

**INFLUENCE OF WATER LEVEL FLUCTUATIONS ON THE PHYSICO- CHEMICAL
PROPERTIES AND PLANKTON COMMUNITIES STRUCTURE IN LAKE NAKURU**



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the Award of Master of Science Degree in Limnology of Egerton University**

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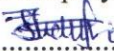
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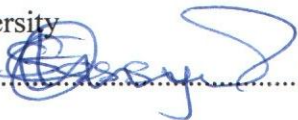
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DEDICATION

To my parents Samwel and Salina Chepkiyeng, brothers Kenneth, Ronald and Mathew, sisters Rosebelah and Dorine and my beloved husband Gilbert for their inspiration and tireless moral support throughout my study period.

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ABSTRACT

Variations in the rainfall pattern in the eastern arm of Mau forest catchment as a result of its deforestation and climate change phenomenon have caused large changes in water quantity flowing into Lake Nakuru thereby affecting its biota. The main objective of this study was to determine the effects of water level fluctuations on the physico-chemical properties and plankton diversity and biomass in Lake Nakuru. This work makes a contribution to the knowledge on the ecology of the saline-alkaline tropical aquatic systems. Three sampling points were chosen at 00° 20.177'S, 036° 05.628'E (North), 00° 21.387'S, 036° 05.519'E (Central) and 00° 22.990'S, 036° 05.327'E (South). Triplicate samples were collected from each site fortnightly for six months, between January and June 2010. Water level was measured using a calibrated dip stick and physico-chemical properties such as temperature, dissolved oxygen, conductivity and salinity were measured *in situ* using their respective portable meters. Integrated water samples were taken in triplicate using a Schindler sampler and transferred into acid-washed plastic sample bottles for analysis of alkalinity and nutrients. Appropriate plankton nets were used to take phytoplankton and zooplankton samples. Plankton were identified using appropriate keys and their diversity, abundance and biomass determined. The data generated was analyzed using Kruskal Wallis Test with those parameters which were significantly different being further analyzed using Mann-Whitney U test. Phytoplankton community was composed of cyanophytes, euglenophytes, chlorophytes and bacillariophytes with the cyanophyte *Arthrospira fusiformis* being the most dominant species contributing over 74.9% of cyanophyte abundance. The zooplankton community comprised mainly three groups of Ciliata, Rotifera and Crustacea whose total abundance ranged from 3.46×10^3 to 5.80×10^5 ind/L. Pearson correlation coefficient showed a significant inverse correlation between water level and salinity, total suspended solids, total phosphorus, soluble reactive phosphorus and nitrate concentrations. Plankton diversity, abundance and biomass were strongly influenced by the changing water level directly or indirectly through the changes in water physico-chemical properties, especially secchi depth, salinity and nutrients. Therefore, there is need for continuous monitoring of the lake plankton dynamics in order to understand the effects of climate variation on its ecology and develop the right mitigation and management measures.

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LIST OF ABBREVIATIONS

AFDM	Ash free dry mass
AM	Ash mass
Chl <i>a</i>	Chlorophyll <i>a</i>
DO	Dissolved oxygen
NH ₄ -N	Ammonium nitrogen
NO ₂ -N	Nitrite nitrogen
NO ₃ -N	Nitrate nitrogen
PA	Phenolphthalein alkalinity
SRP	Soluble reactive phosphorus
SPSS	Statistical Packages for Social Science
TA	Total alkalinity
TP	Total Phosphorus
TSS	Total Suspended Solids

CHAPTER ONE

INTRODUCTION

1.1 Background information

Endorheic saline-alkaline Rift Valley lakes are highly sensitive water bodies to climate changes with small changes in hydrological budget of their catchment being reflected rapidly and directly on changes in their physico-chemical and biological characteristics. These lakes are normally located in arid or semi-arid habitats and therefore undergo water losses through evaporation due to the high temperatures in their localities. Anthropogenic activities such as deforestation, human settlements, agriculture and urbanization are common in most of the catchment regions of such water bodies due to the high population growth, a phenomenon that negatively impact these aquatic systems (Williams, 2002). Such anthropogenic activities alter the natural environment and may cause variation in weather patterns within the catchment, enhance pollution and leads to changes in water quantity and quality of the aquatic systems. Such effects have been observed in the shallow lakes in the endorheic drainage basins of the Rift Valley which appear to be greatly affected by seasonal and stochastic inter-annual fluctuations in rainfall and water input (Talling, 2001). Variations in the rainfall pattern in the eastern arm of Mau forest catchment have caused large changes in water quantity flowing into Lake Nakuru thereby further affecting the water chemistry of this lake. The massive destruction of its catchment forest has accelerated the changes in the discharge of the rivers that flow into this lake. For example, the deforestation of the River Njoro watershed has resulted to changes in water quantity and deterioration of the water quality that flows in this river (Shivoga *et al.*, 2007). These changes have made the lake an extreme ecosystem in which the intervals of dryness alternate with periods of high water levels.

Lake Nakuru is one of the world's most productive natural ecosystems with low biodiversity but very high plankton abundance which has attracted various ecological studies; Vareschi (1978, abundance and feeding of lesser flamingos); Vareschi (1982, abiotic factors and primary production) ; Vareschi and Jacobs (1984 and 1985, production and energy flow); Melack (1979 and 1981, phytoplankton photosynthesis); Finlay *et al.* (1987, soda lakes' microorganisms); Yasindi *et al.* (2000, ciliated protozoa); Oduor and Schagerl (2007 and 2008, plankton community structure). Growth and population dynamics of organisms in any given ecosystem is

dependent on the prevailing physical, chemical and biological parameters operating in such ecosystem. Melack (1979) observed such a dependence in his study of Lake Simbi in which the phytoplankton abundance and production rates were observed to be strongly influenced by physical (e.g. irradiance, mixing and temperature), chemical (e.g. nutrient supply rates) and biological (e.g. grazing by zooplankton and biodegradation by microorganisms) factors operating in the water body. Changes in these variables have profound effects on both the diversity and biomass of organisms in the habitat resulting to changes in the whole ecosystem. Such changes like the increased salinity levels in a water body would lead to decrease in biodiversity due to the decrease in species richness of the particular habitat in question (Williams *et al.*, 1990).

Lake Nakuru is a highly eutrophic system with high amounts of phosphorus but relatively low nitrogen concentrations (Ballot *et al.*, 2004; Oduor and Schagerl, 2007). Its primary producer community is mostly dominated by the cyanobacteria which form the base of the food webs in this lake (Ballot *et al.*, 2004; Oduor and Schagerl, 2007). The dominant primary producer in this lake is the Cyanobacterium *Arthrospira fusiformis* Voronichin, which though has been suspected to be a nitrogen fixer, its nitrogen fixing ability has not been conclusively confirmed. *A. fusiformis* is also the main food of the lesser flamingos *Phoeniconaias minor* Geoffroy, the fish *Oreochromis alcalicus grahami*, the copepod *Lovenula africana* Daday, rotifers, chironomids and ciliates (Vareschi and Jacobs, 1984 and 1985; Finlay *et al.*, 1987; Yasindi *et al.*, 2002). Fluctuations in phytoplankton biomass and changes in the plankton species diversity have been observed in this lake for some times with the major changes observed in 1970's being associated with hydrological changes and the resultant fluctuations in salinity levels (Vareschi, 1982). Other studies have shown that nutrients levels, salinity and alkalinity fluctuations influence phytoplankton biomass and diversity dynamics in Lake Nakuru as shown by changes in temporal biomass and species diversity recorded in the studies (Oduor and Schagerl, 2008) and (Okoth *et al.*, 2009).

Generally, high nutrient concentrations are known to cause phytoplankton blooms. Increases in nutrient level are associated with decreased water level concentrating them and nutrient decreases are a result of increased water level diluting them. The blooms formed are sometimes associated with phytotoxins production which has been suspected to cause massive mortalities of

the flamingos in the 1990s in Lake Nakuru and other alkaline-saline lakes of Kenya (Ballot *et al.*, 2004; Krienitz *et al.*, 2005; Kotut *et al.*, 2006). Harmful microcystin strains and anatoxin-a were detected during these studies.

These observations therefore show that large fluctuations in water quantity may pose great danger to the existence of Lake Nakuru as a centre of biodiversity and tourist attraction. The conservation of its biodiversity would be enhanced through continuous monitoring of its plankton community since they are very sensitive to changes in the physico-chemical variables which reflect changes in hydrology. However, reports on the studies on effects of water level fluctuations on the physico-chemical parameters and plankton dynamics are very few. The aim of this study was to investigate the effects that changes in water level, measured as the lake water depth, has on the water chemistry and plankton community dynamics of the lake. Other than for the sensitivity response of the plankton community to the abiotic changes, this study is also important because plankton communities form the base of energy requirements that supports this ecosystem which also has a very poor macrophyte growth. The poor macrophyte growth, coupled with limited inflow of water from its rivers that could wash organic matter from the catchment, implies that autochthonous energy source is more important in supporting the ecology of this aquatic ecosystem.

1.2 Statement of the problem

Lake Nakuru is one of the world's famous bird sanctuaries, attracting thousands of tourists annually thereby bringing in revenue that supports Kenya's economy. Changes in discharge of the rivers flowing into this lake are the results of the massive destruction of the forests in the catchment region. This affects the volume of water in the lake and is reflected through variations in the water level and the chemical characteristics of the lake such as the salinity levels. Such abiotic variables changes in turn influence the survival of different plankton species such as *Arthrospira fusiformis*, *Lovenula africana* and the only fish found in the lake, *Oreochromis alcalicus grahami*. The extent to which such changes affects the biota in terms of their diversity and biomass has, however, not been well documented. This study therefore aimed at establishing the extent to which the fluctuations in water level in Lake Nakuru affect the biota in this lake through its influence in the chemistry of the lake water

1.3 Objectives

1.3.1 Main objective

The main objective of this study was to determine the effects of water level fluctuations on the physico-chemical properties and plankton diversity and biomass in Lake Nakuru.

1.3.2 Specific objectives

1. To determine temporal and spatial fluctuations in the water level in the lake.
2. To determine temporal and spatial changes in physico-chemical variables and their relationship with the water level in the lake.
3. To determine temporal and spatial changes in diversity and biomass of plankton communities and their relationship with the water level and physico-chemical variables in the lake.

1.4 Hypotheses

1. There is no significant temporal and spatial variation in the water level in the lake.
2. There is no significant temporal and spatial change in the physico-chemical variables with the changes in water level in the lake.
3. There is no significant temporal and spatial change in plankton diversity and biomass with the changes in water level and physico-chemical variables in the lake.

1.5 Justification

Lake Nakuru provides a sanctuary for the conservation of biodiversity and is of immense economic value to Kenya through tourism. The lake is fed mainly by the Rivers Njoro, Makalia and Nderit whose head waters are in the eastern Mau forest which is its main catchment area. The recent massive deforestation of this catchment and climate change has led to a great change in its rainfall pattern and the flow regime of these rivers. The rivers have become highly seasonal resulting into major fluctuations in the water quantity being discharged into the lake. Such large flow regime changes are likely to affect the functioning of the lake's ecosystem. Changes in phytoplankton together with those of the zooplankton influence the general ecology of the lake. The lives of organisms at the higher trophic levels like the flamingos and the pelicans are consequently affected through the energy flow. The information on the plankton dynamics in relation to changes in water quantity and quality is useful in figuring out the effects of the

catchment degradation on the lake's biodiversity and productivity. This work therefore not only makes a contribution to the knowledge on the ecology of the saline-alkaline tropical aquatic systems which is limited in the academic fora, but also contributes to information used in the proper holistic management of aquatic systems which also involves caring for their catchment areas.

1.6 Limitation and scope of the study

This study only focused on the influence of water level fluctuations on the physico-chemical parameters and plankton communities structure in Lake Nakuru. Data on catchment rainfall was used to show the effects of the catchment degradation on the lake water levels. Rainfall pattern in the catchment was considered as a direct influence on the water flow in the rivers emanating from these catchments. Data on the discharge of the inflowing rivers, micro-nutrients, heavy metals and heterotrophic nanoflagellates were outside the scope of this study.

LITERATURE REVIEW

2.1 Occurrence and distribution of saline-alkaline Kenyan Rift Valley lakes

Saline lakes are inland water bodies common in arid and semi-arid basins of the world and having salt concentration of at least 3gL^{-1} . According to Williams (1996), these lakes vary in sizes, salinity levels, ionic composition, flora and fauna. The global volume of inland saline water ($85,000\text{ km}^3$) is only slightly less than that of freshwater ($105,000\text{ km}^3$) (Shiklomanov, 1990). Most African saline lakes are found on the floor of the African Great Rift Valley in Eastern Africa. Some are also located in the North of Chad in the Kanem region and a few in Southern Africa. In Kenya, the saline lakes are mostly located within the floor of the Rift Valley and include the lakes Sonachi, Magadi, Elementaita, Nakuru and Bogoria. The only saline-alkaline lake out of the Rift Valley in Kenya is Lake Simbi, located close to Lake Victoria. These lakes are more in number than freshwater lakes and therefore they often dominate the landscape and provide critical habitats for endemic species, breeding and migratory birds. They have significant economic, ecological, biodiversity, and cultural values (Williams, 1996). Their size and salinity fluctuate whenever the balance between hydrological inputs (precipitation, surface runoff, and groundwater inflows) and outputs (evaporation and seepage losses) changes. These changes are brought about by climatic variations and/or anthropogenic activities. Many human activities threaten these lakes, for instance, surface inflow diversions, mining, pollution, introduction of exotic species and anthropogenically-induced climate changes (Williams, 2002).

Surface freshwater inflow diversions can lead to decrease in the amount of underground water transpired by deep-rooted plants or following the addition to groundwater by excess irrigation water may lead to a rise in water table together with movement of dissolved salts towards the surface (Williams, 2002). Increase in salinity may lead to changes in the natural character of the water bodies, a feature which is more pronounced in semi-arid and arid regions due to the enhanced evaporation as a result of high temperatures. It can also cause a replacement of a less halotolerant biota by a more halotolerant one and a decrease in biodiversity. Changes in the catchment area such as deforestation, overgrazing by livestock and excessive clearance of the

natural vegetation in the catchment areas may enhance salinisation of the receiving water body through soil erosion that has salt deposits, increased sediment load that ends being deposited by the rivers into the lake. Moreover, the removal of the natural vegetation interferes with such processes as precipitation and evapo-transpiration causing changes in temperature and rainfall patterns (timing and amount is altered). The hydrological budget is affected and consequently the natural character of the salt lakes may also be altered.

2.2 Lake Nakuru water level fluctuations

El nino Southern Oscillation (ENSO), increased atmospheric carbon dioxide, depletion of ozone layer, deforestation and dust are factors that lead to human induced climate variations (Williams, 2002). The climatic factor of greatest economic significance in Africa, year-to-year and month-to-month is rainfall variations which are large and frequent in Kenya (Olago et al., 2003). The 1997 to 1998 worst floods experienced in Kenya caused by El-nino led to increased surface area of Lakes in the rift valley. Lake characteristics are intricately tied to the climate of the region where they are located with their water levels and chemical composition reflecting the balance between hydrologic inputs and outputs and the nature of the soil in the catchment areas through which their inflowing rivers pass (Mason *et al.*, 1994). Lake Nakuru receives approximately 800 mm of rainfall annually and experiences an evapotranspiration rate of 96.8% of the annual basin rainfall such that only 3.2% of the annual rainfall is available to recharge the basin (Vareschi, 1978; Raini, 2002). These climatic variations cause large changes in water level and salinity of the lake. This occurs on annual, decadal and longer time scales leading to hydrochemical changes in the lake water which in turn affect the physiological response of its biota. The species composition and biomass of the lake biota are affected and this in turn affects the ecology of the lake (Melack and Kilham, 1974; Talling, 2001).

Lake Nakuru has had wide fluctuations in its water level and even completely dried up seven times in the past seventy years (Vareschi, 1978; Vareschi, 1982). A long term mean depth of 2.5 m and maximum depth of 4.5 m was cited by Vareschi (1982) between the years 1925-1979. The recent mean monthly lake depth from 1992 to 2002 was 1.01 m (range < 0.1 to 4.4 m) (Raini, 2002). Of late, the rainfall patterns within the lake and its catchment have shown great variations from the normal bimodal pattern (long rains in March-May and short rains in October-

November) to unpredictable pattern. For instance, a prolonged dry spell which led to the drying of the inflowing rivers was received in the year 2008-2009 causing a decrease in the lake levels. In 2010, the lake experienced a lot of rainfall with increased discharge in the inflowing rivers thereby increasing the lake level from 40 cm in January 2010 to a maximum depth of 200 cm in May 2010 with a mean depth value of 114 cm. These changes in the weather pattern are associated climate change and the degradation of Mau forest area through deforestation which is the main catchment basin for the lake from an initial 400,000 ha to 48,000 ha in 1986 and 16,500 ha in 2005 (Danida, 2006). Experts have warned that continued destruction of this forest will lead to a water crisis that could extend beyond the country's borders (Boer, 2009). The change in the water level causes changes in the solutes concentration in the lake, with the salinity level being the major variable affected by these changes and eventually the biota in the lake.

2.3 Influence of salinity on biodiversity

The major challenge to any organism in a saline environment is the initial physiological problem of osmoregulatory stress, which once they overcome, the organisms may then be able to occupy a wide salinity range. Negative correlation has been observed between species richness and salinity levels by various authors (Hammer, 1986; Lancaster and Scudder 1987; Kebede and Willén, 1998) which shows that salinity level is an important determinant of fauna and flora in saline water bodies (Remane and Schlieper, 1971). Changes in salinity levels in Lake Nakuru have been observed to influence the existence and biomass of the main primary producer *A. fusiformis* and copepod *L. africana* (Vareschi, 1982; Vareschi and Jacobs, 1985; Schagerl and Oduor, 2008). However, other factors such as predation, food availability, competition among others are also known to come into play, when considering salinity effects on the biota as observed in a study of macroinvertebrates composition in the Australian salt lakes. One study by Williams (1984) showed that salinity level *per se* is relatively unimportant in determining regional distribution and composition of macroinvertebrate species in a particular lake.

2.4 Phytoplankton community of saline lakes

In tropical lakes the principal driving force of the phytoplankton structure appears to be the hydrological cycle which influences the chemical dynamics and nutrients content of lakes and eventually their biota (Sondergaard *et al.*, 1990). This cycle is dependent on the hydrological

budget which has especially a strong influence on the chemistry of shallow endorheic saline-alkaline lakes which experience larger changes as compared to exorheic lakes (Garcia *et al.*, 1997). Large changes in salinity do affect ecosystem structure and functioning (Herbst and Blinn, 1998; Nielsen *et al.*, 2003; Schallenberg *et al.*, 2003). Most saline lakes are dominated by cyanobacterial group of phytoplankton. Lake Nakuru's phytoplankton community is dominated by the cyanobacteria *Arthrospira fusiformis* (Vorochinin) Komarek, *Anabaenopsis arnoldii*, *A. abijatae*, *Synechococcus minutus*, *Synechocystis* sp, *Monoraphidium minutum*, *Anomoeoneis sphaerophora*, *Navicula elkab* and *Nitzschia frustulum* (Vareschi, 1982; Ballot *et al.*, 2004; Schagerl and Oduor, 2008). The filamentous cyanophyte *Oscillatoria* spp have also been observed in Lake Nakuru though its occurrence in this lake is rarely reported. This species had been reported in the saline-alkaline Lake Bogoria by Harper *et al.*, (2003)

Many of these cyanobacterial species are well adapted to the prevailing physical and chemical conditions in this lake. Such conditions include the high alkalinity, high pH (between 9.5 and 10.3), high salinity, warm temperatures and high irradiance. These conditions support rapid growth and development of some of these species, especially *A. fusiformis* resulting in its high biomass. The high biomass is also as a result of high nutrients concentrations in the lake (Grant *et al.*, 1990). This high phytoplankton biomass supports large numbers of zooplankton, zoobenthos and waterfowls which form the lake's main primary consumers (Vareschi and Jacobs, 1984). They also contribute to the detritus (bacteria's food) when they die and settle at the bottom. The lesser flamingoes depend on the cyanobacterium *A. fusiformis* as their preferred food (Tuite, 1979). These flamingos graze on the thick suspensions of the phytoplankton biomass dominated by *A. fusiformis*. It is estimated that a population of about one million birds can harvest about 180 tonnes of the cyanobacterium from the lake in one day (Vareschi, 1982). The fish *O. alcalicus grahami* introduced into Lake Nakuru in 1952, 1959 and 1962 to control mosquito larvae is the other major grazer on *A. fusiformis*. Vareschi and Jacobs (1985) found that zooplankton grazed 57%, flamingos filtered 34% and the fish consumed 9% of the phytoplankton biomass on a daily basis. This implies that zooplankton and flamingos have significant effect on the *A. fusiformis* biomass. These zooplankton include the ciliates, rotifers, copepods and cladocerans

2.5 Limiting nutrients for phytoplankton growth in Lake Nakuru

Nutrient availability and seasonal fluctuations in nutrient supplies have often been used as principal factors controlling phytoplankton abundance in tropical African lakes (Talling and Talling, 1965; Talling, 1966; Moss, 1969; Peters and MacIntyre, 1976; Melack, 1981; Njuguna, 1988). Phosphorus and nitrogen are the main nutrients that tend to limit growth of phytoplankton in most water bodies. Studies in the saline-alkaline lakes of Kenya have shown there is low total nitrogen to total phosphorus ratio which implies that phosphorus is available in high amounts (Ballot *et al.*, 2004; Oduor and Schagerl, 2007). This suggests that nitrogen may be an important limiting nutrient for the growth of aquatic flora in these lakes. One source of high phosphorus concentration in these lakes is likely to be the internal loading from the sediments. This is enhanced by the high phytoplankton biomass whose decomposition on the sediment surface creates an anaerobic condition (Oduor and Schagerl, 2007) which favours the dissolution of adsorbed phosphorus from the sediments into the water phase. In addition some phosphorus in Lake Nakuru may come from non-point pollution sources such as the runoff from agricultural farms within the catchment (Shivoga, 2001). Sources of nitrogen could be the droppings of the large mammals and birds in the lake which are washed into the lake water by the runoffs. Furthermore, presence of nitrogen fixing bacteria such as *A. arnoldii*, *A. abijatae* and *Anabaena* *sp* could be the other nitrogen contributors into the lake (Ballot *et al.*, 2004). Water level fluctuations influence the available nutrients through internal loading, runoff from agricultural lands with poor management practices via the river discharge.

2.5.1 Nitrogen cycle

The nitrogen cycle is one of the complex biochemical cycles where various chemical forms of nitrogen are altered by nitrogen fixation, assimilation, nitrification and denitrification. These processes are mediated by microbial activities whereby bacteria oxidize and reduce nitrogen while photosynthetic organisms assimilate, utilize and build complex molecules from the oxidized/reduced species formed by the bacteria (Wetzel, 1983). Larger animals have a very small role in the N cycle, other than that of excretion of ammonia compounds. However, when bacteria and algae are extensively grazed, relative populations of these species are shifted, altering the amount of nitrogen species produced and assimilated. Extensive bacterial fixation and denitrification occur at the sediment-water interface. Nitrification occurs in the aerobic zone

(epilimnion) while denitrification occurs in anaerobic environments, either in the sediments or in the hypolimnion in eutrophic lakes such as Lake Nakuru. Such a complex cycle is likely to operate in Lake Nakuru due to its high microbial density as found in other studies (Kilham and Kilham, 1990) and the daily changes in its oxygen level from almost an anaerobic condition in the evening and night times, and the very high aerobic state around mid-day due to the high photosynthetic rates recorded in the lake (Oduor and Shagerl, 2007; Melack, 1979). Such a cycle implies that even though Lake Nakuru may appear to be suffering from nitrogen deficiency there could always be adequate supply of nitrogen through such activities supplying enough nitrogen to support high phytoplankton growth that is witnessed in this lake.

2.6 Nutrient influence on phytoplankton community

Occurrence of cyanobacterial blooms have been reported worldwide being associated with high nutrient concentrations (eutrophication) (Pear, 1996; Oliver and Ganf, 2000). Low ratio of nitrogen to phosphorus has been suggested as a major factor favouring cyanobacterial dominance (Smith, 1983; Ballot *et al.*, 2004; Oduor and Schagerl 2007) with the cyanobacterial species that are likely to be nitrogen fixers being favoured to thrive. The presence of *Anabaena sp* and *Anabaenopsis abijatae* in Lake Nakuru has been associated with low nitrogen levels because they are nitrogen fixers (Ballot *et al.*, 2004). However, other studies have found little evidence that the low ratio is important for cyanobacterial dominance (Jensen *et al.*, 1994; Scheffer *et al.*, 1997). A recent study comparing three Kenyan lakes including Nakuru, Elementaita and Bogoria indicated that *A. fusiformis* occurrence coincides with both elevated nitrate concentrations (Shagerl and Oduor, 2008). Though no conclusive evidence has been adduced to support or deny the ability of *A. fusiformis* in fixing atmospheric nitrogen, many authors have suggested the likelihood of this species being capable of nitrogen fixation, a feature that the studies by the two authors also suggest.

2.7 Zooplankton community of saline lakes

Zooplankton community is very important in the energy flow within the lake through their feeding relationships. They feed on phytoplankton and benthos which are in turn the food for other higher trophic level animals. They also contribute to the nutrient pool through their excretion and when they die they are acted upon by microbes to release nutrients. The lake have

low species diversity and high abundance of organisms (Vareschi and Jacobs, 1985; Yasindi *et al.*, 2002). The zooplankton community of Lake Nakuru is dominated by the macrophagous rotifers *Brachionus dimidiatus* Bryce, *B. plicatilis* Müller and *Hexathra jenkiniae* (De Beauchamps). Other zooplankton species found here include, the copepod *Lovenula africana* (= *Paradiaptomus africanus*) Daday, several ciliate species, a few insect species in the order Heteroptera represented by corixids (*Micronecta jenkiniae* Hutchison, *M. scutellaris* Staal, and *Sigara kilimadjaronis* Kirk) and notonectids (*Anisops* var. Fieb) (Vareschi and Vareschi, 1984; Finlay *et al.*, 1987; Yasindi *et al.*, 2002; Harper *et al.*, 2003). The copepods feed on algae and ciliates which in turn are fed on by fish and the greater flamingos. The ciliates feed on algae (nanoplankton) and bacteria. The rotifers feed on algae, bacteria, and detritus and in turn, they are fed on by copepods and fish. The zoobenthos feed on detritus and organic ooze (Vareschi and Vareschi 1984; Finlay *et al.*, 1987; Moreau *et al.*, 2001; Yasindi *et al.*, 2002). The abundance and biomass of zooplankton are influenced by both the physico-chemical parameters and phytoplankton diversity and biomass in a given water body.

The identified zooplankton communities are not all present in the system at the same abundance level all the time. Instead changes in community structure may be observed making the species appear to be undergoing succession pattern. Such a succession of species is regulated by the availability of food, availability of oxygen, toxic products of decay, competition and predator-prey relationships (Laugaste *et al.*, 2007). Studies on the ecology of Lake Nakuru show that the biomass of the copepod *L. africana* changes in response to the changes in the level of salinity and availability of food (Vareschi and Vareschi, 1984). This species was absent in 1974 and 1975, and was found at very low biomass in part of 1976. This was because there was decline in the water quantity and concomitant increase in the salinity and alkalinity levels eliminating them (Vareschi and Vareschi, 1984). The salinity range that favours the growth of this copepod according to LaBarbera and Kilham (1974) is below 15,000 $\mu\text{S}/\text{cm}$ which was exceeded in 1974 ($\sim 24,000 \mu\text{S}/\text{cm}$) accounting for its absence in that year. The rotifer *Brachionus dimidiatus* which was dominant in 1972/73 was outnumbered by *B. plicatilis* throughout most of 1974 to 1976 during high salinity periods ($> 20\%$) while *Hexarthra jenkiniae* occurred in very low numbers.

The work by Yasindi *et al.* (2002) showed that the abundance of ciliates in the lake is higher than in oligotrophic and/or temperate waters. The small bacterivorous ciliates, *Cyclidium* were numerically dominant when *A. fusiformis* was dominant, but the large ciliate *Condylostoma* formed the greatest biomass. Yasindi *et al.*, (2002) estimated that the ciliate contribution to secondary production was estimated to be 58% (*Frontonia*), 33% (*Condylostoma*) and 4% (*Cyclidium*). High abundance of bacterioplankton (2.7×10^8) in Lake Nakuru has also been reported by (Finlay *et al.*, 1987 and Yasindi *et al.*, 2002). This explains the numerical dominance of *Cyclidium* and others bacterivorous ciliates. Herbivorous ciliates such as *Frontonia sp* are also important in terms of production (Yasindi and Taylor, 2006).

MATERIALS AND METHODS

3.1 Study site

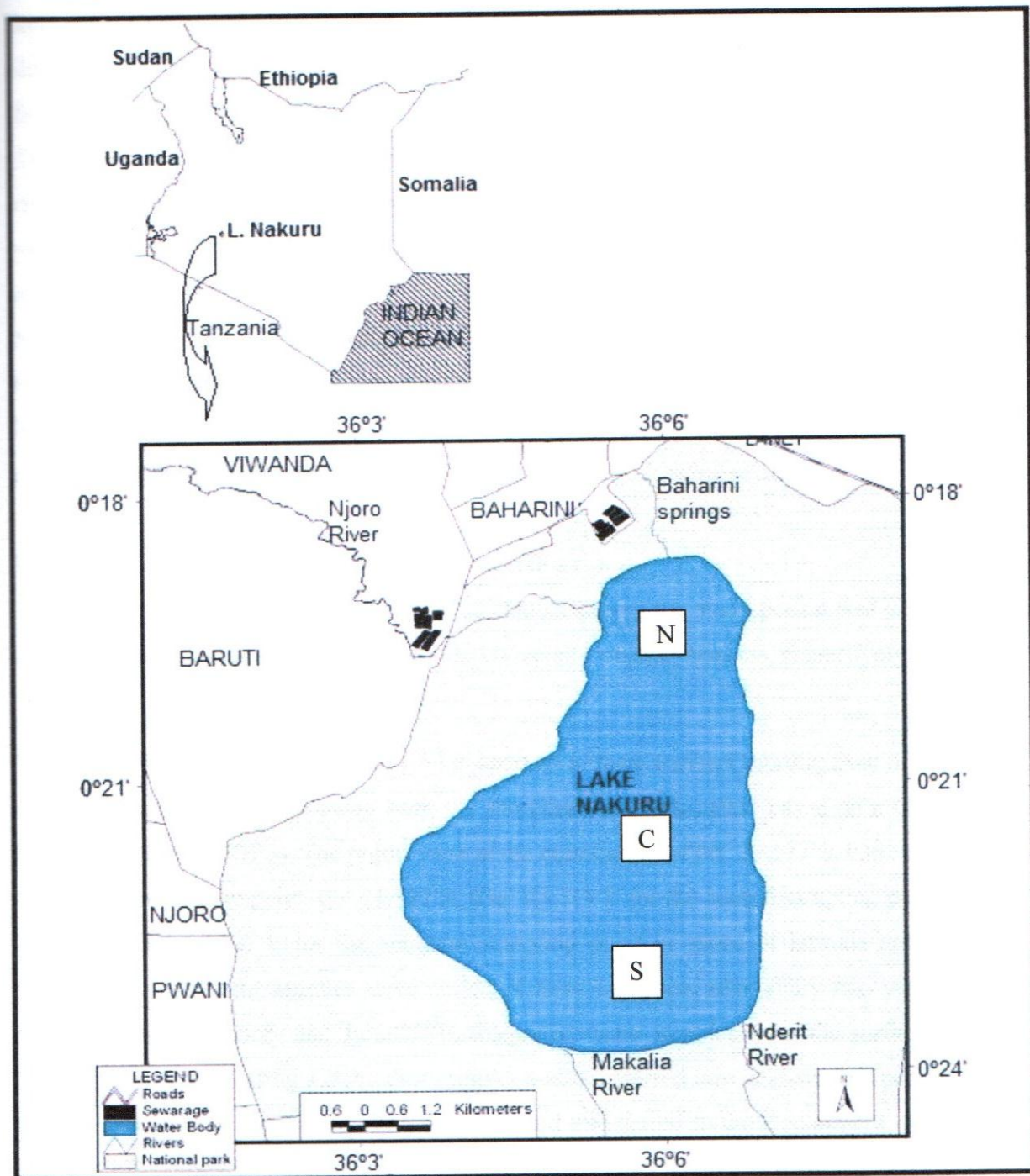


Figure 1: Lake Nakuru, sampling points (North, Central and South) and its location in Kenya

The study was carried out in Lake Nakuru, a shallow saline-alkaline endorheic lake, located in the eastern arm of the Great Rift Valley in Kenya, at an altitude of 1759 meters above sea level and a geographical location of 00° 22'S, 36° 05'E. The lake lies next to Nakuru town and is surrounded by the world famous Lake Nakuru National park. It has an area of approximately 40 km² with a mean depth of less than 2 m. However, its mean depth is highly variable and is dependent on the precipitation and inflow of rivers from its catchment area, and the evaporation from the lake. The lake receives inflows through rivers namely Njoro, Makalia, and Nderit (Fig. 1). It is also fed by the Baharini springs at the northern end and the town's sewage effluent. The rivers are highly seasonal and rarely reach the lake especially during the dry periods. The lake receives an annual rainfall of 800 mm which currently fluctuates greatly probably due to the effects of degradation of Mau forest, a major water tower in this region and climate change. Lake Nakuru is protected internationally as a Ramsar site and is among the most visited National Parks in Kenya with approximately 200,000 tourists annually. The main tourist attraction to the lake is the large population of the lesser flamingos (*Phoeniconaias minor* Geoffroy) whose numbers sometimes range between 500,000 and 1.5 million (Owino *et al.*, 2001).

3.2 Weather data for Lake Nakuru and its catchment

The weather data of Lake Nakuru and its catchment during the study period was obtained from the Lake Nakuru National Park and Egerton University weather stations, respectively.

3.3 Collection of samples

Three sampling points, approximately 5 km apart on a linear transect running from north to south of the lake and about 2kms away from the shoreline, were identified based on a Geographical Positioning System (GPS). The points were at the coordinates of 00° 20.177'S, 036° 05.628'E for the northern sampling point, 00° 21.387'S, 036° 05.519'E for the central sampling point, and 00° 22.990'S, 036° 05.327'E for the southern sampling point in terms of latitude and longitude, respectively. Triplicate samples were collected from each site after every two weeks for six months, between January and June 2010. Integrated water samples from the surface to 60 cm depth were collected using a Schindler sampler and transferred into acid-washed plastic sample bottles. The samples were stored in a cool box and transferred to the Department of Biological Sciences Limnology Laboratory at Egerton University, Njoro for further analyses.

3.4 Physical and chemical properties

During each sampling occasion, water level was measured at each sampling site using a calibrated dip stick. Selected physical and chemical properties including dissolved oxygen concentration and saturation, temperature and pH were measured *in situ* using an HQ 40d dual-input multi-parameter meter and Oxi 330i/Oxi 340i WTW. Conductivity and salinity values were measured *in situ* using VWR EC 300 portable meter. The probes were calibrated before use. Alkalinity was determined in the laboratory using acid titration method with HCl acid (APHA, 1995). Total suspended solids were determined gravimetrically using pre-dried glass fibre filters (Whatman GFC) having pore size of 0.45µm at 95°C, with the ash-free dry weight determined after 3 hours combustion at 500 °C in a muffle furnace. Lake water transparency was measured using a 20 cm diameter secchi disc with alternating black and white quadrants.

3.5 Nutrient analyses

Nutrient analyses were done according to the standard methods of the American Public Health Association (APHA, 1995). Total phosphorus (TP) and soluble reactive phosphorous (SRP) were analyzed using the molybdate method with absorbance read at a wavelength of 885 nm. Nitrate - nitrogen (NO₃-N) was analysed using the salicylate method with the spectrophotometric absorbance read at a wavelength of 420 nm. Nitrite-nitrogen (NO₂-N) concentration was determined based on the reaction between sulfanilamide and N-naphthyl-(1)-ethylendiamin-dihydrochloride. The intensity of colour formed was read at 543 nm. Ammonium-nitrogen (NH₄-N) was analyzed through the reaction between sodium salicylate and hypochlorid solutions with the spectrophotometric absorbance of the treated sample being read at a wavelength of 655 nm.

3.6 Plankton samples

3.6.1 Phytoplankton sampling

Samples for phytoplankton community composition analysis were collected using plankton net with a pore size of 30 µm and placed in 50 ml falcon tubes. These samples were preserved using formalin to achieve a ratio of 4% in the final concentration and transported in a cool box to the laboratory for further analyses.

3.6.2 Phytoplankton identification and enumeration

Phytoplankton species were identified through observation under a compound microscope at the

magnifications of x 200 and x 400 and using identification keys by Wehr and Sheath (2003); David *et al.* (2002) and Preston (1978). The identified species were enumerated by counting all individuals, including single cells, colonies and filaments on a cell-by-cell basis using a 3 ml Sedgwick–Rafter counting chamber.

3.6.3 Phytoplankton biovolume

To estimate cell biovolumes, the cell shapes were approximated to the standard geometric shapes such as spheres, cuboid or cylinders and their standard formulae used to calculate biovolume according to Hillebrand *et al.*, (1999) and Wetzel and Likens (1991). The measurements of the cell dimensions such as the lengths and widths were made using a calibrated stage micrometer and the ocular grids in the microscope. Mean cell volumes were obtained by averaging the volumes of 30 individual cells. The total biovolume for each species was calculated from the product of abundance or cell numbers and the mean biovolume of each species.

3.6.4 Phytoplankton biomass analysis

Total phytoplankton biomass was estimated as chlorophyll *a* concentration. This was done through acetone extraction method in which a known volume of the water sample was filtered through a 0.45 μm pore size GFC filters and the filter together with the seston kept in a freezer overnight to aid in bursting of the cells. The filter and the seston was then ground using tissue grinder with the addition of 10 mls of the acetone and the sample stored for at least eight hours in the refrigerator. Finally the samples were centrifuged and decanted to get the clear extract of the chlorophyll. The extract's absorbance was read using a spectrophotometer at the wavelengths 663 nm, with the turbidity correction being done through re-reading the extract again at 750 nm.

3.6.5 Zooplankton sampling

Zooplankton samples were collected using a four litre bucket and sieved through 50 μm mesh size plankton net. The samples were preserved using a final concentration of 4% formalin in 50 ml falcon tubes.

3.6.6 Zooplankton identification and abundance

The volume of each homogenous sample was recorded first. After thorough shaking, one or two millimeter sub-sample was placed in the three millimeter Sedgwick–Rafter counting chamber

using a calibrated wide mouthed disposable pipette. Identification was done by looking at the water samples through the compound microscope at x 400 magnification. Rotifers and cladocera were identified using keys by Kutikova (1970) and Korinek (1999) respectively. Ciliates were observed and identified under the inverted microscope based on the works of Foissner *et al.* (1999) and Lynn and Small (1985). The various zooplankton groups, including rotifers were sorted using a fine glass capillary tube into glycerine mixed with distilled water on glass slides. The mouth parts of rotifers were examined after dissolving the body tissue using sodium hypochlorite solution. For cladocerans, a slide was prepared for each specimen with various body parts well placed for examination under the microscope. Different zooplankton types were enumerated under an inverted microscope at x 400 magnification. Between 100-200 individuals were counted for each group. The number of individuals per litre (N) of lake water was determined using the formula:

$$N = \frac{(\text{Number counted}) * (\text{Sample volume})}{(\text{Subsample volume}) * (\text{Volume filtered through the net})}$$

Where, the volumes were converted into litres.

3.6.7 Zooplankton biomass

i) Rotifers and ciliates

The biovolumes of these organisms were determined by approximating their body appearance to the standard geometric shapes such as sphere and cylinder (Wetzel and Likens 1991). The measurements of their body dimensions such as lengths and widths were made using a calibrated compound microscope. The geometric formulae for calculating volume of these respective shapes were used to calculate ciliate and rotifer biovolume. Finally, the biovolume was converted to wet weight by assuming a specific gravity of unity ($1\text{mm}^3 = 1\text{mg}$). The obtained wet weight (WW) was converted to dry weight (DW) using a ratio of 0.05 to 0.1 (dry weight: wet weight) to obtain zooplankton biomass (Ralph, 1999).

ii) Cladocera

The Cladocera dry weight was determined by isolating over thirty cladocerans. The isolated

cladocerans were put in an aluminum foil and dried in the oven to a constant weight at 60 °C and then weighed using a fine balance. Their mean weight per animal was calculated by dividing the total dry weight by the number of cladocerans dried. The obtained mean weight was multiplied by the number of cladocerans per litre to get their total biomass.

3.6.8 Plankton diversity

Phytoplankton and zooplankton diversity was determined by the Shannon-Weaver index using the equation (Shannon and Weaver, 1949):

$$H' = - \sum_{i=1}^n P_i \ln P_i$$

Where p_i is the proportion between the number of individuals, the number of cells or biovolume of n species and total number of individuals, cells or biovolume in the sample and n is the number of individuals in species.

3.7 Flamingo population

The number of flamingos was estimated on each occasion by approximating their group numbers of 500 individuals and multiplying by the number of groups.

3.8 Data analysis

The data generated was analyzed statistically using the SPSS (Statistical Packages for the Social Sciences) version 17.0 statistical package. The temporal data for the various variables were subjected to the test of normality (Kolmogorov-Smirnov output) and homogeneity (Levene's test for Equality of Variances). It was concluded that the distribution of the data was not significantly different from a normal distribution and did not meet the assumption of parametric statistics. Therefore it was subjected to log transformation $\ln(n+1)$ in an attempt to equalize the variances but it failed and as a result a non-parametric test was performed using Kruskal Wallis Test and for those parameters which were significantly different Mann-Whitney U test was performed using the original data. Pearson rank correlation coefficients were used to investigate the relationship between the water level, physical and chemical variables in the lake. The variations in the plankton diversity and biomass were established by subjecting their monthly means Mann-Whitney U test. The relationship between phytoplankton diversity, biomass and physico-

chemical variables in the lake was determined using Pearson rank correlation coefficients. The graphs were drawn using Sigma plot (10.0) and Microsoft Excel 2007 computer packages.

RESULTS

4.1. Weather data

4.1.1 Lake Nakuru weather characteristics

The highest and lowest mean rainfall amounts of 183.60 mm and 31.20 mm were recorded in March and January, respectively. Relative humidity during the study period was above 60 %. The maximum air temperature recorded being 19.85 °C in February with a minimum value of 17.77 °C in June. The wind speed decreased from January (5.22 km/hr) to June (1.59 km/hr) (Table 1).

Table 1: Lake Nakuru Park weather conditions from January to June 2010 (mean monthly values).

Month	Rainfall (mm)	Temperature (°C)	Relative humidity (%)	Wind speed (km/hr)
January	31.20	19.21	64.97	5.22
February	139.40	19.85	70.73	4.32
March	183.60	18.89	77.81	3.51
April	135.60	19.02	80.17	2.27
May	159.80	18.65	80.42	1.79
June	42.600	17.77	78.21	1.59

4.1.2 Weather characteristics of the Njoro River catchment area

Temperature and relative humidity values ranged from 19.2 °C to 21.0 °C and 61 % to 72.30 % respectively while the cumulative rainfall received in the Njoro River catchment area during the study period was 916.20 mm. The minimum evaporation value was 3.11 mm/day in June, while the maximum value of 4.42 mm/day was recorded in February (Fig. 2). Compared to the previous first six months records of each year for the past ten years (2000-2010), the rains received in these first six months for this year were exceptionally high suggesting a wide variation in the rainfall pattern in the catchment (Fig. 3a). In 2010, heavy rainfall was received during the long rainy season (March to May) with maximum values in March (285.80 mm) and

minimum values in January (47.30 mm) Fig. 3b. The mean semi-annual rainfalls (from January to June) from 2000 to 2010 were 35, 94, 91, 116, 106, 75, 59, 90, 52, 46 and 153mm, respectively. This shows that the rainfall pattern in Njoro catchment is unpredictable.

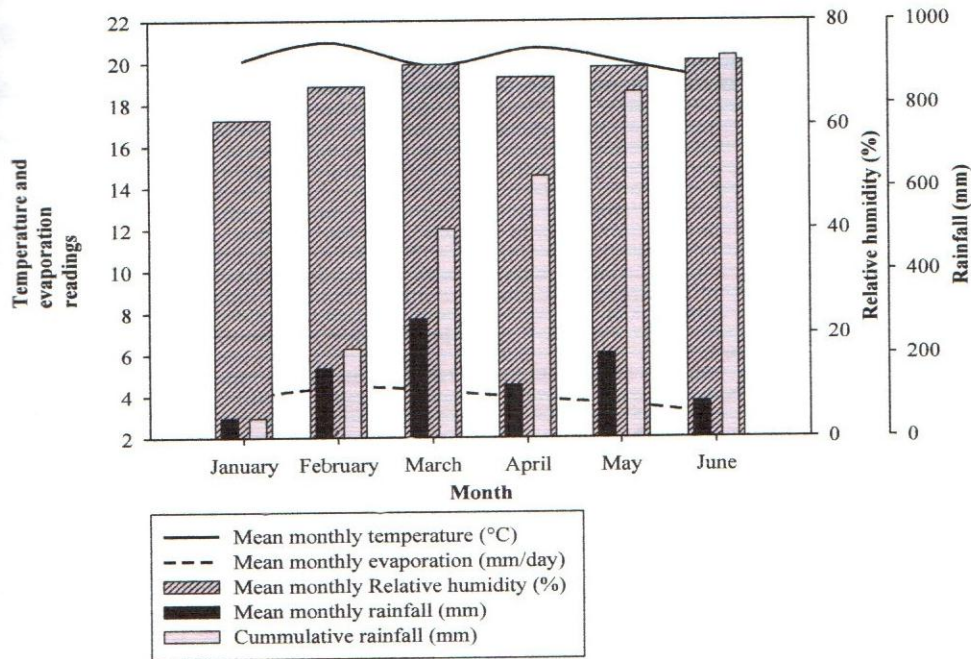
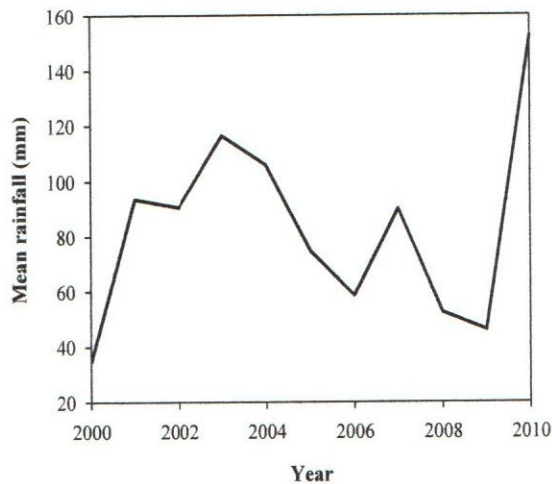
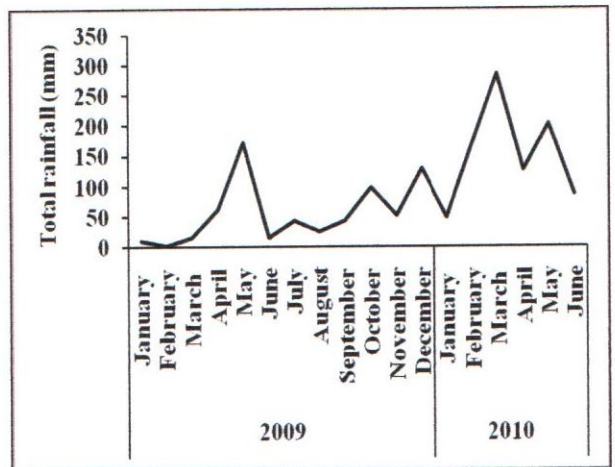


Figure 2: Weather conditions in Njoro catchment from January to June 2010.



(a)



(b)

Figure 3: Total rainfall amounts in Njoro catchment; a) 2000-2010 and b) January 2009 to June 2010.

4.2 Temporal changes in the water level of Lake Nakuru

The water level increased from 42.5 ± 1 cm (S.E) in January to 187.2 ± 2 cm (S.E) in June 2010. There was a strong significant variation in the water level in all the months during the study. Kruskal-Wallis test showed the mean water level was significantly different ($\chi^2 = 94.66$, $p < 0.05$, $df = 5$). The increase in water level was as a result of increased rainfall amounts in the catchment area which resulted in increased discharge from the rivers flowing into the lake Fig. 4 ($r = 0.970$).

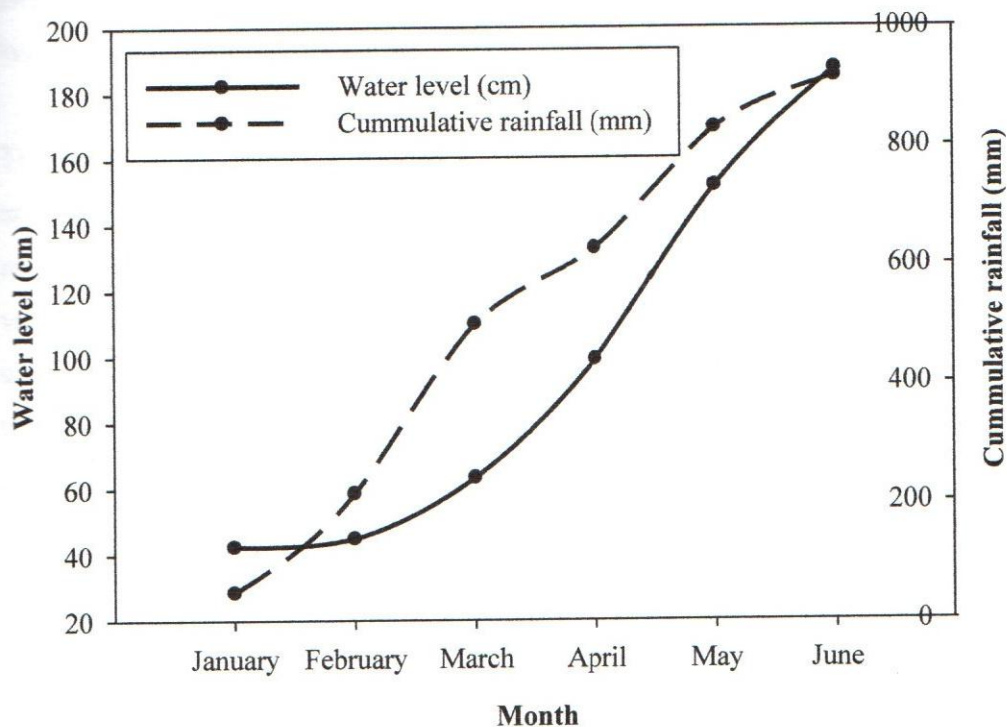


Figure 4: Relationship between Lake Nakuru water level and cumulative rainfall (January to June 2010).

4.3 Temporal changes in the physico-chemical properties of Lake Nakuru

The mean values of the measured physical and chemical properties over the study period in the lake are shown in Table 2. Day water temperatures were relatively high with a mean value of 26.59°C with a minimum reading of 25.90°C in June and a maximum reading of 28.84°C in April. Water temperature readings significantly varied between April and all the other months (Kruskal Wallis test, $\chi^2 = 18.35$, $p < 0.05$, $df = 5$). Temperature variation could as a result of the

variation in sampling, cloud cover and the rain season. High pH values were recorded during the study period with minimum and maximum values of 10.19 (January) and 10.32 (May), respectively with a mean of 10.28. pH values were significantly different between the month of January and all the other months ($\chi^2 = 49.96$, $p < 0.05$, $df = 5$), the February levels varied with those of May and June ($p < 0.05$). March and April pH levels varied with levels of May and June ($p < 0.05$). pH variations can be associated with the changes in carbonate and bicarbonate system and photosynthesis. The lowest dissolved oxygen concentration was 2.04 mg/L in April and the maximum value was 18.39 ± 1 mg/L recorded in February with a mean of 13.98 ± 2 mg/L. Dissolved oxygen concentrations significantly varied between April and all the other months being lowest in April (Kruskal Wallis test, $\chi^2 = 48.41$, $p < 0.05$, $df = 5$).

The mean conductivity and salinity values were 33.20 ± 2 mS/cm and 20.68 ± 1 ‰ respectively, and both decreased between February and June. Their ranges were 16.56 ± 1 to 55.54 ± 4 mS/cm and 9.61 ± 1 to 38.04 ± 3 ‰ respectively. Both variables showed a trend of temporal decrease in value between February and June. Conductivity and salinity levels were significantly different among all the months (Kruskal Wallis test, $\chi^2 = 74.80$ and 76.14 , $p < 0.05$, $df = 5$) while between the months: January and February, January and March, February and March there was no mean significant difference (Kruskal Wallis test, $p > 0.05$). Mean total alkalinity concentration was 420.96 ± 31 meq/L with minimum and maximum value in June (235.79 ± 2 meq/L) and February (1263.98 ± 75 meq/L), respectively. Total alkalinity levels were significantly different among all the months (Kruskal Wallis test, $\chi^2 = 75.50$, $p < 0.05$, $df = 5$). There was no significant mean difference between January and February ($p > 0.05$), May and June ($p > 0.05$), respectively. The minimum and maximum conductivity, salinity and total alkalinity concentrations coincided with the high and low water level periods as a consequence of increased river discharges and dilution of the lake water by direct rain water.

The concentration of total suspended solids in the lake had a mean value of 314 mg/L and showed a steady increase from January (670.00 mg/L) to March (881 mg/L), followed by a progressive decline to June (109.96 mg/L). Total suspended solid significantly varied among all the month (Kruskal Wallis test, $\chi^2 = 58.32$, $p < 0.05$, $df = 5$). There was no mean significant difference of the same between January and February, April and May ($p > 0.05$). The secchi

depth reading was lowest in February (13.03 cm) while the highest value of 38.69 ± 2 cm was recorded in June. Mean secchi depth readings significantly varied among all the months (Kruskal Wallis test, $\chi^2 = 89.64$, $p < 0.01$, $df = 5$).

Table 2: Physico-chemical properties of Lake Nakuru in the period January to June 2010.

Parameter	N	Mean	S. E	Minimum	Maximum	Range
Water depth (cm)	102	114.12	6	40	200	160
Temperature (°C)	102	26.59	0	21.80	32.30	10.500
Dissolved oxygen (mg/L)	102	13.98	1	0.51	31.80	31.29
pH	102	10.28	0	10.14	10.42	0.28
Conductivity (mS/cm)	102	33.20	2	9.10	73.40	64.300
Salinity (‰)	102	20.68	1	5.10	54.30	49.20
Water transparency	102	25.02	1	10.50	59.50	49.00
Total Suspended Solids (mg/L)	84	314.47	36	54.00	1953.33	1899.33
Organic matter (mg/L)	84	160.23	28	0.00	1653.33	1653.33
Inorganic matter (mg/L)	84	154.24	13	15.00	730.00	715.00
Total phosphorus (µg/L)	95	3339.28	183	1537.91	7969.17	6431.26
Soluble Reactive Phosphorus (µg/l)	95	1059.66	140	170.94	7832.16	7661.22
Ammonium nitrogen (µg/L)	95	197.59	33	16.79	1846.62	1829.83
Nitrate nitrogen (µg/L)	95	695.55	45	195.06	1877.98	1682.92
Nitrite nitrogen (µg/L)	95	10.68	1	4.35	64.69	60.34
Phenophthalein alkalinity (meq/L)	90	211.74	16	58.68	797.92	739.24
Total alkalinity (meq/L)	90	420.96	31	151.08	1423.60	1272.52

High concentrations for both total phosphorus and soluble reactive phosphorus were recorded in the lake during this study period. The mean concentration for total phosphorus was 3339 ± 183 µg/L while SRP concentration was 1059 ± 140 µg/L. A steady decrease in the phosphorus nutrients was observed from February (6601 µg/L and 4012 µg/L) to June (1853 µg/L and 391 µg/L), respectively. There was significant variations in total phosphorus concentration among most months (Kruskal Wallis test, $\chi^2 = 80.02$, $p < 0.05$, $df = 5$). However, no mean significant

difference recorded between January and February, May and June ($p > 0.05$). SRP concentration was significantly different among most months (Kruskal Wallis test, $\chi^2 = 63.93$, $p < 0.05$, $df = 5$). However, there was no significant variation between January and February, April and May, April and June, May and June ($p > 0.05$).

Low concentrations were recorded for the various forms of nitrogen investigated. Nitrate-nitrogen had a higher concentration among the nitrogen forms in the lake. Its mean concentration was $695 \pm 45 \mu\text{g/L}$ compared with ammonium-nitrogen mean concentration of $197.59 \pm 33 \mu\text{g/L}$ and nitrite-nitrogen mean concentration of $10.68 \pm 1 \mu\text{g/L}$. Minimum and maximum ammonium concentrations were recorded in January ($43.39 \pm 4 \mu\text{g/L}$) and April ($784.93 \pm 81 \mu\text{g/L}$). Ammonium concentration was significantly different between January and February, January and April, February and March, April and June, March and April, May and June, April and May, April and June (Kruskal Wallis test, $\chi^2 = 51.16$, $p < 0.05$, $df = 5$). There was a significant negative correlation between the concentrations of ammonium-nitrogen and dissolved oxygen ($r = -0.752$, Fig. 5). The minimum and maximum nitrate concentrations were in May ($381.84 \pm 38 \mu\text{g/L}$) and January ($1590.64 \pm 35 \mu\text{g/L}$), respectively. Temporally, nitrate-nitrogen concentration was significantly different in most of the months ($p < 0.05$). However, there was no significant difference between January and February, May and June ($p > 0.05$). The nitrite minimum and maximum values were $5.52 \mu\text{g/L}$ and $28.08 \pm 6 \mu\text{g/L}$ in June and February, respectively. Nitrite-nitrogen concentration was significantly different among most of the months ($p < 0.05$), except between January and February, March and April ($p > 0.05$).

There was a strong relationship between water level fluctuations and changes in concentration of various chemical species in water, especially salinity and nutrient concentrations. These relationships show that the water level inversely correlated with salinity, total suspended solids, total phosphorus, soluble reactive phosphorus and nitrate concentrations ($p < 0.05$, $n = 95$, $r = -0.868$, -0.734 , -0.908 , -0.755 and -0.859 respectively).

4.4 Spatial variation in physical and chemical properties in Lake Nakuru

The mean spatial physico-chemical properties are shown in Fig. 5, 6 and 7. The mean maximum water depth for the Lake Nakuru south, central and north sampling sites was $110.83 \pm 10 \text{ cm}$, $114.17 \pm 11 \text{ cm}$ and $118.00 \pm 10 \text{ cm}$. The mean temperature for the south, central and northern

sampling points were 27.33 °C, 26.35 °C and 26.00 ± 1 °C, respectively. The dissolved oxygen concentration recorded were 15.15 ± 1 mg/L (south), 15.08 ± 1 mg/L (central) and 11.26 ± 1 mg/L for the northern sampling point. The mean pH values were stable among the sites with 10.26 in South, 10.28 in Central and 10.29 in North sampling points. The water transparency values taken as the secchi depth readings for the south, central and north sampling points were 25.24 ± 2 cm, 24.53 ± 2 cm and 25.34 ± 2 cm respectively (Fig.5). Conductivity and salinity values showed an increasing trend from the north through the central to the south part of the lake (31.01 ± 3 mScm⁻¹, 32.72 ± 3 mScm⁻¹ and 35.50 ± 3 mScm⁻¹ and 19.02 ± 2 ‰, 21.16 ± 2 ‰ and 21.58 ± 2 ‰, respectively). The total suspended solids values were 341.97 ± 71 mg/L, 356.34 ± 70 mg/L and 237.10 ± 42 mg/L, respectively for the northern, central and southern sampling points (Fig.6).

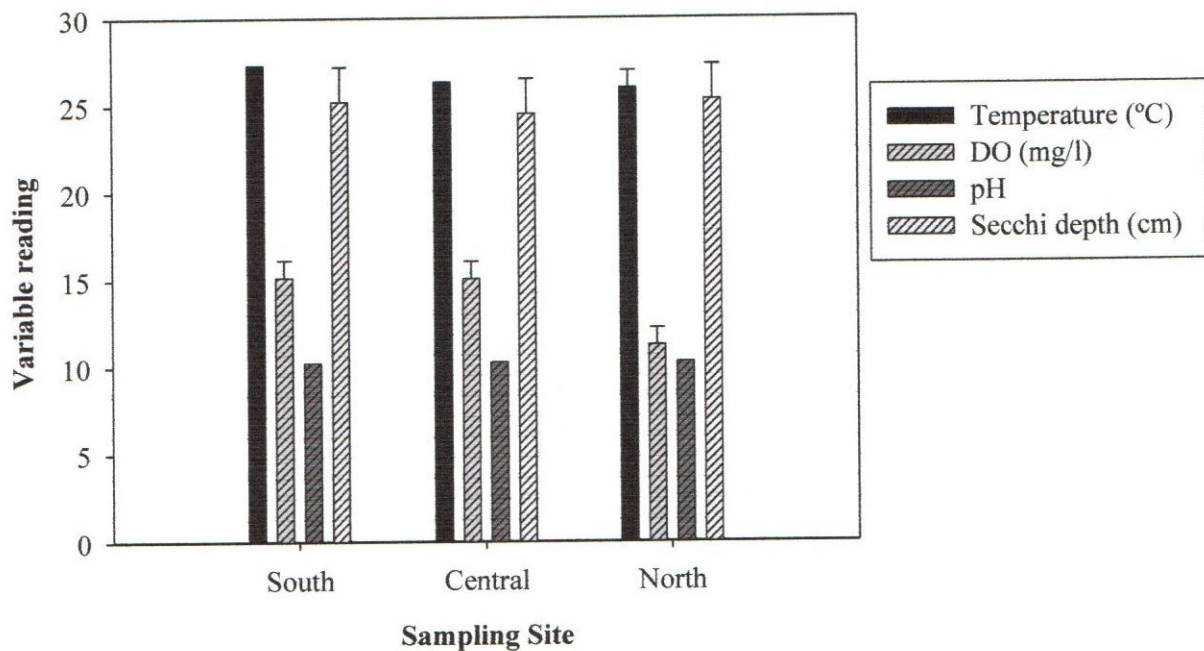


Figure 5: Spatial temperature, DO, pH and secchi depth readings in Lake Nakuru from January to June 2010.

The total phosphorus concentrations showed a decreasing trend from the south through central to the north of the lake with concentrations of 3664.84 ± 344 µg/L, 3425.17 ± 314 µg/L and 2862 ± 266 µg/L, respectively. The mean soluble reactive phosphorus concentrations followed the same

order of decrease as the total phosphorus concentration with $1299.65 \pm 261 \mu\text{g/L}$ recorded in the south, $1008.89 \pm 257 \mu\text{g/L}$ in the central and $834 \pm 189 \mu\text{g/L}$ in the north. The mean nitrate nitrogen values for the three sites south, central and north were $808.43 \pm 79 \mu\text{g/L}$, $743.21 \pm 85 \mu\text{g/L}$ and $510.61 \pm 53 \mu\text{g/L}$, respectively depicting the same pattern of decrease as that of phosphorus nutrients. The ammonium nitrogen concentration values were $200.04 \pm 63 \mu\text{g/L}$, $210.70 \pm 61 \mu\text{g/L}$ and $180.24 \pm 45 \mu\text{g/L}$ for south, central and north sampling sites respectively. The spatial nitrite nitrogen concentration for the southern, central and northern points were $9.87 \pm 1 \mu\text{g/L}$, $13.40 \pm 3 \mu\text{g/L}$ and $8.62 \pm 1 \mu\text{g/L}$ respectively. The total alkalinity values for the respective sampling sites of south, central and north were $451.70 \pm 57 \text{ meq/L}$, $474.03 \pm 60 \text{ meq/L}$ and $328.17 \pm 36 \text{ meq/L}$ (Fig. 7).

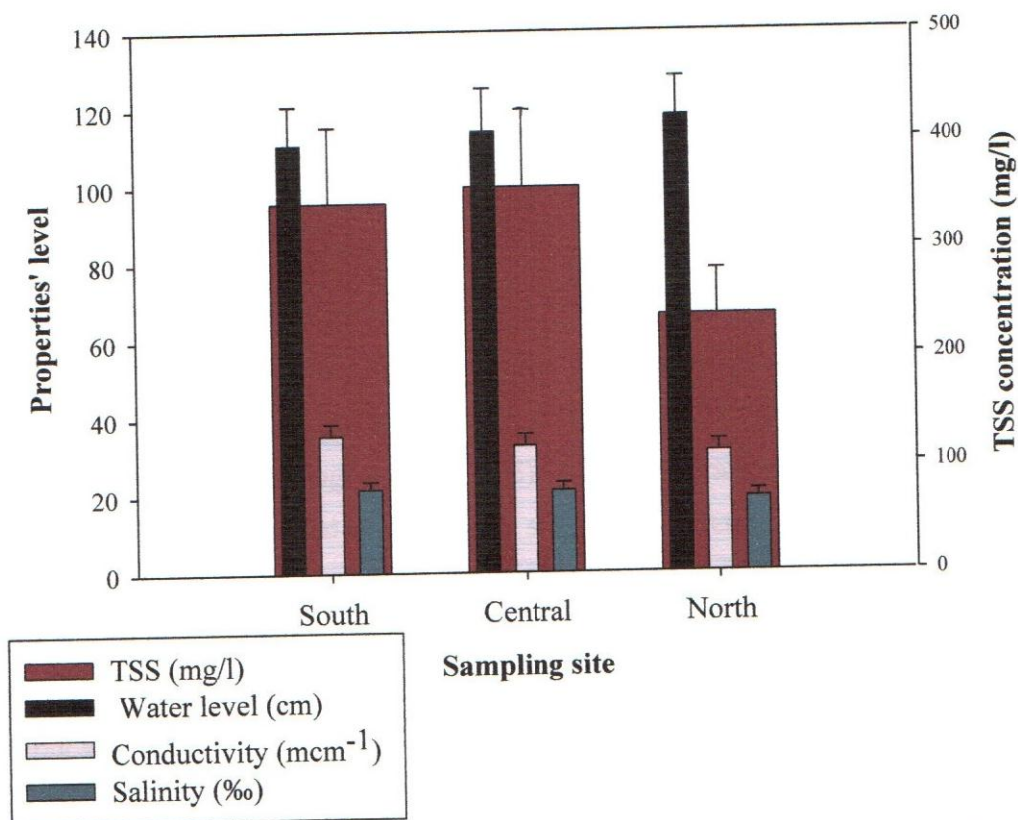


Figure 6: Spatial water level, TSS, conductivity and salinity in Lake Nakuru from January to June 2010.

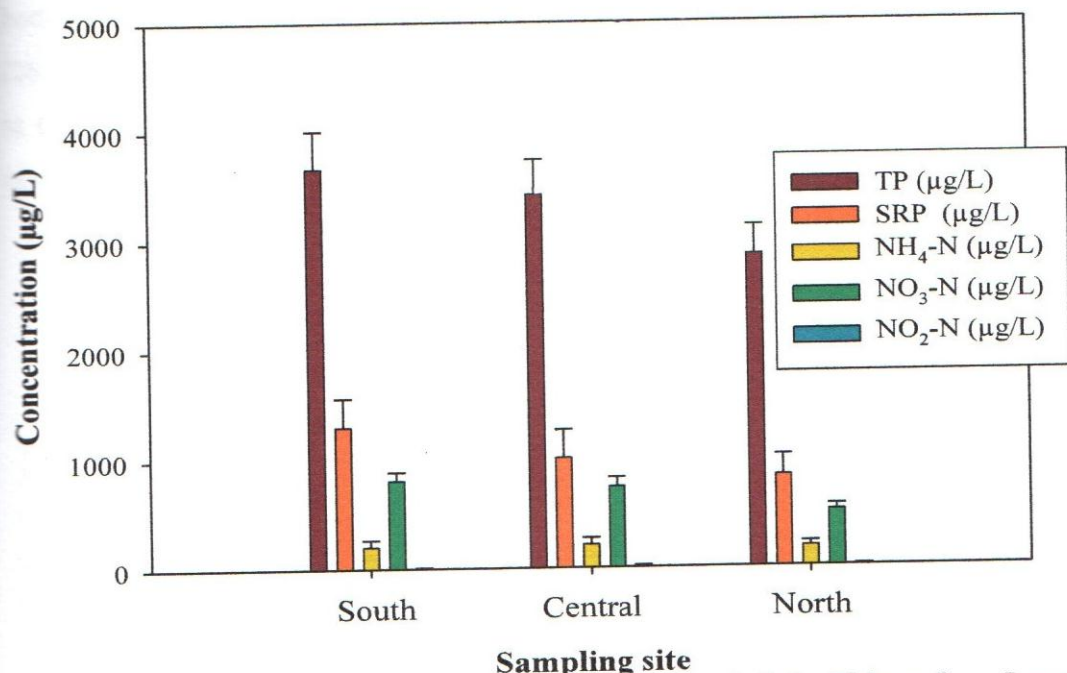


Figure 7: Spatial phosphorus and nitrogen concentrations in Lake Nakuru from January to June 2010.

Statistical analysis of these variables to determine whether the differences between the sites were significant was done using the One-Way ANOVA test and the results showed that the values measured were not significantly different between these sampling points ($p > 0.05$), with the exception of the nitrate-nitrogen ($p < 0.05$). Mean separation using the Least Significant difference post hoc test showed that the mean significant difference in nitrate was between north and central sampling points and, between north and south ($p < 0.05$) while the mean nitrate concentration was not significantly different between the south and central sampling points ($p > 0.05$). The nitrate concentration was higher in the south ($808 \pm 79 \mu\text{g/L}$) than central ($743 \pm 85 \mu\text{g/L}$), but significantly lower in the northern sampling point ($511 \pm 53 \mu\text{g/L}$).

4.5 Depth profile of the physical and chemical properties in Lake Nakuru

The variations in temperature, oxygen concentrations, conductivity and salinity with depth in Lake Nakuru for the study period were significant (One Way ANOVA, $p < 0.05$). However, there was no significant variation in pH with depth, with the values varying between 10.28 and 10.33. The mean dissolved oxygen decreased with depth from the surface to bottom (14.00 ± 1

mg/L to 0.04 mg/L) depicting clinograde profile which is a characteristic of eutrophic water bodies. The lake water showed a temperature difference of approximately 4 °C from the surface (26.56 °C) to the bottom (21.70 °C). Conductivity and salinity concentrations at the surface and at the bottom were 32.14 ± 3 mS/cm, 19.83 ± 2 ‰ and 25.79 ± 4 mS/cm, 16.95 ± 3 ‰, respectively (Fig. 8).

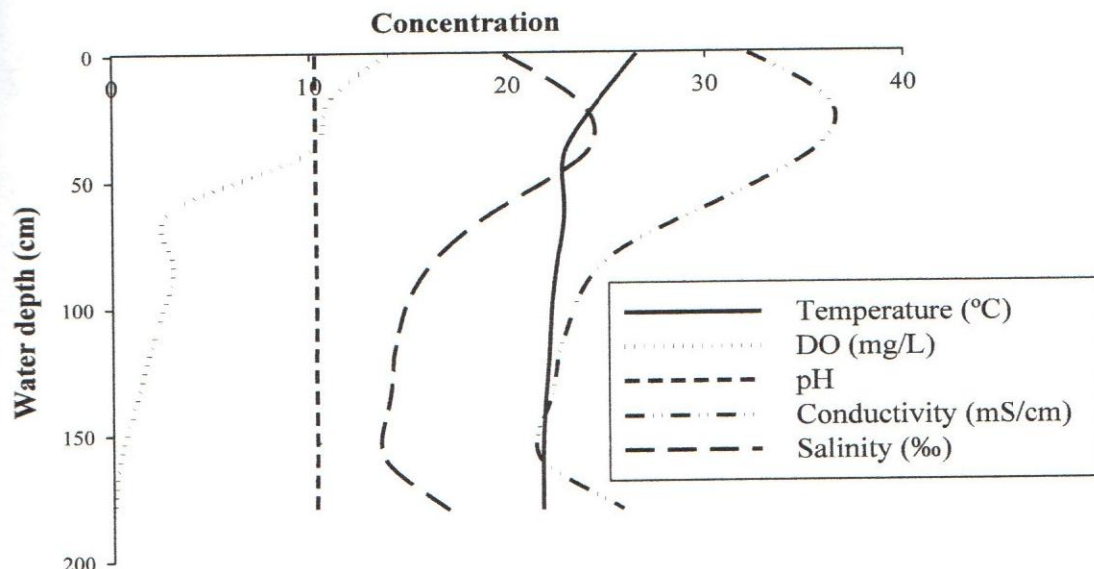


Figure 8: Depth profiles for temperature, DO, pH, conductivity and salinity from January to June 2010 in Lake Nakuru (readings taken between 10:00 am and 13:00 pm).

4. 6 Phytoplankton diversity, abundance and biomass in Lake Nakuru

The phytoplankton community in the lake was represented by four phyla; Cyanophyta, Bacillariophyta, Euglenophyta and Chlorophyta. Members of the phylum Cyanophyta found in this lake included *Arthrospira fusiformis*, *Anabaenopsis abijatae*, *Anabaena* sp, *Oscillatoria* spp, *Synechococcus* sp and *Synechocytis* sp, the Bacillariophyta was represented by species such as *Nitzschia* sp and *Navicula* sp, the Euglenophyta was represented by *Phacus longicauda* and *Euglena acus* while *Pediastrum duplex* and *Scenedesmus communis* were the species identified under the Chlorophyta. Generally very few species among the various groups of phytoplankton were found in the lake showing that phytoplankton diversity is low (Shannon-Weaner diversity index $H' \leq 2.5$, Doods, 2002). The minimum species diversity was observed in January (Shannon-Wiener diversity index (H') = 0.06) while the maximum species diversity was found in February (Shannon-Wiener diversity index (H') = 1.15). In terms of their spatial distribution,

the minimum species diversity occurred in the southern sampling point (Shannon-Wiener diversity index (H') = 0.64) while maximum species diversity was found in the northern sampling point (Shannon-Wiener diversity index (H') = 1.02) (Table 3). Increase in species richness and species evenness led to an increase in phytoplankton diversity and the vice versa was true.

Table 3: Phytoplankton species diversity in Lake Nakuru from January to June 2010.

Month	Species diversity (H')	Species richness (S)	Evenness (E)	Site	H'	S	E
January	0.06	3	0.05	South	0.64	12	0.26
February	1.15	10	0.50	Central	0.88	12	0.35
March	0.77	6	0.43	North	1.02	10	0.44
April	0.41	6	0.23				
May	1.06	4	0.76				
June	0.17	3	0.16				

Phytoplankton biomass contribution by various taxa ranged from 75.5% by cyanophytes, 15.1% by bacillariophytes, 9.1% by euglenophytes and 0.3% by chlorophytes (Fig.9). The biomass of the cyanophytes species which were present in the lake throughout the study period declined from January to February but later increased with time to June. However, the dominant cyanobacterial community was relatively varied; species composition was not always the same, as significant changes in cyanobacterial diversity were observed during the study period. The small coccoid species *Synechococcus* sp and *Synechocystis* sp which were present at the beginning of the study when the water level was low and salinity was high, but were replaced by the filamentous forms *Anabaena* sp, *A. abijatae* and *A. fusiformis* later as the water level increased and salinity decreased. The bacillariophyta species abundance showed an irregular pattern of change from February to May. The abundance of euglenophytes decreased from January to March. Finally, the abundance of the chlorophytes increased from January to February and then decreased in March. The temporal phytoplankton community biovolume ($\mu\text{m}^3/\text{L}$) decreased from January (3.58×10^3) to February (5.51×10^1) then, it increased from March (5.01×10^2) to a maximum value of 1.35×10^5 in June (Fig. 10a). No significant

variation in phytoplankton community biovolume was observed between the sampling sites, with south having of $2.05 \times 10^5 \mu\text{m}^3/\text{L}$, central $2.52 \times 10^5 \mu\text{m}^3/\text{L}$ and north $2.10 \times 10^5 \mu\text{m}^3/\text{L}$ (Fig. 10b).

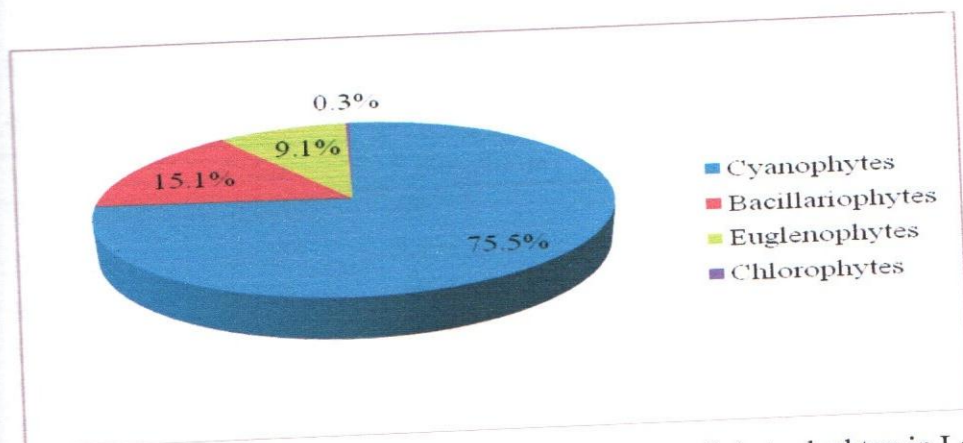
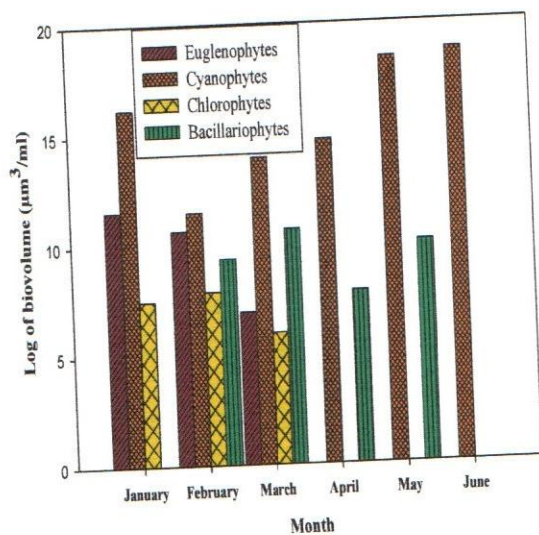
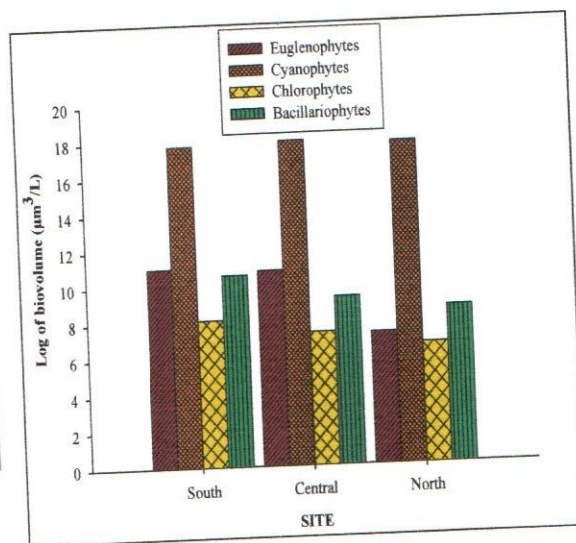


Figure 9: The percentage abundance of major species of phytoplankton in Lake Nakuru between January and June 2010.



(a)



(b)

Figure 10: Variation in biovolume of the different phytoplankton divisions in Lake Nakuru over time (January to June 2010 (a) and b) in space.

Phytoplankton species richness showed a significant positive correlation with conductivity, salinity, total alkalinity, TSS, TP, SRP, NO_3 ($r = 0.671, 0.658, 0.685, 0.701, 0.730, 0.784$ and

0.694 respectively) but negatively correlated with water level, secchi depth and zooplankton diversity (Pearson correlation, $r = -0.701$, -0.656 and -0.691 , respectively) (Table 4). These factors in the same way indirectly influenced phytoplankton diversity through species richness.

Table 4: Correlation matrix of phytoplankton diversity, abundance and biomass with physico-chemical parameters in Lake Nakuru from January to June 2010.

Variable	Chl <i>a</i>	P biovolume	P diversity	P richness	P evenness
Water level	-0.048	.907**	-0.372	-.701*	-0.063
DO	.722**	0.431	-0.063	0.132	-0.103
pH	0.010	.672*	-0.015	-0.422	0.217
Conductivity	-0.039	-.816**	0.286	.671*	-0.039
Salinity	0.003	-.762**	0.256	.658*	-0.072
Secchi depth	-0.407	0.570	-0.481	-.656*	-0.282
TSS	0.328	-.618*	0.273	.701*	-0.011
TP	0.204	-.768**	0.202	.730**	-0.160
SRP	0.275	-.586*	0.234	.784**	-0.129
NH ₄	-.737**	-0.299	0.155	-0.002	0.188
NO ₃	0.244	-.694*	0.165	.694*	-0.191
TA	0.185	-.653*	0.172	.685*	-0.159
P biovolume	0.284	1.000	-0.231	-0.568	0.043
P diversity	0.334	-0.231	1.000	.691*	.904**
P richness	0.186	-0.568	.691*	1.000	0.333
P evenness	0.352	0.043	.904**	0.333	1.000
Z diversity	0.189	0.284	-.696*	-.577*	-0.552

*. Correlation is significant at the 0.05 level.

**. Correlation is significant at the 0.01 level.

Phytoplankton biomass measured as chlorophyll *a* correlated positively with dissolved oxygen, ammonium nitrogen and phytoplankton abundance (Table 4). There was no clear pattern on the temporal trend on phytoplankton biomass changes. The minimum and maximum phytoplankton biomass were recorded in April ($151.70 \pm 24 \mu\text{g/L}$) and May ($872.56 \pm 144 \mu\text{g/L}$), respectively while mean concentration for the whole study period was $567.12 \pm 41 \mu\text{g/L}$. The biomass was highest in the central sampling point (Fig. 11a) and lowest in the northern point with no significant difference (Fig. 11b). Minimum and maximum biomass occurred at the northern ($466.10 \pm 41 \mu\text{g/L}$) and central ($664.71 \pm 100 \mu\text{g/L}$) part of the lake, respectively, though this difference was not statistically significant (Fig. 11b).

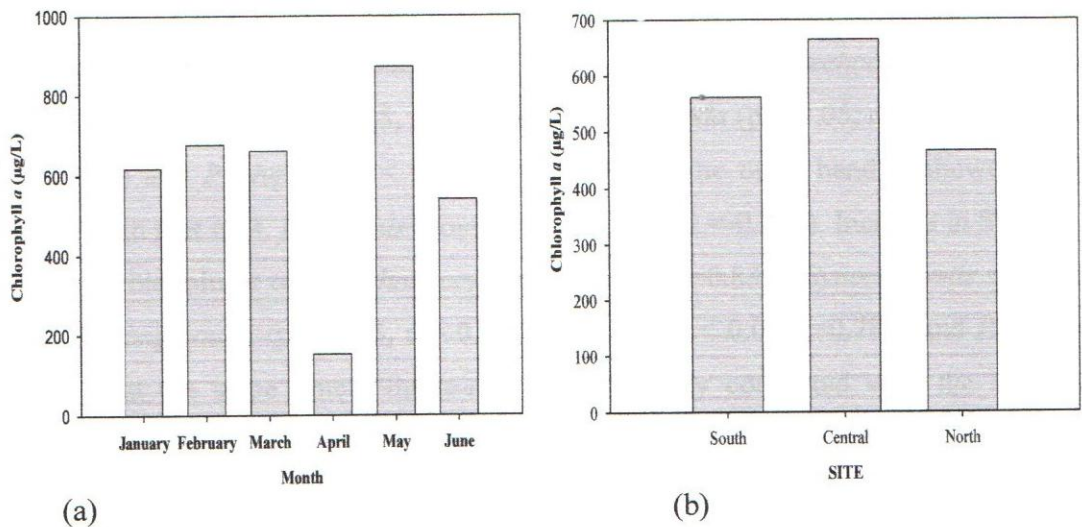


Figure 11: (a) Changes in chlorophyll *a* concentration in Lake Nakuru from January to June 2010: (a) temporal, and b) spatial.

Most of the physical and chemical lake water characteristics measured in this study showed a correlation with the phytoplankton species biovolume. Water level inversely correlated with *Arthrospira fusiformis* biovolume ($p < 0.05$, $r = -0.915$). Temperature inversely correlated with *Scenedesmus communis* biovolume ($p < 0.05$, $r = -0.633$). Increase in total suspended solids led to a significant increase in biovolumes of *Synechococcus* sp ($p < 0.05$, $r = 0.807$), *Phacus longicauda* ($p < 0.05$, $r = 0.757$), *Euglena acus* ($p < 0.05$, $r = 0.796$) and *Pediastrum duplex* ($p < 0.05$, $r = 0.849$), on the other hand its increase led to significant decrease of *A. fusiformis* biovolume ($p < 0.05$, $r = -0.580$). pH had a positive correlation with *A. fusiformis* abundance ($r = 0.640$) and negative significant influence on *Synechococcus* sp ($p < 0.05$, $r = -0.639$), *P. longicauda* ($p < 0.05$, $r = -0.824$) and *P. duplex* ($p < 0.05$, $r = -0.743$). Dissolved oxygen did not show any correlation with phytoplankton species biovolume. Salinity showed an inverse correlation with *A. fusiformis* abundance ($p < 0.05$, $r = -0.693$) and positively correlated with *Synechocystis* sp ($p < 0.05$, $r = 0.657$) and *S. communis* abundances ($p < 0.05$, $r = 0.663$). The water transparency positively correlated with the abundance of *A. fusiformis* ($p < 0.05$, $r = 0.640$) only. Total alkalinity positively correlated with the biovolume of *Synechococcus* sp ($p < 0.05$, $r = 0.807$), *Synechocystis* sp ($p < 0.05$, $r = 0.729$), *P. longicauda* ($p < 0.05$, $r = 0.771$), *E. acus* ($p < 0.05$, $r = 0.771$), *E. acus* ($p < 0.05$, $r = 0.771$), *E. acus* ($p < 0.05$, $r = 0.771$).

0.05, $r=0.724$) and *P. duplex* ($p < 0.05$, $r = 0.785$), on the other hand it negatively correlated with *A. fusiformis* biovolume ($p < 0.05$, $r = -0.597$).

Total phosphorus positively correlated with the biovolume of *Synechococcus sp* ($p < 0.05$, $r = 0.638$), *Synechocystis sp* ($p < 0.05$, $r = 0.582$), *P. longicauda* ($p < 0.05$, $r = 0.743$), *E. acus* ($p < 0.05$, $r=0.646$) and *P. duplex* ($p < 0.05$, $r = 0.749$), on the other hand it showed an inverse correlation with that of *A. fusiformis* biovolume ($p < 0.05$, $r = -0.714$). Increase in SRP there was an increase in biovolume of *Synechococcus sp* ($p < 0.05$, $r = 0.835$), *Synechocystis sp* ($p < 0.05$, $r = 0.794$), *P. longicauda* ($p < 0.05$, $r = 0.733$), *E. acus* ($p < 0.05$, $r=0.789$) and *P. duplex* ($p < 0.05$, $r=0.813$) at the same time. Nitrate-nitrogen positively correlated with the biovolume of *Synechococcus sp* ($p < 0.05$, $r = 0.650$), *Synechocystis sp* ($p < 0.05$, $r = 0.639$), *P. longicauda* ($p < 0.05$, $r = 0.765$), *E. acus* ($p < 0.05$, $r = 0.651$) and *P. duplex* ($p < 0.05$, $r = 0.754$), on the other hand was inversely correlated with *A. fusiformis* biovolume ($p < 0.05$, $r = -0.648$). Ammonium-nitrogen did not have any significant correlation on any of the phytoplankton species biovolume. The relationship between the measured physico-chemical properties and the various phytoplankton species biovolume are shown in below (Table 5).

4.7 Zooplankton diversity, abundance and biomass in Lake Nakuru

Zooplankton community was dominated by members of the Rotifera, Ciliata and Crustacea taxa. The ciliates included *Cyclidium sp*, *Condylostoma magnum*, *Acineria sp*, *Frontonia sp*, rotifers comprised *Brachionus dimidiatus*, *B. plicatilis* and *Hexarthra jenkiniae* while the Crustacea was represented by only one Cladoceran, *Moina micrura*. The copepod *Lovenula africana* and the fish *Oreochromis alcalicus grahami* were absent. Low diversity of zooplankton was recorded with a lowest Shannon-Wiener index of 0.53 in April and highest value of 1.16 in January (Table 6). Spatially, zooplankton diversity was highest in the northern part of the lake followed by the southern site and finally the central sites (Table 6). The zooplankton species richness inversely correlated with the water temperature ($p < 0.05$, $r = -0.592$) while its evenness was positively and negatively influenced by water temperature and salinity, respectively ($p < 0.05$, $r = 0.674$).

Table 5: Correlation matrix of phytoplankton species biomass ($\mu\text{m}^3/\text{ml}$) and physico-chemical parameters in Lake Nakuru from January to June 2010.

	<i>Synechococcus</i> sp	<i>Synechocystis</i> sp	<i>Anabaena</i> sp	<i>A.fusiformis</i>	<i>A.abijatae</i>	<i>Oscillatoria</i> spp	<i>P. longicauda</i>	<i>Euglena</i> acus	<i>Nitzschia</i> sp	<i>Navicula</i> sp	<i>P. duplex</i>	<i>S. communis</i>
Water level	-.398	-.479	.181	.915*	.272	-.420	-.510	-.423	-.232	-.323	-.509	-.342
Temperature	.348	-.427	.186	-.276	.215	-.071	.219	.166	.094	-.156	.204	-.633*
DO	.358	.243	.176	.408	.155	.051	.341	.365	.062	.202	.373	.082
pH	-.639*	-.045	.240	.640*	.289	-.527	-.824**	-.561	-.122	.104	-.743**	.282
Conductivity	.214	.612*	-.325	-.747**	-.405	.407	.314	.263	.087	.328	.320	.604*
Salinity	.210	.657*	-.315	-.693*	-.395	.422	.311	.260	.042	.360	.315	.663*
Secchi depth	-.382	-.450	-.038	.642*	.033	-.327	-.456	-.408	-.248	-.393	-.471	-.315
TSS	.807**	.381	-.192	-.580*	-.279	.185	.757**	.796**	.281	.170	.849**	-.005
TA	.746**	.729**	-.257	-.597*	-.336	.428	.771**	.724**	.060	.380	.785**	.472
TP	.638*	.582*	-.274	-.714**	-.369	.480	.743**	.646*	.127	.286	.749**	.335
SRP	.835**	.794**	-.246	-.524	-.325	.301	.733**	.789**	.015	.429	.813**	.514
NH4	-.142	-.170	-.051	-.338	.033	-.137	-.199	-.158	-.127	-.116	-.197	-.117
NO3	.650*	.639*	-.240	-.648*	-.337	.519	.765**	.651*	.061	.353	.754**	.405

*. Correlation is significant at the 0.05 level.

**, Correlation is significant at the 0.01 level.

Table 6: Zooplankton species diversity in Lake Nakuru from January to June 2010.

Month	Species diversity (H')	Species richness (S)	Evenness (E)	Site	H'	S	E
January	1.16	4	0.83	South	1.07	9	0.49
February	0.71	5	0.44	Central	0.80	9	0.36
March	0.89	6	0.50	North	1.21	9	0.55
April	0.53	2	0.77				
May	0.94	3	0.85				
June	1.08	5	0.67				

The zooplankton abundance correlated negatively with the dissolved oxygen concentration ($p < 0.05$, $r = -0.729$). Zooplankton biomass correlated positively with the water level and secchi depth with correlation coefficients being 0.647 and 0.611, respectively (Table 7).

Table 7: Correlation matrix of zooplankton diversity, abundance with biomass and physico-chemical properties in Lake Nakuru from January to June 2010.

Variable	Z diversity	Z richness	Z evenness	Z abundance	Z biomass
Water level	0.289	0.149	0.246	-0.016	.647*
Temperature	0.102	-.592*	.674*	0.519	-0.228
DO	0.313	0.492	-0.11	-.729**	0.321
pH	-0.240	0.076	-0.269	0.019	0.408
Conductivity	-0.433	-0.042	-0.525	-0.022	-0.485
Salinity	-0.436	0.013	-.577*	-0.089	-0.448
Secchi depth	0.225	0.079	0.236	0.163	.611*
TSS	0.111	0.183	-0.086	-0.241	-0.401

*. Correlation is significant at the 0.05 level.

**. Correlation is significant at the 0.01 level.

NB: Z denotes zooplankton

The zooplankton abundance ranged between 8.65×10^2 Ind/L (January) to 2.90×10^5 Ind/L in April with a mean of 1.97×10^5 Ind/L. Most of the individuals counted were rotifers of the genus *Brachionus* in April and ciliates (*Cyclidium sp.*, *C. magnum* and

Acineria sp, in January (Fig. 12). The rotifer egg production followed the order of April (2.96×10^5) > May (3.36×10^4) > June (9.88×10^3) > March (2.96×10^2).

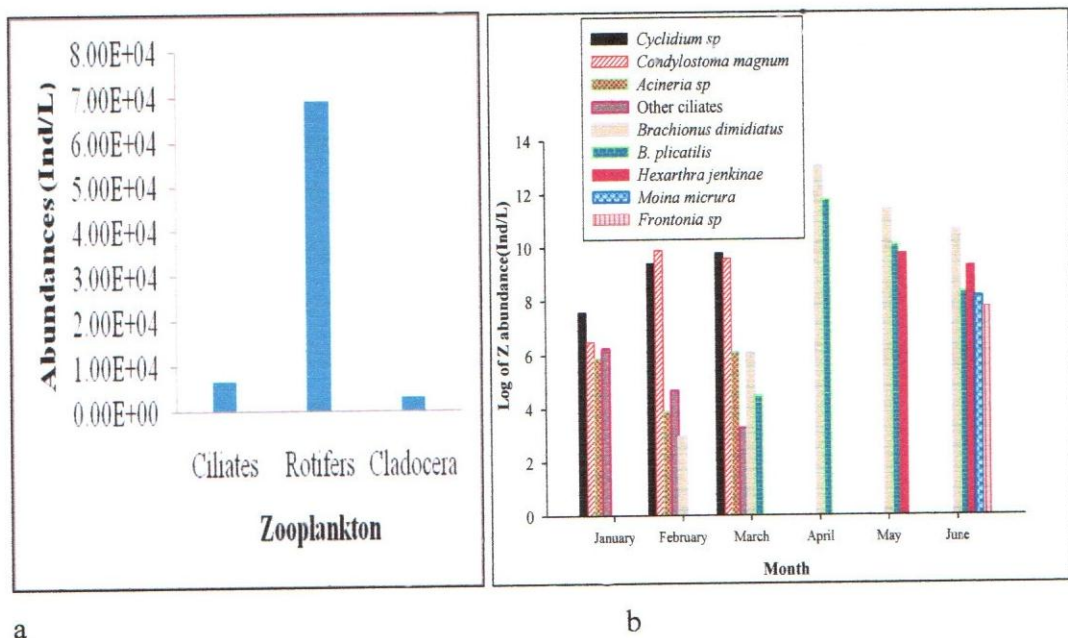


Figure 12: a). Abundance of zooplankton groups and b) Zooplankton species biomass changes in Lake Nakuru (Ciliates, Rotifers and Cladocera are zooplankton taxa).

Total zooplankton biomass ($\mu\text{g/L DW}$) was lowest in January (1.26×10^0) when ciliate species were abundant with the exception of *Frontonia* sp while highest value of 9.41×10^3 was recorded June mainly contributed by the Cladoceran *M. micrura*. The total zooplankton biomass was $9.42 \times 10^6 \mu\text{g/L DW}$ being contributed by cladocera ($9.41 \times 10^6 \mu\text{g/L DW}$), adult rotifer ($9.32 \times 10^2 \mu\text{g/L DW}$), immature rotifers ($9.12 \times 10^1 \mu\text{g/L DW}$) and the ciliates ($6.90 \times 10^1 \mu\text{g/L DW}$). The ciliate biomass ($\mu\text{g/L DW}$) was influenced by ciliate species size and abundance as the order of biomass contribution by each species was from the largest ciliate to the smallest. Their species biomass contribution were from *C. magnum* (6.63×10^1) > *Frontonia* sp (2.09×10^0) > *Acineria* sp (5.45×10^{-2}) > *Cyclidium* sp (5.43×10^{-1}) > other ciliates (1.30×10^{-2}). The rotifer biomass ($\mu\text{g/L DW}$) contribution was in the order of *H. jenkinsae* (7.31×10^2), *B. dimidiatus* (1.20×10^2), immature rotifers (9.12×10^1) and *B. plicatilis* (8.14×10^1).

The water level showed an inverse correlation with the biomass of the *Cyclidium* sp and *Acineria* sp ($p < 0.05$ $r = -0.582$ and -0.653 , respectively). It also correlated positively with the biomass of the large algivorous ciliate *Frontonia* sp, the rotifer *H. jenkinsae* and the cladoceran *M. micrura*, $p < 0.05$, $r = 0.596$, 0.559 and 0.647 , respectively. The *C. magnum* biomass showed an inverse correlation with temperature, ($p < 0.05$, $r = 0.598$). The biomass of *Brachionus* eggs showed an inverse correlation with the dissolved oxygen ($p < 0.05$, $r = -0.641$). Conductivity and salinity positively correlated with most ciliates' biomass; *C. magnum* ($p < 0.05$, $r = 0.730$, 0.737), *Cyclidium* sp ($p < 0.05$, $r = 0.741$, 0.773) and *Acineria* sp ($p < 0.05$, $r = 0.629$, 0.621), respectively. Secchi depth positively correlated with the biomass of *Frontonia* sp and *M. micrura* ($p < 0.05$, $r = 0.776$ and 0.611 , respectively), (Table 8).

Table 8: Correlation matrix of zooplankton biomass and physico-chemical properties in Lake Nakuru from January to June 2010.

Parameter	<i>Cyclidium</i> sp	<i>C. magnum</i>	<i>Acineria</i> sp	<i>Frontonia</i> sp	Other ciliates	<i>B. dimidiatus</i>	<i>B. plicatilis</i>	<i>H. jenkinsae</i>	R.egg	<i>M. micrura</i>
Water level	-.582*	-.498	-.653*	.596*	-.375	.317	.233	.559	-.046	.647*
Temperature	-.430	-.598*	-.146	-.269	-.120	.266	.355	-.329	.510	-.228
DO	.052	.030	.098	-.095	.075	-.405	-.234	.077	-.641*	.321
pH	-.144	.102	-.597*	.293	-.457	.192	.200	.525	-.035	.408
Conductivity	.730**	.741**	.629*	-.549	.380	-.350	-.351	-.468	-.004	-.486
Salinity	.737**	.773**	.621*	-.495	.403	-.366	-.366	-.429	-.070	-.448
Secchi depth	-.529	-.454	-.569	.776**	-.297	.370	.163	.330	.127	.611*

*. Correlation is significant at the 0.05 level.

**. Correlation is significant at the 0.01 level.

NB: R denotes rotifer.

4.8 Flamingo population

The flamingo numbers increased with increase in lake water depth ($r^2 = 0.553$) and ranged approximately from 5,000 to 500, 000. At the beginning of the study, when the water depth was approximately 40 cm there were only a few flamingos but, with increase in water depth the flamingo numbers increased to approximately 500,000 in June when water depth increased to 187.20 cm. The lake water depth and flamingo numbers showed a significant positive correlation with a regression equation; $Y = 2357x - 16171$, $r^2 = 0.553$ and $p < 0.05$ (Fig.13).

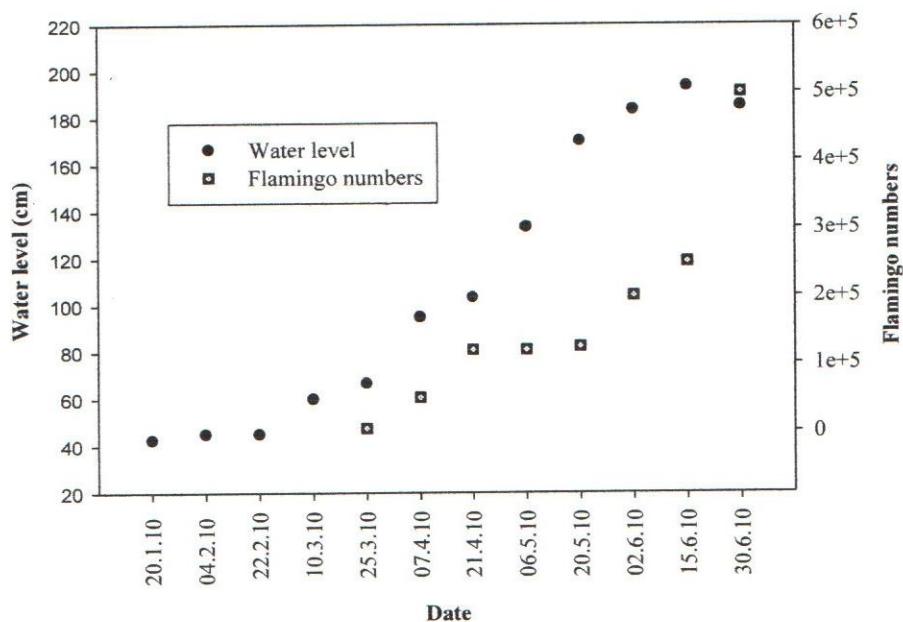


Figure 13: Relationship between Lake Nakuru water depth and its flamingo populations between January and June 2010.

DISCUSSIONS

5.1 Water level fluctuations in Lake Nakuru

The maximum and mean lake water level of 2.0 m and 1.1 m, respectively recorded in this is lower compared those recorded by (Olago *et al.*, 2003; 2.8 m and 2.3 m), (Raini, 2002; 4.4 m and 1.1 m) and (Vareschi, 1982; 4.5 m and 2.5 m). According to Olago *et al.*, 2003 the volumes of water in the lakes depend on the run off from seasonal streams and therefore management of lake levels is dependent on rainfall, which is normally little and erratic for Lake Nakuru. The size and depth of arid-semi arid lakes is controlled by the precipitation received in the catchment area. This study confirms that changes in rainfall pattern in the catchment area of Lake Nakuru strongly influence its water level fluctuations through the amount of water that flows into the lake from inflowing rivers. The flow regime of the Njoro River, the major river flowing into Lake Nakuru (Okoth *et al.*, 2011), had a higher influence on water level fluctuations. Increase in rainfall in Njoro catchment led to gradual increase in the water level in Lake Nakuru. The low rainfall amounts in January and early February had no significant influence on the lake's water level. However, increased rainfall in the subsequent months enhanced the flow of the rivers Njoro, Makalia and Nderit into the lake leading to increase in the lake water level. Therefore, catchment rainfall pattern and magnitude have a direct effect on the lake water volume and consequently the lake water level in this lake.

Compared to the previous years, wide change in the flow regime especially in River Njoro was noted with almost no flow between January and March followed by very high flow rates between March and June that resulted into high water levels in the lake. These changes may be associated with combined effect of climate change and the degradation of Mau forest whose size has been reduced from 48,000 ha in 1986 to 16,500 ha in 2005 (Danida, 2006). The Mau forest is one of the main water towers in this region and its destruction is bound to have profound effects in the climate of this region. Such degradation results in the destruction of the water storing capacity by the forest layer termed the "sponging effects" through which they store rain water in the forest bed and

releases it slowly later into the streams. When this “sponging function” is still operational, the forests will then release water slowly into the forest streams that finally join up to form the rivers from the catchments which then tend to flow permanently. The deforested catchment and reduced riverine vegetation causes high runoff into the river whenever it rains with no water being stored in the catchment. The changes in the lake water level in turn had significant influence on most of the physico-chemical properties in the lake especially the salinity, alkalinity and nutrients (TP, SRP and NO_3) concentrations, through dilution of the lake water.

5.2 Physical and chemical properties in Lake Nakuru

The relatively high temperatures around this area are characteristic of this region, being located in the equatorial tropical zone. The small temporal and spatial temperature variations were due to the changes in the rainfall seasons and the sampling time which were always between 09:30 and 14:00 hours, tended to have different quantities of light and heat received at the water surface and amount transferred into the water column. The rainy seasons tend to have relatively lower temperatures than the dry seasons between January and March, every year.

The high oxygen levels found in the lake are attributed to the high photosynthetic activities that gives out oxygen as a by-product associated with Lake Nakuru due to the high phytoplankton biomass. Such high values are normally measured around mid-day when there tends to be high solar radiation and therefore enhanced photosynthetic activity (Schagerl and Oduor, 2008). However, the exceptionally low dissolved oxygen concentration recorded in April could have been due to decreased production as the phytoplankton biomass broke down and the simultaneous microbial degradation of this biomass by the bacteria and fungi which consumes oxygen. Such microbial activities are enhanced by high temperatures as experienced in this location thus further enhancing the uptake of the available dissolved oxygen through increased respiration.

The high pH values in this lake are associated with the high carbonate and bicarbonate content as observed from the high alkalinity values recorded. These ions have a strong buffering capacity that is responsible for the high stable pH values observed throughout

the sampling period. Carbon fixation as a consequence of photosynthetic activity can displace the carbon dioxide/ bicarbonate/carbonate equilibrium which is the most common pH buffering mechanism in freshwater systems (López-Achilla and Moreira, 2004). This results into high pH levels in hypereutrophic systems with high primary production as is characteristic of this lake.

The reduction in alkalinity, salinity and conductivity in the lake from March to June 2010 is associated with the increased precipitation and river discharge received in the lake which led to the dilution of the respective ions associated as the water level in the lake rose. This point is explained in the present study by the significant negative correlation between the lake water level with conductivity, salinity and alkalinity values. The endorheic nature of this water body implies that the solute content may increase through inflow and evaporation that concentrates them, while there is minimal loss of such solute. Therefore changes in water level play an important role in changing the concentration of such solutes in the lake.

The increase in TSS values from January to March could be attributed to low water depth due to evaporation and very low inflow and low precipitation, with lowered water depth any small wind would disturb the sediment and result into its re-suspension. The reduction in TSS concentration between March and June resulted from reduced re-suspension of the sediments as the water level in the lake rose, due to the increased precipitation in the lake and the flow of rivers as the rain increased in the catchment area. TSS concentration influence turbidity level of lakes with higher TSS giving high turbidity levels (Carnerio *et al.*, 2003). Secchi disk readings are usually inversely related to the suspended solids such that the readings are low when the suspended solids concentration is high (Carnerio *et al.*, 2003). This is reflected by the significant negative correlation between the TSS and the secchi depth. The low values of the Secchi disc reading recorded in February could be due to organic turbidity caused by the high biomass of phytoplankton recorded during this time. This also coincided with the period of high concentration of nutrients in the lake as the water level was also low. This is supported by the negative correlation between secchi depth and TP, SRP, NO₃ and chlorophyll *a*

concentration. The reverse could be true since as the nutrients decreased in the following months, the secchi depth increased with the highest value being recorded in June. But this may also be explained by the increased rainfall that caused high water levels and the high dilution effect on the nutrients and phytoplankton biomass that accompanied high water levels.

5.3 Nutrient concentrations in Lake Nakuru

Generally there was higher concentration of phosphorus than nitrogen with a TN: TP ratio of 4 as compared to the Redfield ratio of 16:1, implies that nitrogen may be a limiting nutrient in Lake Nakuru as noted also in other studies (Oduor and Schagerl, 2007; Ballot *et al.*, 2004). The high phosphorus concentration can be attributed to low oxygen levels and high pH in the lake that could have promoted dissolution of organically bound phosphorus from the sediments into the water phase raising the SRP and contribution by the large mammals' excreta in the park as had been observed in earlier studies (Oduor and Schagerl, 2007). The nitrogen species did not show temporal trend because nitrogen species is usually transformed depending on the prevailing redox reaction through nitrification and denitrification. For instance ammonium nitrogen correlated negatively with dissolved oxygen. The abrupt increase in ammonium nitrogen in April could be as a result of low oxygen levels leading to denitrification otherwise the highest form of nitrogen during other times was nitrate which is a result of nitrification process when the dissolved oxygen levels in the water were high in February.

The physical and chemical properties and nutrients did not show significant variation between the sites because of daily mixing experienced in the lake. The fact that Lake Nakuru is shallow, coupled with its daily mixing makes it more or less homogenous in most of its characteristics at the various sampling sites.

5.4. Plankton community structure in Lake Nakuru

Plankton organisms require specific optimum environmental conditions for rapid growth and reproduction (Wetzel, 1983). Changes in these conditions influence them either directly or indirectly through their growth and reproduction. The rainfall pattern in the

catchment area affects the water level and consequently the physico-chemical parameters in the lake as well as the lake's biota.

5. 4.1 Phytoplankton diversity, abundance and biomass

The decrease in phytoplankton diversity coincided with the onset of the rainfall season. This observation is similar to that made by Figueredo and Giani, (2001) for Pumpulha reservoir in Brazil. In which, the decrease was attributed to the disturbance experienced during the onset of the rainfall season which leads to exploitative competition by other phytoplankton supporting the system. On the contrary, Schargel and Oduor (2008) observed increase in number of phytoplankton groups with onset of rainfall in Lakes Nakuru and Elementaita. Though, it is expected that as water level increases the diversity increases too, this study showed an inverse correlation between water level and phytoplankton diversity. This implies that the water level indirectly influenced phytoplankton diversity through its influence on physico-chemical properties such as salinity and nutrients (TP, SRP and NO_3). This is explained by the positive correlation between these variables with phytoplankton diversity.

Cyanobacteria dominance in an aquatic system are favoured by warm temperature (Shapiro, 1990), alkaline pH (Reynolds and Walsby, 1975), high nutrient concentrations particularly phosphorus (Watson *et al.*, 1997) and low N: P ratio (Smith, 1983). These conditions are found in Lake Nakuru and explain the substantial cyanobacterial biomass in this system compared to other groups. The cyanophytes are of great importance to the lake's productivity because they were present throughout the study period and contributing over 75.5% of the total phytoplankton biomass with only their species composition changing with time. *A. fusiformis* contributed 74.9% of the cyanophyte biomass emphasizing its importance as a primary producer in the lake a feature also observed in other studies (Vareschi, 1982; Vareschi and Jacobs, 1984; Schagerl and Oduor, 2008). It is a food source for the primary consumers that include the zooplankton such as the ciliates, rotifers and Cladocera as well as fish and flamingos.

The low TN to TP ratio may explain the presence of *Anabaena* sp and *Anabaenopsis abijatae* which are nitrogen fixers (Schagerl and Oduor, 2008; Ballot et al., 2004). Among the filamentous cyanophytes *A. fusiformis* was favoured by high water level, pH, secchi depth, and relatively lower conductivity, salinity and alkalinity levels as compared to those favouring *Synechocystis* sp in the lake. Generally, some of the physico-chemical variables such as conductivity ($< 45 \text{ mScm}^{-1}$), salinity ($< 28 \text{ ‰}$), alkalinity ($< 510 \text{ meqL}^{-1}$), water transparency ($> 16 \text{ cm}$), total suspended solids ($< 890 \text{ mgL}^{-1}$), total phosphorus ($< 4.9 \text{ mgL}^{-1}$) and nitrate ($< 1.0 \text{ mgL}^{-1}$) were critical factors influencing the growth of *A. fusiformis*. The high abundance of *Synechocystis* sp when the conductivity, salinity, alkalinity and the nutrient (TP, SRP and NO_3) levels were high shows that its growth was favoured by these conditions which were mainly experienced during the low water levels period between January and March.

The bacillariophytes which contributed 15.1% of the total phytoplankton biomass are the second most important primary producers in Lake Nakuru after cyanophytes. The bacillariophytes population of Lake Nakuru seems to have been controlled by other factors not measured during this study. Their biomass showed no significant correlation with the measured physico-chemical parameters. Previous studies by Schagerl and Oduor, (2008) showed that increase in silica and ammonium, and a decline in conductivity, total phosphorus and water temperature enhance diatom abundances in Kenyan saline lakes. Diatoms have generally been reported to be least affected by changes in salinity (Saros and Fritz, 2000), those in saline lakes have reported that their physiological preference is for a bicarbonate medium due to an increased total carbon concentration or a higher pH, as their sulfate and bicarbonate media had pH values of 7.9 and 10.1, respectively (Sugihara and Kilham, 1977). According to Kousar and Puttaiah (2008), low concentration of dissolved oxygen, high concentration of phosphorus, high temperature and high organic matter, iron and silica triggered an increase diatom population in Shanti Sagar Lake (India).

The euglenophytes usually proliferate in eutrophic environments with high organic matter content (Wetzel, 1983). Its positive correlation with total suspended solids during this

study may explain their existence in a decreasing manner as a consequence of decline in the organic matter. The euglenophytes were abundant at the time when the concentrations of TP, SRP and NO₃ were high in the lake. A study carried out in a freshwater lake Shanti Sagar in India showed that euglenoids population were favoured by low dissolved oxygen concentration, high concentration of nitrate, iron coupled with high concentration of carbon dioxide and chloride (Kousar and Puttaiah, 2008).

The occurrence of least dominant group of phytoplankton, the chlorophytes at the beginning of the study can be explained by the significant positive correlation with nutrients as they are known to proliferate in highly eutrophic systems than oligotrophic, though more preferably freshwaters (Wetzel, 1983). An increase in chlorophyte biomass and diversity increased with increase in water temperature and nutrient concentration (nitrate) in a bicarbonate lake (Kaftar) (Nowrouzi and Valavi, 2011). Temperature is not an issue in Lake Nakuru because of its tropical location but its high pH levels may have controlled the growth of *P. duplex* which mostly occur in freshwaters with low pH.

Generally, phytoplankton composition in tropical lakes appears to be driven by the hydrologic cycle, which influences the chemical dynamics of the water column and ultimately their biota as observed by Melack, (1979); Sondergaard *et al.* (1990).

5.4.2 Zooplankton diversity, abundance and biomass

The succession of zooplankton species is regulated by availability of food, availability of oxygen, toxic products of decay, competition and predator-prey relationships (Laugaste *et al.*, 2007). Water level, temperature, dissolved oxygen, conductivity and phytoplankton biomass concentration appear to be important factors influencing zooplankton composition and abundance in Lake Nakuru. The low biodiversity but with high biomass of the well adapted zooplankton observed in the lake was also recorded in earlier studies (Vareschi and Jacobs, 1985; Finlay *et al.*, 1987; Yasindi *et al.* 2002; Okoth *et al.* 2009). According to Vareschi and Jacobs (1984, 1985), the total consumer biomass in Lake Nakuru is mostly contributed by five taxa; the lesser flamingos *Phoeniconaias minor* (58%), the fish *Oreochromis alcalicus grahami* (22%), the copepod *Lovenula africana*

(14%), chironomids (4%) and rotifers (2%). They observed that although the consumption rates of the phytoplankton by these consumers were roughly correlated with their biomass, flamingos took approximately 34%, rotifers 30%, copepods 18%, fish 9%, while chironomids and Hemiptera together consumed about 9%. Therefore, absence of the fish *O. grahami alcalicus* and copepod *L. africana* in the lake during this study left the lesser flamingo, *P. minor*, Cladoceran (*M. micrura*) and rotifers as the major primary consumers of phytoplankton, especially *A. fusiformis*.

The absence of the copepod, *L. Africana* may be linked to conductivity levels. During this study the mean conductivity varied from 16.56 mS/cm to 55.54 mS/cm which was higher than the copepod's preferred range and could have been the cause of their absence. According to the LaBarbera and Kilham (1974), *L. africana* prefers conductivity range of between 3.35 and 15.00 mS/cm. Vareschi and Vareschi (1984) observed that the high copepod population collapsed when the conductivity increased to 21.20 mS/cm. In the absence of *L. Africana*, the class Crustacea was therefore represented only by the cladoceran *M. micrura* which contributed 4.2% of the total zooplankton abundance. Cladoceran biomass may be attributed to the absence of *L. africana* and fish, which probably prey on them. The proliferation of this cladoceran was also favoured by high water level and low conductivity/salinity as shown by the significant positive and negative correlations, respectively. The large filamentous cyanobacteria (*Anabaena* sp, *A. abijatae* and *A. fusiformis*) biomass in May and June may have provided food to them promoting their abundance and proliferation. This zooplankton has been reported in other tropical freshwaters (Fernando, 2002). Experiments on *M. micrura* feeding from shallow tropical freshwaters showed that they feed on a wide range of phytoplankton particle sizes, from unicellular picoplankton to large phytoplankton where the selectivity depends on the nature and size distribution of the phytoplankton (Pagano, 2008). A suitable upper limit of algae size consumed was determined to be approximately 35 µm with algae 15 µm in length being the most abundant in the diet (Fileto *et al.*, 2004).

The rotifer species (*Brachionus plicatilis*, *B. dimitiatus* and *H. jenkiniae*) recorded in this study were also observed in previous studies (Vareschi and Vareschi, 1984) and in other

saline lakes in various parts of the world (Wetzel, 1983). Vareschi and Vareschi, (1984), suggested that the rotifer densities and species composition appeared to be triggered by salinity changes whereby *H. jenkinsae* proliferated in salinities greater than 20 ‰ and *B. plicatilis* appeared not to be affected by salinity. Rotifers in the genus *Brachionus* are filter feeders utilizing a variety of food sources including microalgae, bacteria and detritus. Their abundance and biomass showed a negative correlation to dissolved oxygen concentration. This could be as a result of high organic matter production through its breakdown by aerobic bacteria and fungi. The *Brachionus* abundance increase with increase in temperature led to their dominance in April. This is possibly because temperature has a major influence on their reproductive rate, feeding, movement and longevity (Wetzel 1983). Theilacker and McMaster (1971), in their mass culturing of *Brachionus plicatilis* at different temperatures, salinities, food concentrations, and on various algal diet found out that a high food concentration was the most important parameter needed to assure a high yield of rotifers. Hence, bacteria appeared to be the preferred food for rotifers because their maximum abundance coincided with the higher abundance of *Brachionus* in April.

Ciliates contributed 8.65% of the total zooplankton abundance. The disappearance of small ciliates in March may be associated with suppression by strong microzooplankton development especially the large predatory ciliate *C. magnum* and rotifers. Their disappearance could also have been contributed by reduced bacterial abundance as they are bacterivorous and appearance of rotifers which feed on them. Furthermore, decrease in salinity and nutrients could explain their reduction as they have been observed in some East African lakes to be abundant at higher salinities in eutrophic lakes (Yasindi *et al.*, 2007). This is similar to *Cyclidium* sp, *Condylostoma magnum* and *Acineria* sp existence which were positively influenced by conductivity and salinity. *Frontonia* sp density and biomass increased with increase in water level and decrease in conductivity and salinity. Filaments of *A. fusiformis* observed inside *Frontonia* sp indicates that they are algivorous as observed in other studies (Finlay *et al.*, 1987). However, In general there was low biodiversity in the lake but with high biomass of the well adapted biota was observed, a phenomenon also noted in earlier studies (Vareschi and Jacobs, 1985; Finlay *et al.*, 1987;

Yasindi *et al.*, 2002; Okoth *et al.*, 2009). This could be as a result of the extreme salinity water characteristics of this lake which favour only the most adapted organism.

The high zooplankton abundance in April was probably contributed by both rotifer species of the genus *Brachionus*, which are known to be microphagus, feeding on bacteria and nanoplankton. Bacteria population was high during April ($> 2.0 \times 10^8$ bacteria ml^{-1}) (Ref. Musikoyo, personal communication) when the dissolved oxygen was low, water temperature high and chlorophyll *a* concentration low. The absence of the bacteriovorous ciliates (*Cyclidium* sp) in April also relieved the rotifers from competition for food as they have been observed to have a greater consumption rate than rotifers in Lake Nakuru (Finlay *et al.* 1987). This observation also suggests that rotifers might have predated on them because their food (bacteria) was not limiting. The zooplankton are important in the ecology of Lake Nakuru through the food web. Their biomass showed an inverse correlation with phytoplankton biomass. This is clearly showed by the presence of the bacterivorous ciliates (*Cyclidium* sp and rotifers), Herbivorous ciliates (*Frontonia* sp) and carnivorous zooplankton (*Brachionus*, *L.africana*).

The increase in flamingo population with increase in the water level was as a result of the positive relationship between water level and *Arthrospira fusiformis* which is the most preferred food for flamingos (Vareschi, 1982) which are a main tourist attraction to the lake. Therefore *Arthrospira fusiformis* existence and maintenance in Lake Nakuru is of critical importance to the tourism industry. This is because flamingos are known to migrate from other saline lakes like Natron, Elementaita and Bogoria to this lake in search for food.

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Lake Nakuru is important water body not only as a source of revenue through tourism but also a wildlife conservatory, hence its designation as a Ramsar site. Climate change and catchment degradation around the lake are therefore a major threat since they affect the water level in the lake. This is because changes in the catchment area associated with vegetation would strongly impact on the hydrology of the rivers flowing into the lake. Large fluctuations in its water level are likely to affect its physico-chemical properties and biota beyond their resilience level that would make the lake lose some of its important biota. Plankton diversity, density and biomass are strongly influenced by the changing water level directly or indirectly through the changes in water physico-chemical properties, especially secchi depth, salinity and nutrients. For instance, some variations were observed in the plankton diversity of Lake Nakuru such as the absence of the only copepod *L. Africana*, the sudden appearance of the phytoplankton *Oscillatoria spp* and the cladoceran species *M. Micrura* in the lake during this study. Therefore, plankton acts as good indicators of the influence of hydrological changes on the whole lake ecology.

6.2 Recommendation

1. The conservation of Lake Nakuru therefore is a very important issue that needs to be carefully undertaken.
2. It is therefore very imperative that the catchment area of this lake has to be well managed and conserved and its re-forestation process speeded up so that the rivers feeding the lake may have sustained flow.
3. There is need of continuous monitoring of its plankton dynamics in order to understand the effects of climate variation on its ecology and develop the right mitigation and management measures.

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APPENDICES

Appendix 1: Mean physico-chemical variables in Lake Nakuru (January to June 2010).

Appendix 2: The bivariate correlations between various parameters in Lake Nakuru.

Appendix 3: Phytoplankton biovolume ($\mu\text{m}^3/\text{L}$) in Lake Nakuru (January to June 2010).

Appendix 4: Spatial phytoplankton biovolume ($\mu\text{m}^3/\text{L}$) in Lake Nakuru from January to June 2010.

Appendix 5: Mean zooplankton abundance in Lake Nakuru from January to June 2010.

Appendix 6: Mean zooplankton biomass in Lake Nakuru from January to June 2010.

Appendix 7: Njoro catchment weather conditions.

Appendix 8: Lake Nakuru weather conditions from January to June 2010.

Appendix 9: Monthly rainfall (mm) in Lake Nakuru from January to June between 2000 and 2010.

Appendix 1: Mean physico-chemical variables in Lake Nakuru from January to June 2010.

Date	Water			Secchi			Organic matter		Inorganic matter	
	depth (cm)	Temp (°C)	DO (mg/l)	pH	Cond. (mS ^{cm} ⁻¹)	Salinity (%)	depth (cm)	TSS (mg/l)	matter (mg/l)	matter (mg/l)
20.1.10	42.50	26.15	15.86	10.19	52.33	35.45	14.58	670.00	316.25	353.75
S.E	1.12	0.37	2.74	0.02	6.16	5.97	0.27	37.46	24.33	41.60
04.2.10	45.00	28.35	21.89	10.16	39.98	24.92	12.67	1753.33	1508.33	245.00
S.E	0.00	0.44	0.05	0.01	0.66	0.24	0.67	200.00	145.00	55.00
22.2.10	45.00	23.29	16.06	10.32	65.91	46.79	13.28	478.56	249.83	228.72
S.E	0.00	0.45	1.84	0.02	2.35	1.90	0.70	28.08	21.94	6.64
10.3.10	60.00	25.89	12.27	10.25	51.42	33.18	16.22	838.89	552.22	286.67
S.E	0.00	0.19	0.95	0.01	0.51	0.52	0.19	85.66	63.04	22.84
25.3.10	66.67	27.13	15.61	10.25	38.29	22.68	15.78	923.06	477.22	445.83
S.E	2.21	0.95	0.31	0.01	5.06	2.87	0.49	43.19	15.88	49.84
07.4.10	95.00	29.10	1.13	10.26	36.00	20.29	27.81	320.89	106.00	214.89
S.E	1.44	0.98	0.18	0.01	0.90	0.14	0.81	64.34	1.37	64.55
21.4.10	103.33	28.59	2.95	10.25	33.32	19.24	29.83	160.67	63.11	97.56
S.E	3.33	0.42	0.37	0.01	0.59	0.18	0.52	22.90	1.84	23.19
06.5.10	133.33	27.78	17.55	10.30	19.14	10.73	23.00	260.44	126.07	134.37
S.E	0.83	0.52	1.89	0.02	1.84	1.29	1.03	11.31	15.27	13.83
20.5.10	170.00	25.58	16.96	10.34	20.92	12.36	23.39	109.89	37.11	72.78
S.E	0.00	0.89	3.49	0.02	0.95	0.40	0.48	4.10	0.92	3.58
02.6.10	183.33	26.12	23.15	10.32	21.53	12.63	32.78	96.89	30.11	66.78
S.E	3.01	0.64	1.81	0.01	0.66	0.25	2.09	3.38	0.89	3.09
15.6.10	193.33	26.58	19.21	10.30	14.72	8.24	33.06	143.00	32.11	110.89
S.E	3.33	0.64	0.63	0.01	2.19	1.20	1.43	5.64	4.18	4.18
30.6.10	185.00	25.01	8.35	10.31	13.43	7.96	50.22	90.00	32.22	57.78
S.E	2.50	0.61	0.34	0.01	1.33	0.99	2.30	18.21	4.64	17.79
Mean	114.12	26.59	13.98	10.28	33.20	20.68	25.02	314.47	160.23	154.24
S.E	5.69	0.24	0.80	0.01	1.72	1.25	1.10	36.26	27.84	13.41

Continuation of Appendix 1....

Date	TP (µg/l)	SRP (µg/l)	NH ₄ -N (µg/l)	NO ₃ -N (µg/l)	NO ₂ -N (µg/l)	PA (meq/l ⁻¹)	TA (meq/l ⁻¹)	Chl <i>a</i> (mg/l)
20.1.10	6546.71	2587.41	43.39	1590.64	19.29	486.75	1102.74	617.74
S.E	65.09	171.47	4.22	35.01	2.02	4.83	9.45	74.62
04.2.10	7530.68	4436.67	56.69	1721.64	16.40	610.44	1376.22	788.50
S.E	187.19	1005.72	4.58	76.99	0.99	23.00	47.38	5.70
22.2.10	5982.17	3729.60	68.57	1473.51	35.88	531.49	1189.15	632.47
S.E	57.84	1004.12	5.87	99.19	8.93	47.83	106.03	22.23
10.3.10	5116.48	1406.37	47.33	953.01	16.73	376.68	375.44	661.88
S.E	68.61	46.30	2.25	25.81	1.96	53.13	53.37	77.01
25.3.10	4571.36	1409.82	59.75	899.47	7.12	277.87	631.17	661.88
S.E	157.64	181.73	5.40	53.94	0.72	5.34	11.83	77.01
07.4.10	2814.56	219.29	558.82	580.09	8.99	209.45	411.68	246.79
S.E	34.75	13.81	36.58	24.60	0.32	8.20	10.40	16.32
21.4.10	2848.45	576.71	1011.04	481.29	9.31	190.48	385.33	56.62
S.E	84.96	19.11	116.81	32.26	0.27	12.05	7.87	2.47
06.5.10	2317.46	416.13	152.04	515.71	8.15	144.81	277.03	1057.88
S.E	161.83	18.46	31.39	35.49	1.08	24.33	31.12	268.42
20.5.10	1775.16	374.69	26.94	247.97	6.06	97.13	230.56	687.25
S.E	30.11	5.46	3.12	18.90	0.26	3.64	8.20	89.52
02.6.10	1890.97	474.83	47.52	400.97	5.22	98.83	236.08	451.74
S.E	42.88	15.99	7.44	27.07	0.18	1.56	3.09	27.55
15.6.10	1606.97	319.43	45.53	384.39	6.44	99.81	237.63	734.03
S.E	24.01	5.25	1.46	14.31	0.13	2.60	5.70	66.74
30.6.10	2061.84	379.87	46.47	424.55	4.90	93.14	232.40	438.01
S.E	118.70	12.98	5.15	22.36	0.18	1.76	4.07	75.32
Mean	3339.28	1059.66	197.59	695.55	10.68	211.74	420.96	567.12
S.E	182.83	139.53	33.19	44.82	0.98	15.83	31.02	40.71

Appendix 2: The bivariate correlations between various parameters in Lake Nakuru.

	DO (mg/l)	Salinity (‰)	TSS (mg/L)	TP (µg/L)	SRP (µg/L)	NH ₄ (µg/L)	NO ₃ (µg/L)
Water depth (cm)	.099	-.868**	-.734**	-.908**	-.755**	-.079	-.860**
Sig. level	.760	.000	.007	.000	.004	.807	.000
DO (mg/L)	1	-.012	.294	.195	.367	-.753**	.253
Sig. level		.971	.353	.544	.241	.005	.427
Salinity (‰)		1	.475	.821**	.749**	-.067	.811**
Sig. level			.119	.001	.005	.835	.001
TSS (mg/L)			1	.856**	.790**	-.243	.799**
Sig. level				.000	.002	.446	.002
TP (µg/L)				1	.929**	-.200	.982**
Sig. level					.000	.534	.000
SRP (µg/L)					1	-.280	.950**
Sig. level						.378	.000
NH ₄ (µg/L)						1	-.248
Sig. level							.436
NO ₃ (µg/L)							1
Sig. level							

Appendix 3: Phytoplankton biovolume ($\times 10^{-6} = \mu\text{m}^3/\text{L}$) in Lake Nakuru from January to June 2010.

Month	Euglenophytes	Cyanophytes	Chlorophytes	Bacillariophytes	Mean
January	1.07E+08	1.06E+10	1.76E+06	-	3.58E+09
February	4.30E+07	1.00E+08	2.62E+06	1.17E+07	5.51E+07
March	1.03E+06	1.15E+09	3.90E+05	4.33E+07	5.01E+08
April	-	2.45E+09	-	2.47E+06	1.67E+09
May	-	9.54E+10	-	2.31E+07	9.04E+10
June	-	1.35E+11	-	-	1.35E+11
Mean	5.03E+07	4.07E+010	1.59E+06	2.01E+07	3.57E+10

Appendix 4: Spatial phytoplankton biovolume ($\times 10^{-3} = \mu\text{m}^3/\text{L}$) in Lake Nakuru from January to June 2010.

Phytoplankton	South	Central	North
<i>Synechococcus sp</i>	7.76E+03	3.97E+03	2.87E+03
<i>Synechocytis sp</i>	1.22E+03	9.54E+01	1.59E+01
<i>Anabaena sp</i>	4.18E+06	1.40E+07	6.52E+07
<i>A. fusiformis</i>	1.59E+08	1.53E+08	1.09E+08
<i>A. abijatae</i>	4.06E+07	8.18E+07	3.56E+07
<i>Oscillatoria spp</i>	1.61E+06	2.41E+06	4.13E+05
<i>P. longicauda</i>	7.85E+04	7.01E+04	1.45E+03
<i>Euglena acus</i>	3.60E+03	9.00E+03	-
<i>Nitzschia sp</i>	6.76E+04	4.86E+02	1.62E+03
<i>Navicula sp</i>	4.90E+03	1.57E+04	7.57E+03
<i>P. duplex</i>	4.68E+03	1.76E+03	-
<i>S. communis</i>	7.43E+02	7.43E+02	7.43E+02
Total	2.06E+08	2.51E+08	2.1E+08

Appendix 5: Mean zooplankton abundance (Ind/L) in Lake Nakuru from January to June 2010.

Date	<i>Cyclidium</i> sp	<i>C. magnum</i>	Other ciliates	<i>Acinertia</i> sp	<i>B. dimidiatus</i>	<i>B. plicatilis</i>	<i>H. jenkiniae</i>	<i>M. micrura</i>	<i>Frontonia</i> sp	R.eggs
20.01.10	1.94E+03	6.53E+02	5.10E+02	3.55E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
04.02.10	3.00E+03	1.05E+03	0.00E+00	8.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22.02.10	8.97E+03	1.84E+04	2.04E+01	4.90E+01	1.91E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10.03.10	1.50E+04	1.31E+04	2.59E+01	2.93E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25.03.10	2.47E+03	1.15E+03	0.00E+00	1.44E+02	4.26E+02	8.58E+01	0.00E+00	0.00E+00	0.00E+00	2.96E+02
07.04.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.37E+05	1.10E+05	0.00E+00	0.00E+00	0.00E+00	2.48E+05
21.04.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E+05	2.07E+04	0.00E+00	0.00E+00	0.00E+00	2.47E+04
06.05.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.57E+04	1.62E+04	0.00E+00	0.00E+00	0.00E+00	1.83E+04
20.05.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.15E+04	7.04E+03	1.67E+04	0.00E+00	0.00E+00	1.54E+04
02.06.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E+04	1.54E+03	1.50E+03	1.92E+03	0.00E+00	3.46E+03
15.06.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.89E+03	7.72E+02	2.30E+03	5.44E+02	9.39E+02	1.91E+03
30.06.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E+04	1.66E+03	6.82E+03	9.01E+02	1.35E+03	4.50E+03

Appendix 6: Mean zooplankton biomass (mg/L DW) in Lake Nakuru from January to June 2010.

Date	<i>Cyclidium</i> sp	<i>C. magnum</i>	Other ciliates	<i>Acinertia</i> sp	<i>B. dimidiatus</i>	<i>B. plicatilis</i>	<i>H. jenkiniae</i>	<i>M. micrura</i>	<i>Frontonia</i> sp	R. eggs
20.01.10	3.49E-05	1.19E-03	1.23E-05	2.09E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
04.02.10	5.38E-05	1.90E-03	0.00E+00	5.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22.02.10	1.61E-04	3.35E-02	4.90E-07	2.88E-06	1.03E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10.03.10	2.51E-04	2.73E-02	2.42E-07	1.72E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25.03.10	4.15E-05	2.40E-03	0.00E+00	8.47E-06	2.31E-04	1.02E-04	0.00E+00	0.00E+00	0.00E+00	6.29E-05
07.04.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-04	1.29E-04	0.00E+00	0.00E+00	0.00E+00	7.29E-02
21.04.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.54E-02	3.13E-02	0.00E+00	0.00E+00	0.00E+00	7.25E-03
06.05.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-02	2.97E-02	0.00E+00	0.00E+00	0.00E+00	4.57E-03
20.05.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.15E-02	1.29E-02	4.40E-01	0.00E+00	0.00E+00	3.85E-03
02.06.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.88E-03	2.85E-03	4.12E-02	5.37E+03	0.00E+00	9.17E-04
15.06.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.85E-03	1.43E-03	6.30E-02	1.52E+03	8.58E-04	5.07E-04
30.06.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-02	3.08E-03	1.87E-01	2.52E+03	1.23E-03	1.19E-03

Appendix 7: Njoro catchment weather conditions.

A) Temperature, Relative humidity, rainfall and evaporation from January to June 2010.

Time	Temperature (°C)	R/humidity (%)	Total rainfall (mm)	Mean Rainfall (mm)	Evaporation (mm/day)
1/1/10-19/1/10	19.17	69.79	45.30	6.47	3.41
20/1/10-03/2/10	21.99	47.27	92.80	23.75	4.93
04/2/10-21/2/10	20.89	67.06	149.40	7.08	4.38
22/2/10-9/3/10	19.66	75.56	284.40	9.64	3.96
10/3/10-24/3/10	19.91	67.40	390.20	13.23	4.37
25/3/10-06/4/10	19.74	75.54	555.10	13.74	4.47
07/4/10-20/4/10	20.81	66.57	578.00	3.82	3.71
21/4/10-05/5/10	21.03	70.87	671.30	11.66	3.73
06/5/10-19/5/10	19.24	77.00	800.60	16.16	3.66
20/5/10-01/6/10	20.89	66.55	830.00	9.80	3.48
02/6/10-14/6/10	19.64	71.54	867.90	4.74	3.51
15/6/10-30/6/10	18.74	73.56	916.20	9.66	2.80

Appendix 8: Lake Nakuru weather conditions from January to June 2010.

Time	Pressure (mbar)	Total rainfall (mm)	Mean rainfall (mm)	PAR (uE)	Temp, (°C)	Relative humidity (%)	Wind Speed (km/hr)
1/1/10-19/1/10	825.79	29.40	0.01	473.69	19.07	71.30	4.84
20/1/10-04/2/10	825.22	31.21	0.00	587.09	19.86	53.93	5.85
04/2/10-21/2/10	825.16	135.41	0.02	476.98	19.96	71.24	4.51
22/2/10-9/3/10	826.16	192.44	0.01	469.78	18.98	80.39	3.34
10/3/10-14/3/10	825.71	253.64	0.01	507.74	18.84	73.79	3.92
15/3/10-06/4/10	826.18	404.04	0.04	485.58	18.61	83.36	2.44
07/4/10-20/4/10	825.96	445.24	0.01	503.46	19.12	78.72	2.36
21/4/10-05/5/10	825.66	514.64	0.02	475.55	19.21	81.65	1.90
06/5/10-19/5/10	826.00	629.24	0.03	423.53	18.61	82.55	1.79
20/5/10-01/6/10	826.17	653.44	0.01	501.21	18.36	76.58	1.84
02/6/10-14/6/10	827.58	685.44	0.01	426.33	17.84	80.49	1.26
15/6/10-30/6/10	826.52	692.24	0.00	432.89	17.76	76.38	1.91

Appendix 9: Monthly rainfall (mm) in Lake Nakuru from January to June between 2000 and 2010.

Year	Jan	Feb	March	April	May	June
2000	1.20	0.80	2.00	56.80	30.60	115.90
2001	93.50	63.60	121.00	119.70	46.80	117.10
2002	39.40	28.40	127.4	60.60	197.60	90.30
2003	59.00	8.60	81.20	172.70	277.80	99.20
2004	118.5	22.90	80.50	185.40	182.80	44.50
2005	47.40	17.80	68.50	82.00	136.20	96.10
2006	22.80	11.50	90.40	91.90	60.10	74.40
2007	56.70	146.80	19.50	64.50	84.10	168.20
2008	17.20	1.40	84.20	99.00	69.40	42.20
2009	10.50	1.40	15.20	61.30	172.70	14.90
2010	47.30	167.20	285.80	126.90	202.80	86.20

