SEASONAL CHANGES IN PHYSICO – CHEMICAL STATUS AND ALGAL BIOMASS OF LAKE NAIVASHA, KENYA

By

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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DECLARATION BY SUPERVISORS

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

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Signature……Date……....

DEDICATION

This work is dedicated to the Almighty Lord Jesus Christ for giving me the opportunity, ability, patience and strength to undertake this study.

Also to my wife Janet, children; Gad, Ann and Olive for the encouragement, patience and understanding during the entire period of this study.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
APHA	American Public Health Association
Chl *a*	Chlorophyll *a*
DO	Dissolved oxygen
FD	Fisheries Department
GFC	Fibre glass filter paper
GoK	Government of Kenya
GPS	Global Positioning System
KMFRI	Kenya Marine & Fisheries Research Institute
KU	Kenyatta University
LNRA	Lake Naivasha Riparian Association
ml	milliliters
$NH_4 - N$	Ammonium Nitrogen
$NO_3 - N$	Nitrate Nitrogen
pH	Potenz hydrogen (Negative logarithm of H^+ in mol dm^{-3} in a solution)
$PO_4 - P$	Phosphate Phosphorous
TN	Total Nitrogen
TP	Total phosphorus
UV	Ultra Violet

ABSTRACT

Lake Naivasha located at latitude 0^0 45' S, and longitude 36^0 20' E, was designated a Ramsar site in 1995. It is an important resource to many stakeholders and has a fragile ecosystem that experiences rapid changes associated with natural and anthropogenic factors such as huge water abstraction for irrigation agriculture, fertilizer residues runoffs from the agro-based farms and sediments discharged by River Malewa among others. The purpose of the study was to evaluate the levels and seasonal changes in physico- chemical properties and algal biomass in order to provide current information on lake's water characteristics and hence propose suitable measures for sustainable management of the lake. This study was conducted in Lake Naivasha from December 2007 to April 2008, covering both dry and wet periods. Surface and bottom water samples were collected in replicates every month using Van Dorn water sampler for nitrate nitrogen (NO_3 – N), ammonium nitrogen (NH_4 – N), total nitrogen (TN), orthophosphate phosphorus (PO_4 –P), total phosphorus (TP) and chlorophyll *a* and measured using standard spectrophotometric methods. Water conductivity, pH, temperature and secchi depth were measured *in situ*. Dissolved Oxygen (DO) was measured by Winkler method. Trophic state index (TSI) was calculated using chlorophyll *a* and total phosphorus. The results show that mean ± SD NO_3 - N values for the lake were 63 ± 31 µg L^{-1}, NH_4 - N 128 ± 46 µg L^{-1}, TN 304 ± 96 µg L^{-1}, PO_4 10 ± 6 µg L^{-1} and TP 43 ± 26 µg L^{-1}. There was significant seasonal and spatial variation for these nutrients $p < 0.001$. Mean ± SD (DO) was 6.0 ± 1.3 mg L^{-1}, temperature 21.8 ± 1.0 ^oC, conductivity 259 ± 23 µs cm^{-1} and chlorophyll *a* 33 ± 13 µg L^{-1}. Gross primary production mean ± SD values ranged from 266 ± 170 mg C m^3 hr^{-1} to 473 ± 230 mg C m^3 hr^{-1}. Based on the above results it can be concluded that the lake: (a) is eutrophic with respect to total phosphorus (TP) Carlson's Trophic State Index (TSI, 59.4) and chlorophyll *a* (TSI, 64.8) with significant seasonal difference being observed. Sewage Discharge Point (Station 2) and Malewa River Mouth (Station 3) are the two point sources for these nutrients entry into the Lake (b) Has high turbidity as indicated by low Secchi depth (c) Has a high algal biomass especially at Sewage Discharge Point and Mid Lake (Station 4). This study recommends: (1) efficient water quality monitoring through coordinated research involving research institutions, universities and nongovernmental organizations (2) Naivasha Municipal council in partnership with other stakeholders managing urban development around Lake Naivasha and the catchment should develop programs for managing waste water and soil erosion.

CHAPTER 1: INTRODUCTION

1.1 Background to the Study

Many fresh water lakes in the world are experiencing changes in water quality, water budget and ecological structures associated with rapid urbanization, agricultural developments and changes in human activities in areas surrounding these water bodies, such as alteration in catchment of detritus and nutrients (Sala *et al* 2000). Changes in hydrological balance of these lakes are associated with variation in rainfall, more so in the catchment areas. This is associated with frequent water level fluctuations in many lakes of the world.

Global warming has made the situation worse, by causing further increase in the water temperatures of lakes, which have an impact on the lakes biota (Schindler *et al* 1996).

Both abiotic factors and biotic processes control the dynamics of lakes as natural systems (Hansson, *et al* 1998). The abiotic conditions differ greatly between regions and also between lakes. Thus a Lake provides an abiotic frame (eg nutrient concentrations, light availability, oxygen concentration, pH and temperature) that determine the survival and reproductive success of various organisms (Bronmark & Hansson, 2002). Changes in the abiotic frame of lakes, thus has a strong effect on the biota altering species composition of phytoplankton, zooplankton, benthic invertebrate and fish (Magnusson *et al* 1997).

The situation in Lake Naivasha is not much different from what is happening in the other tropical lakes. Recent observations show that the Lake's basin water quality and quantity has been under increasing pressure from water fluctuations and increasing demand from the fast expanding agricultural activities around the Lake. Rapid population growth around the Lake basin has contributed to this pressure, through release of partly treated waste water into the wetlands (Plate 1).

Plate 1: Sewage effluents from Naivasha town released into the wetland

However the sizes of these wetlands have drastically declined as a result of clearing, to give way for subsistence farming (Plate 2), beaches or clear lake view for various tourist hotels. This removal of the buffer zone macrophytes has contributed to siltation and degradation of the lake.

Plate 2: Subsistence farming at riparian zone

1.2 Problem statement and justification

Lake Naivasha, a tropical fresh water lake situated in the Kenyan rift valley, has experienced rapid changes in population over the last two decades as a result of commercial farming mainly specializing on flower and horticultural farming (Kitaka *et. al.* 2002 a). This has occurred due to a large number of people seeking employment in these farms (Plate 3). Consequently many poorly planned buildings, often without proper sewer systems, have been constructed to house these people. During heavy rains many of these sewers burst sending their run off into the lake. On the other hand, the rapid expansion of the flower industry has necessitated high water abstraction (Plate 4) and greater usage of fertilizers and pesticides, whose seepage ends up in the lake.

Plate 3: Horticultural farming around Lake Naivasha

Plate 4: Water abstraction for irrigation

A combination of these activities are therefore likely to cause temporal and spatial changes in physico-chemical levels in the lake with the resulting proliferation of macrophytes such as water hyacinth *Eichhornia crassipes* and *Salvinia molesta*, algal blooms (Plate 4) and occasional fish kills experienced in the lake and overall degradation of the water quality.

Plate 5: Water hyacinth, *Eichhornia crassipes* and other invasive plant species

The lake region is also a favourable site for many tourists due to its close proximity to Nairobi (less than 100 Km) and its beautiful sceneries. Ecologically, the lake is a habitat for many species of fish, birds, mammals, reptiles and plants.

Despite many studies conducted in the past on the quality of the water in the lake, there is no recent study which has quantified the levels and seasonal changes of physico - chemical parameters, their sources, algal biomass and the trophic state of the Lake. There is therefore a need to come up with information on the current physico-chemical characteristic of the water in the Lake for proper management of the lake.

The purpose of this study was to evaluate at the levels and seasonal changes in physico-chemical properties and algal biomass in order to provide current information on the lake water quality and therefore propose suitable measures for sustainable management of the lake.

1.3 Research questions

- What are the current levels and trends of physico - chemical properties in Lake Naivasha?
- What are the spatial and seasonal trends of algal biomass of the Lake?
- How are the spatial trends in primary productivity in the Lake?

1.4 Objectives

1.4.1 Overall objective

The overall objective of this study was to evaluate the levels and seasonal changes in physico – chemical properties and algal biomass in order to provide current information on the lake water quality and therefore propose suitable measures for sustainable management of the lake.

1.4.2 Specific objectives

(1) To determine the levels and trends of physico-chemical properties in the lake.
(2) To determine spatial and temporal trends of algal biomass in the lake.
(3) To determine spatial trends of primary productivity in the Lake.

1.5 Significance

This study has therefore come up with current information on the changing water quality of Lake Naivasha and made some recommendations. This information obtained is useful to the lake managers, researchers, fisher folk and other stakeholders for sustainable management of the lake.

1.6 Expected output

(i) Spatial and temporal distribution of parameters such as dissolved oxygen (DO), conductivity, alkalinity, temperature and pH.
(ii) Spatial and temporal distribution of nitrate nitrogen, ammonium nitrogen, total nitrogen, phosphate phosphorus and total phosphorus.
(iii) Temporal and spatial changes in algal biomass.
(iv) Spatial changes in primary productivity.

CHAPTER 2: LITERATURE REVIEW

2.1 Water quality of aquatic ecosystems

Global fresh water is the most precious human resource. Frequently Earth is called the blue planet because water covers about 75% of the globe, but most of the water is saline, less than 5% of the water is fresh (Herdendorf, 1990), and much of this water is in the ice caps, glaciers and ground water. Most of the remainder is in lakes, streams and soil moisture, and an estimated 68% of the fresh liquid surface water is in 189 large lakes with surface areas greater than 500 km^2 (Reid & Beeton 1992).

The maintenance of water quality standards in Lakes and reservoirs is necessary in order to avoid excessive growth of aquatic flora which is a problem to aquatic biota and humans. In many tropical lakes, temporal and spatial changes in the physico- chemical parameters are common in response to surface water runoff, direct precipitation, ground water recharge, rate of evaporation and human interference. These changes have impacts on the flora and fauna by imposing physiological and behavioral adaptations (Kemdirim, 2005).

Mankind in the 21^{st} century is faced with unprecedented challenge imposed by water scarcity, pollution and water quality degradation (Mokaya *et al*, 2004). Furthermore the need to produce more food for a growing population has a link to the quality aspects of aquatic environment as it results in increased soil erosion, chemical pollution by fertilizers and pesticides (Novotny, 1999).

Aquatic ecosystems are more difficult to protect than terrestrial ones because they depend on the quality and quantity of water, which can be affected at any point on the course - way between the catchment and the given system (Shumway, 1999). Changes in land use pattern have lead fundamentally to spatial and temporal

heterogeneity of the limnological characteristics thus influencing ecological structure and functioning of aquatic ecosystems (Nogueira *et al* 1999).

2.2 Nutrient levels in tropical waters

Nutrients such as phosphorus and nitrogen naturally enter water bodies from sources such as overland drainage, which can occur as run off after heavy rains and also through ground water. Human activities however, greatly accelerate the rate of nutrient input through discharge of untreated or partly treated sewage, industrial and urban effluents, as well as from fertilizer seepage from farming activities around a water body. The levels of these nutrients especially phosphorus needed for primary production is rather low. A small increase above the normal levels may however cause many changes in aquatic ecosystems (Smol, 2002).

Eutrophication continues to be ranked as the most common water quality problem in the world. This is because of the many problems associated with it, such as choking of the littoral zones of water bodies with excessive growth of aquatic macrophytes, which can impair recreational and industrial activities as well as altering the structure of the food web. It also causes blue green algal blooms, which can cause serious management problems of the aquatic ecosystems. These include the production of toxins that may harm or even kill mammals, deepwater oxygen depletion which interferes with the distribution and abundance of fish and other biota inhabiting deep water regions of anoxic lakes (Smol, 2002 op.cit).

In tropical lakes nutrient enrichment is not well understood as in the temperate areas. Many lakes, reservoirs and rivers studied within the tropical region have shown an increase in eutrophication especially in southern Africa (Twinch, 1986). In Zimbabwe, Lake Chivero a eutrophic reservoir which has experienced problems with blue – green algal blooms for many years, raising concern for the toxin

produced by *Microcystis* spp and the possible effects of the toxin on the health of the people who drink the water (Ndebele & Magadza, 2006).

The water quality of many tropical lakes has been deteriorating, for example lake Victoria has experienced dramatic changes in water quality over the past few decades, especially in regard to eutrophication as a result of increased nutrient inputs (Lunga'ya *et al* 2000: Mugiddle *et al*, 2005).These changes have been manifested in the occurrence of algal blooms, low levels of oxygen in water, frequent fish kills and the spreading of the water hyacinth (Hecky, 1993).

Eutrophication has been reported to cause undesirable changes in fish species composition, size distribution and abundance (Kubecka, 1993).The density of the fish at the beginning increased, and then fell sharply with the number of species and their body lengths continually decreasing (Bachmann *et a*l, 1996; Jeppesen *et a*l, 2000)

Temperature is of fundamental importance for the life history of aquatic organisms affecting metabolic and development rates. Hence an increase in temperature may affect the hatching date with far reaching effects on size at hatching and food availability (Chen & Folt, 1996).

2.3 Lake Naivasha water quality and related issue

Lake Naivasha is a natural aquatic ecosystem that is highly valued due to its rich biological diversity. It has received immense scientific attention dating as early as 1929 (Jenkins, 1934).

The lake has experienced fluctuating water levels over the last century, with cycles of short term, lake level rises and falls, against a long term pattern of lake level decline, water seeping out of the lake through an underground aquifer, probably southwards towards Longonot and northwards towards Gilgil (Vincent *et al* 1979, Gaudet and Melack 1981, Clark *et al.* 1990). These fluctuations are normally

accompanied by significant variations in limnological factors and productivity within the lake (Harper *et. al*. 1990).

Notable changes in water quality characteristics, especially on the solute levels have been recorded by Gaudet & Melack (1981), who found the water to be alkaline bicarbonate with sodium and calcium as the major cations. The freshness of the lakes water was attributed to dilute river inflows, combined with solute uptake by sediment, and some solute loss through seepage out (Gaudet & Melack 1981).

Two highly productive and damaging exotic floating plants appeared in the Lake i.e. the aquatic fern, *Salvinia molesta* in the 1960s and Water Hyacinth, *Eichhornia crassipes* in 1988. Both plants form dense mats which out compete less vigorous water plants for light and space (Adams *et al* 2002). *S. molesta* was abundant up to 1980s when it occupied about 25% of the Lake surface in mobile mats (Johnson *et al* 1998). Towards the end of 1990s, *Eichhornia crassipes* cover in the Lake was negligible and formed a narrow fringe of about 0 – 5m wide, with larger mats occurring in the sheltered bays and inlets. These mats were found to be a habitat for oligochaetes, insects and arachinids (Adams *et al* 2002). These mats were found to have an important role in the biology and chemistry of the Lake water.

Papyrus (*Cyperus papyrus*), the dominant emergent vegetation in Lake Naivasha, have been documented tohave culms growing to a height of 5 m and above ground standing phytomass which often exceed 12 t C ha^{-1}. Living papyrus vegetation often overlies several metres depth of detritus or peat, which forms in the oxygen depleted environment below established floating rhizome mats (Jones & Muthuri, 1985, 1997).

C. papyrus has been found to filter and retain nutrients in organic particles in the detritus and also have an important role in nutrient recycling (Gaudet 1979, Njuguna, 1982).

Recent development in intensive horticultural around Lake Naivasha, especially in the 1980s and 1990s has been reported to have accelerated papyrus clearance (Boar *et al* 1999).

In shallow lakes, like Lake Naivasha, variations in light intensity have a significant effect on the water column productivity (Schallenberg & Carolyn, 2004; Hubble & Harper, 2001). Hubble & Harper, (2002 a) found Lake Naivasha to be dominated by *Aulacoseira italica* following eutrophication, probably due to land use changes in the early 1980s. He also found a strong spatial homogeneity in the phytoplankton community, controlled by light and nutrient availability, with diatoms which are indicative of high nutrients levels being observed. Nutrient availability and seasonal variations are important factors in controlling phytoplankton abundance in Lakes. According to Njuguna (1982) diatoms and chlorophytes were dominant in Lake Naivasha with eutrophication occurring as a result of natural loading.

A study conducted between 2001 and 2005 in Lake Naivasha by Ballot *et al* (2009) found that phytoplankton community was dominated by cyanobacteria, chlorophytes and Bacillariophytes. Kitaka *et. al.* (2002 b) found the loss of phosphorus from the catchment of Lake Naivasha to be 0.2 kg ha^{-1} per annum, 76% particulate in a normal year of wet and dry period and 1.8 kg ha^{-1} per annum, 90% particulate in the months following 1997 – 98 El Nino rains.

In the 1980s Lake Naivasha zooplankton was found to consist of 2 cyclopods, 1 calanoid copepod, 11 cladocera and 13 rotifera with the composition being fairly stable with minor seasonal changes. In the litoral zone area, fish fry of black bass,

M. salmoides and adult *Gambusia affinis* exerted predatory pressure on the zooplankton (Mavuti, 1990).

The lake was observed to exhibits continuous wind induced mixing after midday with no significant changes in the dial vertical distribution of limnetic zooplankton. Bottom dwelling organisms were usually more exposed to contaminated sediments, although this may not induce direct toxicity to benthic community, as bioavailability of the contaminants depends on prevailing conditions and interactions with the organisms (Mavuti, 1992).

The ecological stability of Lake Naivasha is threatened by the impact of both internal and external factors. Internal factors are exotic species introductions and accidental arrivals while external factors are the impact of intensive horticultural industry (Kitaka *et al* 2002 b). Water in the lake is slowly becoming more concentrated in terms of higher levels of nutrients, more alkaline and higher levels of planktons. This was attributed to lower rainfall, shallowness of the lake and suspension of the sediments by wind as well as more agricultural activities in the area (Harper & Mavuti, 1991).

CHAPTER 3: STUDY AREA, MATERIAL AND METHODS

3.1 Introduction

This study set out to find out the levels of physico-chemical properties and algal biomass in Lake Naivasha. To obtain data surface and bottom water samples were collected in replicates for four days every month using Van Dorn water sampler, preserved and analyzed for nitrate nitrogen (NO_3 – N), ammonium nitrogen (NH_4 – N), total nitrogen (TN), phosphate phosphorus (PO_4 –P) and total phosphorus (TP) and chlorophyll *a* using standard spectrophotometric methods as described in (APHA, 1985). Water conductivity, pH temperature and secchi depth were measured *in situ*. Dissolved oxygen (DO) was measured using Winkler method. Trophic State Index (TSI) was calculated as described in (Carlson, 1977).

3.2 Study area

3.2.1 Location

Lake Naivasha which lies on the floor of Africa's Eastern Rift Valley, is the second largest fresh water lake in Kenya (Ase, 1986). It is located at latitude (0^0 45' S and longitude 36^0 20' E) and an altitude of 1890 m asl. The Lake is saddled between the Kinangop Plateau and Eburru Hills. It covers a surface area varying between 120 Km^2 and 150 Km^2 during the dry and wet spells respectively. Its freshwater condition is maintained due to the inflows from the catchment area, biogeochemical sedimentation and underground seepage (Gaudet & Melack, 1981). The lake ecosystem comprises of the main lake and two other smaller, but ecologically important lakes namely; Oloidien and Sonachi

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3.2.2 Climate and hydrology

The surface inflows come via rivers; Gilgil and Malewa which are perennial and Karati which is seasonal. River Malewa contributes 90% of the water discharged into the lake. Mean air temperatures are moderate with monthly means varying from 15.9 – 18.5° C. The combination of low temperatures, low relative humidity, and low rainfall make January and February the months with the highest evaporation (Gaudet & Melack, 1981).

Rainfall is bimodal occurring in April-July for the long rains and October-November for the short rains. Direct precipitation on the lake is minimal although occasional torrential rains are witnessed. Irregularity of the rainfall pattern is quite common. Rainfall on the surrounding highlands quickly percolates into the ground and from there rapidly seeps through into the lake (Gaudet & Melack, 1981). Rainfall in the basin is highest in the Nyandarua Mountains (1400 – 1600 mm per year). Lake Naivasha, located in the rain shadow, receives between 500 – 700 mm yr^{-1}. Richardson and Richardson (1972) estimated evaporation from the water surface to be around 1366 mm annually. This shows that the lake depends on rainfall at higher altitude, discharged through river Malewa and underground seepage for its survival

3.2.3 Soil

Rocks and sediments around Lake Naivasha can be classified into lavas and lacustrine deposits. Basic lava includes tephrites, basalts, trachytes, pumice ashes, tuffs and agglomerates. The acid lavas consist of rhyolite, obsidian and pyroclastics. The soils on the valley floor around Lake Naivasha are light grey or brown to pinkish non calcareous while in the high parts of the catchment are black or grey non calcareous overlying yellow brown compact subsoils with predominantly montmorillonite clays (Rachillo, 1977; Ongweny, 1973). The soils

along the south eastern shores consist of diatomite while those on the northern and north eastern shores consist of silts and clays (Thompson & Dodson 1963).

3.2.4 Flora and fauna

Dominant aquatic vegetation types are belts of C*yperus papyrus* L. around the lake margins and large stands of submerged macrophytes with *Najas pectinata* being the principal species. Mats of floating plants comprising waterweed *Eichhornia crassipes* and *Salvinia molesta* are found in sheltered lagoons of the lake (Harper, 1992). The lake is a habitat for over 400 bird species. The key species include the African fish eagle (One of the highest in Africa) and the Red – knobbed coot. However the endangered and rare species are now hardly seen such as Great crested Grebe (critical) and Maccoa duck (endangered) (Nasirwa & Bennun, 1994)

The fishery of Lake Naivasha is based on three introduced species namely *Oreochromis leucostictus* (Trewavas), *Tilapia zillii* (Gervais) and black bass *Micropterus salmoides* (Lacépède). Also present in the Lake is a riverine cyprinid *Barbus amphigramma* (Boulenger) and the more recently common carp *Cyprinus carpio* (L.). The tilapiines, the bass and the carp are the main commercially important species at present.

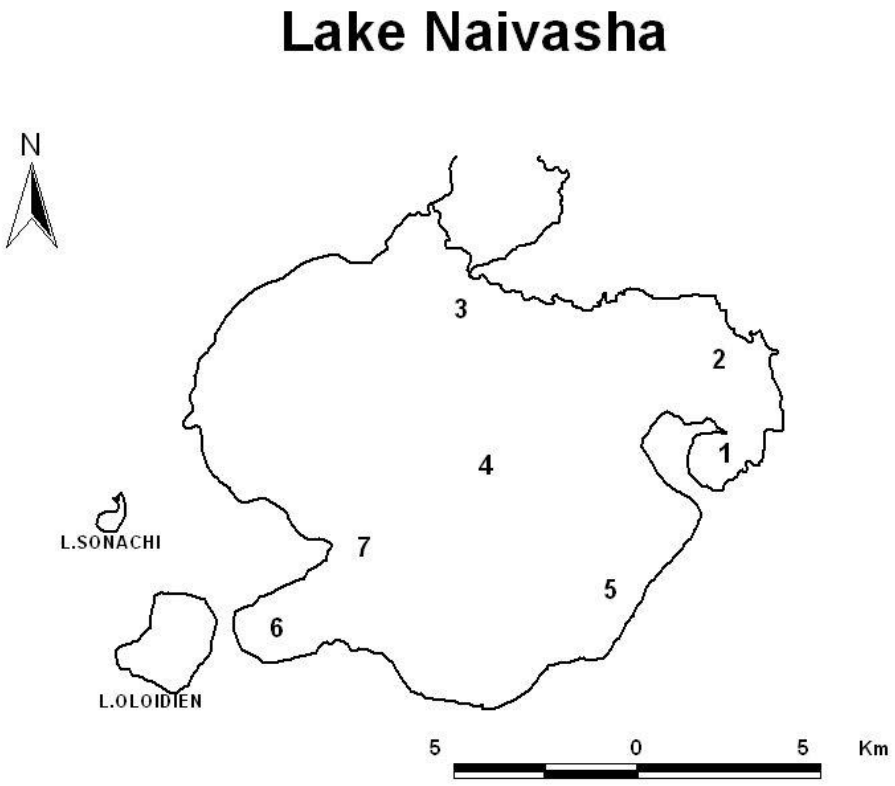
The lake when first studied had only one fish species, the endemic *Aplocheilichthys antinorii* which was last recorded in 1962 (Elder *et al* 1971). Since 1925 various fish introductions have been made (Litterick *et al* 1979, Muchiri & Hickley, 1991). Over the last decade, the fish stocks have drastically declined due to the use of undersize nets, increased fishing effort than permitted and seining by illegal fishers (Muchiri & Hickley 1991; Njiru & Ojuok 1997).

The lake shores is also important for wildlife such as *Hippopotamus amphibious,* waterbuck, buffalo, giraffe, eland, zebra, bush buck, otters, Thomson's and Grant's gazelles, rodents and various snakes.

3.2.5 Demography

According to the 1999 population census (GoK, 2001), Naivasha division had a total population of 158,679 persons in an area covering 1782 km^2 giving a population density of 89 persons km^{-2}. The present population is estimated at over 250,000 persons, with a growth rate of 3.1% per annum. This population is concentrated in the main urban area (mean estimate 468 individuals per square Kilometre) and the satellite centres on the lake. These centres are currently experiencing a rapid population increase as a result of increased migration of people to satisfy the labour force demand in the various horticultural and development farms surrounding the lake. With the increased settlement, an increase in the demand for domestic water supply, waste disposal, food requirement and other demographic issues pose serious challenge in these areas

A sizeable area of the lake basin is currently under large-scale production of flowers, vegetables and fruits mainly for export markets occupying about 4,000 hectares. The agricultural production depends heavily on irrigation from the lake, the rivers and from underground water (boreholes). To sustain these intensive agricultural activities, the farmers apply inputs of fertilizers and pesticides. This industry employs some 25,000 people directly with a similar number also indirectly (Becht *et al*. 2005).



1 = Crescent Island, 2 = Sewage, 3 = Malewa, 4 = Mid Lake, 5 = Sher, 6 = Oseria

7 = Hippo

Figure 1: Map of Lake Naivasha showing the sampling stations

3.3 Research design

This study was carried out through field survey approach in which representative Sampling sites (Figure 1) were identified and then geo – referenced using Global Positioning System (GPS). These sites represented potential influence on the lake's water quality from catchment areas, farms next to the lake, sewage effluents and urban runoff. The study was carried out between December 2007 and April 2008 covering dry (December to February) and wet (March and April) seasons.
The identified sites are described in table 1:

Table 1: Sampling sites GPS coordinates

Station name and Coordinates	Site description
1. Crescent Island 00°45′ 52′′S; 36° 24′ 39′′E	This is the deepest part of the lake (12m) and almost cut off from the main lake. It is sheltered with papyrus, acacia, and other macrophytes and is a breeding ground for fish.
2. Municipal Sewage Discharge Point 00°44′ 08′′S; 36° 24′ 42′′E	This site is adjacent to municipal council sewage plant. It is partly sheltered with papyrus as subsistence farming takes place next to the littoral zone of the lake and is about 1 m in depth.
3. Malewa River Mouth 00°43′ 33′′S; 36° 21′ 21′′E	This is a site through which water from the catchment area enters into the lake. It is a shallow part of the lake (about 2m) which often receives silt from the catchment.

4. Mid Lake 00°45′ 39′′S; 36° 21′ 18′′E	This is the middle part of the lake which is likely to have the least anthropogenic influence. The site is offshore with a depth of about 5m.
5. Sher Agencies 00°48′ 56′′S; 36° 21′ 52′′E	This site borders the main flower farming zone. It is partly sheltered by papyrus and has a depth of about 4 m and has muddy bottom
6. Oserian Bay 00°48′ 30′′S; 36° 18′ 09′′E	This is a site where fish breed especially the tilapiines. It is well sheltered with papyrus and also borders the flower farms and has muddy bottom
7. Hippo Point 00°47′ 23′′S; 36° 19′ 03′′E	This is a site next to livestock grazing area. It has a sandy and rocky bottom with clear water. Depth of about 6m.

3.3 Sampling procedures

3.3.1 Physico-chemical properties

The physico-chemical properties of water including pH, temperature and conductivity were determined in *situ* using their respective metres as follows: pH and temperature measurements were done using membrane pH meter model HANNA HI 8314 which was equipped with a temperature sensor. Conductivity was determined using conductivity meter model HANNA HI 98304. Dissolved oxygen was determined using Winkler method in the laboratory.

3.3.2 Water depth and transparency

The total water depth was determined using a well marked string tied to heavy metal. This was then lowered from one side of the canoe and the water depth determined in the sampling stations. Water transparency which is an indirect measure of the contents of various coloured and suspended organic and mineral substances in the water was determined using a Secchi disc 20cm diameter with alternating black and white quadrants.

3.3.3 Total alkalinity

Water samples were collected using a 500 ml bottle cleaned and rinsed with distilled water. The samples were then analysed in the laboratory the same day of sampling. Alkalinity was determined using 0.05M sulphuric acid titrated with mixed bromocresol green – methyl orange and phenolphthalein as indicator. A 50 ml aliquot of the sample was used for this determination. Total alkalinity as $CaCO_3$ was determined using the following formula:

$$T = \frac{100{,}000 \times B \times M}{V} \quad mg\ L^{-1}$$

Where

T = Total alkalinity

B = Volume of standard acid solution (ml) to reach the end point of methyl orange or mixed indicator

M = Concentration of acid (mol L^{-1})

V = Volume of sample (ml)

3.3.4 Nutrients

Acid soaked and cleaned water bottles (500ml polyethylene) rinsed with distilled, deionised water were used to collect and preserve samples according to standard methods (APHA 1985; Bartram & Balance 1996) for the determination of phosphate phosphorus (PO_4-P), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4 – N), total phosphorus (TP) and total nitrogen (TN). Nutrient samples were stored under refrigeration, processed in the laboratory and analyzed using the UV – visible spectrophotometer

3.3.4.1 Ortho phosphate phosphorus (PO_4 – P)

Soluble reactive phosphorus or ortho phosphate was analysed according to the ascorbic acid method in which ortho-phosphate and molybdate ions react, in the presence of an antimonyl catalyst to form antimonyl-phosphorous-molybdate complex which is further reduced to phosphor-molybdate, shown by an intense blue colour under acid conditions created by the addition of ascorbic acid. Spectrophotometric measurement of the colour intensity at 885 nm, gives an indication of the concentration of the PO_4^{-3}. Reagents used in the determination were prepared as follows;

(i) Ammonium molybdate solution. Prepared by dissolving 15g of analytical reagent grade ammonium paramolybdate $(NH4)_6\ Mo_7O_{24}.4H_2O$ in 500 ml distilled water.
(ii) Sulfuric acid solution. Prepared by adding 140 ml concentrated analytical grade sulfuric acid to 900ml of distilled water.
(iii) Potassium antimonyl – tartrate solution. Prepared by dissolving 0.34 g of potassium antimonyl - tartrate in 250 ml distilled water.
(iv) Ascorbic acid solution. Prepared by dissolving 27 g of ascorbic acid in 500 ml distilled water.

(v) Mixed reagent prepared as follows: 100 ml of ammonium molybdate + 250 ml sulfuric acid + 100 ml ascorbic acid + 50 ml of Potassium antimonyl tartrate.

3.3.4.2 Total phosphorus (TP)

Total phosphorous represents the concentrations of all the various forms of phosphorus including the free orthophosphate PO_4 and organic or particulate PO_4. To release phosphorus from combination with organic matter, wet oxidation using potassium peroxy disulphate was done as described in (Bartram & Balance 1996). The orthophosphate released reacted with ammonium molybdate to form molybdophosphoric acid which is then reduced to intensively coloured complex molybdenum blue whose absorbance was measured spectrophotometically at 880 nm wavelength.

The reagents were prepared as follows:
(i) 2.5 M H_2SO_4 for acidification; prepared by careful dilution of 140 ml of the concentrated acid to 1 L with distilled water.
(ii) Pottasium peroxy disulfate solution ($K_2S_2O_8$) prepared by dissolving 5g of $K_2S_2O_8$ in 100 ml.
(iii) Potassium antimonyl solution: Prepared by dissolving 2.7g potassium antimonyl tartrate in water and making up to 1 litre.

100 ml of unfiltered water sample was put in a conical flask and digested with potassium peroxy disulphate and 2 ml 2M sulphuric acid and then heated for about 30 minutes. After cooling the solution was neutralized by adding sodium hydroxide solution until the solution turned pale pink by adding a drop of phenolphthalein indicator. Thereafter a series of standards in 50ml volumetric flask were prepared in order to determine the concentration of TP in the sample.

TP mg L^{-1} = (mg Phosphate x 1000) / ml of sample

3.3.4.2 Nitrate nitrogen (NO_3 – N)

The cadmium reduction method was used in which nitrate is reduced to nitrite when a sample is passed through a column containing amalgamated cadmium filings. Nitrite that was originally present plus that reduced from nitrate was then determined at 543 nm wavelength.

Reagents used were prepared as follows:

(i) Concentrated ammonium chloride solution. Prepared by dissolving 125g of analytical grade ammonium chloride in 500 ml of distilled water and stored in a glass bottle.

(ii) Dilute ammonium chloride solution. Prepared by diluting 50 ml of concentrated ammonium chloride solution to 2000 ml with distilled water.

(iii) Sulfanilamide solution. Prepared by dissolving 5 g of sulfonamide in a mixture of 50 ml of concentrated hydrochloric acid and 300 ml of distilled water, then diluting to 500 ml.

(iv) N- (1 – naphthyl) – ethlenediamine dihydrochloride solution. Prepared by dissolving 0.5 g of the dihydrochloride in 500 ml of distilled water.

3.3.4.4 Total nitrogen (TN)

Total Nitrogen (TN) was determined on a 25 ml volume pre-filtered water sample, in 50-ml Erlenmeyer flasks. This was done as follows: addition of 1ml phenol, followed by 1ml 0.5 % Na-Nitroprusside and then 2.5 ml of the Oxidizing solution. A series of standards were then prepared with NH_4Cl salt and de-ionized water, from a stock solution of 1000 mg/l TN concentration. All the standards and samples were then covered with parafilm and placed in the dark for 1 hour for colour development. Absorbance was then measured at 640 nm on a

spectrophotometer. A calibration curve drawn from the readings of the prepared standards was used to calculate the concentration of TN in the sample water.

3.3.5 Algal biomass

Water samples for chlorophyll *a* was collected using a water sampler at various depth of the lake and immediately stored in a cool box for transportation into laboratory where they were filtered using a GFC 47mm diameter. Thereafter chlorophyll *a* as a measure of phytoplankton biomass was determined using 90% acetone as a solvent and biomass calculated from absorbencies of the extract as read on the UV visible spectrophotometer at 665 nm, 663 nm and 750 nm wavelength as described in (Bartram & Balance 1996). Chlorophyll *a* concentration was then determined using the following formula:

$$\text{Chlorophyll } a = \frac{26.73\,(663a - 665b) \times Ve}{Vs \times 1} \quad \text{mg m}^{-3}$$

Where:

Ve = Volume of acetone extract (litres)

Vs = Volume of water sample (m^3)

663a – 750a = corrected 663a absorbance

665b – 750b = corrected 665b absorbance

3.3.6 Primary production

Primary production was measured using light and dark bottle technique. A series of small glass bottles with stoppers were used. Half of the bottles were wrapped with black polythene bags to prevent light penetrating, these represented the dark bottles while the other with no wrapping representing the light bottles. Water samples were then collected at various depths and put in the light and dark bottles

and suspended at their respective depth for 2 hours. Thereafter the oxygen concentration was determined in each bottle using Winkler method and primary production calculated (APHA 1985).

Gross production was calculated using the formula of (Wetzel & Likens 1991).

$$GP = \frac{O_2\ LB - (O_2\ DB)\ x(1000)\ x\ (0.375)}{(PQ)\ x\ (t)}$$

GP = gross photosynthesis in mg C m^{-3} hr^{-1}

O_2 = oxygen in mg L^{-1}

LB = light bottle

DB = dark bottle

PQ = photosynthetic quotient (1.2)

t = hours of incubation

0.375 = ratio of moles of carbon to moles of oxygen

Trophic State Index (TSI) was used to classify Lake Naivasha trophic status as described in (Carlson's 1977). This index uses three independent variables which are correlated: chlorophyll *a*, total phosphorus and secchi depth. The formulae used were as follows;

Secchi depth calculations; TSI = 60 – 14.41 (In secchi depth m)

Total phosphorus calculations. TSI = 14.42 (In total phosphorus (µg/l) + 4.15)

Chlorophyll *a* calculations; TSI = (9.81) (In chlorophyll *a* (µg/l) + 30.6)

Where In = natural logarithm

TSI = Carlson's tropic State Index.

The index has a classification ranging from 1 to 100.

Where 0 – 30 being minimally productive lakes, but good areas for water sports and drinking water.

30 – 45 being reasonably productive, supporting fair amount of algae, aquatic plants, birds, fish, insects and other wildlife.
46 – 70 having high productivity, supporting an abundance of algae, aquatic plants, birds, fish, insects and other wildlife.
71-100 have the potential to support the highest level of biological productivity, such as algae, aquatic plants, birds, fish, insects and other wildlife.

3.3.7 Data analysis

Data on temporal and spatial distribution patterns of the physico-chemical parameters was entered in excel work sheets, and summarized according to stations and months. This was then analyzed and any significant differences between seasons tested using t test while spatial variations were assessed using one way analysis of variance (ANOVA).

Carlson's Trophic State Index (TSI) was used to classify Lake Naivasha trophic status using chlorophyll *a*, total phosphorus and Secchi depth as described in (Carson 1977).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1. Transparency and lake depth

Secchi depth

Mean Secchi depth values showed a peak of 49 cm ± 14 SD in December 2007 and lowest values of 41 cm ± 14 SD in April 2008, thus showing a general decrease in transparency towards the rainy season of March / April (Figure 2). Crescent Island (Station 1) and Hippo (Station 7) recorded the highest Secchi depth in all the months, with mean values ranging from 49 to 82 cm and 34 to 64 cm respectively. Malewa River Mouth (Station 3) and Sewage Discharge Point (Station 2) recorded the lowest Secchi depth in all the months except January with mean values ranging from 24 - 42 cm and 17 - 27.5 cm respectively (Figure 3).

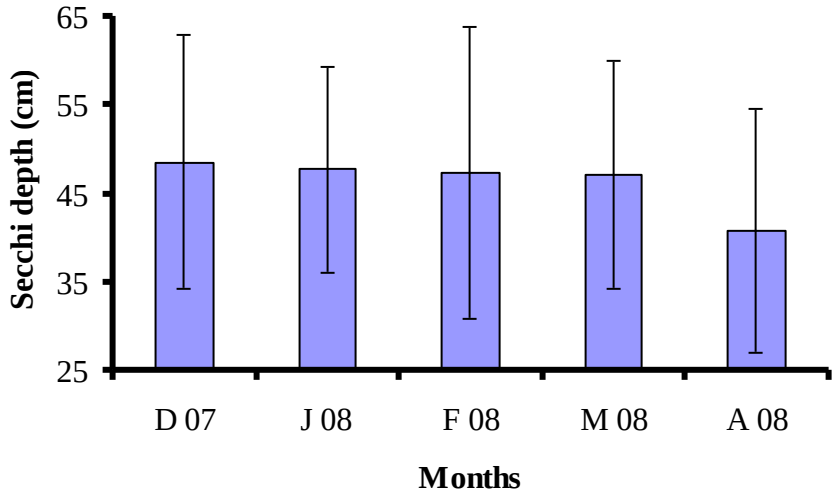


Figure 2: Monthly variation in mean (± SD) Secchi depth

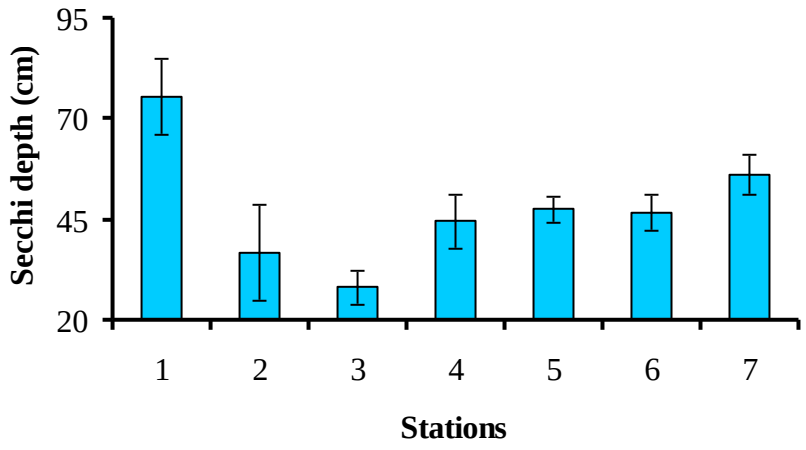


Figure 3: Spatial variation in mean (± SD) Secchi depth.

Lake depth

The lake recorded a mean depth of 4.1m ± 2.9 SD with the shallow areas of lake being Sewage Discharge Point and Malewa River Mouth with a mean depth of 1 m. The deepest part of the lake, Crescent Island was 12 m.

4.1.2 Physico-chemical properties

4.1.2.1 Temperature

Mean temperature values for the entire lake showed a gradual increase with peaks in January 22.3 ^{o} C ± 1.1 SD and April 2008 and the lowest value of 20.8 ^{o} C ± 1.1 SD in March 2008 (Figure 5). Mean temperature variation between the highest and lowest values between station rarely exceeded 2 ^{o}C in each month, with Malewa, (Station 3) Mid lake (Station 4) , Sher (Station 5) and Crescent Island (Station 1) recording the highest mean temperatures within the period December 07 to April 2008 (Table 2).

Table 2: Mean monthly temperature (± SD) for the stations sampled

Station	Dec 07		Jan 08		Feb 08		Mar 08		Apr 08	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	21.6	0.9	23.0	0.4	21.5	1.4	22.0	0.8	22.0	0.6
2	22.9	0.5	21.2	1.1	21.8	0.5	21.7	0.7	22.1	0.5
3	23.1	0.9	22.0	1.2	21.8	1.0	21.8	1.0	23.2	0.6
4	22.1	0.7	23.0	1.1	21.6	0.5	20.8	0.6	22.5	0.7
5	21.5	0.7	22.0	0.7	22.5	0.7	19.9	0.7	21.8	0.7
6	21.6	0.7	22.8	0.6	21.6	0.9	19.6	0.7	21.3	0.6
7	21.0	0.2	22.2	1.0	22.4	0.7	20.2	0.7	21.8	0.8

Mean temperature values for Crescent Island (Station 1), the deepest station decreased sharply with depth from 23.3 on the surface to 21.3 at depth of 3 metres. There after there was a more gradual decrease (Figure 4).

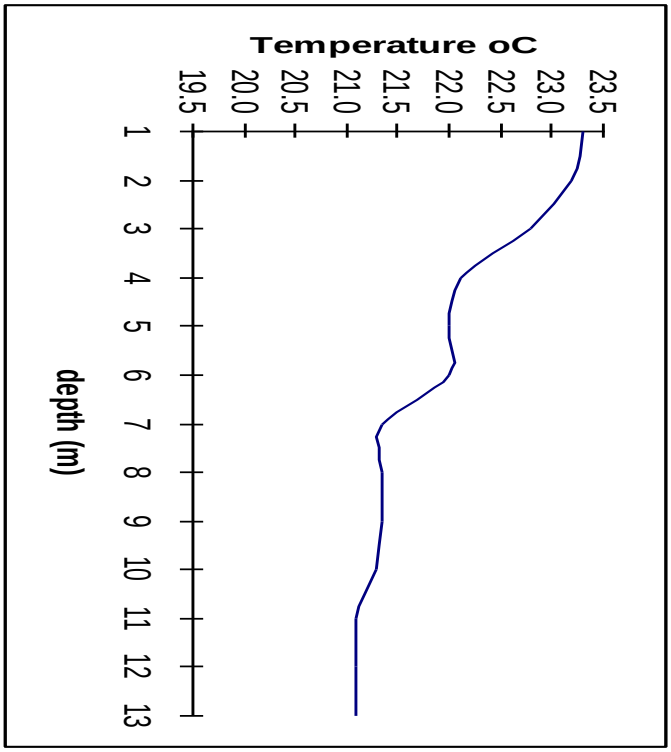


Figure 4: Depth profile of Temperature at Crescent Island

Comparison of mean water temperature values using t – test revealed that there was significant difference between dry and wet seasons (t =3.38, P < 0.001) as well as between surface and bottom waters (t = 7.84, P < 0.001), (Table 3).

Table 3: Temperature, DO, pH and conductivity t test values

	Temperature		Dissolved oxygen		pH		Conductivity	
	Dry/wet	S/B	Dry/wet	S/B	Dry/wet	S/B	Dry/wet	S/B
df	208	208	208	208	208	208	208	208
t	3.38	7.84	6.92	11.67	5.14	0.51	3.33	0.62
P	P <0.001	P <0.001	P<0.001	P<0.001	P <0.001	P>0.05	P <0.001	P>0.05

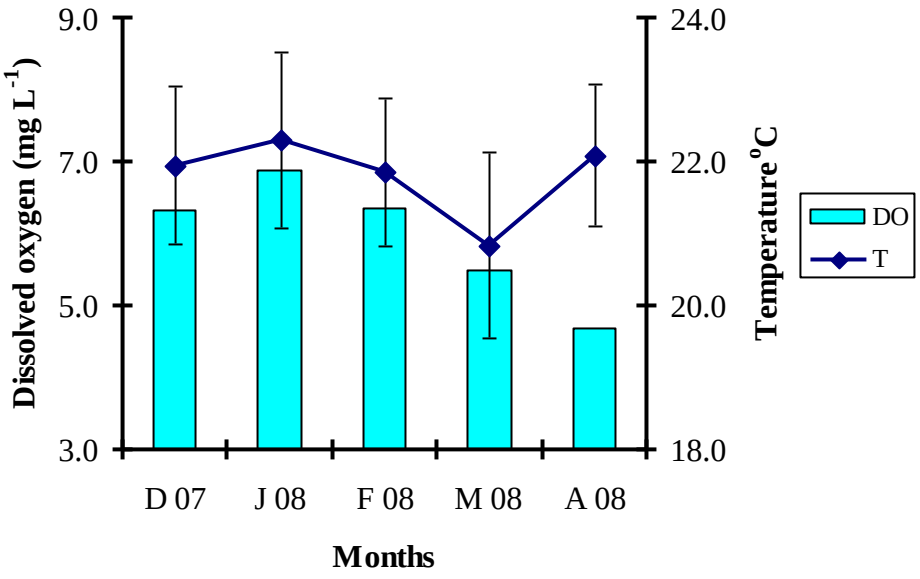


Figure 5: Monthly variation in mean (± SD) temperature and oxygen

Spatial variations among different stations for temperature was compared using single factor ANOVA, which showed significant variations between stations ($F_{2.14} = 2.65$, $P < 0.05$ (Table 8).

Seasonal variations in the mean temperatures were observed. Wet season March /April) recorded relatively lower temperatures, 21.5 ± 1.0 than dry season (December to February) 22.0 ± 0.9 (Table 7).

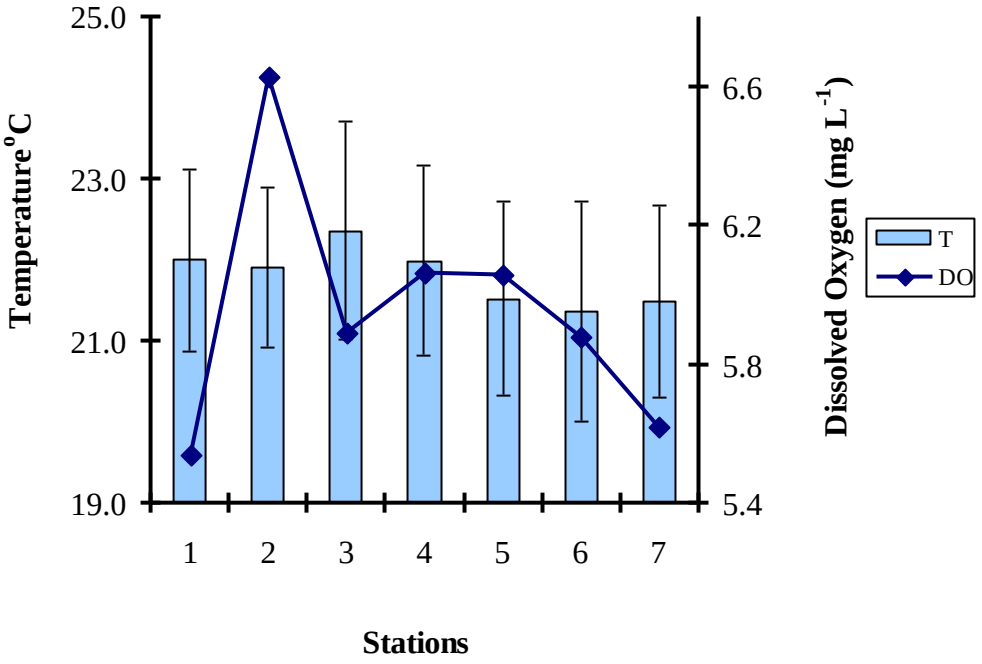


Figure 6: Spatial variation in mean (± SD) temperature and dissolved oxygen

4.1.2.2 Dissolved oxygen

Mean dissolved oxygen values for the entire Lake showed a general decline as from January to April 2008, with a peak value of 7.2 mg L^{-1} ± 1.5 SD in January 2008 and the lowest value of 4.7 mg L^{-1} ± 1.3 SD in April 2008 (Figure 5).

Mean surface dissolve oxygen values were generally higher than bottom values in all the months, with an overall mean of 7.0 ± 0.9 mg L^{-1}. The mean value for bottom dissolved oxygen was 4.9 ± 1.2 mg L^{-1}. December to February (dry season) had relatively higher mean values than March and April (wet season) for both surface and bottom values (Figure 8).

Single factor ANOVA showed that there were no significant variations on mean dissolved oxygen values among stations $P > 0.05$ (Table 8). However there was

significant difference between dry and wet season (t =3.38, P < 0.001) and between surface and bottom waters (t = 11.67, P < 0.001) (Table 3).

Depth profile for dissolved oxygen at Crescent Island showed that stratification was took place with an oxycline occurring at 2 – 3 metres (Figure 7).

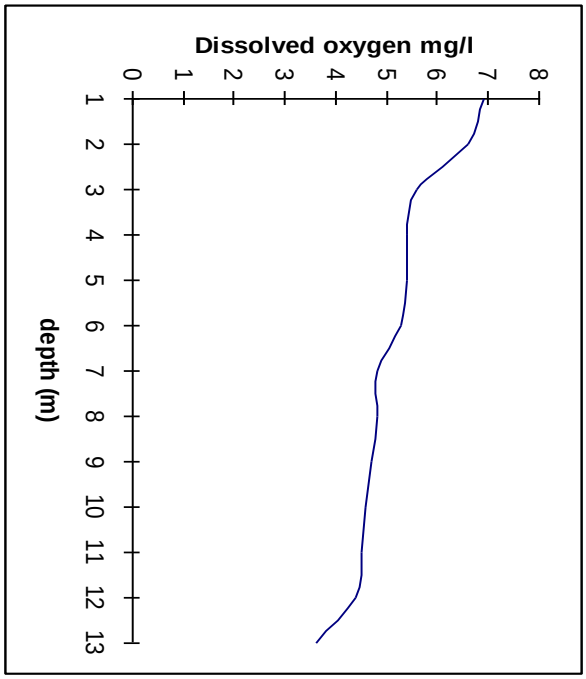


Figure 7: Depth profile of dissolved oxygen at Crescent Island

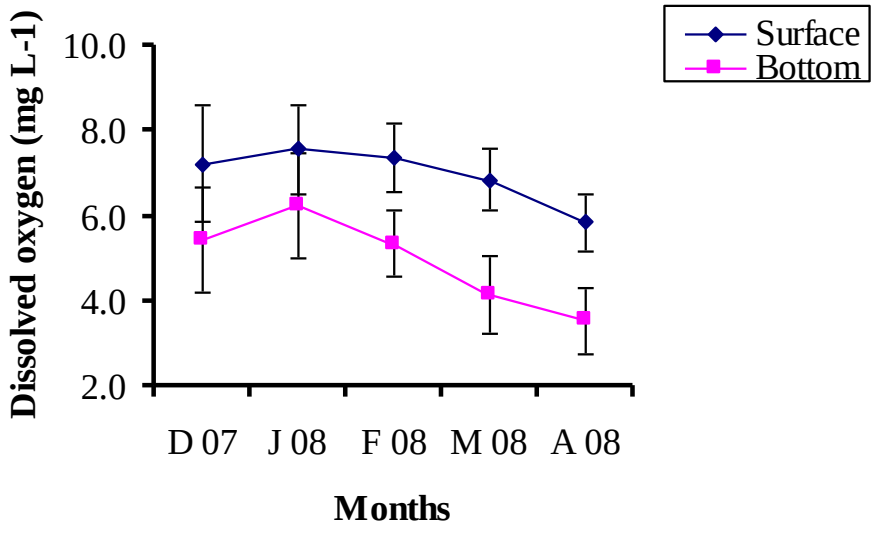


Figure 8: Monthly variation in mean surface and bottom dissolved oxygen

The highest Mean Dissolved oxygen for the period December 2007 to April 2008 was at Sher (Station 5), Mid Lake (Station 4) and Hippo (Station 7) while the lowest was at Crescent Island (Station 1) (Table 4).

Table 4: Mean monthly (±SD) dissolved oxygen

Station	Dec 07		Jan 08		Feb 08		Mar 08		Apr 08	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	4.7	1.3	5.3	2.0	4.8	1.7	5.2	2.5	4.5	2.1
2	5.9	1.4	7.0	1.4	6.2	1.9	5.8	1.2	5.0	1
3	4.9	0.6	6.4	1.1	6.3	1.1	5.3	1.2	4.5	1
4	6.6	1.4	7.2	1.1	5.5	1.0	5.1	1.4	4.4	1.2
5	7.5	1.0	7.2	1.2	6.1	1.0	4.7	1.5	4.1	1.3
6	6.3	2.1	6.9	0.9	6.4	0.9	5.3	1.1	4.6	1.1
7	6.1	0.9	5.4	0.6	6.9	0.7	5.7	1.3	5.0	1.2

4.1.2.3 pH

The pH ranges for the period December 2007 to April 2008 were as shown in (Table 5). In December 07 a wide pH range of 1.3 was observed in Malewa River Mouth (Station 3). Other Stations where a range of 1 and above was recorded was in Sher (Station 5), Sewage (Station 2) and Hippo (Station 7).

Table 5: Monthly pH ranges

Station	Dec 07	Jan 08	Feb 08	Mar 08	Apr 08
	Range	Range	Range	Range	Range
1	7.9 - 8.3	8 – 8.2	8.1 – 8.5	7.6 – 8.4	6.5 – 7.8
2	7.9 – 8.4	7.5 – 8.8	8.4 – 8.7	7.2 – 7.9	6 – 7.4
3	7.1 – 8.4	7.5 – 8.3	7.9 – 8.3	7.1 – 8.1	6.8 - 7.6
4	7.9 - 8.3	7.6 – 8.1	7.9 – 8.4	7.8 – 8.5	7.1 – 8.1
5	8.1 – 8.5	7.3 – 8.4	7.7 – 8.4	8 – 8.8	7.5 – 8.4
6	8 – 8.4	7.9 – 8.1	7.8 – 8.6	7.9 – 8.7	7.4 – 8.4
7	8.2 – 8.3	7.3 – 8.1	7.8 – 8.6	8.1 – 8.8	7.3 – 8.4

Spatial variation in pH showed that Station 5 (Sher Agencies) had the highest values while Station 3 (Malewa River Mouth) had the lowest (Figure 10).

Comparison on the pH values among the months recorded significant variations ($F_{2.14} = 4.04$, $P < 0.001$) (Table 8). There was significant difference on pH means values for dry and wet season ($t = 5.14$, $P < 0.001$). However there was no significant difference on the values for surface and bottom water ($t = 0.51$, $P > 0.05$) (Table 3)

4.1.2.4 Conductivity

Mean conductivity values showed a peak, 278 ± 35 µS cm-1SD, in January 2008 and lowest value of 249 ± 14 µS cm-1SD in December 2007 (Figure 9). Seasonally, the dry season December to February, had relatively higher values than the wet season, March and April. Conductivity is widely used as an index of ionic concentration in the water as well as an approximation of total dissolved solids. The mean conductivity range observed in this study was 249 – 278 µS $cm^{-1}$with Crescent Island (Station 1) having the highest mean value, followed by Sewage Discharge Point (Station 2), while Malewa River Mouth (Station 3) had the lowest values (Figure 10).

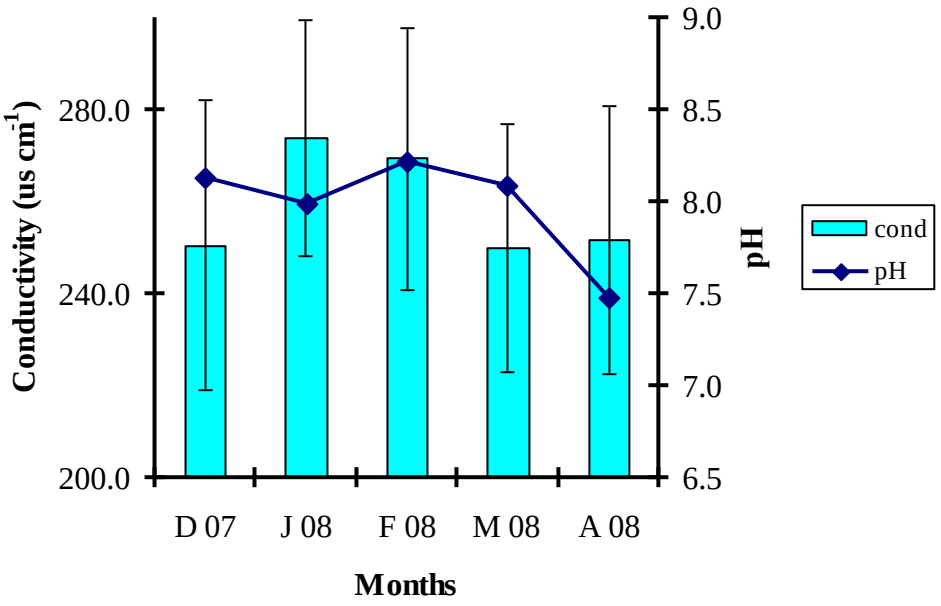


Figure 9: Monthly variation of pH and mean conductivity

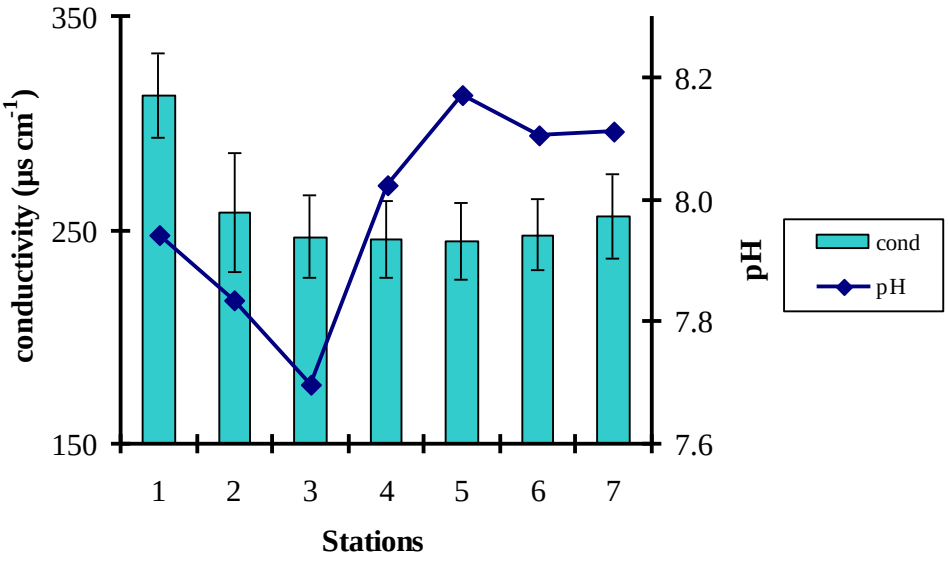


Figure 10: Spatial variation of mean pH and conductivity

Mean conductivity values were highest in all the months at Crescent Island (Station 1), with the highest mean value being 320 ± 3.3 being recorded in December 2007. The lowest mean values were recorded at Sher (Station 5) (Table 6).

Table 6: Mean monthly (±SD) conductivity values

Station	Dec 07		Jan 08		Feb 08		Mar 08		Apr 08	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	320	3.3	325	3.5	327	7.2	295	15.4	297	19.6
2	242	11.5	288	10.9	288	4.0	237	12.4	239	15.7
3	239	17.7	260	15.7	259	9.8	239	12.5	240	15.8
4	244	16.4	260	13.3	250	9.9	237	12.4	238	15.7
5	245	5.7	266	7.0	252	7.2	230	12	231	15.2
6	233	5.6	258	3.5	260	6.3	244	14.2	245	16.3
7	232	5.6	261	5.8	251	10.7	269	14.1	271	17.9

Comparison on the mean conductivity values showed that there was significant difference between the mean values of dry and wet season ($t = 3.33$, $P < 0.001$) (Table 3). This however was not the case for surface and bottom water, where there was no significant variation $P > 0.05$.

Single factor ANOVA showed that there was significant variation on the mean values between stations ($F_{2.14} = 43.2$, $P < 0.001$) (Table 8).

Mean values for dissolved oxygen, temperature, pH and conductivity and Algal biomass as indicated by the levels of chlorophyll *a*, were higher for the dry than those for the wet season. Total nitrogen, Total phosphorus, $NO_3 – N$, $NH_4 – N$ and PO_4 - P were higher during the wet season (Table 4).

Table 7: Mean physico-chemical values (±SD) for dry and wet season

Parameter	**Mean values**	
	Dry season	**Wet season**
Dissolved oxygen	6.5 ± 1.2 mg L^{-1}	5.1 ± 1.3 mg L^{-1}
Temperature	22.0 ± 0.9 ^oC	21.5 ± 1.0 ^oC
pH	8.1 ± 0.2	7.8 ± 0.5
Conductivity	264.7 ± 23.5 µS cm^{-1}	250.9 ± 21.3 µS cm^{-1}
$PO_4 – P$	7.0 ± 2.4 µg L^{-1}	15.4 ± 4.9 µg L^{-1}
Total phosphorus (TP)	27.7 ± 9.6 µg L^{-1}	65.3 ± 20.9 µg L^{-1}
$NO_3 – N$	51.4 ± 22.4 µg L^{-1}	79.5 ± 46.1 µg L^{-1}
NH4 – N	104.8 ± 32.1 µg L^{-1}	162.2 ± 56.8 µg L^{-1}
TN	255.9 ± 78.9 µg L^{-1}	376.6 ± 147.1 µg L^{-1}
Chlorophyll *a*	36.5 ± 15.2 µg L^{-1}	28.0 ± 9.8 µg L^{-1}

Table 8: Single factor ANOVA table

	Cond.	pH	Temp.	DO	TN	TP	NO3	Chl. *a*
Df	209	209	209	209	209	209	209	209
F	43.62	4.04	2.65	1.48	10.34	2.21	12.34	5.33
P	P<0.001	P<0.001	P>0.05	P>0.05	P<0.001	P<0.05	P<0.001	P<0.001

Table 9: Summary of mean physico-chemical for this study and previous ones

Parameter	Njuguna 1982	Kitaka 1991	Malala &Mwamburi 2002	Mwamburi *et al* 2007	This Study (Range)	This Study (mean)
Secchi depth (cm)	76 -227	70-180	67.6 ± 46	56 ± 11.4	24 – 82	48± 10
pH	7.3-8.6		8.6 ± 0.6	7.4 ± 0.1	6.0 – 8.9	8.0 ± 0.4
Conductivity (µS/cm)	300-347	220-297	320 ±70	265 ±8.7	204 – 338	259.2± 23.2
Temperature ^{o}C	19 -25	19 – 24	21.6 ± 1.6	22.9 ± 0.4	18.5 – 24.8	21.8 ±1.0
Disssolved oxygen (mg L^{-1})	3.5-7.9		7.2±1.4	5.1 ± 0.2	2.3 -9.1	6.0 ± 1.3
PO4 – P (µg L^{-1})			0.1 - 2.2	22.2 ±3.2	3 -35	10.0 ± 6.0
NO3 – N (µg L^{-1})			6 ± 6.8	103 ± 45	14 – 238	62.7± 31.2
NH4 – N (µg L^{-1})			36.4 ± 31.2	480 ± 158	34 – 346	127.7± 45.8
TN (µg L^{-1})	1106 - 2509			4347 ± 607	113 - 698	304± 96.3
TP (µg L^{-1})	39.8 - 116			157 ± 12	10 – 138	42.7± 26.0
N/P	12 -63				5- 11	
Chlorophyll *a* (µg L^{-1})	21.3	26.5 - 54.7	26.4 ± 13.6	26.7 ±2.6	12 – 90	32.6± 13.4

4.1.2.5 Alkalinity

There was relatively higher mean values between December and February corresponding with dry period (82.5 ± 12.8 mg $CaCO_3$ SD) and lower mean values during the wet season (52.2 ± 11.7 mg $CaCO_3$ SD) (Figure 11).

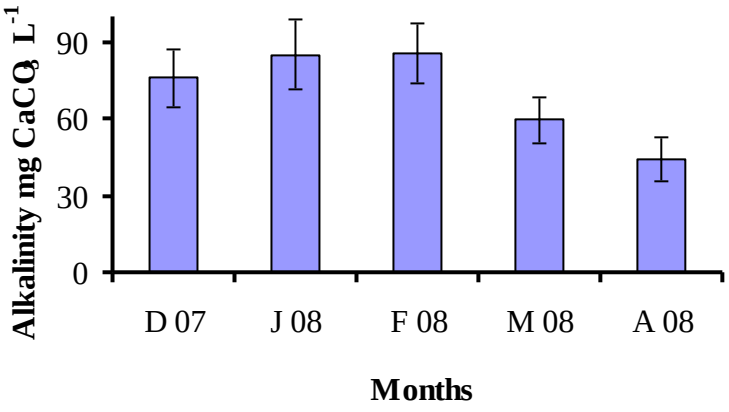


Figure 11: Monthly variation of mean alkalinity

Crescent Island (Station 1) recorded higher mean values than the main lake (Station 4) (73.5 ±19.3 mg $CaCO_3$ SD compared with 69.9 ± 5.5 mg $CaCO_3$ SD, although Mid Lake and Sher had individual mean values higher than the mean for the main lake. The mean values by sites varied from 65.3 ±18.3 mg $CaCO_3$ SD at Malewa to 80 .6 ± 20.3 mg $CaCO_3$ SD at Mid Lake (Figure 12).

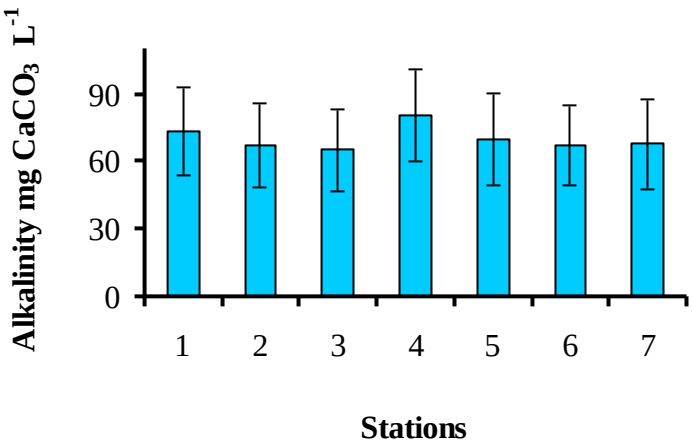


Figure 12: Spatial variation of mean alkalinity

4.1.3 Nutrients

4.1.3.1 Total nitrogen

Total nitrogen mean ± SD values was 268.7 ± 112.6 and 339.6 ± 128.9 µg L^{-1} for the surface and bottom waters respectively, with over all mean ± SD value 304 ± 96.3 µg L^{-1} with relatively high values being observed during the wet season in comparison with the dry season (Figure 13). The high values observed during the wet season can be as a result of inflow of organic matter through the rivers and run off after the rain (Figure 13).

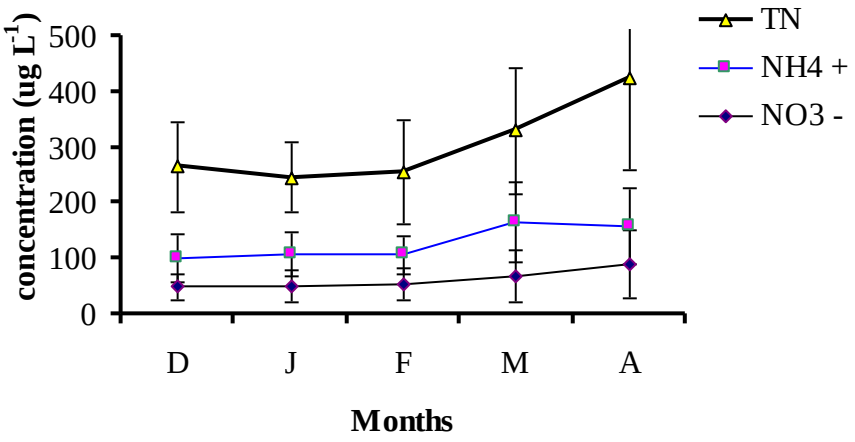


Figure 13: Monthly variation of mean total nitrogen, ammonium nitrogen and nitrate nitrogen

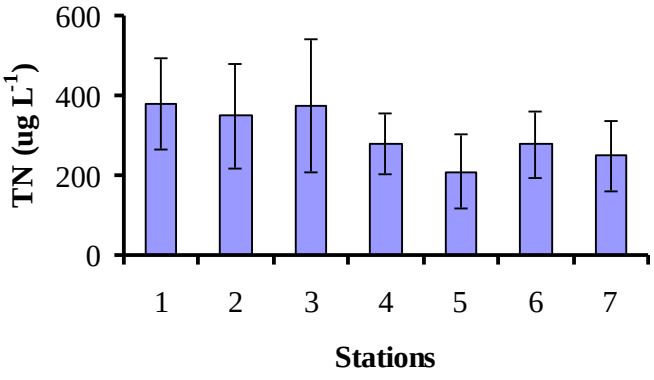


Figure 14: Spatial variation of mean total nitrogen

The highest mean total nitrogen for the period December 2007 to April was recorded at Crescent Island (Station 1), Sewage (Station 2) and Malewa (Station 3) while the lowest at Sher (Station 5) and Hippo (Station 7) (Figure 14 and Table 10).

Table 10: Mean monthly (± SD) values for total nitrogen

Station	Dec 07	Jan 08	Feb 08	Mar 08	Apr 08
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
1	353.1 ± 61.7	282.6 ± 26.9	315.5 ± 64.6	424.9 ± 40.4	527.8 ± 92.4
2	265.7 ± 31.8	214.2 ± 44.6	393.8 ± 105.2	383 ± 39.5	496.7 ± 95.1
3	292.9 ± 44.4	267.1 ± 25.4	226.7 ± 49.9	475.6 ± 51	614.2 ± 117.5
4	225.2 ± 21.5	247.3 ± 26.5	246.2 ± 24.4	298.9 ± 17.5	394.5 ± 70.3
5	269.2 ± 111.9	317.1 ± 35.2	163 ± 19.8	131.4 ± 11.9	172.3 ± 32.7
6	249.9 ± 24.2	230.3 ± 48	209.5 ± 41.5	313.1 ± 28.5	390.8 ± 68.4
7	195 ± 51.1	165.5 ± 23.7	243.6 ± 23.2	280.3 ± 25.2	368.5 ± 70.5

4.1.3.2. Nitrate nitrogen

Nitrate nitrogen mean ± SD values observed were 52.5 ± 40.7 and 72.9 ± 42.8 µg L^{-1} for surface and bottom waters respectively with the overall mean ± SD value

being 62.7 ± 31.2 µg L^{-1}. The highest values were observed during the rainy season when there was high run off from urban and unsheltered shores with lower values during the dry season (Figure 13).

Mean values for nitrate nitrogen for all bottom samples recorded relatively higher values for all the stations, with Malewa River Mouth (Station 3) and Crescent Island (Station 1) recording the highest values, while Sher (Station 5) and Oserian Bay (Station 6) recording the lowest values (Figure 15 and Table 11).

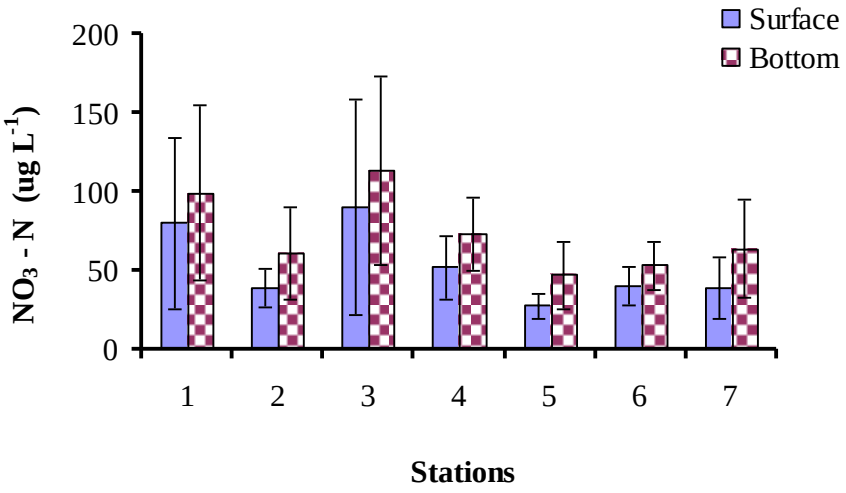


Figure 15: Spatial variation of mean surface and bottom nitrate nitrogen

Table 11: Mean Monthly (±SD) nitrate nitrogen values

Months	Dec 07		Jan 08		Feb 08		Mar 08		Apr 08	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	65.4	14.8	42.7	15.3	41.8	14.6	130.7	11.5	166.7	25.8
2	62.8	15.1	39.3	10.4	68.6	34.6	35.1	2.9	44.6	6.5
3	45	15.5	48.2	20.9	73.2	19.1	150	11.5	191.5	27.2
4	41.8	18.3	83.3	19.7	75.3	22.5	49.4	4.3	62.8	9.6
5	49.4	27.6	35.6	8.5	21.8	5	35.1	6.5	44.6	8.8
6	54.4	13	44.3	14.2	55.9	12.1	34.6	3.6	44.1	7.3
7	22.2	5.1	63.6	41	46	15.7	54.5	4.5	69.4	10.3

4.1.3.3 Ammonium nitrogen

Ammonium nitrogen mean ± SD values were 106.5 ± 53.7 µg L^{-1} and 149 ± 59.7 µg L^{-1} for surface and bottom waters respectively. The overall mean ± SD value being 127.7 ± 45.8 µg L^{-1} with the highest values being observed during the wet season march – April and relatively lower values being observed during the dry season. The highest mean ammonium nitrogen values recorded were at Oserian Bay and Sewage Discharge Point while the lowest were at Hippo Point and Crescent Island.

4.1.3.4 Total phosphorus (TP)

The mean TP value for the lake was 43 ± 26 µg/l, ranging from 10 – 138 µg/l, with Malewa River Mouth (Station 3) and Sewage Discharge Point (Station 2) having the highest mean values while Mid Lake (Station 4) and Crescent Island (Station 1) having the lowest (Figure 16).

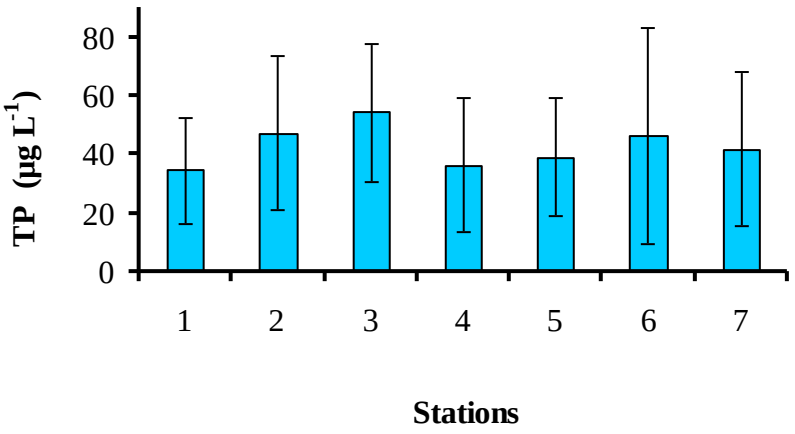


Figure 16: Spatial variation of mean total phosphorus

Mean TP for the surface water was 39.5 ± 24.8 µg L-1 while that of bottom was 46.0 ± 26.8 µg L^{-1}. Malewa Rriver Mouth (Station 3) and Sewage (Station 2) had

the highest values while Crescent Island (Station 1) and Sher (Station 5), had the lowest mean values for TP (Figure 17).

There was significant differences between dry and wet season for TP mean values ($t = 14.54$, $p < 0.001$) (Table 13).

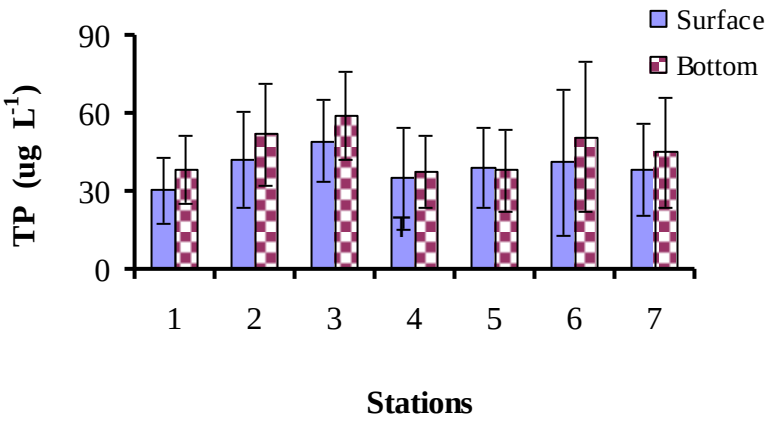


Figure 17: Spatial variation of mean total phosphorus (surface & bottom)

The N:P ratios observed ranged from 5 – 11 with the lowest value being in March and the highest in February (Table 12). Schindler (1978) observed that N:P ratios of 9 – 10 usually resulted in a balanced growth of phytoplankton. Most algae seem to require N: P at a ratio of 10:1 by weight (Vallentyne, 1974). In lakes with a ratio less than 10, Nitrogen becomes a critical factor limiting phytoplankton productivity (Njuguna, 1982).

Table 12: Nitrogen Phosphorus (N:P) ration for Lake Naivasha

Month	TN	TP	N:P
Dec	264	36	7
Jan	246	24	10
Feb	257	23	11
Mar	330	69	5
Apr	424	69	6

4.1.3.5 Orthophosphate phosphorus

Orthophosphate mean values ranged from 3 – 28 µg L^{-1}, with an overall mean for the lake being 10.0 ± 6.0 µg L^{-1}. These values varied from one station to another, with Malewa River Mouth (Station 3) and Sewage Discharge Point (Station 2) having relatively higher values (Figure 18).

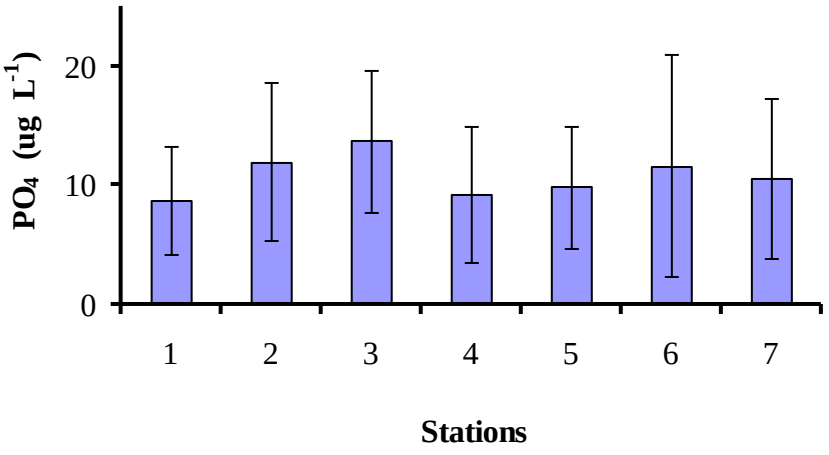


Figure 18: Spatial variation of mean (± SD) orthophosphate phosphorus

Mean ± SD orthophosphate phosphorus values observed was 9.2 ± 5.6 and 10.8 ± 6.3 µg L^{-1} for surface and bottom waters respectively, with wet season having the highest values. This followed the similar pattern to that of TP in terms of seasonality.

Wet season had relatively higher values than the dry season for orthophosphate which can be attributed to run off from the surrounding farms and waste water from the urban area.

Table 13: TN, NO_3, TP and Chlorophyll *a* t test values

	TN		NO_3		TP		Chl. *a*	
	Dry/wet	S/B	Dry/wet	S/B	Dry/wet	S/B	Dry/wet	S/B
df.	208	208	208	208	208	208	208	208
t	7.7	4.24	4.89	3.54	14.54	1.80	3.25	10.79
P	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.05	P<0.001	P<0.001

4.1.4 Algal biomass and primary production

4.1.4.1 Algal biomass

Mean overall ± SD chlorophyll *a* concentration was 32.6 ± 13.4 µg L^{-1} with surface water having higher values than bottom waters (Figure 19). There was significant variations on the mean values among stations ($F_{2.14}$ = 5.33, P < 0.001) (Table 8) with mid lake and Sewage Discharge Point (57.2 ± 13.2 µg L^{-1}) having the highest overall mean values while Hippo Point (Station 7) 28.7 ± 6.4 µg L^{-1}, and Crescent Island (Station 1) having the lowest algal biomass (Table 14).
Seasonally, there was a general decline of mean chlorophyll *a* concentration from December to April, with the wet season having relatively lower values than the dry season.

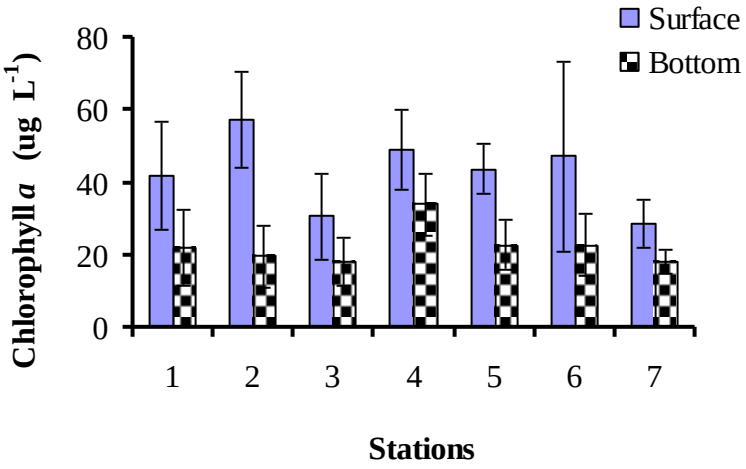


Figure 19: Spatial variation of mean chlorophyll *a*

Table 14: Mean monthly (± SD) values for chlorophyll *a*

	Dec 07		Jan 08		Feb 08		Mar 08		Apr 08	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	54.3	13.9	29.3	8.2	28.2	10.6	23.4	10.6	24.5	7.5
2	47.7	31	33.3	22.2	34.3	17.7	43.9	9	32.9	14.1
3	18.3	3.5	12.8	3.9	36.5	10.3	29.9	7	24.8	6.8
4	48.4	9.5	49	8.9	44.6	9.6	34.3	7.2	31.2	6.2
5	30.3	4.6	33.8	14.9	40	7.2	31.5	13.5	30.7	12.7
6	40.3	12.1	62.5	27.5	33.1	14.1	17.7	3.6	21.6	6.2
7	27.5	8.4	22.6	7.8	20.9	3.2	21	2.8	25.2	6.5

4.1.4.2 Primary production

Mean Gross Primary Production (GPP) values were highest at Crescent Island (Station 1) (473 ± 230 SD mg C m^{-3} hr^{-1}) while Hippo Point (Station 7) had the lowest value (266 ± 170 SD mg C m^3 hr^{-1}) with a mean value of (361 ± 98 SD mg C m^3 hr^{-1}) for the lake (Figure 20).

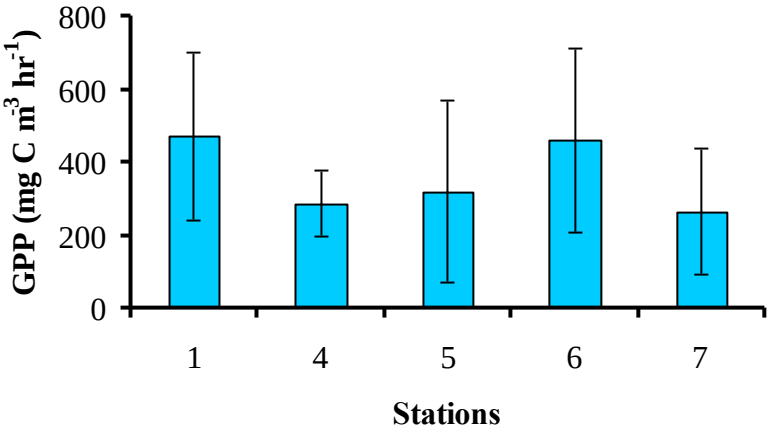


Figure 20: Spatial variation of mean primary productivity

4.1.5 Trophic State

Nutrient values obtained were used in an attempt to find how appropriate Carlson's trophic state index is to Lake Naivasha. The index classifies the lake as eutrophic with respect to total phosphorus and chlorophyll *a*. The result used the overall mean values for the lake during the study period as follows:

Total phosphorus calculations. TSI = 14.42 (In 39 + 4.15)

TSI = 59.4

Chlorophyll *a* calculations; TSI = (9.81) (In 42 + 30.6)

TSI = 64.8

This is based on Carlson's classification (Table 15)

Table 15: Carlson's Trophic State Index (TSI) classification

Trophic Index	Chlorophyll a	Total phosphorus	Secchi depth	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

The Lake is also eutrophic based on the mean concentrations of total phosphorus, chlorophyll *a* and secchi depth, using OECD classification as shown in (Table 16)

Table 16: OECD Trophic classification

Trophic category	Mean TP (mg m^{-3})	Mean yearly chlorophyll a (mg m^{-3})	Chlorophyll *a* maxima (mg m^{-3})	Mean yearly secchi disc trasparency (m)	Secchi disc trasparency minimum (m)	Oxygen % saturation
Utra – oligotrophic	4.0	1.0	2.5	12	6.0	<90
Oligotrophic	10.0	2.5	8.0	6.0	3.0	<80
Mesotrophic	10 - 35	2.5 – 8	8 – 25	6 – 3	3 – 1.5	40 - 89
Eutrophic	35 - 100	8 – 25	25 – 75	3 – 1.5	1.5 – 0.7	40 - 0
Hypertrophic	100	25	75	1.5	0.7	10 -0

4.1.6 WHO recommended guidelines

The mean values of critical physico - chemical parameters for survival of most fauna in Lake Naivasha were compared with WHO values. Dissolved oxygen values were found to range from 2.3 to 9.1 mg L^{-1} with a mean value of 6.0 mg L^{-1}. pH values ranged from 6.0 to 8.9 with a mean value of 8.0. Conductivity values ranged from 204 to 338 µS $cm^{-1.}$ WHO dissolved oxygen values for optimal survival of most aquatic life is between 5 and 9 mg L^{-1} and pH of between 6.5 and 8.5.

4.2 DISCUSSION

Results on dissolved oxygen and temperature from the main lake and Crescent Island showed that the lake is generally well mixed with stratification occurring occasionally at Crescent Island, with an oxycline occurring at between 2 – 3 m depth (Figure 7). These results are comparable with observations of Hubble (2000), Kitaka (1991) and Njuguna (1982). Temperature changes in aquatic ecosystems have an impact on conductivity values, with changes in temperature by 1 ^{o}C causing a 2 % change on the electrical conductivity UNEP/ WHO (1978). The high values of conductivity observed in Station 1 (Crescent Island), Station 2 (sewage) and Station 3 (Malewa River Mouth), can be partly attributed to the high surface water temperatures observed in these stations.

The mean temperature value for the lake was 21.8 ± 1.0 ^{o}C with stations towards the western side of the lake (Oseria and Hippo) having the lowest values while Malewa River Mouth, a shallow station recorded the highest values (Figure 6). Dissolved oxygen mean values were lowest at Crescent Island 5.4 ± 0.6 ^{o}C with the Main Lake showing higher values. There was weak stratification observed at Crescent Island, a deep station with a maximm depth of 12 metres. The sheltering effect of vegetation around and depth of the station prevent wind currents from completely mixing the water. Similar observations have been made by Litterick *et al* (1979), Njuguna (1982) and Kitaka (1991)

The levels of dissolved oxygen have an impact on the well being of fish and other aquatic organisms depending on other factors like temperature, pH, light, pollutants etc. At higher temperatures the capacity of water to dissolve oxygen decreases while the metabolic rate of fish increases causing more water to be pumped through the gills at a faster rate to supply the required oxygen. As a result of this toxic chemicals may come into contact with the gills at a faster rate, so that greater amount may enter the body within a given period of time. Lake Naivasha

has four commercial fish species namely; common carp, black bass, and 2 tilapia species (*Oreochromis leucostictus* & *Tilapia zillii*) all of which are able to tolerate oxygen levels to the lowest mean value of 4.7 ± 1.3 mg L^{-1} SD observed in April. However some of the bottom oxygen levels especially in Crescent Island, were quite low (2.5 mg L^{-1}) for these fish habitation.

Secchi disc transparency for the lake was quite low (41 cm ± 14 SD to 49 cm ± 14 SD) thus indicating high water turbidity. This was particularly so in the shallow stations, Sewage (Station 2) and Malewa (Station 3), where wind currents easily causes bottom sediments to be suspended in water. The frequent lake level fluctuations, mixing and soil erosion from the catchment and unsheltered shores of the Lake, greatly determine the turbidity of water in the lake. In this study the Lake was more turbid, when compared with Mwamburi *et al* (2007) 56 ± 11.4 cm, Malala and Mwamburi (2002) 67.6 ± 46 cm, Kitaka *et al* (2002 b) 126 cm, and Njuguna (1982) 76 – 227 cm (Table 6). Studies conducted in Lake Victoria showed that suspended material in water can clog the gills of fish and kill them (Ochumba, 1990). According to Ojuok *et al* (2007), the increased turbidity in Lake Naivasha will have an impact on the piscivorus black bass which depends on the clarity of water to find its prey. Changes in one organism ability to play their part in the food web can affect the entire lake ecosystem.

Conductivity of water is widely used as an indicator of ionic concentration. The mean value for the lake was 259 ± 23 µS cm^{-1} with Crescent Island having the highest value 312 ±15 µS $cm^{-1}$and Malewa the lowest 239 ± 17 µS cm^{-1}. These values do not vary so much from those observed by (Lind 1965; 250 µS/cm, Harper 1987; 259 µS cm^{-1}, Kitaka 1991; 220 – 297 µS cm^{-1}, Mwamburi *et al* 2007; 265 ± 8.7 µS cm^{-1}). These values are however different from those of

Njuguna (1982); 300- 347 µS/cm, Melack (1976); 311 – 353 µS cm^{-1} and Malala & Mwamburi (2002) ; 322 ± 70 µS cm^{-1}

The conductivity values observed were usually high during the dry season (265 ±24 SD µS cm^{-1}) and lower during the wet season (251 ± 21 SD µS cm^{-1}). This can be attributed to dilution effect from the river, rainfall falling directly into the lake and seepage in. However during the dry season solutes were concentrated by evaporation, thus the higher values.

Alkalinity also showed a similar pattern to that of conductivity, with a range of (52.2 ± 11.7 mg $CaCO_3$ - 82.5 ± 12. mg $CaCO_3$ SD) This is comparable with Malala & Mwamburi (2002), Mwamburi *et al* (2007) and Njuguna (1982).

The mean pH value for the dry season was 8.1 ± 0.2 while for the wet season was 7.8 ± 0.5 showing only a small difference. The pH is affected by the rains due to the dilution effect as was observed in March & April, when the pH was low (Figure 9). The pH of bicarbonate buffered water is also dependant on the concentration of carbon dioxide present, where an increase of CO_2 will make the water more acidic.

Different levels of the various form of nitrogen were recorded in the lake with TN mean ± SD value of 304 ± 96.3 µg L^{-1} with surface and bottom water mean ± SD being 269 ± 113 and 340 ± 129 µg L^{-1} respectively. These values are however lower from those recorded by Njuguna (1982); 1106 – 2509 µg L^{-1} and Kitaka (1991). Nitrate - nitrogen mean ± SD values was 63 ± 31 µg L^{-1}, while ammonium nitrogen values was 128 ± 46 µg L^{-1}. Both Nitrate and ammonium nitrogen showed seasonal variation with the wet season having higher values in comparison with the dry season, while bottom values were higher than surface in all the

stations. Malewa River Mouth and Crescent Island had the highest nitrate nitrogen mean ± SD bottom values (113 ± 60 µg L^{-1} and 99 ± 56 µg L^{-1}). The high value at Crescent Island can be associated with temporal stratification leading to deoxygenation at the deeper levels (Figure 7) and hence release of nutrients into the water column. This is consistent with observation of Njuguna (1982), Hubble & Harper (2001 & 2002 b).

The amount of various forms of nitrogen in the water is dependent on a number of factors such as: spatial distribution of degradable organic matter, diffusion of the decomposed products, and presence of rooted macrophytes, Concentration of oxygen, ammonium and nitrate already in the water column Herbert (1999). Phytoplanktons are capable of taking up a wide range of nitrogen from water but generally prefer ammonium to nitrate which is driven passively by diffusion into the cell.

Total phosphorus (TP) was highest at Malewa River mouth (Station 3) and Sewage (Station 2). For station 3, this can be attributed to fertilizers and organic material being discharged through the river especially during the wet season. This is evidenced by the high TP values observed during the wet season and also low secchi depth observed at this station. The high TP values in station 2, can be attributed to discharge of partially treated sewage effluents from Naivasha municipality sewage plant. Kitaka *et al* (2002 b), found most of the phosphorus entering the lake to be bound to the sediment particles. Total phosphorus is important in stimulating algal growth and other aquatic plants. High algal biomass was observed at sewage (Station 2) 38 ± 22.1 µg L^{-1}. Kitaka *et al* (2002 b) also found a very strong correlation between algal biomass and TP. Hubble & Harper (2002 b) also observed that nutrient input into the lake can be attributed to riverine transport, with flow and nutrient load being regulated by climatic and anthropogenic factors.

Algal biomass showed seasonal variations, with the dry season having higher values. Algal growth is very much dependant on the amount of light available for photosynthesis to take place as well as availability of nutrients. The high algal biomass in Mid Lake (Station 4) can be attributed to nutrient flow through river Malewa extending to this point. Sewage Discharge Point (Station 2) also had high algal biomass corresponding to the high nutrient levels especially total phosphorus and ammonium nitrogen. The concentration of algal biomass observed in this study was within the same range to Kitaka's (1991); 26.5 – 54.7 µg L^{-1} for Safariland station, but higher than that observed by Njuguna (1982); 12.65 – 26.08 µg L^{-1}.

Studies on algal biomass in other tropical water bodies such as Lake Victoria recorded chlorophyll *a* values of 9.3 – 71.5 µg L^{-1} Lung'ayia *et al* (2000), which are within the same range as the concentrations for this study.

Lake Naivasha is eutrophic according to the classification of Carlson (1997) and OECD (1982). This means that the Lake water is enriched with nutrients, with the highest values being recorded from the point sources stations 2 and 3 (Sewage discharge Point and Malewa River Mouth respectively).
Kitaka *et al* (2002 b) found the lake to be eutrophic during a normal rainfall period September 1998 to February 1999 with respect to TP (46.9 µg L^{-1}), Chlorophyll *a* 11.5 µg L^{-1} and Secchi depth 1.26 m according to OECD (1982) classification. This study found Lake Water transparency to be half what it was in 1997/98 while chlorophyll *a* is 3 times. This is an indication that the lake is heading towards a hyper eutrophic state.

Increased nutrient enrichment of the lake means that there is more algal growth as was observed at Mid Lake (Station 4) where there was a green scum on the surface

of the water thus lowering the recreational value of the water as well as giving the water bad taste and odour. Other consequence of increased algal bloom is that as the algae die they fall to the bottom of the lake where decomposition by bacteria uses a lot of oxygen leading to anoxic condition in the bottom waters.

Mean gross primary production for the lake was 361 ± 98 mg $C/m^3/hr$ with Crescent Island (Station 1) having the highest values 473 ± 230 mg $C/m^3/hr$ SD and Hippo point (Station 7) the lowest 266 ± 170 mg $C/m^3/hr$ SD**.** The high values observed at crescent Island can be attributed to low turbidity (High euphotic zone), which is favourable for photosynthesis (Figure 3). Depth profile values indicated that subsurface values up to 1m were highest and declined with depth. Hubble & Harper (2001) attributed this to photo inhibition and light attenuation with productivity being optimal between 0.25 and 0.5 m depth.

Comparison of the physico-chemical information obtained show that bottom dissolved oxygen concentration especially at the deep station Crescent Island (2.3 mg L^{-1}) was not within WHO guidelines for aquatic life. However the mean dissolved oxygen value of 6 mg L^{-1} for the whole lake was within WHO guidelines. The low oxygen levels can cause stress on benthic invertebrates which are less mobile, and also decrease the habitat available for optimal life for many aquatic organisms. The prolonged anaerobic conditions lead to chemical reduction of some elements and compounds which result to accumulation of carbon dioxide and ammonia which can increase the toxicity of the bottom waters.

The low levels of oxygen observed contribute to release of phosphorus from the sediments which enhance proliferation of algal growth.

The other parameters were however within WHO values for aquatic life.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In an attempt to assess the physico – chemical status and algal biomass of Lake Naivasha, representative sampling points were identified and physico-chemical and algal biomass observations were made. The data obtained was analysed and statistical inferences made. Based on the findings, conclusions and recommendations were made.

5.2 Conclusion

The nutrient levels in the lake are high, showing that the Lake is eutrophic with respect to total phosphorus and algal biomass (chlorophyll *a*), with significant seasonal differences being observed. Two point sources for these nutrients were identified as Sewage Discharge Point (Station 2) and Malewa River Mouth (Station 3). Their contribution to Lake's nutrient enrichment was prominent during the wet season when there was an increased river discharge and sewage effluent.

Algal biomass showed significant seasonal differences with the dry season having higher values than the wet season. This can be attributed to low turbidity during dry season, which allows more light into the water (high euphotic zone) which is necessary for the phytoplankton growth.

Temperature, pH, Dissolve oxygen and conductivity showed significant seasonal differences, indicating that environmental conditions have an impact on these parameters.

The physico-chemical parameters critical for survival of aquatic life of the Lake are within WHO recommended level except for bottom dissolved oxygen at the deep station, Crescent Island.

Nutrient enrichment of the lake at Sewage area can be partly attributed to solid and waste water from urban developments. The contribution of nutrients from intensive horticultural farming around the lake, could not however be conclusively assessed due to their diffuse sources. However run off during wet season find their way into the lake. This enriched lake water favoured rapid growth of the phytoplankton as was observed at sewage (Station 2). Subsequent death and decomposition of these phytoplankton lead to anoxic conditions, which can lead to periodic fish kills as was observed recently.

These together with natural lake level fluctuations negatively affect the water quality and availability, and hence the biota that lives in this water. The turbid water conditions are unhealthy to piscivorus black bass which depends on its visual ability to capture the prey (Ojuok *et al* 2007). The biota in the lake would therefore eventually change in favour of those organisms that are more tolerant to current conditions in the Lake. The biodiversity of the lake will also be affected as a result of human activities around the Lake and the catchment

An increasing supply of limiting nutrients such as phosphorus and nitrogen from non point and point sources will cause Lake Naivasha to remain eutrophic to hyper eutrophic, unless strict management measures are put in place

5.3 Recommendations

(i) An efficient monitoring system for nutrients and other chemicals entering into the lake should be established by having a coordinated research involving research institutions, universities and non governmental organisations.

(ii) Naivasha Municipal council in partnership with other stakeholders managing urban development around Lake Naivasha and the catchment

should develop programs for managing solid waste, waste water an.cod soil erosion.

5.4 Future Research

(i) More studies to be done on the impact of common carp on the water quality, fishery and general ecology of the lake

(ii) More research on lakes sustainable water utilization or the safe abstraction during different cycle periods.

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