ESTIMATION OF TROPHIC STATE INDICES AND PHYTOPLANKTON QUOTIENTS IN KISUMU BAY, NYANZA GULF, LAKE VICTORIA

BY

MISIKO FLORENCE MONICAH

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN AQUATIC SCIENCE

DEPARTMENT OF ZOOLOGY

MASENO UNIVERSITY

ABSTRACT

Kisumu Bay is greatly impacted by pollution from anthropogenic activities around Nyanza Gulf and from increasing levels of industrial and municipal waste discharges from Kisumu City. This has resulted in significant changes in the level of eutrophication and the general ecology of the bay, impacting negatively on water quality, biodiversity, fisheries and livelihoods. These changes need to be monitored constantly for the effective environmental management of the gulf. The level of eutrophication of the Kisumu Bay has, however, not been determined. This study aimed at estimating the Trophic State Indices and Phytoplankton Quotients, as key indicators of eutrophication, in Kisumu Bay, and to determine the level of eutrophication of Kisumu Bay. Water quality measurements were conducted from April 2009 to March 2010. Physico-chemical parameters including Secchi depth was determined with a Secchi disc, turbidity, temperature, conductivity, alkalinity and dissolved oxygen concentration were measured *in situ* using a seabird multi-parameter water quality probe, whereas nutrients levels (ammonia, nitrates, nitrite, total nitrogen, soluble reactive phosphorus, total phosphorus and chlorophyll *a*) and phytoplankton analyses were done by spectrophotometric and microscopic techniques, respectively. There were significant spatial differences in the dissolved oxygen concentrations (ANOVA, $p < 0.01$) within the bay. These differences were highly pronounced at the Kisat, Maboko and Yacht Club stations which are associated with sewage discharges from Kisumu City. Significant differences (ANOVA, $p < 0.05$) associated with discharges from Kisumu City and seasonal nutrient runoffs from storm water were also observed in the spatial and temporal distribution of phosphorous, ammonia, nitrates, nitrites and silicates within the bay. Significantly higher (ANOVA, $p<0.05$) chlorophyll *a* concentrations were recorded during the dry season when compared to the rainy season, probably as a result of higher turbidity during the rainy season, which reduces light penetration into the water, and thereby reducing the rates of phytoplankton production. Cyanophyceae was the most abundant phytoplankton group contributing 57% of the total phytoplankton count, followed by Chlorophyceae (28%), Desmidaceae (11%), Bacillariophyceae (4%) and Euglenophyceae (1%). Among the Cyanophyceae, the most dominant species were *Microcystis* spp,*Chroococcus* spp, *Anabaena* spp and *Cylindrospermopsis* spp. Different phytoplankton distribution patterns were observed between the offshore Maboko station and the inshore stations. The mean phytoplankton quotient for Kisumu Bay was 4.1, whereas the Trophic State Index mean value was 145.3, indicating that the bay is highly eutrophic. The study attributes this observation to high nutrient loads from anthropogenic activities in the catchment area and industrial and municipal waste discharges from Kisumu City, and recommends stricter enforcement of the established policies on waste discharges from municipal and industrial establishments. The study also recommends the institution of environmental education and awareness creation targeting the catchment area and lake side communities as a policy to abate pollution in the bay and Lake Victoria as a whole.

CHAPTER ONE

1.0. INTRODUCTION

1.1. General Introduction

Lake Victoria is the second largest freshwater lake after Superior in United State of America. Like many freshwater bodies in the world, Lake Victoria has experienced a deterioration of water quality and high levels of ecological stress in recent years, a situation that has largely been attributed to an escalation of anthropogenic activities within the catchment (Plate 1 & 2).These have contributed to the eutrophication and contamination of the lake, with grave implications for the fisheries economy of the region. With a population of approximately 550 persons / km^2, the Nyanza Gulf (also known as Winam Gulf or Kavirondo Gulf) of Lake. Victoria is one of the most densely populated areas in Kenya, and probably the most affected of the Lake Victoria ecosystems (U.N., 1998; EPA, 2007; Gichuki *et al.*, 2006).

Recent studies show that Nyanza Gulf waters are highly turbid, rich in organic matter, and has a higher pH value compared to inflowing fresh river waters (Gichuki, 2000; Gichuki *et al.,* 2006; LVEMP, 2005). The Lake waters are warmer than in the 1960s, while thermal stability has increased since the 1990s (Hecky and Bugenyi, 1992; Hecky 1993; Lehman *and Branstrator*., 1994). Dissolved oxygen levels as low as 1 mgl^{-1} have been recorded in the deeper parts of the gulf for up to 10 months in a year (Verschuren *et al*., 2002; Odada *et al*., 2004). Secchi transparency index has also declined from an average 5 meters in the 1930s to less than one meter in 1990s (Lehman *and Branstrator*., 1994). The lake has also undergone remarkable nutrient enrichment since the 1920's,(Sitoki et al,2010)

Evidence from the water samples indicates that total phosphorus concentration have doubled since the 1960s (Talling, 1987; Lehman *and Branstrator.*, 1994), whereas total nitrogen concentration is high (Average of353.8 μgl^{-1}) and varied (Gichuki *et al.* 2006). Meanwhile, algal growth has increased, and fish kills have been reported (Ochumba, 1987; 1990). Lake Victoria also receives 2.3 million m^3 of sediment load per year from runoffs in agricultural and deforested areas (Odada, 2003), exacerbating the eutrophication problem in the lake.

Kisumu Bay, situated in the north eastern corner of the Nyanza Gulf, is greatly impacted by the effects of urbanization and industrialization centred on Kisumu City. Raw and partially treated sewage from the municipal sewage treatment works and the Nyalenda sewage stabilization ponds (Fig. 1) discharge their effluents directly into the bay through the River Kisat and the Nyalenda stream respectively. In addition, runoffs from the peri-urban areas of Obunga, Nyalenda, Manyatta, Kondele and the many small processing industries in Kisumu City also discharge their effluents into the bay. This has resulted in significant changes in the trophic state and general ecology of the bay, impacting negatively on water quality, as evidenced by the presence of large patches of aquatic macrophytes (plate 3) and algal blooms. The quality of a water body is determined by its suitability for life sustaining activities for both resident and non-resident organisms as well as for human use.

Consequently, water quality may be determined by a combination of physico-chemical and biological factors including, dissolved oxygen(DO), pH, alkalinity, conductivity, nutrients and other dissolved and suspended solids, and the trophic state of the water body. Measuring these parameters provides the baseline information that enables determination of the trophic state and level of eutrophication of the water body. Determination of the trophic state of a water body, indicated by the Trophic State Index (TSI), is based upon the levels of phosphorus and nitrogen, and the phytoplankton biomass in the water. TSI (Carlson, 1977; Carlson and Simpson, 1996) and the Phytoplankton Quotient (PQ) (Nyagaard, 1949) are used as biological pollution monitoring tools(OECD,1982). Despite their obvious importance, information relating to the TSI and PQ for Kisumu Bay, indeed for the whole of Nyanza Gulf is lacking, making it difficult to determine the trophic status of the gulf. The objective of this study was, therefore, to estimate the TSI and PQ for Kisumu Bay, and to determine the level of eutrophication of the bay.

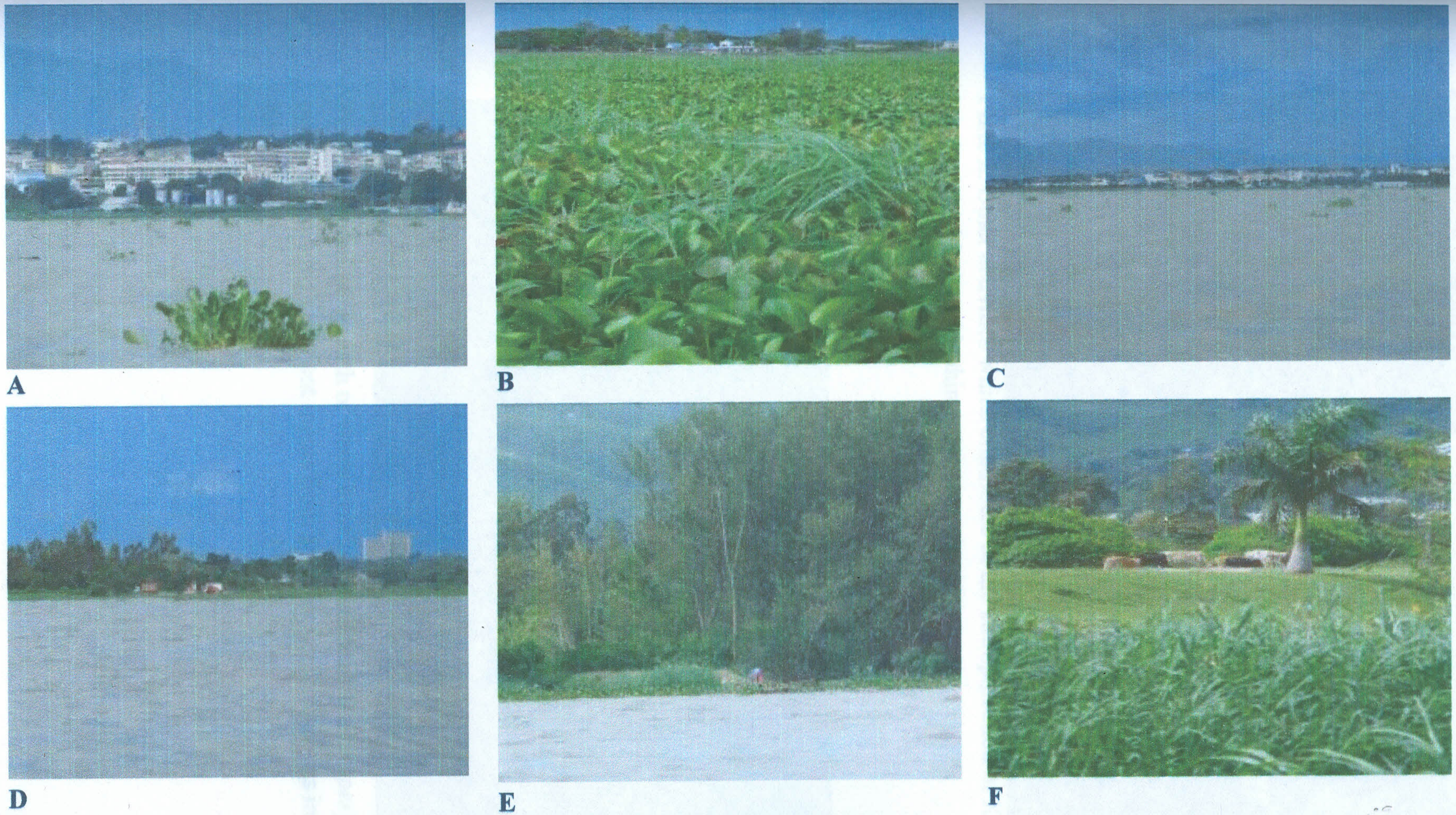

Plate 1: Anthropogenic activities are possible sources of eutrophication and general degradation of Kisumu Bay, A, B, and C; show the impact of urbanization; D sand harvesting, E deforestation, and F agriculture (farming and livestock keeping).

Plate 2: Other activities which contribute to the eutrophication of Kisumu Bay include: boating, washing, and bathing.

Plate 3: Luxurious growth of water hyacinth(*Eichhornia crassipes*) and hippo grass mats resulting from high nutrient inputs from anthropogenic activities in the catchments of Kisumu Bay.

1.2. Justification

Although a dynamic ecosystem, characterized by spatial and temporal fluctuations in the levels of the various ecosystem components, the Nyanza Gulf is currently exhibiting characteristic symptoms of eutrophication, as evidenced by large mats and forests of floating plants, high turbidity, oxygen depletion, and changing phytoplankton community structure. This has resulted to decreasing quality and quantity of the Lake Victoria waters which destabilizes the trophic level equilibrium creating a utilization crises and safety which threatens the multi-fold uses of the lake water; yet, the level of eutrophication remains unknown. Investigations on the subject have been mainly on the symptomatic aspects of eutrophication neglecting the quantitative aspects, required policy formulation and mitigation of environmental quality. Furthermore, information relating to the TSI and PQ for Kisumu Bay, and indeed for the whole of the Nyanza Gulf is lacking, making it difficult to determine the trophic status of the gulf.

This study aimed at determining the level of eutrophication using the TSI and PQ evaluation tools and then, the trophic status of Kisumu Bay. This information was used to assess whether the bay is able to withstand the current levels of point and non-point discharge of pollutions. It is our hope that information reported here will, in conjunction with other established criteria, enable policy formulation for restoration, management and conservation of the gulf waters and its flora and fauna.

1.3. Objectives

1.3.1. Overall objective

To determine the level of eutrophication of the Kisumu Bay

1.3.2. Specific objectives

1. To monitor the levels of nutrients and other physico-chemical parameters in Kisumu Bay during a 12-month period
2. To assess the phytoplankton composition, abundance and distribution in the Kisumu Bay.
3. To estimate the prevailing trophic state indices and phytoplankton quotients for the Kisumu Bay.

1.4. Assumptions

This study was conducted with the assumptions that:

1. Physico-chemical characteristics of a water body vary with the season and distance from the shoreline.
2. The phytoplankton composition, relative abundance and distribution are nutrient, season and environment-dependent.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. General Aspects of Water Quality

The quality of a water body is predicated on its suitability for life sustaining activities for both resident and non-resident organisms. Water quality is determined by a combination of physico-chemical and biological factors including temperature, dissolved oxygen concentration, pH, alkalinity, conductivity, nutrients and other dissolved and suspended solids in the water.

2.1.1. Dissolved oxygen concentration

The importance of dissolved oxygen (DO) to life in the aquatic environment cannot be gainsaid. Apart from its requirements for metabolic activity, DO content of water is a major factor influencing the rate of biodegradation and mineral recycling in the water. In lentic water bodies, dissolved oxygen concentration varies proportionally with atmospheric pressure and inversely with temperature (Ellis, 1989), and ranges in concentration between 8 – 10 mgl^{-1}. Low levels of DO are usually associated with high nutrient inputs from fertilizer, decomposing organic matter and municipal wastes discharges (USEPA 2002).

2.1.2. Temperature

Temperature affects physico-chemical and biological processes in water. When water temperature increases, the rate of chemical reactions generally increases together with the evaporation and volatilization of substances from the water. Increased temperature also decreases the solubility of gases in water (Coit, 1984). The metabolic rate of aquatic organisms is also related to temperature, and in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter (Coit, 1984). Growth rates also increase when nutrient conditions are favourable. This is most noticeable in bacteria and phytoplankton, which double their populations in very short time periods when subjected to high levels of nutrients leading to increased water turbidity and algal blooms.

2.1.3. pH

The pH of water is a measure of its acidity (APHA, 1995). pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body and all processes associated with water supply and treatment. The pH of water is dependent on environmental conditions (Michael *et al*,. 1993; USEPA, 2002; EPA, 2007), and hence may be influenced by anthropogenic activities such as discharges of industrial effluents and atmospheric deposition of acid-forming substances that affect the natural acid-base balance of the water body. Diel variations in pH can be caused by the photosynthesis and respiration cycles of algae in eutrophic waters. The pH of a water body may also affect phytoplankton diversity and abundance in the water. The acceptable pH values for most natural waters range between 6.0 and 8.5 (USEPA, 2002). pH values above 9.5 and below 4.5 are unsuitable for life (USEPA, 1992).

2.1.4. Conductivity

Conductivity, or specific conductance, is a measure of the ability of water to conduct an electric current. It is an indicator of the amount of dissolved solids in water, and thus an indirect indicator of pollution. It is sensitive to variations in dissolved solids, especially mineral salts. The degrees to which mineral salts dissociate into ions, the amount of electrical charge on each ion, ion mobility and the temperature of the solution all have an influence on conductivity. The Conductivity in micro Siemens per centimeter (µS cm^{-1}) for a given water body is related to the concentrations of total dissolved solids and major ions, and remains more or less constant provided the ionic composition of the water body remains stable. The conductivity of most freshwaters ranges between 10 to 1,000 µS cm^{-1} (EPA, 2007), but may be higher in polluted waters, or those receiving large quantities of run-off. In addition to being a rough indicator of mineral content of water, conductivity levels can be used to delineate pollution zones, e.g., around an effluent discharge, or the extent of influence of run-off waters.

2.1.5. Alkalinity

Alkalinity is the measure of the buffering capacity of water, indicated by the concentration of phosphates and silicates in the water (Ellis, 1989). It plays a significant role in the regulation of pH and reduction of toxicity by precipitating toxic metals. It measures the ability of water bodies to neutralize acids and bases thereby maintaining a fairly stable pH. Water that is a good buffer contains compounds, such as bicarbonates, carbonates, and hydroxides, which combine with H+ ions from the water thereby raising the pH (more basic) of the water. Without this buffering capacity, any acid added to a lake would immediately change its pH. Aquatic organisms benefit from a stable pH value in their optimal range. To maintain a fairly constant pH in a water body, a higher alkalinity is preferable. High alkalinity means that the water body has the ability to neutralize acidic pollution from rainfall or basic inputs from wastewater. A well buffered lake also means that daily fluctuations of CO2 concentrations (discussed above) result in only minor changes in pH throughout the course of a day. The alkalinity of freshwaters range between 20-200 mg l^{-1} (EPA, 2007) .Waters of low alkalinity (< 24 mg l^{-1} as $CaCO_3$) have a low buffering capacity and can, therefore, be susceptible to alterations in pH.

2.1.6. Turbidity

Turbidity refers to the cloudiness of water as a result of suspended and dissolved material. The level of turbidity of water depends on the type and concentration of suspended matter, and as such it is an indirect measure of water quality. The transparency of water can also be used to indicate the level of biological activity in the water. High turbidity raises the temperature of water leading to low DO concentrations. It also reduces light penetration, and hence limits algal production (Gikuma-Njuru and Hecky, 2005). Turbidity may vary seasonally as a result of surface run-off variations, and also according to biological activity in the water column. Turbidity is an important consideration for water recreation. Normal turbidity values range from 1 to 1,000 Nephelometric turbidity units (NTU).

2.1.7. Nutrients

Natural waters contain varied quantities of chemical elements, whose effects on biological processes lead to the production of organic material. Scarcity of these nutrients may limit production, while overabundance of particular nutrients can affect ecological stability and the population structure of the ecosystem. For example, high concentrations of nitrogen and phosphorus are associated with eutrophication and algal blooms, whereas water rich in silica will normally contain a high population of diatoms.

2.1.7.1. Nitrates, nitrites and ammonia

Nitrogen occurs in natural waters in the form of numerous compounds, in inorganic form as nitrate, nitrite and ammonia, and in organic form as intermediate stages of microbial protein decomposition, excretory products and free compounds like amino acids and enzymes. Nitrates and ammonia are the most important inorganic compounds in water, as they form important sources of nitrogen for photosynthesis. Nitrate concentrations seldom exceed 0.1 mg l^{-1} in natural freshwaters, except where there is industrial and municipal wastewater discharges.

In rural and suburban areas, the use of inorganic fertilizers can also be a significant source of nitrates. Nitrate concentrations in excess of 5 mg l^{-1} usually indicate pollution effects; in cases of extreme pollution, such as where there is high fertilizer application, nitrates concentrations of up to 500 mg l^{-1} have been recorded (UNEP and WHRC, 2007). In lakes, nitrates concentrations in excess of 0.2 mg l^{-1} tend to stimulate algal growth. Similarly, the concentrations of nitrites, a more toxic form of nitrogen, rarely exceed 1 mg l^{-1} in freshwaters. High nitrite concentrations are generally indicative of industrial effluents and are often associated with unsatisfactory microbiological quality of water. Thus, the levels of nitrate and nitrite in surface waters give a general indication of the nutrient status and level of organic pollution.

Decomposition of nitrogenous organic matter and the interruption of the nitrification of the ammonia liberated by the decomposition process, and the anaerobic ammonification of nitrate to ammonia may lead to accumulation of ammonia in water. Ammonia can also enter the water through discharges by industrial processes such as ammonia-based pulp and paper production and municipal wastes. High concentrations of ammonia are toxic to aquatic life and, therefore, detrimental to the ecological balance of water bodies. Unpolluted waters contain less than 0.2 mg l^{-1} ammonia (EPA, 2007). Higher concentrations of ammonia are indicative of organic pollution.

2.1.7.2. Phosphates

Phosphorus exists in water bodies as dissolved orthophosphate and as particulate species, derived mainly from weathering of phosphorus-bearing rocks and the decomposition of organic matter. It is generally the limiting nutrient for algal growth and, therefore, controls the primary productivity of a water body (Selman and Greenhalgh, 2008). Elevated levels of this nutrient are usually a result of anthropogenic inputs from domestic wastewaters, industrial effluents and fertilizer run-off (UNEP and WHRC, 2007), and are the principal cause of eutrophication in freshwaters. The concentration of phosphorus as orthophosphates in most freshwaters ranges between 0.005 and 0.020 mg l^{-1}. However, concentrations as low as 0.001 mg l^{-1} have been recorded in some pristine waters, while some as high as 200 mg l^{-1} have been reported in some enclosed saline waters (Selman and Greenhalgh, 2008).

2.1.7.3. Silicates

Dissolved silica (SiO_2) usually occurs in moderate abundance in fresh water. Although essentially unionized and relatively unreactive chemically, dissolved silica is assimilated in large quantities by diatoms for the synthesis of their cell walls. Its availability can therefore have a marked influence on the productivity and succession of algal populations. Silica may be discharged into water bodies with wastewaters from industries using siliceous compounds in their processes such as potteries, glass works and abrasive manufacture. It is also released during decomposition and decay of siliceous organisms, giving rise to seasonal fluctuations in concentrations, particularly in lakes. The silica content of rivers and lakes usually varies within the range 1-30 mg l^{-1} (EPA, 2007).

2.2. Nutrients availability, eutrophication and the trophic state of water

Natural waters contain varied quantities of chemical elements, whose effects on biological processes lead to the production of organic material. Scarcity of these elements especially those that are plant nutrients may limit production, while overabundance of particular nutrients can affect ecological stability, and hence affect the population structure of the ecosystem. For example, high concentrations of nitrogen and phosphorus species are associated with eutrophication and algal blooms, whereas water rich in silica normally contain a high population of diatoms. Studies by Ochumba and Kibaara (1989), Hecky (1993), Lehman and Branstrator (1994), Lungayia *et al.*, (2000) and Kling *et al.* (2001) also demonstrated the influence of the N: P ratio in the water on the dominance control of phytoplankton community structure, whereby a reduction of the N: P ratio from 16:1 to 8:1 favoured proliferation of the heterocystous blue green algae, whereas a change in the N: P ratio to 5:10 led to cyanobacterial blooms. High N: P ratios on the other hand favoured the development of Chlorococcales.

Voinov and Svirezhev (1984), defines eutrophication as the nutrients enrichment of a water mass that stimulates an array of changes that may interfere with its uses. It is normally caused by oversupply of nutrients, particularly phosphorus and nitrogen, in the water. Eutrophication is manifested through algal blooms and the proliferation of aquatic macrophytes that occur due to the destabilization of trophic level equilibrium. High phytoplankton densities lower the recreational value of the water, while bloom forming species of cyanobacteria are known to produce harmful toxins (Sitoki, *et al.*, 2010). Furthermore, excessive phytoplankton growth may result in low dissolved oxygen levels due to respiration or decomposition of dead algae, high turbidity and production of toxic hydrogen sulphide gas. In general, eutrophication undermines water quality and is a threat to the sustainability of the multi-fold beneficial uses of a water body.

The trophic state or degree of fertility of a water body refers to the production potential of major phytoplankton species in the water. The trophic state of the water mass is correlated with the level of eutrophication of the water (Vollenweider, 1975). Its determination is based upon the levels of phosphorus and nitrogen, and the phytoplankton biomass in the water, and is indicated by the Trophic State Index (TSI).

2.3. Physico-Chemical Characteristics of Nyanza Gulf

Recent studies by Gichuki (2000), Mugidde *et al.* (2004), Gikuma- Njuru and Hecky (2005), LVEMP (2005) and Gichuki, *et al.* (2006) have shown that Nyanza Gulf waters are highly turbid, rich in organic matter, contain more chlorides, and have a higher pH value compared to normal river water. The Lake waters are also reported to be warmer than in the 1960's (Hecky and Bugenyi, 1992; Lehman and Branstrator, 1993; 1994). DO levels as low as 1 mgl^{-1} have been recorded in the deeper parts of the gulf for up to 10 months in a year (Verschuren *et al.*, 2002; Odada *et al.*, 2004). In addition, Secchi transparency index has declined from 5 meters in the 1930's to less than one meter in the 1990's (Lehman and Branstrator, 1994, Lehman, 1998). The lake has also undergone remarkable nutrient enrichment since the 1920's,(Sitoki et al.2010). Evidence from water sample analyses indicate that total phosphorus concentration have doubled since 1960's (Talling, 1987; Lehman *and Branstrator.*, 1994), and that total nitrogen concentration is high (Av. 353.8 $\mu g\ l^{-1}$) and varied (Gichuki *et al.* 2006). Algal growth has also increased, and massive fish kills are frequently observed (Ochumba, 1987; 1990).

Higher than normal nutrient concentrations, increased primary productivity, and biomass and phytoplankton population build up were reported by Lung'ayia *et al*., (2000), Gikuma- Njuru and Hecky (2005), LVEMP (2002, 2005), Gichuki *et al.* (2006) and UNEP (2006) indicating an increasing trend in eutrophication of Nyanza Gulf waters. In his report, Lung'ayia *et al*.,(2000) observed that where nitrogen, phosphorus and dissolved solids were higher in concentration, blue green algae (Cyanobacteria) were dominant over other phytoplankton. Data collected by Talling (1987) and Hecky (1993) also indicated serious eutrophication trends in the inshore waters of Nyanza Gulf. They also noted the dominance of blue–green algae over diatoms and green algae, a pointer to environmental disequilibrium within the gulf.

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. Description of Study Area

Kisumu Bay is situated in the North – East corner of the Nyanza gulf (Fig. 1). It stretches 4.5 km in length and 3 km in width, and covers a total area of 8 km^2. The area has an average rainfall of 1150 $mmyr^{-1}$, with double maxima from March–May (long season) and August-November (short season). Daily temperatures range between 16°C at night and 31°C during the day. Winds are mostly south-westerly and are strongest in the afternoons. The shallow nature of the bay coupled with the south-westerly winds results in a homogenous vertical mixing of the water column. The main sources of surface water input into the bay are the rivers Kisat and Kisian, and the Nyalenda and Auji streams and swamp seepage. Two wastewater treatment facilities, the municipal sewage treatment works and the Nyalenda waste water stabilization ponds discharge their effluents into the river Kisat and Nyalenda stream, respectively. Runoffs from the slums of Obunga, Auji, Siany, Nyalenda, Nyawita, Manyatta, Kondele and Car wash, and the many small scale processing industries in Kisumu town also drain into the bay.

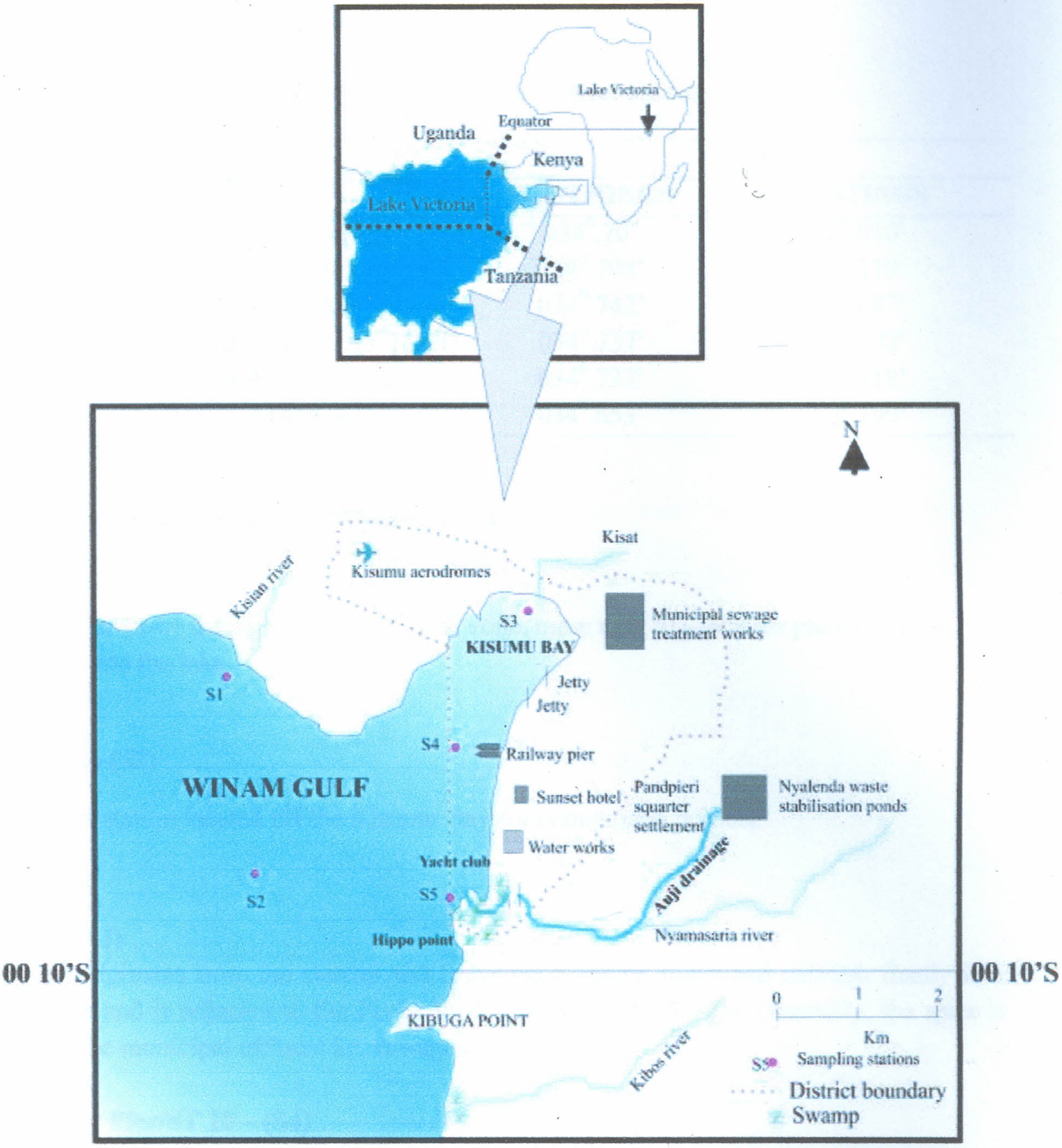

Figure 1: Map of Nyanza(Winam) Gulf showing Kisumu Bay, its drainage system, and the sampling stations (S1- River Kisian, S2 – Maboko, S3 - River Kisat, S4 - Railway Pier (ST10) and S5 - Kisumu Yacht Club)

3.1.1. Mapping of the sampling sites

Table 1: GPS Coordinates, station codes and station names

STATION CODE	STATION NAME	GPS	
		SOUTHINGS	EASTINGS
S1	KISIAN	034^0.70’	00^0.010’
S2	ST 10B	034^0.708’	00^0.119’
S3	KISAT	034^0.742’	00^0.087’
S4	ST 10 (RAILWAY PIER)	034^0.737’	00^0.102’
S5	YATCH CLUB	034^0.737’	00^0.119’
S6	MABOKO	034^0.653’	00^0.199’

3.1.2. Description of the sampling stations

Kisian(S1)

The River flows through the Agricultural zone, more next to Molasses plant drainage system into the lake.

Maboko (S2)

Outskirt station located off the Kisumu Bay for comparison purpose

Kisat (S3)

River originates from the swamp and flows via Kondele slums and carwash finally into the lake and is adjacent to the Peche food factory and Golf club. Generally, the river is full of the municipal effluent i.e. sewage.

Railway Pier/ST 10 – (S4)

Captures the effluents at the pier and runoffs from the town.

Yatch Club (S5)

Is a river input. The Auji and Nyamasaria streams converge and flow via the Nyalenda slums and the waste stabilization tanks. Finally, the streams flow via the papyrus swamps where self purification occurs.

3.2. Sampling

Three sampling stations were set at the mouths points of rivers Kisian (S1) and Kisat (S3), and the Yacht club (S5) to capture the effects of stream inputs. Two other stations were located at the railways pier (S4) and Maboko (S2), in the inner Nyanza Gulf, to capture the effects of runoff and the ensuing dilution. The sampling stations were positioned using a Magellan Global Positioning System (GPS) 315 meridian. Sampling was done on a monthly basis from April 2009 to March 2010 All samples were taken at a depth of 1 m. Temperature, Secchi depth transparency, and pH. were measured in situ before sampling. Secchi depth transparency was measured using a Standard 20 cm diameter Secchi disk (Plate 4), whereas water turbidity and pH were measured using a Hatch Turbidimeter 2100 P and a digital Mini pH meter Model 49, respectively. Water depth, temperature, conductivity and chlorophyll *a* were measured using a submersible Conductivity-Temperature-Depth, CTD (Sea-bird Electronics®, Plate 5) profiling system.

Water samples were collected following the methods outlined in Wetzel and Likens (2000). The samples were collected using a 2.5 L Van Dorn water sampler, and placed in sterile plastic sample bottles. Samples for nutrient analysis were fixed using 0.1M hydrochloric acid (HCl) and stored at 4°C pending analysis. Phytoplankton samples were collected using phytoplankton nets and the Van Dorn water sampler were fixed using acidic Lugol's solution and stored in plastic vials for laboratory analysis.

Plate 4: Standard Secchi disk Depth

Plate 5: Conductivity-Temperature-(CTD) profiling meter

The Standard Secchi disk (Plate 4) being lowered in water and the Conductivity-Temperature-Depth (CTD) profiling system (Plate 5) used to measure water transparency, conductivity ,temperature and chlorophyll *a* in Kisumu Bay.

3.3. Sample analysis

3.3.1. Alkalinity and Hardness

Alkalinity and Hardness were determined using the methods of APHA (1995). 50 ml water sample was titrated using 0.02 N HCl to a pH of 4.5, using methyl orange indicator. A similar quantity of sample water was analyzed for total hardness using 0.02 N EDTA,(Ethylene di amine tetra acetic acid).

3.3.2. Nutrients

The standard methods outlined in Wetzel and Likens (2000) were used in nutrient analysis. Ammonia content was analyzed using the phenol hypochlorite method, with nitroprusside as a catalyst. The analysis is based on the fact that under alkaline conditions, ammonium reacts with hypochlorite to form monochloroamine which further reacts with phenol, forming a transitory intermediate precursor leading to formation of a stable indophenol blue complex. The colour development is proportional to the concentration of ammonium within the water. The resulting extinctions were measured at a wave length of 630 nm on a spectrophotometer. Nitrates and nitrites were analyzed using the Cadmium – reduction method. Nitrate in alkaline–buffered solution was reduced to nitrite by passing the sample through a column of copperized cadmium metal filings. Nitrite reacts with the amine group of sulphanilamide in the presence of HCl forming a diazonium salt which on reaction with N-(1–naphthyl)ethylenediamine dihydrochloride formed a stable quantifiable pink azo dye, which resulting extinction was measured at 540 nm. Total Nitrogen was determined using unfiltered water samples. After digestion with potassium per sulfate, the samples were autoclaved to convert organic nitrogen to nitrate nitrogen and allowed to cool to room temperature. The samples were then passed through a reduction column after the addition of an alkaline buffer.

Soluble reactive phosphorous ($PO_4 - P$) was analyzed using the Ascorbic acid method. 50 ml samples were allowed to react with a composite reagent of molybdate, ascorbic acid and trivalent antimony. The molybdic acid formed was then converted by reducing agents to a blue coloured complex. Samples for the determination of total phosphorus were oxidized using hot 5% potassium per sulfate in distilled water, autoclaved for 30 min, then further cooled at room temperature to liberate organic phosphorus as inorganic phosphate (absorbance read at 880nm wavelength). Silicates were analyzed using the heteropoli blue technique according to APHA (1995). The reactive silicates were oxidized to a silico-molybdate complex which was then reduced with a solution of metal sulphate and oxalic acid to produce a blue colour. The resulting extinctions were measured at a wave length of 810 nm on a spectrophotometer.

3.3.3. Phytoplankton

A 2 ml sub-sample was taken from the preserved water sample, placed in an Utermöhl sedimentation chamber and left to settle for three hours before analysis. During the analysis, phytoplankton cells were identified to species level where possible and counted using an inverted microscope at 400x magnification. Ten fields of view were counted for the smaller coccoid cyanobacteria, whereas a 12.42 mm^2 transect was counted for the larger algae. The whole bottom area of the chamber was examined for the big and rare taxa under low (100x) magnification. Counts were made of all individual cells, colonies and filaments. Phytoplankton identification was done using the methods of Huber–

Pestalozzi (1938) and Cocquyt *et al.* (1993) and Cocquyt and Vyverman, (1994). To determine algal biomass, the algal cells were counted and measured using micrometer scale, and the total cell count converted to cell biovolume using appropriate geometric formulae as outlined in Rott, 1981, Hillebrand *and Sommer,* (1999) and Wetzel and Likens (2000).

3.4. Data Analysis

3.4.1. Estimation of trophic state indices and phytoplankton quotients

Trophic state indices (TSI) were determined using the methods outlined in Carlson, 1977; Carlson and Simpson (1996). The TSI's were used to define the trophic state and, based on index variables which correlate and were independent: the chlorophyll (almost accurate); Total phosphorus; and Secchi depth. Separate TSI values were calculated based on; empirical equations employed use of natural Logarithmic (In), a natural classification system, where (In) is 2.71828+ of chlorophyll, total nitrogen, total phosphorus. Values were combined by addition

Calculations;

Equation1,Eq 1 $\mathrm{TSI}\ (\mathrm{Chl.}\ a) = 1.68 + 14.4 \times \ln \mathrm{chl.}\ a$

Equation1,Eq 21 $\mathrm{TSI}\ (\mathrm{TP}) = 18.6 \times [\ln (\mathrm{TP} \times 1000)] - 18.4$

Equation1,Eq 3 $\mathrm{TSI}\ (\mathrm{TN}) = 56 + 19 \times \ln \mathrm{TN}$

Equation1,Eq 4 $\mathrm{TSI}_2\ (\mathrm{TP}) = 10 \times [2.36 \times \ln (\mathrm{TP} \times 1000) - 2.38]$

Equation1,Eq 5 $\mathrm{TSI}_2\ (\mathrm{TN}) = 10 \times [5.96 + 2.15 \times \ln (\mathrm{TN} + 0.001)]$

A combined TSI (final TSI) for each station was then obtained by averaging the separate values, taking into account the limiting nutrient for Kisumu Bay using the final equation A-C below:

$$TSI = TSI\ (chl\ a + TSI_2\ (TN)]\ /\ 2$$

N/B: Limiting nutrient considerations for calculating the combined (NUTR) TSI are:

A: Nutrient Balanced **($10 \leq TN/TP \leq 30$)**

$$TSI = (TSI\ chlo\ a\ [TSI\ (TN) + TSI\ (TP)]\ /2$$

B: Phosphorus-Limited Lakes ($TN/TP \geq 30$)

$$TSI = (TSI\ (Chlo\ a + TSI_2\ (TP))/2$$

C: Nitrogen. Limited lakes ($TN/TP < 10$)

$$TSI\ (TSI\ (Chloro\ a + TSI2\ (TN))/2$$

The relationship between the variables was then used as objective classifiers of the lake and other water bodies (Table 2 below).

Table 2: Relationship between Trophic state index (TSI), chlorophyll *a* (ch, phosphorus (p), both micrograms per litre, Secchi depth (SD metres), and Trophic class (after Carlson, 1977, Carlson and Simpson, 1996).

TI	Chlo	P	SD	Trophic Class
<30-40	0-2.6	0-12	>8-4	Oligotrophic
40-50	2.6-7.3	12-24	4-2	Mesotrophic
50-70	7.3-56	24-96	2-0.5	Eutrophic
70-100+	56-155+	96-384+	0.5-<0.25	Hypereutrophic

In addition, the phytoplankton quotients for the bay were determined as outlined in the methods of Nyagaard (1949) and Wetzel and Likens (2000)

Calculation of phytoplankton Quotient

(Of 1pg μm^{-3} as in Wetzel and Likens, 2000).

Calculations – Phytoplankton Quotient

$$\text{Chlorophycean quotient} = \frac{\text{Chlorococcales}}{\text{Desmidaceae}}$$

$$\text{Myxophycean quotient} = \frac{\text{Myxophyceae}}{\text{Desmidaceae}}$$

$$\text{Chlorophycean quotient} = \frac{\text{Chlorococcales}}{\text{Desmidaceae}}$$

$$\text{Diatom quotient} = \frac{\text{Centric Diatoms}}{\text{Pennate Diatoms}}$$

$$\text{Euglenoid quotient} = \frac{\text{Euglininae}}{\text{Myxophyceae + Chlorococcales}}$$

Compound quotient

$$\text{(Nyaggaard, 1949)} = \frac{\text{Myxophyceae + Chlorococcales +Centrales + Euglininae}}{\text{Desmidaceae}}$$

PQs were determined separately for Chlorophyceae, Myxophyceae, Diatomiceae and Euglenophyceae and a compound PQ for the bay computed using the formula:

Compound quotient (Nyaggard, 1949)

$$= \frac{\text{Myxophyceae + Chlorophyceae + Diatomiceae + Euglenophyceae}}{\text{Desmidaceae}}$$

The phytoplankton Quotients were employed in the classification of the lake (as Table 3):

Table 3: Classification of lakes based on phytoplankton Quotients

Phytoplankton Quotients(PQ)	Oligotrophic lakes	Eutrophic Lakes
Myxophycean/cyanophycean quotient	0.0-0.4	0.8-3.0
Chlorophycean quotient	0.0-0.7	0.7-3.5
Diatom quotient	0.0	0.2-3.0
Euglenoid quotient	0.0-0.2	>0.2
Compound quotient	0.0-1.0	2.0-8.7

3.4.2. Statistical analysis

Analysis of variance (ANOVA) and Schaeffé post-hoc tests was used to compare the various sampling stations with respect to the different environmental criteria. Regression analysis and Pearson's correlation were used to establish the relationships between nutrient concentrations and other physico-chemical parameters and chlorophyll *a* in different stations and to determine the variations in the levels of the different nutrients during the study period.

CHAPTER FOUR

4.0. RESULTS

4.1. Physico-Chemical Parameters

The physical and chemical characteristics of Kisumu Bay for the period from April 2009 to March 2010 are shown in Tables 4 and 5 Ambient water temperatures for Kisumu Bay ranged between 26.3°C and 28.5°C, with significantly lower temperatures (ANOVA, $p<0.05$, Table 4) being experienced during the rainy season. Dissolved oxygen levels varied significantly among sampling stations (ANOVA, $p<0.05$), with the lowest (4.6 ± 0.4 mgl^{-1}l) being recorded at the inlet of River Kisat (S3) and the highest (8.0 ± 0.2 mgl^{-1}l) at the offshore Maboko station (S5). The concentrations of dissolved and suspended solids in the water also varied among sampling stations.

The highest levels of TDS (746.4 ± 48.1 mg^{l-1}) was recorded at the mouth of River Kisian, while the lowest (292.2 ± 26.9 mgl$^{-1/}$) was recorded at the Auji drainage/River Nyamasaria outlet or inflow discharge. Similarly, the highest (1597.7 ± 57.9 mgl^{-1}) and lowest (621.7 ± 7.4 mgl^{-1}) levels of TSS were recorded at the inlets of rivers Kisat and Auji, respectively. An average pH of 7.7 ± 0.1 was recorded for the bay during this period. Kisumu Bay waters recorded low conductivity levels (Av. 178.7 ± 12.1 µScm^{-1}) and even lower Secchi depth measurements (< 0.3 m) during the same period. There were turbidity variations among sampling stations (Table 3) and between the rainy and dry seasons (Table 5), with the highest (358.2 ± 7.2 NTU) and the lowest (197.4 ± 17.3 NTU) levels being recorded at the Railways pier (S4) and the Yatch club (S5) inlet stations, respectively. Significant spatial variations (ANOVA, $p<0.05$) in the levels of total phosphorus (TP) and total nitrogen (TN) were also observed within Kisumu Bay, with

River. Kisat and River Kisian recording higher levels of both nutrients compared to the other stations. The relative quantities of the two nutrients and the TN/TP ratio in the bay, however, remained constant throughout the year. The levels of silica in the bay also varied with location and season.

Spatial and seasonal variations in the levels of chlorophyll *a* were also observed in the bay. While the highest concentrations of chlorophyll *a* ($32.6 \pm 5.7\ \mu gl^{-1}$) were measured at the mouth River or discharge Kisat inlet, the offshore Maboko station recorded significantly lower mean chlorophyll *a* levels ($18.4 \pm 1.1 \mu gl^{-1}$, Table 6) during the wet season. Regression analysis of data from this study revealed a significant negative relationship between chlorophyll *a* levels in the water and the total suspended solids, water turbidity, total nitrogen and total phosphorus levels in the water ($p < 0.01$, Fig. 2). Secchi transparency measurements were also significantly negatively related to the chlorophyll *a* levels. However, a significant positive relationship was found between the TSS and chlorophyll *a* levels in the water. From these regression analyses it was evident that TN ($r^2 = 0.8888$, $p < 0.01$) and Turbidity ($r^2 = 0.8451$, $p < 0.01$) were the best indicators of the trophic state of Kisumu bay. Other good indicators included TP ($r^2 = 0.8309$) and Secchi depth ($r^2 = 0.733$).

Table 4: Mean (± S.E.) values for physico-chemical parameters and chlorophyll *a* for Kisumu Bay from April2009 – March 2010. (Significant spatial differences ($p < 0.05$) are depicted by different superscripts).

Parameter	**Kisian**	**Maboko**	**Kisat**	**Railways pier**	**Yatch Club**
Temperature (° C)	28.5 ± 0.4^b	26.3 ± 0.5^a	28.5 ± 0.5^b	27.5 ± 0.4^b	27.0 ± 0.4^b
Conductivity (μScm^{-1})	184.3 ± 2.4	165.4 ± 4.5	195.2 ± 2.6	184.6 ± 2.8	163.8 ± 8.1
Secchi depth (m)	0.2 ± 0.01	0.3 ± 0.03	0.1 ± 0.01	0.2 ± 0.01	0.2 ± 0.01
DO (mgl^{-1})	5.6 ± 0.4^b	8.0 ± 0.2^c	4.6 ± 0.4^a	5.6 ± 0.4^b	5.7 ± 0.3^b
Ph	7.8 ± 0.1	7.87 ± 0.08	7.9 ± 0.07	7.5 ± 0.08	7.7 ± 0.06
TDS (mgl^{-1})	746.4 ± 48.1^c	392.2 ± 36.5^b	687.1 ± 38.6^c	620.2 ± 14.6^c	292.2 ± 26.9^a
TSS (mgl^{-1})	1597.7 ± 57.9^c	795.0 ± 26.8a	1147.3 ± 28.8^b	1171.7 ± 16.3^b	621.7 ± 7.4^a
Turbidity (NTU)	296.7 ± 13.3^b	243.5 ± 10.6^b	261.6 ± 11.5^b	358.2 ± 7.2^c	197.4 ± 17.3^a
Chlorophyll *a* (mgl^{-1})	30.5 ± 3.5^b	13.2 ± 1.9^a	32.6 ± 5.7^b	30.3 ± 3.3^b	31.9 ± 3^b

Table 5: Mean (± S.E.) values for nutrients concentrations for Kisumu Bay from, April 2009 – March 2010. (Significant spatial differences ($p < 0.05$) are depicted by different superscripts).

Parameter	R. Kisian	Maboko	R. Kisat	Railways pier	Yatch Club
NO_3 (µgl^{-1})	40.6 ± 2,8^a	42.1 ± 3^a	46.3 ± 3.3^b	42.0 ± 2^a	46.3 ± 2.9^b
NO_2 (µgl^{-1})	20.9 ± 2.1^a	28.6 ± 2.6^b	25.3 ± 2.9^b	21.3 ± 1.6^a	21.5 ± 1.76^a
NH_4 (µgl^{-1})	91.4 ± 5.8^a	104.6 ± 8.7^b	136.1 ± 8^c	111.3 ± 31^b	117.6 ± 12.1^b
TN (µgl^{-1})	1572.1 ± 2.2^b	1483.2 ± 15^a	1527.8 ± 12.2^b	1480.3 ± 19.9^a	1466.8 ± 2.4^a
SRP (µgl^{-1})	141.9 ± 10.3	139.3 ± 6.9	138.1 ± 12.7	141.2 ± 9.1	132.9 ± 8.13
TP (µgl^{-1})	307.6 ± 4.6^b	280.6 ± 4.3^a	315.2 ± 3.7^b	276.1 ± 2.3^a	256.7 ± 3.7^a
SiO_2mg^{-1}	12.2 ± 1.7^a	25.0 ± 1.3^b	28.4 ± 2.5^b	26 ± 2.5^b	23.7 ± 1.9^b
TN:TP ratio	5.1 ± 0.07	5.3 ± 0.11	4.8 ± 0.06	5.4 ± 0.04	5.7 ± 0.07

Table 6: Seasonal variations in physico-chemical parameters and nutrient concentrations in KisumuBay during the 2009 – 2010 period. Significant seasonal differences ($p < 0.05$) are depicted by different superscripts.

PARAMETER	DRY SEASON	RAINY SEASON
Temperature ^{0}C	28.1 ± 0.2^b	26.7 ± 0.1^a
Conductivity (μScm^{-1})	165.0 ± 3.6	166.7 ± 3.7
D.O.(mg/l^{-1})	5.9 ± 0.2	6.3 ± 0.2
Secchi depth(m)	0.22 ± 0.01	0.22 ± 0.01
TDS(mgl^{-1})	287.7 ± 2.0	286.99 ± 2.0
TSS(mgl^{-1})	1427.2 ± 5.0	1327.0 ± 4.0
Turbidity (NTU)	227.4 ± 8.8^a	268.6 ± 8.9^b
pH	7.7 ± 0.1	7.8 ± 0.0
Chlorophyll *a(ugl^{-1})*	28.8 ± 2.4^b	18.4 ± 1.1^a
SiO$_{2(}$mgl$^{-1)}$	23.9 ± 1.3^a	28.1 ± 1.2^b
SRP$_($mgl$^{-1)}$	140.2 ± 4.8	139.4 ± 5.8
NH$_{4(}$mgl$^{-1)}$	107.6 ± 5.4	109.7 ± 6.3
N0$_{3(}$mgl$^{-1)}$	41.7 ± 1.6	44.5 ± 1.6
N0$_{2(}$mgl$^{-1)}$	20.8 ± 0.9^a	25.5 ± 1.5^b
TN$_($mgl$^{-1)}$	1501.2 ± 8	1518.5 ± 7.0
TP$_($mgl$^{-1)}$	280.8 ± 4.1	289.6 ± 3.8
TN:TP	5.4 ± 0.1	5.3 ± 0.1

NB: Significant seasonal differences ($p<0.05$) are depicted by different superscripts. The dry season was an average of 5months: long dry (December, January and February) and Short dry (June and July) while the rainy/wet season was an average of seven months: long rains (March, April, and May) and short rains (August, September, October and November)

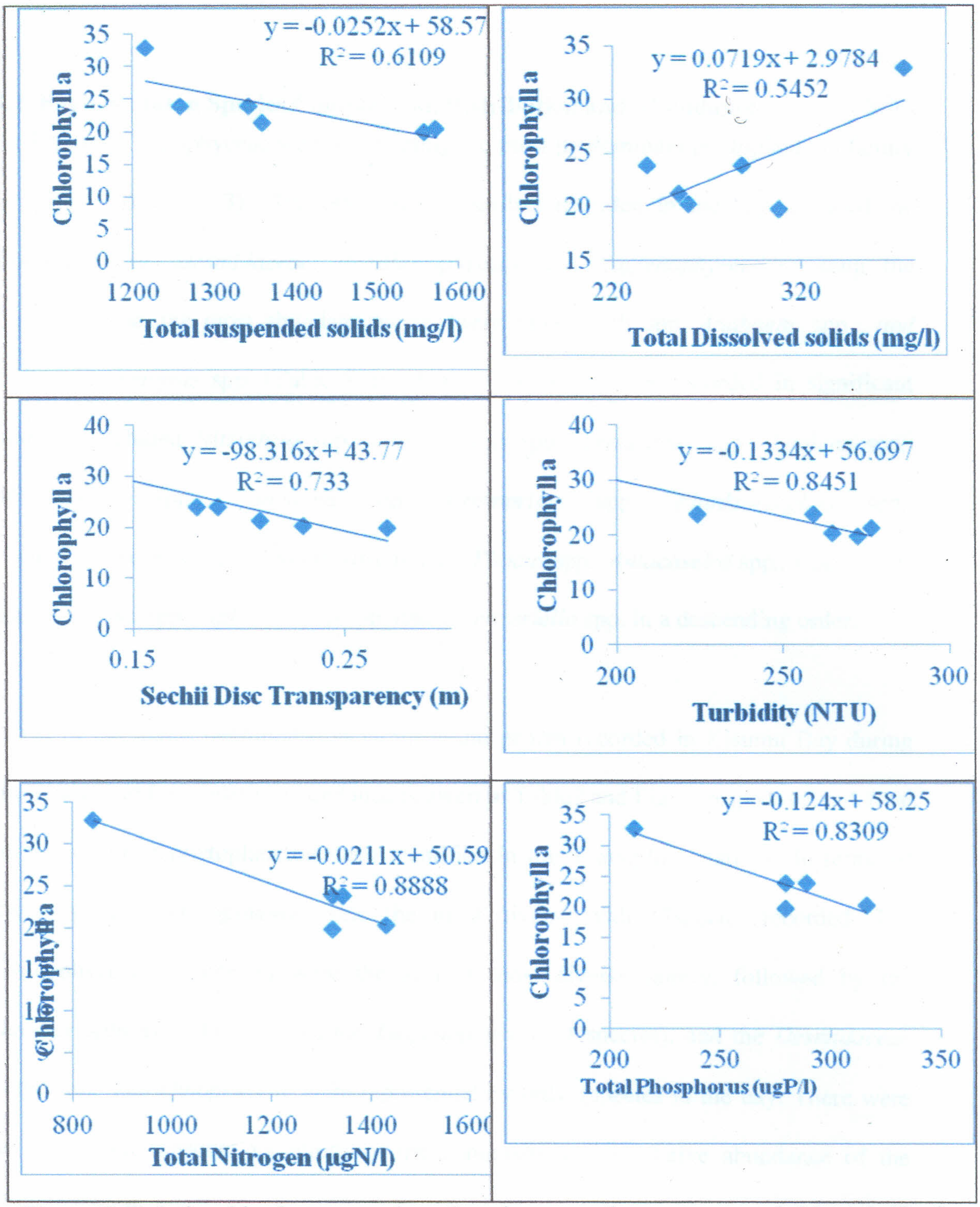

Figure 2: Relationships between selected environmental parameters and chlorophyll *a* in Kisumu Bay.

4.2. Phytoplankton Species Composition, Distribution and Abundance.

At 57% the Cyanophyceae were persistently the most predominant phytoplankton family in Kisumu Bay(Fig. 3),. The other major families recorded in the bay included the *Chlorophyceae*, *Desmidaceae*, *Bacillariophyceae* and *Euglenophyceae*. Among the *Cyanophyceae*, the most abundant species were *Microcystis* spp, *Anabaena* spp , *and Cylindrospermopsis* spp. (Table 7 and Plate 6). Other species recorded in significant numbers included *Nitzschzia* spp., *Chroococcus* spp., *Tetraedron* spp., *Euglena* spp., *Microcycstis* spp., *Anabaena* spp., *Cosmarium* spp., *Planktolyngbya* spp., *Cylindrosprmopsis* spp., *Stephanodiscus* spp., *Phacus* spp., *Aulacoseira* spp., *Coelastrum* spp., *Navicula* spp., *Aphanocapsa* spp. *and Kirchneriella* spp. in a descending order.

A list of the major phytoplankton families and genera recorded in Kisumu Bay during this study, and their relative abundance is given in Table7 and Fig. 3, respectively. A total of 50 genera of phytoplankton were identified in the 5 sampling stations. In terms of diversity, the *Chlorophyceae* were the most diverse with 17species recorded. The Cyanophyceae (13species) were the second most diverse family, followed by the *Bacillariophyceae* (11 species), the *Euglenophyceae* (4 species), and the *Desmidaceae* (4species). The *Dinophyceae* were represented by only 1species in the bay. There were no significant seasonal variations in the composition and relative abundance of the phytoplankton

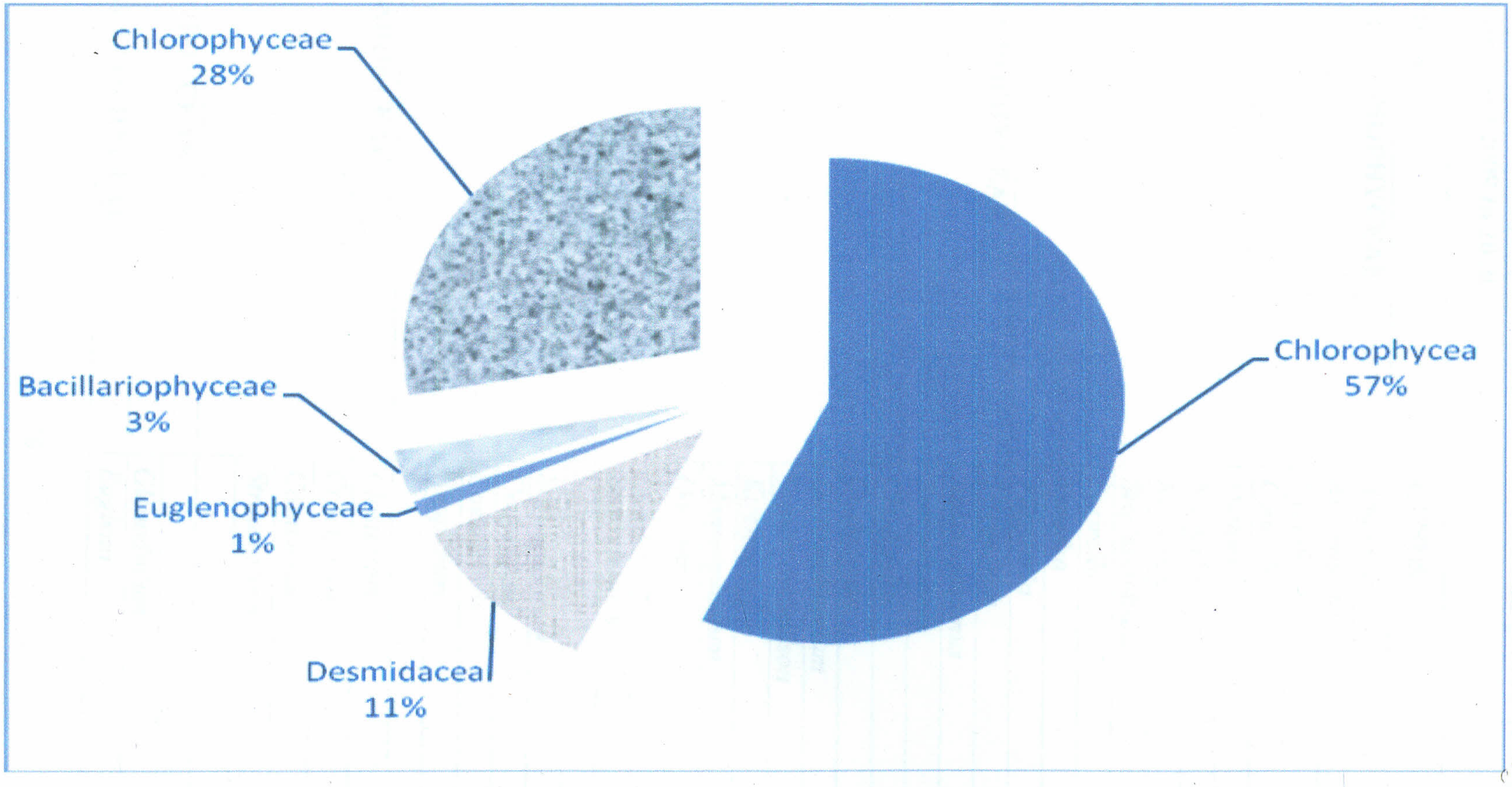

Figure 3: The composition and relative abundance of the major phytoplankton families found in Kisumu Bay from April 2009 to March 2010.

Table 7: **List of the major phytoplankton families and genera recorded in Kisumu Bay from April 2009 to 2010.**

FAMILY	**GENUS**
BACILLARIOPHYCEAE	*Amphora*
	Aulacoseira
	Cyclotella
	Cymbella
	Diatoma
	Navicula
	Nitzschzia
	Stephanodiscus
	Surirella
	Synedra
	Flagilaria
CHLOROPHYCEAE	*Tetraedron*
	Ankistrodesmus
	Botryococcus
	Chodatella
	Coelastrum
	Dictyosphaerium
	Gonatodesmidson
	Kirchneriella
	Monoraphidium
	Oocystis
	Pediastrum
	Scenedesmus
	Schroederia
	Schroederiella
	Coelastrum
	Coenocystis
	Rhapidium
DESMIDACEAE	*Closterium*
	Crucigenia
	Cosmarium
	Straurastrum
DINOPHYCEAE	
	Glenodinium
EUGLENOPHYCEAE	*Euglena*

FAMILY	GENUS
	Phacus
	Strombomonas
	Trachelomonas
CYANOPHYCEAE	*Coelomoron*
	Anabaena
	Aphanocapsa
	Chroococcus
	Cylindrospermopsis
	Microcycstis
	Planktolyngbya
	Pseudonabaena
	Romeria
	Anabaenopsis
	Merismopedia
	Aphanothece

4.3. Trophic state indices and Phytoplankton Quotients

4.3.1 Trophic State Indices

The Trophic State Indices for Kisumu Bay are given in Table 6. While there were no spatial differences in the TSI values for TP and TN, the TSIs for chlorophyll *a* differed markedly between stations, with the highest TSI (51.8 ± 0.4) being recorded at the Kisat station while the lowest TSI (37.2 ± 0.3) was recorded at the offshore Maboko station. The combined TSI for the bay was estimated to be 145.263 ± 4.1, a value that was much higher than the universally acceptable values for quality waters (< 70),(Carlson,1977;Carlson and Simpson,1996). Secchi transparency for the bay was quite low (0.21 ± 0.02). Phosphorus levels (285.22 ±8.9) were quite high. The values revealed a hyperetrophied system. However, chlorophyll *a* levels were in a range (28.19±3.0) showing eutrophic system.

Table 8: Estimates of the Trophic State Indices for Kisumu Bay for the period April 2009 –March, 2010. Stations marked with different superscripts were significantly different ($p < 0.05$) for the respective indices.

Station	**Kisat**	**Kisian**	**Maboko**	**Railway Pier**	**Yatch club**
TSI (Chloro a)	$51.8+.3^{c}$	$42.0+.5^{ab}$	$37.2 + .3^{a}$	$43.5 +.4^{b}$	$45.1+.4^{bc}$
TSI (TP)	180.3 ± 9.0	185.7 ± 5.6	195.5 ±7.1	189.6 ± 3.6	187.2 ± 4.4^{A}
TSI (TN)	180.3 ± 9.9	185.9 ± 5.6	195.5 ±7.1	189.6 ± 3.6	187.2 ± 4.4
TSI$_2$ (TP)	272.3 ± 3.2	270.3 ± 9.1	270.6 ± 3.6	265.4 ± 4.9	266.5 ± 5.2
TSI$_2$ (TN)	216.2 ± 4.0	206. 6± 6.3	210.9 ± 4.3	216.0 ± 6.6	208.0 ± 5.0
TSI AVER	**139.3 ± 5.4**	**144.3 ± 13.8**	**132.6 ± 17.8**	**143.5 ± 12.9**	**150.0 ± 13.8**

4.3.2. Phytoplankton Quotients

The phytoplankton quotients for Kisumu Bay are given in Table 9. The phytoplankton quotients varied significantly with location and season. The highest PQ (6.4 ± 1.6) was recorded at the mouth of R. Nyamasaria, whereas the lowest PQ recorded (2.3 ± 1.5) was at the mouth of R. Kisat. The compound PQ for the bay was estimated to be 4.09.

Table 9: Estimates of the phytoplankton quotients for the different sampling stations and the compound quotient for Kisumu Bay for the period April 2009 March,- 2010. Stations marked with different superscripts were significantly different ($p < 0.05$) for the respective quotients.

Station	Kisat	Kisian	Maboko	Railway Pier	Yatch Club	Average
Bacillar Q	2.2 ± 0.5^{a}	2.2 ± 1.1^{a}	0.7 ± 0.3^{b}	2.2 ± 1.0^{a}	2.5 ± 1.3^{a}	**2.0 ± 0.3**
Chloro Q	3.1 ± 1.0^{b}	1.4 ± 0.5^{a}	2.0 ± 1.5^{ab}	1.5 ± 0.8^{a}	0.7 ± 0.3^{c}	**2.1 ± 0.5**
Eugl Q	2.4 ± 0.9^{c}	0.2 ± 0.1^{a}	0.2 ± 0.4^{a}	1.1 ± 0.5^{b}	1.9 ± 0.9^{c}	**1.1 ± 0.4**
Myxo Q	0.3 ± 0.2^{a}	2.7 ± 1.7^{c}	3.3 ± 1.3	4.6 ± 1.8^{C}	1.7 ± 0.7^{b}	**2.9 ± 0.7**
CQ	2.3 ± 1.5^{a}	2.9 ± 1.3^{a}	2.7 ± 1.6^{a}	4.9 ± 1.9^{b}	6.4 ± 1.6^{c}	**4.1 ± 0.7**

CHAPTER FIVE

5.0. DISCUSSION AND CONCLUSIONS

5.1. Discussion

Kisumu Bay is impacted by pollution from anthropogenic activities around Nyanza Gulf and from industrial and municipal discharges from Kisumu City, that has resulted in significant changes in the level of eutrophication and the general ecology of the bay, changes that need to be monitored constantly for the effective environmental management of the gulf. This study aimed at determining the level of eutrophication of Kisumu Bay by estimating the Trophic State Indices and Phytoplankton Quotients that are key indicators of eutrophication and using them, in conjunction with other water quality parameters, to determine the level of eutrophication of the Bay. Water quality measurements were conducted from April 2009 to March, 2010, and the results used to make key deductions that are presented here.

5.1. 1. Physico-chemical Parameters

Results from this study showed that ambient water temperatures for Kisumu Bay ranged between 26.3°C and 28.5°C; with significantly lower temperatures being experienced during the rainy season. The results also indicated that dissolved oxygen levels in the bay varied significantly among sampling stations, but were within the internationally acceptable levels in the range of 8-15 mgl^{-1},probably due to seif purification (WHO, 2009, APHA, 1995; USEPA, 2002; OECD, 1982) (Table 7). The temperature measurements recorded in Kisumu bay reflected the general diurnal temperatures reported for Lake. Victoria waters (LVEMP, 2000), while the low DO levels at the Kisat

Station(4.6±0.4), which coincided with the high levels of TSS(1147±28.8 mgl^{-1}) that were recorded at this station, reflected the effect of point discharges from the river, consistent with the often-reported inverse correlation between DO and TSS levels (USEPA, 2000; Gichuki *et al*, 2006) that is usually associated with high nutrient inputs. Even though DO levels as low as 1 mgl^{-1} have been recorded in the wider Lake. Victoria waters (Verschuren *et al.*, 2002; Odada *et al.*, 2004), the levels reported here indicate that the bay has enough dissolved oxygen for sustaining a healthy ecological diversity.The low levels are attributed sedimentation,nutrient input and suffocation of the system due to algal bloom The highest levels of TDS (746.4 ± 48.1 mgl^{-1}) were recorded at the mouth of R. Kisian, a river that is surrounded by a rocky, continuously weathering catchment that contributes to the relatively high suspended solids load into the bay, while the lowest (292.2 ± 26.9 mgl^{-1}) was recorded at the Auji drainage/R. Nyamasaria inlet that maenders into the Bay allowing for the sedimentation of solids before reaching the mouth of the inlet. The Secchi depth measurements (< 0.3 m) recorded during this study were even lower than those reported by Lehman and Brandstrator (1994) and Sitoki *et al.* (2010), indicating a state of continual degradation of the Bay,mainly due to increased material,phytoplankton production etc.. The Kisumu bay waters, however, recorded low conductivity levels (Av. 178.7 μScm^{-1}) similar to that reported by Sitoki *et al.* (2010). The low conductivity levels were probably expected considering the low TDS levels recorded in the bay during this study. High turbidity levels (> 197 NTU) were also recorded in the bay indicating that the bay's watersmay need refrasing.. The variability of the environmental parameters among sampling stations indicate that there are significant environmental impacts exerted on the quality of the bay's waters by the inflows from the riparian areas around Kisumu Bay, and that seasonality has a significant influence on these impacts.

5.1.2. Nutrients levels and the trophic state of Kisumu Bay

Significant spatial variations (ANOVA, $p<0.05$) in the levels of total phosphorus (TP) and total nitrogen (TN) were also observed within Kisumu Bay, with River. Kisat and River. Kisian recording higher levels of both nutrients compared to the other stations. The relative quantities of the two nutrients and the TN/TP ratio in the Bay, however, remained constant throughout the year. The levels of silica in the bay also varied with location and season.

Spatial and seasonal variations in the levels of chlorophyll *a* were also observed in the Bay. While the highest concentrations of chlorophyll *a* (32.6 ± 5.7 $\mu g l^{-1}$) were measured at the River Kisat inlet, the offshore Maboko station recorded significantly lower mean chlorophyll *a* levels (18.4 ± 1.1 $\mu g l^{-1}$, Table 6) during the wet season. Regression analysis of data from this study revealed a significant negative relationship between chlorophyll *a* levels in the water and the total suspended solids, water turbidity, total nitrogen and total phosphorus levels in the water ($p < 0.01$, Fig. 2). Secchi transparency measurements were also significantly negatively related to the chlorophyll *a* levels. However, a significant positive relationship was found between the TSS and chlorophyll *a* levels in the water. From these regression analyses it was evident that TN ($r^2 = 0.8888$, $p < 0.01$) and

Turbidity ($r^2 = 0.8451$, $p < 0.01$) were the best indicators of the trophic state of Kisumu bay. Other good indicators included TP ($r^2 = 0.8309$) and Secchi depth ($r^2 = 0.733$).

Significant differences (ANOVA, $p < 0.05$) associated with discharges from Kisumu town and seasonal nutrient runoffs from storm water were also observed in the spatial and temporal distribution of phosphorous, ammonia, nitrates, nitrites and silicates within the bay. Significantly higher (ANOVA, $p<0.05$) chlorophyll *a* concentrations were recorded during the dry season compared to the rainy season, probably as a result of higher turbidity during the rainy season, which reduces light penetration into the water, and thereby reducing the rates of phytoplankton production.

The high nutrient levels experienced in the Bay were independent of the time and location. This could be associated with depth (shallow <5m deep) and experiences high evaporation rates, therefore, complete mixing occurs resulting to a homogeneous state in nutrients. The high values experienced reflect high nutrient input and cultural eutrophication in the Bay. This is presumably because of the locality of the bay in the town centre and the impact of Kisat known for the municipal and sewage effluents (Gichuki, 2000) and the several rivers flowing through the rich agricultural catchment area for example Kisian river (Gichuki, 1995; Hecky, 1993; Mugidde, 1993; Lungaiya *et al.*, 2000).

The elevated TP (332± 35.3 $\mu g\ Pl^{-1}$) and SRP (174± 36 $\mu g\ Pl^{-1}$ values were pronounced at Kisat and Kisian which are influenced by sewage effluents and municipal effluents and agrochemicals respectively. The high levels of TP inputs in Yatch are associated with storm water, runoffs. However, the relatively low values are presumably attributed to self purification by the macrophytes. Kisumu Bay located, like most urban watersheds, produces significant secondary phosphorus loads from diverse range of sources including municipal wastewater discharges, failing septic systems and sewage overflows (Schueler and Simpson, 2001). This addresses point and nonpoint sources of pollution from catchment area (Carlson and Simpson, 1996) The observed TP results were much higher (> 100 μg P/l) than the previously reported works which were observed to be indicative of eutrophic state in fresh waters (Wetzel and Likens, 2000). SRP values are in line with the works of Peterka and Kent, (1976) on African lakes, 2000 μg P/l to <3 μg P/l. The high phosphorus loads result to a domain shift in aquatic vegetation promoting establishment of turbid waters, phytoplankton dominated, ecological state (Scheffer *et al.*, 1997) and change in the structure of aquatic biota.

TN concentrations observed were quite high and this state is attributed to nutrient loadings manure, fertilizers present in storm water run offs, sewage and municipal effluents. The high values notable in the rainy season were due to storm water runoffs. The high levels were independent of the seasonality due to dominance of cyanophyceae which was reported to be nitrogen fixing. However, different forms of nitrogen, NH^4-N (119.8±13.1 μg N/l); NO^3-N (53.21±5.6 μg N/l) and NO^2-N (31.32±3.7 μg N/l were relatively due to nitrification and denitrification processes.

TN:TP ratios ranged between 5.72±0.07 (Yatch) to 4.85±0.06 (Kisat) in Kisumu Bay displaying very low values(<7:1) compared to the Redfield ratio (1:16),typical of eutrophied waters. The results revealed high phosphorus loading, and nitrogen limitation favouring the proliferation of the cyanophyte (Cyanobacteria) which currently dominates. Nitrogen limitation could probably be due to the nitrification and denitrification processes confirmed by the high biovolumes and dominance of the cyanophyceae. Cyanophyceae posses a threat to aquatic life particularly, the blue- *Anabaena and Planktothrix* green algae may produce algal toxins both neurotoxins such as anatoxin and hepatotoxins (from microcystis and other taxa), (Gichuki *et al*, 2006; Kilham, 1990;Kilham and Kilham,1990; Hecky, 1993). Besides, the high levels in phosphorus are presumably sedimentary cycle hence not easily lost.

Silica, SiO_2 levels displayed were quite low, probably associated with the low proliferation of the bacillariophyceae in the bay. SiO_2 shows a positive correlation with nitrates (r=0.61503) at $p<0.05$. Chlorophyll *a* concentration in Kisumu Bay varied ranged between 13.2 µg/l (Maboko) and -32.6 µg/l (Kisat) which was a notable increase from 11.9 µg/l (2000-2001) to 15.3 µg/l in (2005-2008) to 28.19±3.5 µg/l in (May, 2009-April, 2010) as recorded in Nyanza Gulf, Sitoki *et al*., 2010). According to an average concentration of 28.190 ± 3.5, the bay belongs to eutrophic scale as per the trophic scale (Carlson and Simpson, 1996; Carlson, 1977). Mugidde (1993), Hecky (1993), Tallying, (1966) argued that the elevated values in chlorophyll a were higher photosynthesis activity which could be attributed to cultural Eutrophication in the watershed. Seasonality in chlorophyll a was distinct; with high values experienced during the dry season rather than the rainy season .chlorophyll a, therefore is inhibited by turbidity.

5.1.3. Phytoplankton

Species composition is in line with the works of Muggide, (1993) and Lung'aiya, (2000). This research confirms the increasing level of Myxophyceae/Cyanophyceae family and decreasing levels of Chlorophyceae in Nyanza gulf. The low levels in green algae are attributed to decreasing levels in silica and high turbidity within the bay, a fact supported by Lung'aiya *et al*., (2000). High temperature and turbidity inhibits the growth of the green algae and contrary, favours the growth of Myxophyceae/Cyanophyceae.

Cyanophyceae (blue-green algae) dominance was attributed to increased nutrient loading in the catchment, resultant to land degradation hence eutrophication This research associates the blue-green algae to algal bloom which negatively impacts on the affect water and the change in the phytoplankton community structure (Krienitz *et al*., 2002; Lung'aiya *et al*., 2000; Hecky, 1993; Bootsman and Hecky, 1993; Hecky, 1993; Muggidde, 1990; Ochumba, 1990)

Cyanophyceae family was the highest independent of the time and space, >50 biovolume /litre (57%) Kisat presumably having the most (>70 biovolume/l) followed by Kisian. This was attributed to high phosphorus loading resulting from sewage and municipal effluents from the river(Kisat) and; agrochemicals and fertilizers from Kisian river ,hence the pollution tolerant species. Bacillariophyceae biomass, revealed minimal values (< 15 biovolume/l), due to intolerance to pollution. The phytoplankton structure observed in the bay could be associated with the shallowness of the bay coupled with the wind action; kinetic energy and surface forcing which causes re suspension and transport of sediments whose source could be point and nonpoint sources, hence creates a vertically homogeneous condition in the bay. The highest nutrient loads into the bay should have supported the growth of highly diversified and abundant algal population. This is not the case; the algal bloom is entirely of cyanophyceae family which is tolerant to pollution, high silt content in the bay limiting light penetration, consistent with low values of Secchi transparency and also algal bloom.

5.1.4. Phytoplankton Quotients (P.Q.) and Trophic State Indices (TSI)

The sampling stations in Kisumu Bay were observed to have a compound quotient in the range: 2.268±1.5 (Kisat)-6.424±1.6 (Yatch). The values range was within Nyaggard, (1949) (2-8.7) classification of a typical eutrophic class. A eutrophic lake has P.Q. [Chlorophycea *Q* (0.7-3.5) Myxophycea Q; (0.8-3.0) Bacillariophyceae Q (0.2-3); Compound quotients (2-8.7)]. Kisumu bay had values much higher than the stipulated eutrophic class. This could have implied that the bay was in worse state than what was previously documented (Gichuki, 2000; Gichuki *et al*., 2006). Therefore, research asserts that the bay was hypereutrophied. The P.Q. result, therefore, gave the bay a hypereutrophic class; a state that confirms that the lake is dying. Indeed, eutrophication is serious in Nyanza Gulf particularly Kisumu Bay, caused by nutrient loading-phosphorus. Besides, being associated with proliferation of water hyacinth and hippo grass, it triggers cyanobacterial blooms; some are toxic.

TSI values were used to define the trophic state of a water body. The TSI values within the bay were much higher than the expected values (70-100+) which categorizes the bay as hypereutrophic trophic class (OECD, 1982; Carlson and Simpson 1996; Carlson, 1977). The Secchi depth, SD (0.5-<0.25); Phosphorus, P (96-384+) and TSI (70-100+)

are typical of a hypereutrophic class, Kisumu Bay was observed to have SD, P and TSI values within the stipulated range, hence asserts that the bay is hypereutrophied. However, the chlorophyll *a* values were in the range of 13.207±1.9 and 32.611±5.7µg/l, values lying in the stipulated range of eutrophied waters (7.3-56µg/l).

5.2. CONCLUSIONS

P.Q. and TSI values of Kisumu Bay are a signal to what could be happening to the larger lake. The results are: 2.0-8.7 and 70-100+ respectively, indicative of the hypereutrophied state, hence the decline in the water quality with far reaching consequences on the ecology and the livelihood of the resource.

The shift in the trophic state (hypereutrophic) is as a result of nutrient loading (phosphorus and Nitrogen) which is associated with anthropogenic activities in the watershed.

Eutrophication results to ecological changes revealed in the shifting phytoplankton composition, distribution and structure, hence the algal bloom.

Spatial-temporal trends in water quality and phytoplankton distribution asserts that the lake is a dynamic ecosystem; and is environment-dependent.

5.3. RECOMMENDATIONS

Law enforcement on the discharge of effluents into the lake, hence the lake isn't a dumping site for treated and untreated sewage.

Farming activities should be discouraged on the lake shore and a minimum distance to the lake set beyond which no farming.

Proper farming technique should be practiced to prevent soil erosion.

Create awareness on significance of environmental management and conservation.

Education on the sustainable and environmentally friendly agriculture.

Monitoring of the lake water quality and catchment area should be carried out to tract environmental changes facing the lake.

Rehabilitate and maintain waste treatment facilities in all municipalities and industries in the region so as to reduce pollution and eutrophication in the lake. Industries should endeavour to initiate cleaner production technologies as a way of safeguarding and protecting the environment.

REFERENCES

APHA (1995). *Standard methods for analyses of water and wastewater*. Port City Press, Baitimore, MD.

Bootsma, H. A.and Hecky, R. E. (1993). Conservation of African Great Lakes: '*A limnological perspective*'. Conservation Biology, 7(3):644-656.

Carlson, R. E. (1977). A trophic state index for lakes. Limnology and Oceanography. 22:2, 361-369.

Carlson, R. E. and Simpson, J. (1996). A coordinator's Guide to volunteer Lake Monitoring methods. North American Lake Management society,pp 96.

Cocquyt, C. and Vyverman W. (1994). Composition and diversity of the algal flora in the East African Great Lakes: a comparative survey of Lakes Tanganyika, Malawi (Nyasa) and Victoria. *Archiv für Hydrobiologie, Ergebnisse der Limnologie* **44**: 161-172.

Cocquyt, C., Vyverman, W. and Compere , P. (1993).A check List of the algal Flora of East African Great Lakes(Malawi, Tanganyika, and Victoria).National Botanic Garden of Belgium,Meise.

Colt, J. (1984). Computation of dissolved gas concentrations in water as functions of temperature and salinity and pressure. American Fisheries Society Spec. Pub. 14, Bethesda, MD. pp.81.

Downing, J.A., Watson, S.B., and McCauley, E. (2001). Predicting cyanobacteria dominance in lakes. Canadian Journal of Fisheries and Aquatic Sciences 58: 1905- 1908

Duce, R. A. (1986). *The impact of atmospheric nitrogen, phosphorus,and iron species on marine biological productivity* 497-529. In P. Buat-MCnard [ed.] The role of air-sea exchange in geochemical cycling. Reidel.

Ellis, K. V. (1989). *Surface water pollution and its control.* Macmillan puplic.U.K.,pp. 172-174, 177-181.

Environmental Protection Agency (EPA) (2007). *Combined Sewer Overflows* 2007. Available at: http://cfpub.epa.gov/npdes/home.cfm?program_id=5.

EPA (2009) Edition of the Drinking Water Standards and Health Advisories.EPA 822-R-09-11.Office of Water U.S. Environmental Protection Agencies Washington, D.C.

Gichuki, J. (2000). The chemical environment of Lake Victoria (Kenya) with special reference to nutrient dynamics. In: L. Victoria Fisheries Org. 2005, proceeding of L.V. 2000, a New Beginning Conference 15 – 19 May 2000, Jinja, Uganda.

Gichuki, J., Mugidde, R., Lung'aiya, H. B. O., Muli, J. R., Osumo, W., Kulekana, Y., Kishe, M., Katunzi, E. F. B., Mwamburi, J., and Werimo, K. (2006). Diversity of Aquatic Ecosystems. In aquatic Biodiversity of Lake Victoria Basin: Its conservation and sustainable use. Edited by P. Kansoma. Lake Victoria management Project. Pp. 9-30. Book Chapter (in Press).

Gikuma-Njuru, P. and Hecky, and R. E. (2005). Nutrient concentrations in Nyanza Gulf, Lake Victoria,Kenya:light limits algal demand abundance.*Hydrobiologia*.534:131-140.

Hecky, R. E. (1993). The eutrophication of L. Victoria. Proc. Int. Ass. Teory. *Appl. Limnol*, **25:** 39 – 48.

Hecky, R. E., and Bugenyi, F. W. B. (1992). Hydrology and chemistry of the great lakes and water qualityissues:problems and solutions.*mitteilungen der international Vereinigung fur Theoretische Angewandte Limnologie,2:,45-54.*

Hecky, R. E., Bootsma, H. A., Mugidde, R. and Bugenyi, F. W. B. (1996). Phosphorus pumps, nitrogen sinks and silicon drains: Plumbing nutrients in the African Great Lakes. In: Johnson, T. C. and E. Odada (Eds) The limnology, Climatology and pale climatology of the East African Great Lakes. Gordon and Breach. Toronto. Pp. 205-224.

Hillebrand, H., and Sommer, U.(1999). The nutrient stoichiometry of benthic microalgal growth: Redfield proportions are optimal. Limnol. Oceanogr. 44: 440-446.

Huber-Pestalozzi, G. (1938). Allgemeiner Tei.Blaualgen.Bacterien.Pilze.Das Phytoplankton des suss-swassers, 1.Teil (ed.G.Huber-Pestallozi),pp.1-6+1-342.Schweizerbat'sche-Verlagsbuchhandslung,Stuttgart.

Kilham, P., and Kilham, S. S. (1990). Endless summer: internal loading processes dominate nutrient cycling in tropical lakes. *Freshu. Biol.,* **24,** 379-389.

Kilham, P. (1990). Ecology of *Melosira* species in the Great Lakes of Africa. In Tilzer,M.M. and Seruya, C.(ed) *Large lakes: ecological structure and function.* Berlin: Springer.pp.414-427

Kling, H. J., Mugidde, R. and Hecky, R. E. (2001). "Recent changes in the phytoplankton community of Lake Victoria in response to Eutrophication." *The great Lakes of the world (GLOW): Food-web, health and integrity.* The Netherlands Backhuys Publishers, pp.47-65.

Krienitz L. Ustinova I. Friedl T. Huss V. A. R. (2001). "Traditional generic concepts versus 18S rDNA phylogeny in the green algal family Selenastraceae (Chlorophyceae, Chlorophyta)." *Journal of Phycology* 37: 852-865

Krienitz, L., ***Ballot, A., Kotut, K., Wiegand, C., Pütz, S., Metcalf, J. S., Codd, G. A. and Pflugmacher, S. (2003).*** *Contribution of hot spring cyanobacteria to the mysterious deaths of Lesser Flamingos at Lake Bogoria, Kenya.* FEMS Microbiol. Ecol., 43, 141–*148.*

Lehman, J. T. (1998). Environmental Change and Response in East African Lakes. The Netherlands, Kluwer Academic Publishers, , ISBN 0-7923-5118-5. 236 pp.

Lehman, J.T. and Brandstrator, D.K. (1993). Effects of nutrients and grazing on the phytoplanktons of Lake Victoria.Verhandlunger der.Internationales Vereiniguigung fur Theoretische und.Angewandte Limnologie 25,850-855.

Lehman, J.T. and Brandstrator, D.K. (1994). Nutrient dynamics and turnover rates of phosphate and sulfate in Lake Victoria, East Africa. Limnology and oceanography 39(2), 227-233.

Lung'aiya, H. B .O., M'Harzi, A., Tackx, M., Gichuki, J. and Symeons, J. J. (2000). Phytoplankton community structure and Environment in the Kenyan waters of Lake Victoria. Freshwater Biology **43** (4): 529-543.

Lung'ayia, H., L. Sitoki, and M. Kenyanya.(2001).The nutrient enrichment of Lake Victoria, Hydrobiologica. 458:72-82.

LVEMP, (2000). Water hyacinth and other invasive weeds in Lake Victoria: A status report. Lake Victoria Environmental Management Project, Jinja, Uganda. Fisheries Resources and Research Institute.

LVEMP, (2002). Integrated water quality/limnology study of Lake Victoria. Final technical report. COWI/DHI, Denmark. Maitland, P.S.1990, Biology of freshwaters, Second edn. Blackie and Sons Limited, USA.

LVEMP, (2005). Lake Victoria Environmental Management Project Phase I, Draft, Kenya Stocktaking Report, World Bank.

Michael, J., Pelczar, J., Chan, E . C. S., and Noel, R . (1993). Microbiology; concepts and applications, MuGran-hill,inc .pp.88-810.

Mugidde , R. ,Hecky , R. E., Hendzel, L. L. and Taylor, W. D. (2003). Pelagic nitrogen fixation in Lake Victoria (East Africa).

Mugidde, R. (1993). "The increase in phytoplankton productivity and biomass in Lake Victoria (Uganda)." *International Association of Theoretical & Applied Limnology*, proceedings, **25:** 846-849.

Mugidde, R. (2001). Nutrient status and planktonic nitrogen fixation in Lake Victoria, Africa. Ph. D. Thesis, Ontario, Canada , University of Waterloo. pp 196.

Nygaard, G. (1949). Hydrobiological studies in some ponds and lakes. Part II: The quotient hypothesis and some new or little known phytoplankton organisms. Kgl. Danske. Vidensk. Selsk. Biol. Skrifter 7(1): 1-293.

Ochumba, P. B. O. (1990). "Massive Fish Kills within Nyanza Gulf of Lake Victoria, Kenya." *Hydrodrobio*, **208:**93-99.

Ochumba, P. B. O. and Kibaara, D. I. (1989). "Observations on blue-green algal blooms in the open waters of lake Victoria, Kenya." *African Journal of Ecology*.

Ochumba, P. B. O., Calamari, D. A., Akech, M. O. (1992). Conservation of the aquatic Environment "Winam Gulf area". Preliminary Hard Assesment.F.A.O., Rome.

Ochumba, P. O. (1987). Periodic massive fish kills in the Kenyan part of Lake Victoria. *Water quality Bulletin, 12,119-122.*

Odada, E., Olango, D., Kulindwa, K., Ntiba, M., Wangida, E. (2004): Mitigation of environmental problems in L. Victoria, East Africa: Causal chain and policy options analyzes. Royal Swedish Academy of Science, **33**: 13 – 17.

Odada, E.O. (2003). " Environmental Assessment of the E.A. Rift Valley lakes." *Aquat. Sc.* 65, 254 – 271.

OECD (Organization for Economic Cooperation and Development) *(***1982***).* Eutrophication of Waters. Monitoring, Assessment and Control. Final Report. OECD Cooperative Programme on Monitoring of Inland Waters (Eutrophication Control), Environment Directorate, OECD, Paris, pp. 154

.

Peterka, J. J. and Kent, J.S. (1976). Dissolved oxygen, temperature and survival of young at fish spawning sites. Environmental Protection Agency Report No. EPA-600/3-76-113, Ecological Research Series. pp. 36. (Cited In: US EPA, 1986).

Rosén G., (1981) Phytoplankton indicators and their relations to certain chemical and physical factors. Limnologica (Berlin) **13** (2), 263, **1981**.

Scheffer, M., Rinald, S., Gragnani, A., Mur, L. R., Van Nes, E.H. (1997). On the dominance of filamentous cyanobacteria in shallow turbid lakes ecology 78:272-282.

Schueler,T., and Simpson ,J.,(2001).Why urban lakes are different. Water protection Techniques 3(4):747-750.

Selma, M.S., Greenhalgh, S., (2008). Eutrophication: sources and drives of nutrient pollution. *Water Quality. Eutrophication and Hypoxia policy Note series* No.2 Washington, D.C. world resource institute.

Selman, M., Greenhalgh, S., Diaz, R. and Sugg, Z.(2008). *Eutrophication and Hypoxia in Coastal Areas: A Global Assessment of the State of Knowledge.* Water Quality: Eutrophication and Hypoxia Policy Note Series No.1. Washington, DC: World Resources Institute.

Sitoki, L., Gichuki, J., Ezekiel, C., Wanda, F., Mkumbo, C. O., Marshall, M. B. (2010). "The Environment of Lake Victoria (East Africa):Current Status and Historical Changes ."*Internat. Rev. Hydrobiol.* **95** 2010(3): 209–223.

Talling, J. F. (1966). The annual cycle of stratification and phytoplankton growth in Lake Victoria. International Revue der gesamten Hydrobiologie und Hydrographie 51(4), 545-621

Tallying, J. F. (1987). The phytoplankton of Lake Victoria (East Africa).Archiv fur Hydrobiologie,Ergebnisse der Limnologie,Beihefte,25,229-256.

Tate, E., J. Sutcliffe, D. Conway and F. Farquharson (2004). "Water balance of Lake Victoria: update to 2000 and climate change modelling to 2100." *Hydrological Sciences Journal* 49: 563–574.

U.N.(1998). World population prospects: The 1998 Revision. United Nations Secretariat, Department of Economic and Social Affairs, Population Division. New York: UN. 492 pp.

U.S. Environmental Protection Agency (EPA), (1986). Ambient water quality criteria for dissolved oxygen. Criteria and Standards Division. US Environmental Protection Agency, Washington, D.C. EPA. 440/5-86-003.

UNEP and Woods Hole Research Center (WHRC), (2007). "Reactive Nitrogen in the Environment: Too much or too little of a good thing." Paris: UNEP.

UNEP, (2006). African Environmental outlook, Earthscan Ltd, UK. United Nations Environment Program

USEPA (1992). NPDS STORM water sampling Guidance Document, EPA/833/B-92-001, Washington D.C.

USEPA, (2002). Office of water Washington D.C. 20460, EPA 821-r-02-024, 2002.

Verschuren, D., Thomas C. J., Kling, H.J., Edgington, D.N., Leavit, P.R., Brown, T.E., Michael R. T., and Hecky, R.E.(2002). "History and Timing of Human Impact of L. Victoria, E. Africa." Proc. Roy. Soc. London B, 269, 289 – 294.

Voinov, A. A. and Svirezhev, Y. M.,(1984).A minimal model of Eutrophication in freshwater ecosystems.Ecol.Modelling,23;277-292.

Volleweider, R.A. (1975). Input-output models with special reference to the phosphosrus loading concept in limnology.Scweizerische Zeitschrift fur hydroboilogie 37:53-84.

Wetzel, R. G. and Likens, G. E. (2000). Limnological analyses 3rd Edn. Springer-verlag New York, Inc. pp.73– 113.

WHO, (2009): WHO Guidelines for drinking-water quality. Policies and Procedures used in updating the WHO Guidelines for Drinking-Water quality. WHO Geneva 2009.WHO/HSE/WSH/09.05.