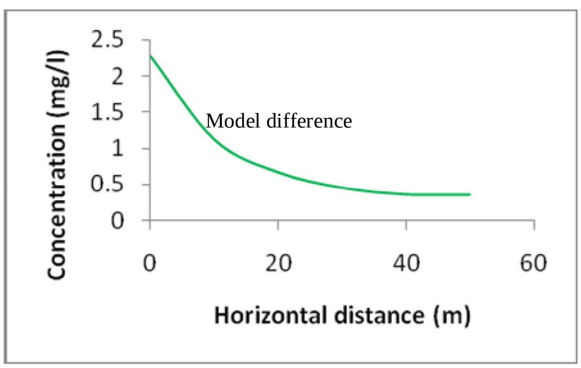

Figure 4.16: Differences between Model and Measured ammonia-N Concentration

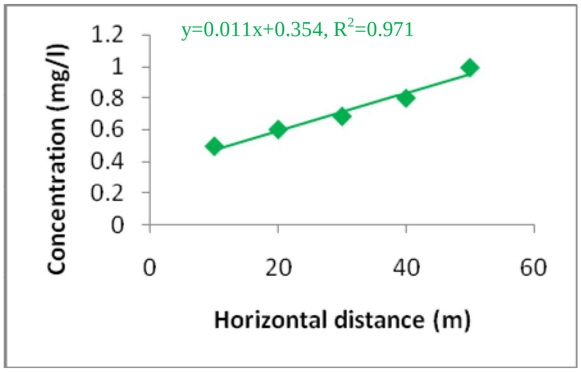

Figure 4.17: Dispersion Coefficient for Calibrating Ammonia-N Model

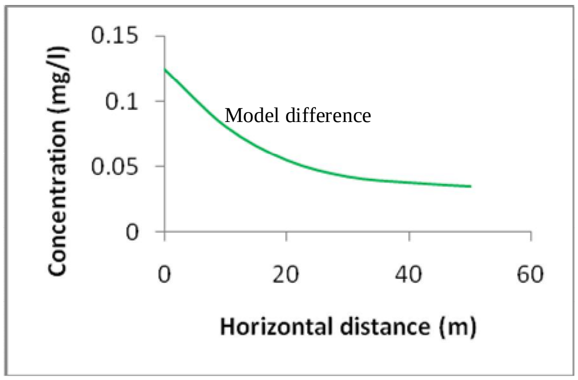

Figure 4.18: Differences between Model and Measured nitrite-N Concentration

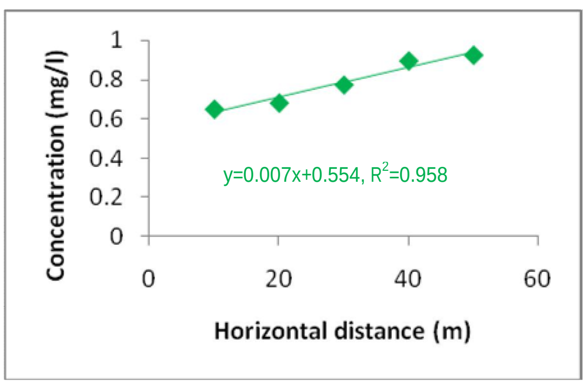

Figure 4.19: Dispersion Coefficient for Calibrating Nitrite-N Model

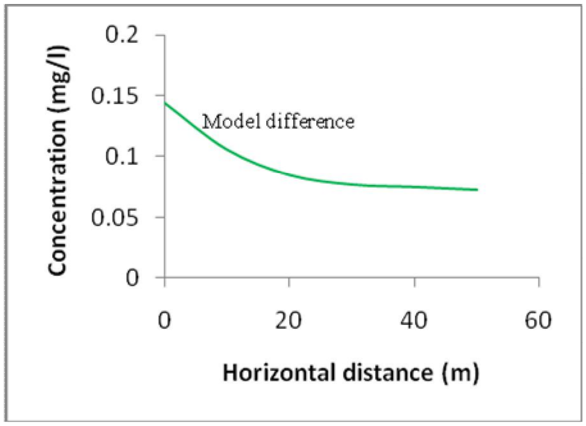

Figure 4.20: Differences between Model and Measured nitrate-N Concentration

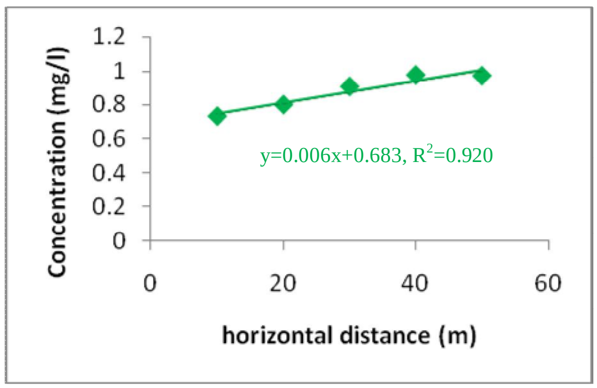

Figure 4.21: Dispersion Coefficient for Calibrating Nitrate-N Model

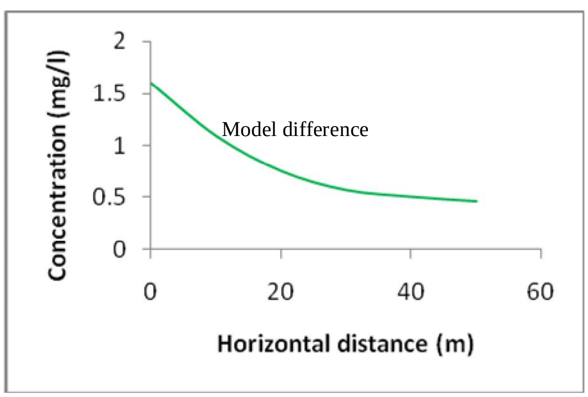

Figure 4.22: Differences between Model and Measured ortho-phosphate Concentration

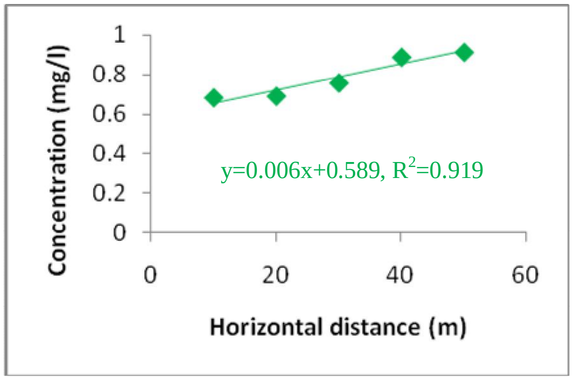

Figure 4.23: Dispersion Coefficient for Calibrating ortho-phosphate Model

4.8.2 Difference between Lake and Surface Runoff Nutrients Concentrations

During data collection process, it was determined that concentrations C_i of nutrients in surface runoffs before discharge into the Lake was much higher than lake concentrations. We are trying to generate a model which would predict dispersion distances given any known concentration of a particular nutrient in surface runoff being discharged into the lake. The dispersion coefficients being generated are valid for dispersions within the lake only yet the concentration of surface runoff being discharged at the shore i.e. zero meters does not follow the dispersion coefficient since it is abnormally high. Therefore the number of times this runoff concentration can be diluted to give concentration at zero horizontal distance was determined i.e. $(0.75C_i)$ for ammonia-N, $(0.41C_i)$ for nitrite-N, $(0.46C_i)$ for nitrate-N and $(0.86C_i)$ for ortho-phosphate. Representing these equivalent runoff concentrations at zero meter by a single parameter i.e. λ_i for ammonia-N, μ_i for nitrite-N, γ_i for nitrate-N, ε_i for ortho-phosphate and multiplying by the respective dispersion coefficients e.g. $(0.011x + 0.354)$ for ammonia-N gave the calibrating functions f_c shown below (Equation 4.1). For subsequent computation from shore, $C_i, \lambda_i, \mu_i, \gamma_i$ and ε_i takes on resultant concentrations of the un-calibrated model and calibrating functions for each nutrient respectively.

(a) Calibrating function for ammonia-N

$$f_c = (0.011x + 0.354).\lambda_i \qquad (4.1)$$

(b) Calibrating function for nitrite-N

$$f_c = (0.007x + 0.554).\ \mu_i \tag{4.2}$$

(c) Calibrating function for nitrate-N

$$f_c = (0.006x + 0.683).\ \gamma_i \tag{4.3}$$

(d) Calibrating function for Ortho-phosphate

$$f_c = (0.006x + 0.589).\ \varepsilon_i \tag{4.4}$$

4.9 Calibrated Model Output

This difference was then subtracted from the un-calibrated model to give a model equation. The horizontal distances within the Lake where model concentrations equal to Lake concentration is considered as the distances these nutrients disperses into the Lake when discharged into the Lake by surface runoff from the graphical plot shown below (Figures 24 to 27).

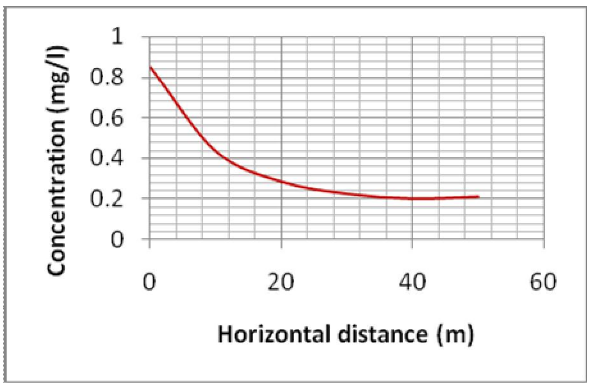

Figure 4.24: Validated Ammonia-N Model

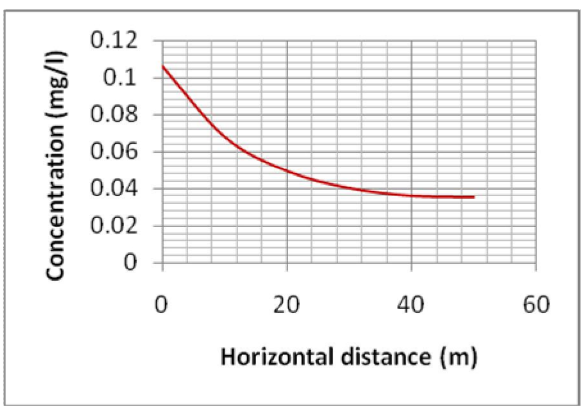

Figure 4.25: Validated Nitrite-N Model

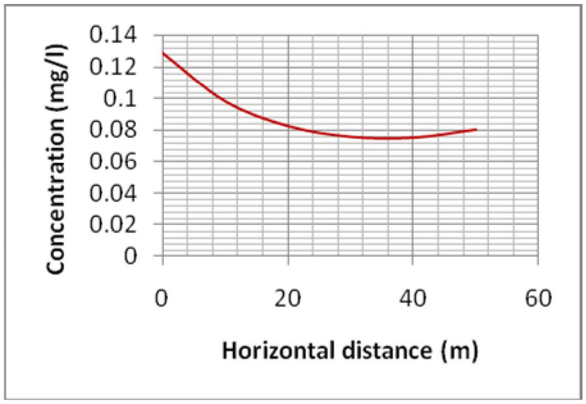

Figure 4.26: Validated Nitrate-N Model

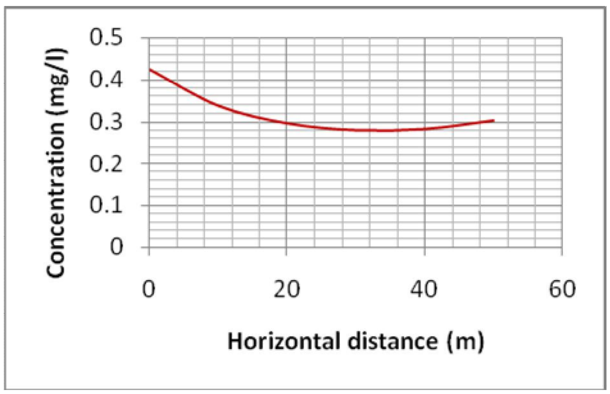

Figure 4.27: Validated ortho-phosphate Model

4.10 Model Validation

Validation of model equations were performed using separate surface runoff data collected during second rain seasons. Ammonia-N was validated using 9.0mg/l, 0.33mg/l for nitrite-N, 0.35mg/l for nitrate-N and 4.32mg/l for ortho-phosphate. The concentrations generated were plotted against measured lake concentration and the correlation between the two parameters are as shown below (Figures 28 to 31).

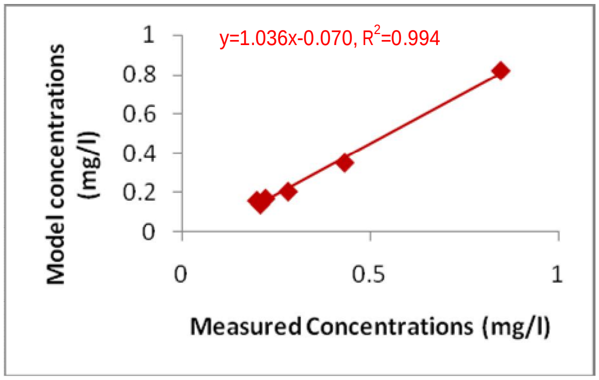

Figure 4.28: Relation between Validated Model and Measured Concentration of ammonia-N

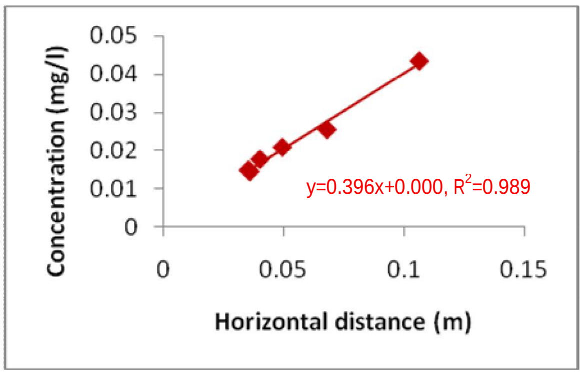

Figure 4.29: Relation between Validated Model and Measured Nitrite-N Concentration

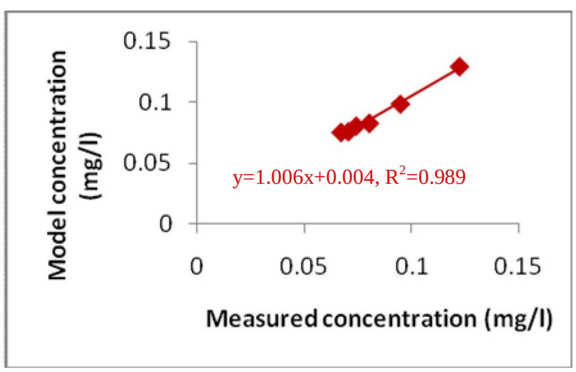

Figure 4.30: Relation between Validated Model and Measured Nitrate-N Concentration

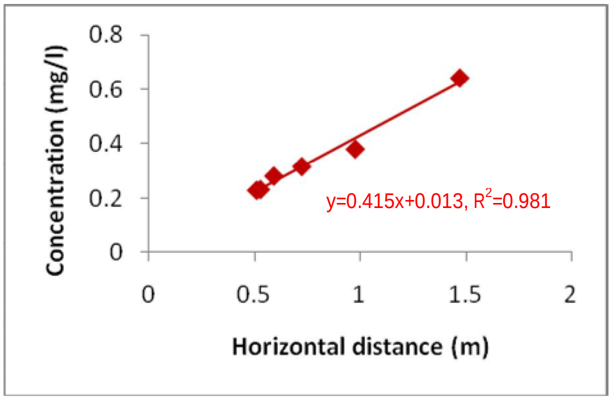

Figure 4.31: Relation between Validated Model and Measured ortho-phosphate Concentration

Due to the strong positive correlation shown, respective equations for each model can be used to generate the concentration of nutrients $C_{i,\,x}$ at any point x of interest given that the concentration of surface runoff C_i is known

4.11 Model Equations for Nutrients

The equations given below represents the models that can be used to predict dispersion distances for nutrients within the Lake.

(a) General Model Equation Characterizing Ammonia-N Dispersion

$$C_{i,\,x} = (0.012x + 0.356)C_i - (0.011x + 0.354).\,\lambda_i \tag{4.5}$$

(b) General Model Equation Characterizing Nitrite-N Dispersion

$$C_{i,\,x} = (0.008x + 0.553).\,C_i - (0.007x + 0.554).\,\mu_i \tag{4.6}$$

(c) General Model Equation Characterizing Nitrate-N Dispersion

$$C_{i,\,x} = (0.007x + 0.683).\,C_i - (0.006x + 0.683).\,\lambda_i \tag{4.7}$$

(d) General Model Equation Characterizing ortho-phosphate Dispersion

$$C_{i,\,x} = (0.007x + 0.587).\,C_i - (0.006x + 0.589).\,\varepsilon_i \tag{4.8}$$

4.12 Predicted Horizontal Distances of Dispersion for Nutrients using Model

From the Ammonia-N model (Figure 4.24), ammonia released as surface runoff into the lake disperses to a distance of 38 meters. At this distance, its concentration in water was about 0.185mg/l as compared with the measured concentration of 0.162mg/l. Nitrite-N dispersed to 45 meters (Figure 4.25) with a model concentration of about 0.034mg/l as compared with the measured concentration of 0.02mg/l. Nitrate-N dispersed to 34 meters with a model concentration of 0.076mg/l as compared with measured concentration of 0.0692mg/l (Figure 4.26). Ortho-phosphate (Figure 4.27) reached horizontal distance of 34 meters with model concentration of 0.28mg/l as compared with measured concentration of 0.26mg/l.

CHAPTER FIVE

DISCUSSION

5.1 Land Use Contribution to Lake Victoria Pollution

Waste water originating from Gaba fish landing site community discharges into lake Victoria as surface runoff without any treatment. This surface runoff were sampled and analysed for both physico-chemical parameters and nutrients. The average concentrations of nutrients discharged into Lake Victoria were 8.47±0.18mg/l for ammonia-N, 0.4±0.02mg/l for nitrite-N, 0.56±0.04mg/l for nitrate-N, and 6.8±3.20mg/l for PO_4-P. The contributions of ammonia-N, nitrite-N, and PO_4-P were found to be significant at 5% significance level (p = 0.287, 0.054 and 0.274 respectively). Nitrate-N contribution was not significant (p = 1.000). Average concentrations of physico-chemical parameters in surface runoffs were; DO=16.70±0.04, pH=7.02±0.39, EC=431.50±26.1, TDS=300.0±8.73, TSS=50.2±2.61

Zampella (2007) analyzed graphically the general relationships between land use and water quality and demonstrated that increases in pH, specific conductance, and dissolved solids are associated with an increase in the extent of urban and upland-agricultural lands in a drainage basin. His average values were 0.43±0.35 for pH and 10.5±7.5 for EC for samples taken from areas draining a basin-Basin Wide Approach. Using Spearman's Rank Correlation for basin wide approach and distance weight, his study revealed a significant correlation between NOx-N and each of the three land use categories (Urban land-Rank=0.71, Upland Agriculture-Rank=0.68, Altered land-Rank=0.76 for Nitrite Plus Nitrate as Nitrogen). The strongest relationship was between nutrients and total altered land, compared with urban land and upland agriculture. Basin wide approach had similar results as smaller sub classes of land used. This study demonstrates that water-quality degradation is associated with upland land uses which are generally good predictors of water-quality conditions.

Chapman (1999) reported that concentrations of nitrate-N in excess of 0.2mg/l NO_3–N within lakes tends to simulates algal growth, an indication of possible eutrophic conditions. The concentrations of nutrients being released into the lake was greater than the recommended concentration for eutrophication to begin but because of dilution, when runoff mixes with the lake water, it concentration drops below the maximum eutrophic limit (Table 4.12).

5.2 Physico-chemical Parameter Variation within the Lake

DO concentration in surface runoff was 16.7±0.04mg/l. In lake water its concentration ranged between 9.92±0.01mg/l to 5.78±0.60mg/l for rain season (Table 4.11). Dry season (Table 4.12) DO range was between 3.60±0.60mg/l to 7.60±0.27mg/l. Total Dissolved Solids (TDS) concentration in surface runoff was 300±8.73mg/l, lower than the maximum recommended concentration of 500mg/l. In lake water its average concentration ranges from 157.65±6.40mg/l at the shore to 62.85±5.64mg/l. In dry season, its concentration ranged between 170.0±1.80mg/l to 40.8±1.47mg/l and showed a slight decrease from water surface vertically downwards and an exponential decrease from shore into the lake. There was slight increase in concentration in the vertical direction for rain season. The concentrations in rainy seasons were higher than its corresponding dry seasons. TSS in rain surface runoff was 50.2mg/l and had a lake concentration range between 32.6mg/l to 2.0mg/l. EC value in runoff was 431.5±26.14µS/cm, still lower than the maximum recommended value of 1000µS/cm. The values ranged from 313.0±64.02µS/cm to 103.89±22.42µS/cm. This showed an increase in EC concentrations during rain seasons than in dry season (Table 4.11 and Table 4.12) but in the horizontal direction, an exponential decrease was observed. The pH of runoff was very close to neutral (7.02±0.39). Within the lake, pH had a range of between 6.63±0.46 to 7.69±0.43 for rainy season and 7.02±0.72 to 8.98±0.69 for dry season. With no clearly marked variation in the vertical direction. pH concentrations above the recommended range of between 6.8 to 8.4 (Gordon et al., 1968) is an indication of possible biological impairment of lake functioning and its suitability for other purposes. A comparison between dry and rainy season values however revealed that the pH level in dry season was higher than its corresponding rain seasons values and some of the concentrations lie above the recommended range of between 6.8 to 8.4. The runoff temperature was 24.35±1.21^{o}C and ranged between 24.32±1.33^{o}C to 25.30±1.95^{o}C in rain season and 25.86±1.02 to 26.70±1.07 in dry season and water temperature was higher in dry season than its rain season values.

5.3 Physico-chemical Parameters and Species Availability

Several biological assessment techniques have been used to quantify the effects of human activities on the biotic condition of aquatic ecosystems, following the idea that biological components respond to environmental degradation by modifying their functional and structural characteristics. Species abundance models provide a more detailed relationship between environmental conditions and fish assemblage structure, because the abundance of a species is a consequence of its ability to exploit the environment (Lima-Junior et al., 2006). The model represent distinct patterns of resource partitioning among species in the assemblage and reported that within physico-chemical parameter ranges of (T= 24.87 ± 3.14^{o}C, pH= 7.42 ± 0.65, DO= 8.31 ± 1.77mg/l, EC= 32.11 ± 22.36µS/cm, TDS= 16.00 ± 10.76mg/l, Phosphorus= 0.1183 ± 0.0343mg/l) fish was less available in one study site and more available in the other site where their concentrations were less than the indicated values, Suggesting poorer environmental conditions at the site. From (Table 4.11), in rain seasons under the measured ranges of (T=24.32±1.33^{o}C to 25.3±1.95^{o}C for rain season and T=25.9±1.02^{o}C to 26.7±1.07^{o}C for dry season, pH=6.63±0.46 to 7.69±0.43 for rain season and pH=7.02±0.72 to 8.98±0.69 for dry season, DO=9.92±0.01mg/l to 5.78±0.60mg/l for rain season and DO=3.60±0.60mg/l to 7.60±0.27mg/l for dry season, EC=313±64.02µS/cm to 103.9±22.42µS/cm for rain season and EC=368.6±23.9µS/cm to 91.2±28.6µS/cm, TDS=157.65±6.4mg/l to 62.85±5.64mg/l for rain season and 170.0±1.80mg/l to 40.8±1.47mg/l for dry season, ortho-phosphate=0.66±2.97mg/l to 0.08±3.59mg/l for rain season and 2.46±0.11mg/l to 0.12±0.08mg/l for dry season), fish species would most likely become unavailable in these near shore waters because they are unable to exploit their environment properly. Similar concentrations are seen in dry seasons though with lower concentrations. In the vertically direction, physico-chemical parameter concentrations increased, a further indication that the environment is no longer suitable for fish to occupy therefore they will assemble in other areas where pollutant levels are low. The findings could provide an alternative explanation to the ever dwindling fish stock within the lake and reduced fish catch by fishermen in Lake Victoria especially along shore settlement. The major causes of low fish catch was said to be over fishing within the Lake by fishermen who harvest even young fish.

5.4 Nitrification Process and Nutrient Availability

Water temperature is one of the primary underlying variables driving or constraining a range of biotic processes in streams (Karen et al., 2007). High input of nutrients in form of surface runoff increases EC, pH, TDS, and Temperature causing an elevation in their level. The effect of nutrient flow into lake over a short period of time may not be visible (Biswas, 1976), but over a long period of time, these nutrients cause an elevation in nutrient level within the lake (Figures 4.5 and 4.7). Organic nitrogen released into water undergoes a hydrolytic reaction, producing ammonia as one of the end products, which in addition to the ammonia present in the waste water, provides a food source for the nitrifying bacteria. The oxidation process proceeds sequentially from ammonia through nitrite to nitrate. (Biswas, 1976) reported that the conditions under which these reactions occur result into a large depletion of dissolved oxygen. During dry season, the nitrate-N concentration was more than the rain season concentration. Since there are no more sources of organic nitrogen through runoff in dry seasons, the ammonia-N after undergoing hydrolysis is oxidized by bacteria of the genus *nitrosomonas*, and nitrite-N oxidized by bacteria of the genus *nitrobacter* to their stable form, nitrate-N resulting into its high concentration being recorded in dry season than in rain season (Figure 4.6), and this process results into depletion in oxygen level (Figure 4.2) and release of energy. The proteinous substances are broken down by hydrolysis in a series of steps into a variety of amino acids according to Equation 4.9 and 4.10. The decomposition of amino acids results into release of ammonia. The ammonia is highly soluble, combines with the hydrogen ions to form the ammonium ion, thus tending to raise the pH (Figure 4.5) during dry season

$$(NH_4)^+ + (OH)^- + 0.5O_2 \xrightarrow{Nitrosomonas} H^+ + NO_2^- + 2H_2 + 59.4KCal \qquad (4.9)$$

$$(NO_2)^- + 0.5O_2 \xrightarrow{Nitrobacter} NO_3^- + 18KCal \qquad (4.10)$$

5.5 Toxic Effect of Nutrients on Aquatic Life

5.5.1 Ammonia

Ammonia is a well-known toxicant in aquatic systems. Ammonia in aqueous environment exists in equilibrium between the un-ionized ammonia (NH_3) fraction and ammonium (NH_4^+) fraction (Eddy, 2005). This equilibrium is governed by parameters of aqueous solutions such as ionic composition, temperature and pH. Although temperature increases the amount of NH_3 present, it is also known to increase permeability of tissues to NH_3. As pH and temperature rise, a higher percentage of NH_3 is present, therefore increasing toxicity. Spencer (2008) also reported that the lowest observed un-ionized ammonia concentration of 0.84mg/l caused severe changes in gill structure, decreased liver size at 0.834mg/l for both male and female fish, and decreased food consumption by fish. Given ammonia-N concentration range (Table 4.13) of between 0.82mg/l to 0.13mg/l or (0.984mg/l to 0.156mg/l un-ionized ammonia), these measured lake concentrations may already be exerting negative effects on fish species especially the female ones.

Swimming performance and equilibrium are two physiological processes affected by NH_3. Spencer (2008) observed that exposure of fish to varying concentrations of un-ionized ammonia concentrations and concluded that below 0.556mg/l concentration, un-ionised ammonia had no effects in fish but beyond this concentration, fish will begin to exhibit abnormal swimming behaviours, and an increased concentration will cause instability and when this concentration is increased further, there is lethal effect. Very close to the shore waters may therefore not be suitable as fish habitat because very close to lake shore unionized concentration exceeds the concentrations at which no behavioral change can be seen yet it is known that the shallow waters are used as habitat and reproductive grounds for amphibians.

Water temperature is one of the primary underlying variables driving or constraining a range of biotic processes in streams (Karen et al., 2007). Wolter (2007) studied the effect of temperature within the range (9.0^{o}C to 13^{o}C) on fish length in spring and reported a reduction in length and density of perch with increased temperature but improved spawning. Within the high temperature range of 24.55^{o}C to 25.3^{o}C (Table 4.11 and Table 4.13), fish growth would be retarded though this is a normal temperature, and reduced density since body temperature of majority of fish species is a direct function of water temperature but spawning would increase. The growth and reproductive frequency would be reduced since the fish will take long to grow. Temperature affects virtually all biochemical and physiological activities of fish due to the universal temperature dependence of metabolism.

5.5.2 Nitrite and Nitrate

Nitrite impairs the ability of fish blood to transport oxygen and transportation of oxygen is dependent on the ease with which haemoglobin combines with oxygen (Gary and Petrocelli, 1985). Nitrite oxidizes haemoglobin to methaemoglobin increasing the amount of methaemoglobin present and impairing oxygen transport by blood. Increased environmental nitrite concentrations, even as low as 0.015mg/l NO_2-N produces increased methaemoglobin levels in fish blood. Given the nitrite concentration ranges of between 0.06±0.01mg/l to 0.016±0.006mg/l in rain season and 0.1±0.011mg/l to 0.01±0.008mg/l in dry season, the ease with which oxygen was being transported in fish's blood has probably been reduced. Nitrate is considered less toxic to aquatic organisms than are ammonia and nitrite. It is considered essentially less toxic, and consequently there are few reports of studies on its toxicity

5.5.3 Phosphorus

Phosphorus is an essential nutrient for living organisms and is the limiting nutrient for algal growth. It is rarely found in high concentrations in fresh water as it is actively taken up by plants. As a result, there can be considerable seasonal fluctuations in concentrations in surface water. Phosphorus concentration ranges from 0.005mg/l to 0.02mg/l PO_4-P. Measured ortho-phosphate concentration ranged between 0.66±2.97mg/l to 0.08±3.59mg/l in rain season and between 2.46±0.11mg/l to 0.12±0.08mg/l in dry seasons. Phosphorus concentration in dry season closer to the shore was higher than the corresponding rain season values probably because of human activities of washing clothes in shallow water thus altering the true concentration. The measured concentrations are higher than the given range in surface water and a large concentration could lead to algal growth

5.6 Comparison between Model and Measured Concentration of Nutrients

The model concentrations for Ammonia-N, Nitrite-N, and Nitrate-N and ortho-phosphate all compared well with concentrations measured within the lake and their equation can be used to predict their dispersion (Equations 4.5, 4.6, 4.7 and 4.8 respectively). Therefore the distances these nutrients disperses to after rainfall event represents zone of polluted water which is unfit for use and aquatic habitat

5.7 Possible Solution to Nutrient Flow into Lake Victoria

Currently, no solution is in place to reduce the flow of nutrient from Gaba fish landing site to the inner Murchison Bay, Lake Victoria. In natural conditions, a high percentage of rainfall infiltrates into the ground and their nutrient content is reduced during the infiltration process.

Urban development is unique in that most of the pollutant sources are the result of nonpoint influences which normally discharges directly into surface waters subsequently impacting on water quality and stream hydrology. When rain falls in the urban environment with increased impervious surfaces, there is a sudden introduction of pollutant load into lake.

Both structural and non structural practices have been recommended to try and mitigate such flows. Each practice addresses a particular group of potential pollutant source with each measure reflecting the greatest degree of pollutant reduction achievable through application of the Management Practice (MP). The MPs reflect the best control practices, technologies, processes, and operating methods available to address nonpoint source pollution problems in the study area.

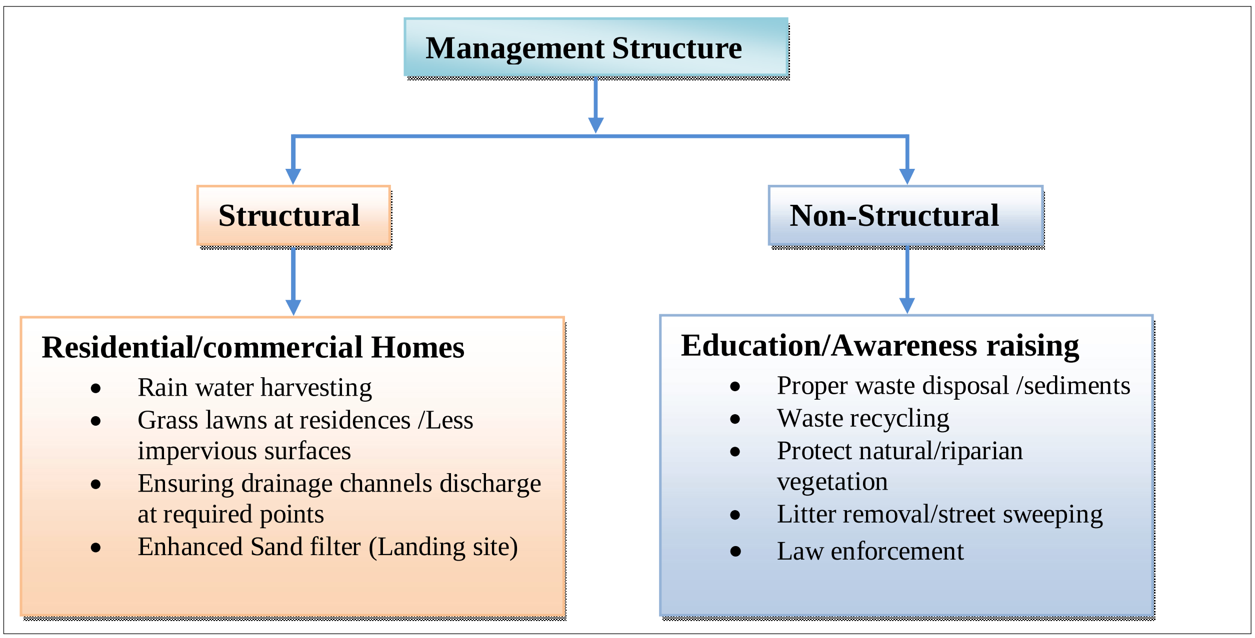

Figure 5.1: Management Structure for Controlling Surface Water Pollution

5.8 Structural Management Practice

5.8.1 Rain Water Harvesting

At household level, pollutant load concentrations originating at household levels may not be much but because of environmental carelessness of many people, their combined pollution load becomes significant. It is therefore important to reduce the volume of surface runoff flows at household levels. Incorporating rain water harvesting technology in all residential and commercial homes will help in reducing the volume of runoff generated from home.

Zoning of development areas can be applied to allow residential development styles that reduce impervious areas and increase green space maintained in natural conditions, where a high percentage of rainfall infiltrates into the ground. As a result of the filtering effect by the soil, the resultant water reaching the lake will be cleaner and free from pollutants

Most of the roadside drainage channels in the study area lack connectivity. They discharge runoff at lowland areas without any prior treatment done to them. The channels are frequently blocked with debris causing runoff to find its own way onto the street. This causes adverse effects. Ensuring that these runoff are discharged into treatment facility or wetland will improve on their quality

5.8.2 Enhanced Sand Filters

In this technique surface runoff is diverted into a self-contained bed of sand. The runoff is then strained through the sand, collected in underground pipes and allowed to flow into the lake due to the location of the site. Enhanced Sand Filters utilize layers of peat, limestone, leaf compost and/or topsoil, and may also have a grass cover crop. The adsorptive media of enhanced sand filters are expected to improve removal rates and have the advantage of little space requirement for an already developed area like Gaba fish landing site. However, Sand filters require frequent manual maintenance, primarily raking, surface sediment removal, and removal of trash, debris and leaf litter.

5.9 Non Structural Measures

5.9.1 Education/Awareness Raising

Much of urban nonpoint source (NPS) pollution is the result of cumulative actions by many individuals, businesses and industries. The reduction of NPS pollution, in turn depends the choices and actions of individuals, businesses, and industries. Often individuals and business owners are not aware that storm drains deliver runoff to nearby water bodies without treatment. Nor are many aware that some of their common practices (Improper garbage dumping, encroachment on wetlands, unplanned settlements etc) may contribute to pollution. Residents should also understand that while the actions of a single person may seem insignificant, when combined with similar actions of hundreds or thousands of other residents, the potential to pollute their local waters is very real.

Awareness raising among community members is one of the most effective ways of preventing storm water pollution. Businesses, developers, and homeowners are all part of the NPS pollution puzzle and public awareness programs must be tailored to meet the individual needs and interests of each segment of the community. Community incentives should be given to people to motivate them in keeping the environment clean. Sanitation days should be organized more frequently at family levels to try and maintain our environment clean. The role of community leaders on such days will be to move around and try to ensure that every household is cleaning their environment.

Educating children at school, or community groups (from youth level to elderly people) on the consequences of their actions on the quality of water can encourage behavioral change in that respect. Educational materials or presentations can be made available at a variety of community gatherings such as churches, town meetings, service organizations, and local festivals. Educational efforts on the effects of pollution in storm water runoff should be made known to everyone. Best management practice should be taught to members through those forums. At Gaba fish landing site, there are beach management units trying to maintain the areas clean though the problem has still persisted

5.9.2 Proper Disposal of Accumulated Waste and Sediment

Solid wastes and Sediment removed form our environment is often disposed of in lowland areas and drainage channels by community members without any care being taken to control their effects on water bodies. Sediments removed from blocked drains take long to be disposed properly. These sediments become re-suspended in the channels by storm water runoff or wind erosion.

Frequent unblocking and disposal of these drains will ensure that storm water does not flood the road thus reducing on their ability to destroy the road surface and causing unnecessary flooding.

5.9.3 Recycling

Management of household wastes can be done by proper collecting and composting. Educating household members on waste minimization will help reduce on the volume of waste generated Materials like plastics can be sorted at household levels and recycled. Composting reduces landfill volumes and the need for fertilizer by increasing soil nutrients and organic matter. Since most of the wastes are of vegetative nature, they can be composted into manure and used by farmers to increase on their soil fertility. Developing a convenient, low-cost household waste collection program encourages proper disposal of potential pollutants. Promote pollution prevention as a means of waste reduction within business and government.

5.9.4 Protect Natural and Riparian Vegetation

In the natural state, shorelines are relatively erosion resistant. Stripping of natural vegetation can result in increased soil erosion sediment loadings in surface waters. Further, in most instances, native vegetation provides better ground cover than developed plant communities, storage for flood waters. Removal of riparian vegetation results into lake siltation, increased water temperatures, decreases in DO and changes to stream natural flow.

5.9.5 Litter Removal / Street Sweeping

Litter enters surface waters via wind and runoff events. Litter and yard wastes can clog storm water control and conveyance structures making the structures ineffective in storm water pollutant control. Contaminants such as plastics degrade slowly, while presenting environmental risks to fish and wildlife

There is need to promote frequent litter removal programs and clean-up days within the community especially Gaba fish and vegetable market and nearby business areas. Encourage local pride within the community through civic organizations to promote individual actions affecting litter removal. Municipal facilities maintenance programs like garbage collection should be implemented more vigorously than its current level state. Particles that accumulate along streets and market places needs to be swept and collected so that they do not find their way into surface waters during storm events

5.9.6 Local Regulations/Policy Formulation

The Water Act (1999) stipulates that there must be mitigation measures for any pollutant being discharged into water body. In Uganda there is no specific measure regarding storm water. They are discharged through swamps which are constantly being encroached on. Local regulations by KCC concerning solid waste management exist but the situation has persisted. Vigorous implementation of these by-laws will ensure that community members conform to the required regulations

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The research was conducted in Gaba fish landing site located in Makindye Division. The site was identified as a hotspot from preliminary studies done on shore settlements. This was mainly due to the nature of land use which resembles peri-urban settlement, and its proximity to the lake causing observable effect on lake water after every rainfall event.

Different land uses were identified and characterized using Arc View GIS and Ilwis Version 3.3 with each land use contributing; (Built up areas=36.1%, Wetland=30.6%, Lake=25% and Subsistence Farmland=8.3%). The study area has poor drainage network, bare soil surface cover and poor garbage dumping habits.

Due to the urban nature of this area, storm water generated from this hotspot carries within it sediments and nutrients that are directly discharged into lake Victoria and surrounding lowland areas which are pathways for runoff into lake Victoria.

The nutrients and physico-chemical parameters discharged into lake Victoria mixes uniformly with lake water. Their discharge has caused an elevation in lake concentrations thus affecting fish availability close to shore settlement due to poor water quality. Migration of fish species to areas of better water quality is possible probably explaining the low fish catch and dwindling fish stock in Lake Victoria.

From the dispersion trends generated using the mathematical model, the respective distances traversed by each nutrient were; ammonia-N=38m, nitrite-N=45m, nitrate-N=34m and orthophosphate=34m. Their lake concentrations decreased exponentially from shore into the lake and the point where the curve levels represent the distances traversed by each nutrient when plotted graphically. These predicted dispersion distances represents zone of polluted lake Water from shoreline when it rains. Water within this zone is considered unfit for aquatic habitat and human purposes.

Gaba fish landing site consist of a number of land use activities with development taking place without putting in place measures which controls water pollution. Therefore a number of management measures have been suggested with each management measure suggested complementing one another. Implementing them altogether will improve water quality and environmental conditions within the study area.

6.2 Recommendations

To reduce flow of nutrients into Lake Victoria by such means, suggested management measures need to be implemented.

Urban planners need to incorporate storm water management systems into their development plans to improve water quality instead of incorporating management strategies into already existing plans. This will generally become simpler and more cost-effective than attempting to retrofit management practices into existing sites. Most of these measures require large spaces and where development has already taken place, it becomes difficult to put in place such measures.

Data collection can be extended for many years instead of one year used for the purpose of this study. This will help improve on the accuracy of the results obtained by model.

During this research, only soluble nutrients were measured. Therefore, there is need to measure nutrient concentration as Total concentration. When this is done, the outcome will indicate exactly the nutrient levels within the Lake Victoria for rainfall event.

More research is needed to quantify precisely the dispersion coefficient in terms of factors that affects it (wind and wave movement, shear force due to flow, and net production and consumption of nutrients within the Lake). Currently, the dispersion coefficient does not take into account the interaction among the factors when nutrients are being dispersed, instead takes them as the net outcome causing the observed linear trend in the coefficient.

The model equations can be tried at different sites to test whether it is applicable to such sites given that their land uses are similar

REFERENCES

Aaike, D. W., Koenraad, M, Denis, L, Laurent, A, Jean, D, Luc, A, Christine, C & Wim, V. (2008), Differential response of phytoplankton to additions of nitrogen, phosphorus and iron in Lake Tanganyika *A Journal of Freshwater Biology,* 53, 264–277

Ackerman, D. and Stein, E. D. (2008), Estimating the Variability and Confidence of Land Use and Impervi-ousness Relationships at a Regional Scale. *Journal of the American Water Resources Association (JAWRA), 44(4):996-1008.*

Adong, F. G (2001), *Laboratory methods manual, analytical work instruction*, volume 1

Banadda, N. E., Kansiime, F. & Nhapi, I. (2006), *Landuse-based non-point source pollution: a threat to Murchison Bay water quality in Uganda*. In Proceedings of the International Forum on Water and Food, Vientiane (Lao Peoples' Democratic Republic)

Biswas, A. K. (1976), *Systems approach to water management*, McGraw-Hill, inc.

Chapman, D. (1992), *Water quality assessment, A guide to the use of biota, sediments and water in environmental monitoring, 2nd edition,* Taylor and Francis group.

Chege, N. (1995), *Lake Victoria, A sick giant. Technical report, World watch institute*

Dougherty, M. (2004), *Quantifying long term hydrologic and NPS pollutant response in an urbanizing watershed*, PhD thesis, Polytechnic Institute and State University, Blacksburg, Virginia.

Eddy, F.B. (2005), Ammonia in estuaries and effects of fish, *Journal of Fish Biology, 67, 1495–1513*

Fresenius, W., Quentin, K. E., Scheneider, W. (1988), *Water analysis, A practical guide to physic-chemical, chemical and microbiological water examination and quality assurance,* Deutsche Gesellschaft fur Techansche Zusamnenabeit (GTZ)

Gordon F. M., John, C., Geyer, Daniel, O. A. (1968), *Water and waste water engineering, Volume 2,* Wiley and sons inc. New York

Graves, G. A., Yongshan, W., and Fike, D. L. (2004), Water Quality Characteristics of Storm Water From Major Land Uses in South Florida. *Journal of the American Water Resources Association (JAWRA) 40(6):1405-1419.*

Hecky, R. E., Mugidde, R., Bugenyi, F. W. B. (2000b), *Phosphorus in Lake Victoria waters and sediments: sources, loadings, sinks and anthropogenic mobilization.* Proceedings of the International Conference on Lake Victoria, Jinja, Uganda <http://www.lvemp.org/L_Publications/tanzania/Bibliography_limnology.htm> December 16th 2008

Herb, W. R., & Heinz, G. S. (2005), Model for wind-driven vertical mixing in shallow lake with submersed macrophytes, *Journal of hydraulic engineering,* Vol. 131, No. 6, June1, pp 488-496

Howard, G., Mutabazi, R. & Nalubega, M. (2000), Rehabilitation of protected springs in Kampala, Uganda, water, sanitation and hygiene: challenges of the millennium, 26th WEDC conference, Dhaka, Bangladesh

ILEC (International Lake Environment Committee) (2001), *Lake Victoria database,* Viewed August 15th 2008 <http://www.ilec.or.jp/database/afr/dafr05.html>

Ilker, F,Ulrich, L., and Thorpe, S. A. (2002), Observations of mixing near the sides of a deep lake in winter, *American Society of Limnology and Oceanography Inc, 47(2), 2002, 535–544*

Isabirye, M. (2005), *Land evaluation around Lake Victoria,* Environmental implications of land use changes PhD thesis, Katholieke Universiteit Leuven, Belgium

Isabirye, M., Magunda, M., Ssali, C. K. (2001), *People and agro ecosystems: Issues and strategies for sustainable land management in Mayuge district,* Land use management technical report No.7. Lake Victoria Environment Management Project, NARO-Kawanda, Uganda

Ivey, G. N. and Patterson, J. C. (1984), A model of the vertical mixing in lake eric in summer, *American society of limnology and oceanography,* 29(3), pp 553-568

Kulabako, N.R., Nalubega, M. & Roger, T. (2004), *Characterization of peri-urban anthropogenic pollution in Kampala, Uganda,* People-centered approaches to water and environmental sanitation, 30th WEDC International Conference, Vientiane, Lao PDR

Kyomuhendo, P. (2002), *A bioeconomic model for Uganda's Lake Victoria Nile Perch fishery, M.Sc thesis, international fisheries management*, Universitetet Tromso (Norway), p24

Larsson, P. (2002), *Lake Victoria and Kampala-history of man and water,* Technical report, Kampala

Liang, T., Hao, W., Hsiang-te, K., and Chao-sheng, Z. (2004), Agriculture Land-Use Effects on Nutrient Losses in West Tiaoxi Watershed, China. *Journal of the American Water Resources Association (JAWRA) 40(6):1499-1510.*

Lillesand, T. M. and Ralph W. K. (2000), R*emote sensing and image interpretation*, 4th edition, John Wiley and sons, inc new York ISBN 0 – 471 – 25515 – 7

Lima-Junior, S. E., Cardone, I. B. and Goitein, R. (2006), Fish assemblage structure and aquatic pollution in a Brazilian stream: some limitations of diversity indices and models for environmental impact studies, *Ecology of Freshwater Fish 2006: 15: 284–290*

Livingston, E. H. & Borja, C. A. (1985), *A review of urban storm water retrofitting in Florida*, Florida Department of Environmental Protection, Florida

LVEMP (2004b), Preliminary findings on water quality / limnology studies for Lake Victoria. Lake Victoria Environment Management Program, Kampala, Uganda.http://www.lvemp.org/L_Whats%20new/wq_preliminary_findings.htm, 05/14/08.

Makundi, I. N. (2001), *A study of heavy metal pollution in Lake Victoria sediments by energy dispersive X-Ray fluorescence,* Environmental science and health part A-Toxic/hazardous substances and environmental engineering, 36(6): 909-921

Matagi, S. V. (2002), *Some issues of environmental concern in Kampala, the capital City of Uganda.* Environmental monitoring and assessment, 77: 121-138

Mukwaya, I. P. (2004), *Urban change in Uganda: The challenge of managing urban areas in a global environment.* Paper for the College of Urban Planning and Public Affairs (CUPPA) conference at the University of Illinois Chicago USA

MWLE (2006), *Land sector strategic plan 2001-2011, Utilizing Uganda's land resources for sustainable development,* Ministry of Water, Land and Environment, Kampala (Uganda)

N.E.M.A (2006/2007), *State of environment report for Uganda.*

Nkonya, E., Pender, J., Sserunkuuma, D. & Jagger P. (2002), *Development pathways and land management in Uganda,* In proceedings of conference on policies for sustainable land management in the East African highlands, United Nations Economic Commission for Africa, Addis Ababa (Ethiopia).

Nyangababo, J. T. (1987), Lichens as monitors of aerial heavy metal pollutants in and around Kampala, *Bulletin of environmental contamination and toxicology*, 38: 91-95

Ojok, J. (2002), *Assessment of pollution of sediments from selected Lake Victoria bays.* M.Sc. Thesis, Faculty of Science, Makerere University, Kampala, Uganda.

Rizzolio, D. K. (2000), Water sharing in the Nile river valley: Using GIS/Remote sensing for the sustainable use of natural resources (UNEP)

Rosenberger, E. E., Hampton, S. E., Fradkin, S. C., Brian, P. K. (2008), Effects of shoreline development on the nearshore environment in large deep oligotrophic lakes *A Journal of Freshwater Biology* 53, 1673–1691

Spencer, P. R., Pollock, M. D. (2008), Effects of un-ionized ammonia on histological, endocrine, and whole organism endpoints in slimy sculpin (*Cottus cognatus*), Aquatic Toxicology journal homepage: www.elsevier.com/locate/aquatox

Ssenteza, J. & Kahembwe, F. (1998), *Assessment of the adoption of afforestation Technology in Rakai District,* Land use management technical report No. 3. Lake Victoria environment management project, NARO - Kawanda, 1998

Tonderski, A. (1996), Land use based nonpoint source pollution, a threat to water resources in developing countries, *Elsevier science limited*, Vol. 33, No.4-5, pp 53-61

Uganda Bureau of Statistics (2002), *Population and Housing Census report*

US geological survey (2008), *Earth water: Runoff Science for a changing world*<http://ga.water.usgs.gov/edu/runoff.html> June 18th 2007

USEPA (2005), *Draft Handbook for developing watershed plans to restore and protect our waters*, Washington, DC 20460

Wolter, C. (2007), Temperature influence on the fish assemblage structure in a large lowland river, the lower Oder River, Germany, Ecology of Freshwater Fish, Journal compilation, Blackwell Munksgaard, 16: 493–503.

Zampella, R. A., Procopio, N. A., Lathrop, R. G., and Dow, C. L. (2007), Relationship of Land-Use ⁄ Land-Cover Patterns and Surface-Water Quality in the Mullica River Basin. *Journal of the American Water Resources Association (JAWRA) 43(3):594-604.*

APPENDICES

Appendix A1: Raw Data for Ammonia-N Concentrations over two Rain Seasons

First Rain Season							
		Horizontal Distance (m)					
Vertical Depth (m)	**Runoff**	**0**	**10**	**20**	**30**	**40**	**50**
0.5	3.00	0.59	0.15	0.12	0.18	0.19	0.15
	15.80	0.09	0.56	0.24	0.23	0.18	0.16
	2.34	0.43	0.49	0.00	0.05	0.02	0.01
	2.28	0.93	0.15	0.15	0.12	0.09	0.07
	3.32		0.39	0.20	0.20	0.46	0.24
1.0			0.12	0.17	0.17	0.15	0.15
			0.41	0.22	0.17	0.15	0.14
				0.05	0.05	0.08	0.07
				0.44	0.17	0.07	0.11
				0.28	0.22	0.20	0.22
1.5				0.21	0.15	0.14	0.17
				0.24	0.17	0.16	0.13
				0.06	0.07	0.06	0.32
					0.17	0.15	0.08
					0.58	0.23	0.23
Second Rain Season							
0.5	16.34	0.49	0.38	0.13	0.14	0.14	0.14
	12.60	2.44	0.22	0.14	0.13	0.13	0.12
	14.55	0.45	0.35	0.28	0.20	0.18	0.17
1.0	2.85			0.15	0.15	0.16	0.14
				0.17	0.11	0.13	0.09
				0.22	0.21	0.21	0.15
1.5				0.17	0.13	0.16	0.13
				0.21	0.14	0.13	0.10
					0.25	0.20	0.14

Appendix A2: Raw Data for Nitrite-N Concentrations over two Rain Seasons

		Horizontal distance (m)					
Vertical depth (m)	**Runoff**	**0**	**10**	**20**	**30**	**40**	**50**
0.5	0.070	0.015	0.032	0.029	0.027	0.028	0.026
	0.125	0.032	0.013	0.011	0.013	0.012	0.015
	0.720	0.092	0.020	0.019	0.010	0.012	0.012
	0.420	0.120	0.020	0.015	0.019	0.014	0.012
	0.112		0.022	0.014	0.015	0.015	0.014
1.0			0.039	0.026	0.029	0.033	0.031
			0.006	0.016	0.014	0.014	0.019
				0.015	0.009	0.013	0.012
				0.030	0.020	0.014	0.016
				0.017	0.014	0.015	0.015
1.5				0.029	0.028	0.033	0.032
				0.014	0.023	0.013	0.018
				0.018	0.011	0.007	0.013
					0.020	0.018	0.015
					0.017	0.017	0.014
Second Rain Season							
0.5	0.900	0.026	0.086	0.018	0.017	0.016	0.015
	0.080	0.084	0.020	0.015	0.017	0.013	0.013
	0.092	0.055	0.031	0.017	0.026	0.018	0.018
1.0	0.960			0.018	0.015	0.017	0.016
				0.014	0.016	0.014	0.013
				0.023	0.016	0.016	0.017
1.5				0.018	0.018	0.016	0.016
				0.019	0.016	0.014	0.014
					0.017	0.016	0.016

Appendix A3: Raw Data for Nitrate-N Concentrations over two Rain Seasons

First Season							
		Horizontal Distance (m)					
Vertical Depth (m)	**Runoff**	**0**	**10**	**20**	**30**	**40**	**50**
0.5	0.600	0.142	0.056	0.060	0.063	0.040	0.052
	0.249	0.156	0.143	0.137	0.060	0.035	0.093
	0.624	0.107	0.061	0.053	0.062	0.053	0.048
	0.297		0.066	0.067	0.065	0.063	0.079
1.0			0.036	0.063	0.049	0.060	0.072
				0.119	0.045	0.065	0.098
				0.096	0.064	0.057	0.049
				0.064	0.068	0.077	0.061
1.5				0.079	0.051	0.045	0.049
				0.090	0.034	0.083	0.140
					0.066	0.058	0.054
					0.061	0.068	0.071
Second Season							
0.5	0.345	0.077	0.194	0.095	0.091	0.086	0.085
	0.228	0.150	0.102	0.085	0.099	0.097	0.109
	0.224	0.120	0.089	0.063	0.082	0.072	0.079
1.0	1.918			0.086	0.084	0.094	0.094
				0.091	0.096	0.094	0.098
				0.087	0.077	0.072	0.087
1.5				0.090	0.089	0.082	0.100
				0.095	0.098	0.103	0.102
					0.078	0.085	0.091

Appendix A4: Raw Data for Ortho-phosphate Concentrations over two Rain Seasons

First Season							
		Horizontal Distance (m)					
Vertical Depth (m)	**Runoff**	**0**	**10**	**20**	**30**	**40**	**50**
0.5	5.50	0.41	0.04	0.03	0.06	0.00	0.11
	4.05	1.05	0.20	0.33	0.21	0.13	0.15
	1.92	0.38	0.38	0.50	0.40	0.25	0.35
	1.72		0.06	0.05	0.05	0.04	0.03
1.0			0.08	0.05		0.03	0.06
				0.19	0.15	0.30	0.24
				0.46	0.31	0.39	0.32
				0.06	0.04	0.06	0.05
1.5				0.06	0.02	0.00	0.11
				0.22	0.11	0.17	0.24
					0.33	0.31	0.26
					0.04	0.04	0.05
Second Season							
0.5	26.10	0.26	0.33	0.22	0.41	0.26	0.22
	6.10	1.56	0.25	0.23	0.19	0.28	0.32
	7.05	0.30	0.41	0.44	0.39	0.22	0.83
1.0	1.95			0.28	1.15	0.21	0.17
				0.21	0.38	0.23	0.23
				0.48	0.32	0.30	0.44
1.5				0.20	0.22	0.26	0.27
				0.32	0.26	0.21	0.24
					0.50	0.72	0.53

Appendix A5: Raw Data for Ammonia-N, Nitrite-N, Nitrate-N and ortho-phosphate during Dry Seasons

Vertical Depth (m)	Horizontal Distance (m) 0	10	20	30	40	50
0.5	0.080	-	-	-	-	-
	0.040	-	-	-	-	0.030
	0.030	-	-	-	-	-
	0.010	-	-	-	-	-
1.0		-	-	-	-	-
1.5		-	-	-	0.000	-
Nitrite						
0.5	0.009	0.004	0.008	0.001	0.001	0.000
	0.080	0.015	0.033	0.017	0.018	0.016
	0.055	0.020	0.018	0.016	0.015	0.015
	0.300	0.033	0.034	0.025	0.023	0.023
	0.066	0.019	0.018	0.015	0.016	0.018
1.0			0.004	0.002	0.000	0.000
			0.017	0.014	0.016	0.020
			0.018	0.016	0.017	0.017
			0.034	0.024	0.026	0.020
			0.019	0.019	0.017	0.019
1.5				0.002	0.002	0.001
			0.017	0.022	0.015	0.015
				0.015	0.018	0.016
				0.024	0.023	0.022
				0.017	0.019	0.019

Appendix A5 Continues

Nitrate						
0.5	0.049	0.057	0.034	0.038	0.050	0.032
	0.269	0.127	0.166	0.166	0.166	0.091
	0.050	0.020	0.018	0.016	0.015	0.015
	0.349	0.155	0.157	0.130	0.123	0.130
	0.163	0.149	0.121	0.099	0.154	0.110
1.0			0.049	0.061	0.044	0.028
			0.118	0.130	0.118	0.107
			0.018	0.016	0.017	0.017
			0.153	0.131	0.101	0.123
			0.151	0.136	0.148	0.155
1.5			0.105	0.052	0.040	0.029
				0.098	0.100	0.098
				0.015	0.018	0.016
				0.112	0.113	0.085
				0.138	0.109	0.146
Ortho-phosphate						
0.5	2.200	0.130	0.010	0.070	0.100	0.020
	4.600	0.540	0.500	0.350	0.320	0.270
	2.200	0.270	0.060	0.050	0.100	0.060
	0.910	0.280	0.230	0.180	0.110	0.260
	2.400	0.190	0.250	0.170	0.280	0.250
1.0			0.070	0.100	0.020	0.050
			0.160	0.280	0.290	0.270
			0.050	0.040	0.080	0.020
			0.220	0.220	0.260	0.130
			0.190	0.260	0.230	0.170
1.5			0.230	0.010	0.100	0.050
				0.230	0.230	0.190
				0.110	0.050	0.030
				0.150	0.210	0.130
				0.250	0.300	0.220

Appendix A6: DO Data for First Rain, Second Rain, and Dry Period

First Rain Season							
		Horizontal Distance (m)					
Vertical Depth (m)	**Runoff**	**0**	**10**	**20**	**30**	**40**	**50**
0.5	16.70	10.13	6.81	6.24	5.81	5.61	5.76
		9.70	7.70	6.44	7.56	7.11	7.27
		9.92	9.02	8.49	8.16	8.38	7.56
			6.81	6.24	5.81	5.61	5.76
1.0			6.20	5.50	5.47	9.50	5.45
			6.10	6.42	6.75	6.78	7.02
			6.00	8.03	7.90	7.73	7.56
			6.20	5.50	5.47	9.50	5.45
1.5				5.13	5.31	5.10	5.23
				6.43	6.44	6.31	6.49
				5.50	7.53	7.36	7.25
				5.13	5.31	5.10	5.23
Second Rain Season							
0.5	15.20	10.20	6.80	6.28	5.79	5.61	5.77
		9.93	9.00	8.49	8.16	8.37	7.55
1.0			6.20	8.03	8.00	7.73	7.60
			6.23	5.50	5.47	9.50	5.45
1.5				6.43	6.44	6.31	6.50
				5.53	7.53	7.36	7.25
Dry Season							
0.5		3.60	4.80	5.70	6.40	7.20	7.60
1.0				4.90	6.00	7.20	7.50
1.5					5.90	6.10	6.40

Appendix A7: TDS Data for First Rain, Second Rain, and Dry Period

First Rain Season							
		Horizontal Distance (m)					
Vertical Depth (m)	**Runoff**	**0**	**10**	**20**	**30**	**40**	**50**
0.5	214.0		59.4	58.7	59.1	59.5	61.8
	386.0	69.1	65.3	59.4	61.0	59.7	56.1
		65.9	62.1	62.8	60.5	61.4	61.0
		94.4	64.6	63.8	63.5	63.9	63.4
		131.0	68.5	64.3	63.6	63.5	68.2
		71.5	74.8	72.0	70.0	69.0	69.6
		514.0	74.0	73.0	72.3	72.5	73.1
1.0			59.1	58.5	59.0	60.3	59.5
			63.0	59.8	60.5	59.6	59.2
				61.9	67.2	61.3	60.9
				69.9	63.9	64.3	63.3
				65.0	63.6	64.2	64.1
			73.0	73.3	71.0	70.0	70.4
				72.6	72.6	72.5	72.3
1.5				58.1	57.4	60.7	60.4
				58.7	59.6	60.0	60.0
				61.5	60.7	61.4	62.2
					64.2	65.0	63.9
					64.5	64.8	63.8
					74.6	73.0	71.3
				73.1	74.7	73.6	74.4

Appendix A7 Continues

Second Rain Season							
0.5	158.0	94.2	64.6	63.9	63.5	63.9	63.4
	163.0	136.0	68.5	64.3	63.6	63.5	68.2
		74.0	74.8	72.0	70.0	69.0	69.9
		520.0	74.0	73.2	72.3	72.8	73.0
1.0			63.5	59.8	60.5	59.6	59.0
				62.0	67.2	61.4	60.9
				69.9	64.0	64.3	63.3
				65.0	63.6	64.3	64.3
1.5				59.0	59.6	60.4	60.0
				61.5	60.7	61.4	62.2
					64.1	65.0	64.0
					64.6	64.8	63.9
Dry Season							
0.5		309.0	66.7	71.9	66.0	65.3	65.5
		198.0	68.6	66.8	66.9	65.8	66.1
		261.0	70.7	67.6	67.6	68.3	68.3
1.0				65.7	65.9	65.8	66.7
				67.8	65.9	65.5	67.0
				68.9	68.2	68.2	66.7
1.5				66.4	66.6	65.7	65.8
					66.7	66.8	66.0
					67.9	68.0	66.6

Appendix A8: Temperature Data for First Rain, Second Rain, and Dry Period

First Rain Season							
		Horizontal Distance (m)					
Vertical Depth (m)	**Runoff**	**0**	**10**	**20**	**30**	**40**	**50**
0.5	23.3		23.4	23.5	23.5	23.6	23.6
	24.9	27.9	26.2	26.5	24.4	25.6	28.2
	25.7	26.2	25.5	25.5	25.8	25.9	27.8
	23.5	21.6	21.9	22	22	22.2	22.4
		24.7	24.6	24.8	25	24.9	24.8
		25.4	24.8	25.2	26	26.4	26
		22.8	24.4	24.2	24.7	24.3	23.6
		23.7	25.7	25.5	25.7	25.6	25.9
1.0			23.4	23.5	23.5	23.6	23.6
			25.5	24.8	24.4	24.6	25.2
				25.6	25.6	25.7	25.8
				22	21.9	22	22.2
				24.9	25	24.8	24.8
			25	25.3	25.6	26	25.8
				24.3	24.4	24.5	24.3
1.5				23.5	23.5	23.6	23.5
				26.2	24.7	24.6	24.7
				25.5	25.5	25.4	25.5
					21.9	21.9	22
					24.9	24.8	24.9
					25.4	26.1	25.8
				24.1	23.1	24	24
				25.5	25.6	25.8	25.9
Second Rain Seasons							
0.5	24.9	23.7	25.7	25.5	25.7	25.6	25.9
1.0				25.6	25.7	25.6	25.9
1.5				25.5	25.6	25.8	25.9

Appendix A9: EC Data for First Rain, Second Rain, and Dry Period

First Rain Season

Vertical Depth (m)	Runoff	Horizontal Distance (m)					
		0	10	20	30	40	50
0.5	436		99	95	95	95	96
		135	132	118	121.8	120	116
		208	110	111	109	108	108
		166	118	115	115	115	115
		274	142.9	133	130.7	129.9	141.6
		143	146	145	140	137	138.8
	634	1030	148	145.8	144.4	145.3	146.4
1			95	95	95	95	96
			125	120	121.4	120.2	119.2
				109	108	107	108
				116	115	115	115
				133.9	130.5	130.5	131
			145.5	154	144	140	140
				145.5	145.3	144.8	144.4
1.5				95	95	95	96
				117	119	119.7	120
				133	107	107	107
					116	116	115
					132	131.6	129.4
					148.8	147	143
				146.1	150.1	147.2	149

Appendix A9 Continues

Second Rain Season

0.5	328	334	90	70.8	93.6	98.1	98.8
		266	296	111.1	79.6	78.9	78.3
1				87.2	93.3	93.3	98.8
				113	79.1	78.7	77.8
1.5				98.4	98.5	95.7	98.8
				79.5	78.5	79.6	76.9
Dry Season							
0.5		243	84	82	78	72.5	69.8
		363	82	109	90	85.6	102
		412	137	132.8	132.7	131.9	132.2
		516	141.7	137	135	136.2	137
		309	60	70.8	66.3	70.7	72.3
1				82	76	72	70.1
				92	89	104	101
				136	132.2	131	133.1
				137	135.8	137	134
				70.7	66.4	70.8	70.5
1.5					75.7	72	70.7
				91.2	86	103	92
					132.9	133	132
					136	136	133.4
					67.4	74.3	74.2

Appendix A10: pH Data for First Rain, Second Rain, and Dry Period

First Rain Season							
		Horizontal Distance (m)					
Vertical Depth (m)	**Runoff**	**0**	**10**	**20**	**30**	**40**	**50**
0.5	7.03		7.08	7.09	7.1	7.11	7.42
		7.65	6.5	7.98	8.62	8.39	8.28
		6.39	6.71	6.96	7.36	7.63	8.17
		6.31	6.57	6.58	6.68	6.8	6.87
		6.89	7.42	7.45	7.23	8	8.18
	7.31	6.71	7.41	7.38	7.53	7.52	7.64
1.0			7.08	7.1	7.1	7.04	7.6
				8.33	8.38	8.31	8.32
				6.84	7.34	7.38	8.11
				6.63	6.68	6.84	6.9
			7.29	7.11	7.23	7.98	8.1
				7.67	7.49	7.54	7.63
1.5				7.1	7.09	7.09	7.52
				8.36	8.18	8.08	8.18
					7.22	7.32	7.94
					6.74	6.86	6.92
					7.69	8.18	8.02
				7.66	7.79	7.77	7.98
Second rain							
0.5	6.87	6.44	7.66	7.8	7.15	6.93	6.46
1.0				7.94	7.8	6.78	6.75
1.5				6.95	7.92	6.63	7.62

Appendix A10 continues

Dry Season							
0.5		7.14	7.49	7.48	8.16	7.95	7.95
		8.2	8.74	8.33	8.96	10	9.74
		7.33	8.05	8.71	8.61	8.65	8.76
		6.17	8.17	8.38	8.83	8.94	9.01
		6.24	6.12	7.76	8.12	8.92	9.45
1.0				7.74	7.92	7.94	8
				8.2	9.21	9.84	9.74
				8.24	8.55	8.71	8.59
				8.22	8.81	8.8	8.89
				8.12	8.57	9.31	9.62
1.5					7.91	7.96	8.07
				7.78	9.33	9.74	8.9
					8.34	8.4	8.61
					8.63	8.78	8.68
					9.22	9.7	9.45

Appendix A11: Horizontal Variation in Physico-chemical Concentration for First, Second and Dry Season using One Way ANOVA Test

Descriptives Statistics

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Total Dissolved Solids (mg/l)	First rain season	97	7.07E+01	46.355478	4.706686	61.36555	80.05094	56.1	514
	Second rain season	55	7.52E+01	62.092523	8.372554	58.42131	91.99323	59	520
	Dry season	40	8.12E+01	51.97252	8.217577	64.60088	97.84412	65.3	309
	Total	192	7.42E+01	52.32997	3.77659	66.73832	81.63668	56.1	520
Temperature (Celsius)	First rain season	107	2.46E+01	1.383687	0.133766	24.34601	24.87642	21.6	28.2
	Second rain season	14	2.56E+01	0.550175	0.14704	25.23234	25.86766	23.7	25.9
	Dry season	66	2.61E+01	0.844586	0.103961	25.89995	26.3152	24.7	27.3
	Total	187	2.52E+01	1.36469	0.099796	25.01275	25.4065	21.6	28.2
Electrical Conductivity (uS/cm)	First rain season	96	1.26E+02	25.131372	2.56496	121.3527	131.53688	95	274
	Second rain season	28	1.12E+02	67.532332	1.28E+01	85.32441	137.69702	70.8	334
	Dry season	66	1.22E+02	80.514523	9.910653	102.05403	141.63991	60	516
	Total	190	1.23E+02	56.783487	4.119507	114.52072	130.77296	60	516
pH	First rain season	82	7.43073	0.567948	0.062719	7.30594	7.55552	6.31	8.62
	Second rain season	14	7.20214	0.564381	0.150837	6.87628	7.52801	6.44	7.94
	Dry season	66	8.46788	0.82166	0.101139	8.26589	8.66987	6.12	10
	Total	162	7.83352	0.861875	0.067715	7.69979	7.96724	6.12	10
Dissolved Oxygen (mg/l)	First rain season	59	6.73356	1.355204	0.176433	6.38039	7.08673	5.1	10.13
	Second rain season	30	7.167	1.372506	0.250584	6.6545	7.6795	5.45	10.2
	Dry season	12	5.975	1.12664	0.325233	5.25917	6.69083	3.6	7.5
	Total	101	6.77218	1.369321	0.136253	6.50186	7.0425	3.6	10.2

Appendix A11.1: ANOVA for physic-chemical parameters in horizontal direction

		Sum of Squares	Df	Mean Square	F	Sig.
Total Dissolved Solids (mg/l)	Between Groups	3211.05	2	1605.525	0.584	0.559
	Within Groups	519828.28	189	2750.414		
	Total	523039.33	191			
Temperature (Celsius)	Between Groups	93.155	2	46.577	33.841	0
	Within Groups	253.248	184	1.376		
	Total	346.403	186			
Electrical Conductivity (uS/cm)	Between Groups	4899.345	2	2449.672	0.758	0.47
	Within Groups	604505.53	187	3232.65		
	Total	609404.87	189			
pH	Between Groups	45.444	2	22.722	48.721	0
	Within Groups	74.152	159	0.466		
	Total	119.595	161			
Dissolved Oxygen (mg/l)	Between Groups	12.39	2	6.195	3.467	0.035
	Within Groups	175.113	98	1.787		
	Total	187.504	100			

Appendix A11.2: Multiple Comparisons (LSD test) for physico-chemical parameters in horizontal direction

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Total Dissolved Solids (mg/l)	First rain season	Second rain season	-4.499025	8.852249	0.612	-21.96093	12.96288
		Dry season	-10.514253	9.854701	0.287	-29.95359	8.92508
	Second rain season	First rain season	4.499025	8.852249	0.612	-12.96288	21.96093
		Dry season	-6.015227	1.09E+01	0.582	-27.5127	15.48225
	Dry season	First rain season	10.514253	9.854701	0.287	-8.92508	29.95359
		Second rain season	6.015227	1.09E+01	0.582	-15.48225	27.5127
Temperature (Celsius)	First rain season	Second rain season	-.938785*	0.333427	0.005	-1.59662	-0.28095
		Dry season	-1.496361*	0.183621	0	-1.85863	-1.13409
	Second rain season	First rain season	.938785*	0.333427	0.005	0.28095	1.59662
		Dry season	-0.557576	0.345202	0.108	-1.23864	0.12349
	Dry season	First rain season	1.496361*	0.183621	0	1.13409	1.85863
		Second rain season	0.557576	0.345202	0.108	-0.12349	1.23864
Electrical Conductivity (uS/cm)	First rain season	Second rain season	14.934077	1.22E+01	0.223	-9.15629	39.02444
		Dry season	4.597822	9.091368	0.614	-13.337	22.53265
	Second rain season	First rain season	-14.934077	1.22E+01	0.223	-39.02444	9.15629
		Dry season	-10.336255	1.28E+01	0.421	-35.63274	14.96023
	Dry season	First rain season	-4.597822	9.091368	0.614	-22.53265	13.337
		Second rain season	10.336255	1.28E+01	0.421	-14.96023	35.63274
pH	First rain season	Second rain season	0.228589	0.197482	0.249	-0.16144	0.61861
		Dry season	-1.037147*	0.112931	0	-1.26019	-0.81411
	Second rain season	First rain season	-0.228589	0.197482	0.249	-0.61861	0.16144
		Dry season	-1.265736*	0.200942	0	-1.6626	-0.86888
	Dry season	First rain season	1.037147*	0.112931	0	0.81411	1.26019
		Second rain	1.265736*	0.200942	0	0.86888	1.6626

		season					
Dissolved Oxygen (mg/l)	First rain season	Second rain season	-0.433441	0.299747	0.151	-1.02828	0.1614
		Dry season	0.758559	0.423311	0.076	-0.08149	1.59861
	Second rain season	First rain season	0.433441	0.299747	0.151	-0.1614	1.02828
		Dry season	1.192000*	0.456583	0.01	0.28593	2.09807
	Dry season	First rain season	-0.758559	0.423311	0.076	-1.59861	0.08149
		Second rain season	-1.192000*	0.456583	0.01	-2.09807	-0.28593

*. The mean difference is significant at the 0.05 level.

Appendix A12: Vertical Variation in Physico-chemical parameters for First, Second and Dry Season using One Way ANOVA Test

Descriptives Statistics

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Total Dissolved Solids (mg/l)	First rain season	97	7.07E+01	46.355478	4.706686	61.36555	80.05094	56.1	514
	Second rain season	55	7.52E+01	62.092523	8.372554	58.42131	91.99323	59	520
	Dry season	40	8.12E+01	51.97252	8.217577	64.60088	97.84412	65.3	309
	Total	192	7.42E+01	52.32997	3.77659	66.73832	81.63668	56.1	520
Temperature (Celsius)	First rain season	107	2.46E+01	1.383687	0.133766	24.34601	24.87642	21.6	28.2
	Second rain season	14	2.56E+01	0.550175	0.14704	25.23234	25.86766	23.7	25.9
	Dry season	66	2.61E+01	0.844586	0.103961	25.89995	26.3152	24.7	27.3
	Total	187	2.52E+01	1.36469	0.099796	25.01275	25.4065	21.6	28.2
Electrical Conductivity (uS/cm)	First rain season	97	1.36E+02	95.087463	9.654669	116.59543	154.92416	95	1030
	Second rain season	28	1.12E+02	67.532332	1.28E+01	85.32441	137.69702	70.8	334
	Dry season	66	1.22E+02	80.514523	9.910653	102.05403	141.63991	60	516
	Total	191	1.27E+02	86.705315	6.273776	115.02218	139.77258	60	1030
pH	First rain season	82	7.43073	0.567948	0.062719	7.30594	7.55552	6.31	8.62
	Second rain season	14	7.20214	0.564381	0.150837	6.87628	7.52801	6.44	7.94
	Dry season	66	8.46788	0.82166	0.101139	8.26589	8.66987	6.12	10
	Total	162	7.83352	0.861875	0.067715	7.69979	7.96724	6.12	10
Dissolved Oxygen (mg/l)	First rain season	59	6.73356	1.355204	0.176433	6.38039	7.08673	5.1	10.13
	Second rain season	30	7.167	1.372506	0.250584	6.6545	7.6795	5.45	10.2
	Dry season	13	6.1	1.169045	0.324235	5.39355	6.80645	3.6	7.6
	Total	102	6.78029	1.364988	0.135154	6.51218	7.0484	3.6	10.2

Appendix A12.1: ANOVA for physic-chemical parameters in vertical direction

		Sum of Squares	Df	Mean Square	F	Sig.
Total Dissolved Solids (mg/l)	Between Groups	3211.05	2	1605.525	0.584	0.559
	Within Groups	519828.28	189	2750.414		
	Total	523039.33	191			
Temperature (Celsius)	Between Groups	93.155	2	46.577	33.841	0
	Within Groups	253.248	184	1.376		
	Total	346.403	186			
Electrical Conductivity (uS/cm)	Between Groups	15883.284	2	7941.642	1.057	0.35
	Within Groups	1412500.9	188	7513.303		
	Total	1428384.2	190			
pH	Between Groups	45.444	2	22.722	48.721	0
	Within Groups	74.152	159	0.466		
	Total	119.595	161			
Dissolved Oxygen (mg/l)	Between Groups	10.632	2	5.316	2.964	0.056
	Within Groups	177.551	99	1.793		
	Total	188.182	101			

Appendix A12.2: Multiple comparison (LSD test) for physico-chemical parameters in the vertical direction

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Total Dissolved Solids (mg/l)	First rain season	Second rain season	-4.499025	8.852249	0.612	-21.96093	12.96288
		Dry season	-10.514253	9.854701	0.287	-29.95359	8.92508
	Second rain season	First rain season	4.499025	8.852249	0.612	-12.96288	21.96093
		Dry season	-6.015227	1.09E+01	0.582	-27.5127	15.48225
	Dry season	First rain season	10.514253	9.854701	0.287	-8.92508	29.95359
		Second rain season	6.015227	1.09E+01	0.582	-15.48225	27.5127
Temperature (Celsius)	First rain season	Second rain season	-.938785*	0.333427	0.005	-1.59662	-0.28095
		Dry season	-1.496361*	0.183621	0	-1.85863	-1.13409
	Second rain season	First rain season	.938785*	0.333427	0.005	0.28095	1.59662
		Dry season	-0.557576	0.345202	0.108	-1.23864	0.12349
	Dry season	First rain season	1.496361*	0.183621	0	1.13409	1.85863
		Second rain season	0.557576	0.345202	0.108	-0.12349	1.23864
Electrical Conductivity (uS/cm)	First rain season	Second rain season	24.24908	1.86E+01	0.194	-12.43338	60.93154
		Dry season	13.912824	1.38E+01	0.316	-13.37094	41.19659
	Second rain season	First rain season	-24.24908	1.86E+01	0.194	-60.93154	12.43338
		Dry season	-10.336255	1.95E+01	0.598	-48.90018	28.22767
	Dry season	First rain season	-13.912824	1.38E+01	0.316	-41.19659	13.37094
		Second rain season	10.336255	1.95E+01	0.598	-28.22767	48.90018
pH	First rain season	Second rain season	0.228589	0.197482	0.249	-0.16144	0.61861
		Dry season	-1.037147*	0.112931	0	-1.26019	-0.81411
	Second rain season	First rain season	-0.228589	0.197482	0.249	-0.61861	0.16144
		Dry season	-1.265736*	0.200942	0	-1.6626	-0.86888
	Dry season	First rain season	1.037147*	0.112931	0	0.81411	1.26019
		Second rain season	1.265736*	0.200942	0	0.86888	1.6626
Dissolved Oxygen (mg/l)	First rain season	Second rain season	-0.433441	0.300298	0.152	-1.0293	0.16242
		Dry season	0.633559	0.41031	0.126	-0.18059	1.4477
	Second rain season	First rain season	0.433441	0.300298	0.152	-0.16242	1.0293
		Dry season	1.067000*	0.444678	0.018	0.18466	1.94934
	Dry season	First rain season	-0.633559	0.41031	0.126	-1.4477	0.18059
		Second rain season	-1.067000*	0.444678	0.018	-1.94934	-0.18466

*. The mean difference is significant at the 0.05 level.

Appendix A13: Vertical Variation in Nutrient Concentration for First, Second and Dry Season using One Way ANOVA Test

Descriptives Statistics

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Concentration of ammonia (mg/l)	First rain season	69	0.20246	0.159903	0.01925	0.16405	0.24088	0	0.93
	Second rain season	64	0.21141	0.292959	0.03662	0.13823	0.28459	0.09	2.44
	Dry season	0	.	.	.	.	.	.	.
	Total	133	0.20677	0.23271	0.020179	0.16685	0.24668	0	2.44
Concentration of nitrite (mg/l)	First rain season	68	0.02119	0.016771	0.002034	0.01713	0.02525	0.006	0.12
	Second rain season	41	0.02146	0.016122	0.002518	0.01637	0.02655	0.013	0.086
	Dry season	66	0.02268	0.037243	0.004584	0.01353	0.03184	0	0.3
	Total	175	0.02182	0.026204	0.001981	0.01791	0.02573	0	0.3
Concentration of nitrate (mg/l)	First rain season	54	0.07135	0.028921	0.003936	0.06346	0.07925	0.034	0.156
	Second rain season	41	0.09385	0.021384	0.00334	0.0871	0.1006	0.063	0.194
	Dry season	66	0.09567	0.064429	0.007931	0.07983	0.11151	0.015	0.349
	Total	161	0.08705	0.046941	0.003699	0.07974	0.09436	0.015	0.349
Concentration of phosphate	First rain season	53	0.18792	0.184957	0.025406	0.13694	0.2389	0	1.05
	Second rain season	41	0.37195	0.268246	0.041893	0.28728	0.45662	0.17	1.56
	Dry season	66	0.34788	0.702531	0.086476	0.17518	0.52058	0.01	4.6
	Total	160	0.30106	0.487368	0.03853	0.22497	0.37716	0	4.6

Appendix A13.1: ANOVA for nutrient variation in the vertical direction

		Sum of Squares	Df	Mean Square	F	Sig.
Concentration of ammonia (mg/l)	Between Groups	0.003	1	0.003	0.049	0.826
	Within Groups	7.146	131	0.055		
	Total	7.148	132			
Concentration of nitrite (mg/l)	Between Groups	0	2	0	0.058	0.943
	Within Groups	0.119	172	0.001		
	Total	0.119	174			
Concentration of nitrate (mg/l)	Between Groups	0.02	2	0.01	4.778	0.01
	Within Groups	0.332	158	0.002		
	Total	0.353	160			
Concentration of phosphate	Between Groups	1.029	2	0.515	2.199	0.114
	Within Groups	36.738	157	0.234		
	Total	37.767	159			

Appendix A13.2: Multiple Comparisons (LSD test) for nutrient variation in the vertical direction

Dependent Variable	(I) Rain Seasons	(J) Rain Seasons	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Concentration of nitrite (mg/l)	First rain season	Second rain season	-0.000272	0.00521	0.958	-0.01056	0.01001
		Dry season	-0.001491	0.004553	0.744	-0.01048	0.0075
	Second rain season	First rain season	0.000272	0.00521	0.958	-0.01001	0.01056
		Dry season	-0.001218	0.005239	0.816	-0.01156	0.00912
	Dry season	First rain season	0.001491	0.004553	0.744	-0.0075	0.01048
		Second rain season	0.001218	0.005239	0.816	-0.00912	0.01156
Concentration of nitrate (mg/l)	First rain season	Second rain season	-.022502*	0.009502	0.019	-0.04127	-0.00374
		Dry season	-.024315*	0.008417	0.004	-0.04094	-0.00769
	Second rain season	First rain season	.022502*	0.009502	0.019	0.00374	0.04127
		Dry season	-0.001813	0.009121	0.843	-0.01983	0.0162
	Dry season	First rain season	.024315*	0.008417	0.004	0.00769	0.04094
		Second rain season	0.001813	0.009121	0.843	-0.0162	0.01983
Concentration of phosphate	First rain season	Second rain season	-0.184027	0.10061	0.069	-0.38275	0.0147
		Dry season	-0.159954	0.089222	0.075	-0.33618	0.01628
	Second rain season	First rain season	0.184027	0.10061	0.069	-0.0147	0.38275
		Dry season	0.024072	0.096191	0.803	-0.16592	0.21407
	Dry season	First rain season	0.159954	0.089222	0.075	-0.01628	0.33618
		Second rain season	-0.024072	0.096191	0.803	-0.21407	0.16592

*. The mean difference is significant at the 0.05 level.

Appendix A14: Horizontal Variation in Nutrient Concentration for First, Second and Dry Season using One Way ANOVA Test

Descriptives Statistics

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound	Minimum	Maximum
Concentration of Ammonia (mg/l)	First rain season	69	0.20246	0.159903	0.01925	0.16405	0.24088	0	0.93
	second rain season	41	0.24098	0.362979	0.056688	0.12641	0.35555	0.09	2.44
	Dry season	4	0.04	0.029439	0.01472	-0.00684	0.08684	0.01	0.08
	Total	114	0.21061	0.2519	0.023593	0.16387	0.25736	0	2.44
Concentration of nitrite	First rain season	69	0.02109	0.01667	0.002007	0.01708	0.02509	0.006	0.12
	second rain season	41	0.02146	0.016122	0.002518	0.01637	0.02655	0.013	0.086
	Dry season	66	0.02268	0.037243	0.004584	0.01353	0.03184	0	0.3
	Total	176	0.02177	0.026136	0.00197	0.01788	0.02566	0	0.3
Concentration of nitrate	First rain season	54	0.07135	0.028921	0.003936	0.06346	0.07925	0.034	0.156
	second rain season	41	0.09385	0.021384	0.00334	0.0871	0.1006	0.063	0.194
	Dry season	66	0.09567	0.064429	0.007931	0.07983	0.11151	0.015	0.349
	Total	161	0.08705	0.046941	0.003699	0.07974	0.09436	0.015	0.349
Concentration of phosphate	First rain season	53	0.18792	0.184957	0.025406	0.13694	0.2389	0	1.05
	second rain season	41	0.37195	0.268246	0.041893	0.28728	0.45662	0.17	1.56
	Dry season	66	0.34788	0.702531	0.086476	0.17518	0.52058	0.01	4.6
	Total	160	0.30106	0.487368	0.03853	0.22497	0.37716	0	4.6

Appendix A14.1: ANOVA for nutrient variation in the horizontal direction

		Sum of Squares	Df	Mean Square	F	Sig.
Concentration of Ammonia (mg/l)	Between Groups	0.159	2	0.079	1.257	0.288
	Within Groups	7.011	111	0.063		
	Total	7.17	113			
Concentration of nitrite	Between Groups	0	2	0	0.066	0.936
	Within Groups	0.119	173	0.001		
	Total	0.12	175			
Concentration of nitrate	Between Groups	0.02	2	0.01	4.778	0.01
	Within Groups	0.332	158	0.002		
	Total	0.353	160			
Concentration of phosphate	Between Groups	1.029	2	0.515	2.199	0.114
	Within Groups	36.738	157	0.234		
	Total	37.767	159			

Appendix A14.2: Multiple Comparisons (LSD test) for nutrient variation in the horizontal direction

						95% Confidence Interval	
Dependent Variable	(I) Rainfall Seasons	(J) Rainfall Seasons	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Concentration of Ammonia (mg/l)	First rain season	second rain season	-0.038512	0.049559	0.439	-0.13672	0.05969
		Dry season	0.162464	0.129256	0.211	-0.09366	0.41859
	second rain season	First rain season	0.038512	0.049559	0.439	-0.05969	0.13672
		Dry season	0.200976	0.131652	0.13	-0.0599	0.46185
	Dry season	First rain season	-0.162464	0.129256	0.211	-0.41859	0.09366
		second rain season	-0.200976	0.131652	0.13	-0.46185	0.0599
Concentration of nitrite	First rain season	second rain season	-0.000376	0.005181	0.942	-0.0106	0.00985
		Dry season	-0.001595	0.004524	0.725	-0.01052	0.00733
	second rain season	First rain season	0.000376	0.005181	0.942	-0.00985	0.0106
		Dry season	-0.001218	0.005225	0.816	-0.01153	0.00909
	Dry season	First rain season	0.001595	0.004524	0.725	-0.00733	0.01052
		second rain season	0.001218	0.005225	0.816	-0.00909	0.01153
Concentration of nitrate	First rain season	second rain season	-.022502*	0.009502	0.019	-0.04127	-0.00374
		Dry season	-.024315*	0.008417	0.004	-0.04094	-0.00769
	second rain season	First rain season	.022502*	0.009502	0.019	0.00374	0.04127
		Dry season	-0.001813	0.009121	0.843	-0.01983	0.0162
	Dry season	First rain season	.024315*	0.008417	0.004	0.00769	0.04094
		second rain season	0.001813	0.009121	0.843	-0.0162	0.01983
Concentration of phosphate	First rain season	second rain season	-0.184027	0.10061	0.069	-0.38275	0.0147
		Dry season	-0.159954	0.089222	0.075	-0.33618	0.01628
	second rain season	First rain season	0.184027	0.10061	0.069	-0.0147	0.38275
		Dry season	0.024072	0.096191	0.803	-0.16592	0.21407
	Dry season	First rain season	0.159954	0.089222	0.075	-0.01628	0.33618
		second rain season	-0.024072	0.096191	0.803	-0.21407	0.16592

*. The mean difference is significant at the 0.05 level.