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# A COMPARATIVE STUDY OF THE INFLUENCE OF VARIATIONS IN ENVIRONMENTAL FACTORS ON PHYTOPLANKTON ROPERTIES OF SELECTED RESERVOIRS IN CENTRAL KENYA.


**BY**

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## DECLARATION

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

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## DEDICATION

To my late father, Mr. Samuel Lesan, and mother, Mrs. Mary Koe Lesan,
for their love for education

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## ABRREVIATIONS AND ACRONYMS

| | |
|---|---|
| APHA | America Public Health Association |
| UNEP | United Nation Environmental Programme |
| UNESCO | United Nation Educational Scientific Cultural Organization |
| OCED | Organization for Economic Cooperation and Development |
| ICOLD | International Commission on Large Dams |
| $NO_2$-N | Nitrite-nitrogen |
| $NO_3$-N | Nitrate- nitrogen |
| TN | Total nitrogen |
| $PO_4$-P | Ortho-phosphate phosphorus |
| TP | Total phosphorus |

## ABSTRACT

Limnological information on reservoirs is important as it forms a vital baseline for among others the detection of undesirable changes in water quality. The physico-chemical and phytoplankton properties were investigated in Uhuru, Ruiru, Ngewa, Comte and Kianjjibbe reservoirs in central and Nairobi provinces of Kenya, over a period of 12 months (between February 2002 and January 2003). The aim of the study was to determine the nature and level of variation in the physico-chemical properties and its influence on phytoplankton composition, diversity and biomass. Sampling was done during day time and samples analyzed within four hours of sample collection. Among the limnological properties measured were: Secchi depth, temperature, electrical conductivity, dissolved oxygen pH, total alkalinity, nitrite-nitrogen, nitrate-nitrogen, total nitrogen, ortho-phosphate, total phosphate, soluble reactive silica, phytoplankton composition and phytoplankton biomass. The study revealed varied degrees of seasonal changes in physico-chemical and phytoplankton properties of the reservoirs. Mean Secchi depth (SD) ranged from 0.1± 0.4 (Ngewa) to 0.9 ± 0.43 m (Ruiru). In general, the highest variation was noted during the dry season. Mean EC ranged from 45.8 ± 5.7 $\mu S\ cm^{-1}$ (Ruiru) to 298.9 ± 41.5 $\mu S\ cm^{-1}$ in Kianjjibbe with the highest EC being recorded during the dry season. Mean total alkalinity (TA) at the reservoirs ranged from 18.0 ± 0.24 mg $L^{-1}$(Ruiru) to 110.2 ± 15.9 mg $L^{-1}$ (Kianjjibbe). Mean nitrate nitrogen ($NO_3$-N) concentration ranged from 4.2 ± 0.43 µg $L^{-1}$ in (Ngewa) to 13.6 ± 1.14 µg $L^{-1}$ in (Kianjjibbe). Low mean $NO_3$-N concentration was recorded during the dry season. Mean total nitrogen (TN) concentration at the reservoirs ranged from 32.5 ± 28.7 µg $L^{-1}$ (Kianjjibbe) to 40.5 ± 36.9 µg $L^{-1}$ (Comte). High (TN) concentration was recorded during the wet season. Mean total phosphorous (TP) ranged from 0.70 ± 0.25 µg $L^{-1}$ (Kianjjibbe) to 1.03 ± 0.82 µg $L^{-1}$ (Comte). High mean TP concentration was recorded during the wet season. Mean soluble reactive silica (SRS) concentration ranged from 3.2 ± 0.47 (Uhuru) to 7.3 ± 0.74 µg $L^{-1}$ (Ngewa). High SRS concentration was recorded during the dry season. A significant difference in Secchi depth electrical conductivity, total alkalinity, nitrate nitrogen, total nitrogen, total phosphorus and Soluble reactive silica was noted in all the five reservoirs ($P<0.001$). A total of 35 phytoplankton genera belonging to 7 divisions were identified in all the five reservoirs. However the largest number of genera (16) belonged to the Chlorophyta while Cryptophyta had only one genus. Total biomass ranged from 3291.87 mg $L^{-1}$ (Ngewa) to 22,338.763 mg $L^{-1}$ (Kianjjibbe). Most of the biomass was due to Dinophyta. Wet season was characterized by high biomass. Total biomass between the reservoirs were significantly different ($p<0.001$). Phytoplankton biodiversity was high during the dry season. Uhuru reservoir had the highest diversity of 2.4 bits. The study concludes that the reservoirs investigated vary in levels of physico-chemical and phytoplankton properties investigated. This variation was attributed to differences in rainfall, volume of outflow and use dynamics of the water of the reservoirs.

# CHAPTER ONE: INTRODUCTION

## 1.1 Background to the problem

Freshwater reservoirs play an important role in the livelihood of human populations. They are mainly used as a source of domestic water and for irrigation, fishery development and hydroelectric-power generation (Adeniji *et al.,* 1981). Phytoplankton in freshwater reservoirs serve as important biological indicators of the status of the water quality. They also trap solar energy and convert it to chemical energy through the photosynthetic process. They are therefore the main primary producers in pelagic systems. Phytoplankton are primary sources of food for the zooplankton. They are also rich sources of protein and are used directly as human food (Bookmark and Hansson 2005).

Phytoplankton in freshwater bodies are adapted to different physico-chemical conditions at which their growth and reproduction are at optimum level. However, human activities such as agricultural, domestic, recreational and industrial activities, may adversely affect the physico-chemical conditions of water in reservoirs (UNEP, 1991, 2000; Hemond and Fechner, 1994; Ballance and Batram, 1996; Gleick, 1993, Nathashon, 2000 and Gleick *et al.,* 2001). The consequence of the above activities results in changes in physico-chemical conditions of the reservoir, which may influence the phytoplankton species found in the water body. Changes in phytoplankton species composition may adversely affect other aquatic organisms (Hinnawi, 1987).

Recent studies on phytoplankton changes in large reservoirs have reported qualitative changes resulting from several years of cultural eutrophication (Oriola, 2003). One important biological consequence of eutrophication is excessive algal growth, which has adverse effects on human, livestock and aquatic organisms (Codd *et al.,* 1989). Toxic algal blooms have been reported in a number of African man made lakes (Adeniji *et al.*, 1981). Toxicity associated with *Cylindrospermopsis* has been reported in the Solomon dam in Australia, five hypereutropic dams in Florida (Chapman, 1997), shallow reservoirs in semi-arid and arid regions of northwest Brazil (Bouvy, 1997), in eutrophic reservoirs in China (Li *et al.*, 2002), and in the Sheldon reservoir in Colorado U.S.A. (Obserholsten *et al.,* 2006). *Cylindrospermopsis* releases a cyanotoxin called cylindrospermopsin, which has been found to have herpatotoxic effects on livestock and humans (Hawkins *et al*, 1997; Falconer *et al.,* 2001 and Falconer, 2005). Fish kills caused by cylindrospermopsin herpatotoxins has been reported in South Africa's Hartebbesport reservoir (Falconer, *et al.*, 2001). Although the problem of algal blooms is cosmopolitan, it has been shown to be more severe at formative stages of man made lakes (Adeniji *et al.,* 1981).

In Kenya, several reservoirs have been built for diverse purposes. Despite their widespread distribution in the country, our understanding of their limnology remains limited. To harness the diverse reservoir resources sustainably, an understanding of their limnological conditions is necessary. Our limited understanding, especially of the small reservoirs, partly explains their underexploitation for recreation, ecotourism, fishery development and biodiversity conservation.

Limited or totally no limnological studies have been carried out in the reservoirs located in central Kenya. Most reservoirs in this part of Kenya are small in size and located in areas of intense human activities. Uhuru, Ruiru, Ngewa, Comte and Kianjjibbe reservoirs are surrounded by diverse agricultural and industrial/commercial activities. It is therefore likely that human activities in their catchments influence the physico-chemical properties, phytoplankton characteristics and resource sustainability.

Limnological information on the selected small reservoirs is limited yet they are the most vulnerable to human activities owing to their small size. Hence there is need to closely monitor their environmental conditions. Reservoir information forms a vital baseline for the understanding of reservoir ecosystem dynamics and detection of undesirable changes in water quality that may stem from human activities. Small freshwater water reservoirs in Kenya are mainly used for domestic water supply and plant irrigation as well as recreation and fishery development. In general, human activities in reservoir catchments have resulted in a rapid deterioration in reservoir water quality. As the phytoplankton are important biological indicators of the water quality in reservoirs, their identification and characterization play a role in the management and sustainable use of the reservoirs (Kotut *et al.*, 1998a).

## 1.2 Problem statement and study justification

Data on status and temporal variation of physico-chemical and phytoplankton characteristics on the chosen reservoirs is scanty or totally absent. Owing to their small size, these reservoirs are vulnerable to human activities. The chosen reservoirs, Uhuru, Ruiru, Ngewa, Comte, and Kianjjibbe are heavily utilized for diverse socio-economic activities that include water for irrigation, municipal water supply, recreation and

fisheries. Owing to their multiple uses, close monitoring of their limnological characteristics is necessary. The data collected will form vital baseline information on the status of reservoirs, which is helpful in the sustainable use of the reservoir resources.

Spatial and temporal variations controlling environmental conditions bring about unique physico-chemical and biological characteristics of different reservoirs. The extent to which these variations occur within each reservoir and between reservoirs is necessary for the understanding of reservoir ecosystem dynamics.

It is important to obtain ecological data on each water system because such information would enhance formulation of optimal management strategies for the resources in the reservoirs and avoid errors common to the wholesale transfer of management strategies workable in different systems.

## 1.3 Research questions

The general research questions that the study sought to answer were as follows:

- How do the physico-chemical properties in the reservoirs compare?
- What is the phytoplankton composition, diversity and biomass in the reservoirs?
- Do the physico-chemical properties and phytoplankton characteristics of the different reservoirs vary with season?
- What is the relationship between variation in the physico-chemical properties and phytoplankton characteristics of the selected reservoirs?

## 1.4 Hypotheses of the study

The hypotheses of the study were as follows

- The levels of physico-chemical properties are the same in selected reservoirs.
- Phytoplankton composition, biomass and levels are the same in the study reservoirs.
- The physico-chemical properties and phytoplankton characteristics of the study reservoirs do not exhibit any seasonal changes.
- There is no relationship between variations in physico-chemical properties and

## 1.5 Objectives of the study

The general objective of the study was to establish levels and variation in the physico-chemical and phytoplankton properties of selected reservoirs in central Kenya. The specific objectives of the study were:

- To determine levels of the physico-chemical properties at selected reservoirs.
- Establish the phytoplankton composition, biomass levels in the study reservoirs.
- To find out whether there are seasonal variation in physico-chemical properties and phytoplankton characteristics of the study reservoirs.
- To find out whether there is a relationship between variations in physico-chemical properties and phytoplankton characteristics of the study reservoirs.

## 1.6 Significance of the study

The present study makes an important contribution to an improved understanding of the limnology of small water reservoirs in Kenya. Such an understanding is necessary for the assessment of the impact of poor land use practices in the catchments. The study generates specific information on the physico-chemical properties and phytoplankton composition, diversity and biomass in freshwater reservoirs. These will assist resource

managers to formulate the most economical and ecologically sound resource management strategies for the selected reservoirs and other reservoirs with similar characteristics.

## 1.7 Scope, limitations and assumptions of the study

The study concentrated on five reservoirs located in Nairobi and Central Province of Kenya. The study was carried out over a period of 18 months and may not have captured long term changes. The study was undertaken on the assumption that the sites sampled represented the whole reservoir and reservoirs selected were representative of all other reservoirs within the same area.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Introduction

This chapter looks at the nature of reservoirs, reservoir conditions in Africa and status of reservoirs in Kenya. In looking at the nature of reservoirs, trends in reservoir construction, reasons for their construction and their relations with natural lakes are considered. The chapter also presents review of literature on the influence of variations in physico-chemical condition on phytoplankton properties.

## 2.2 Nature of reservoirs

### 2.2.1 Trends in reservoir construction

Reservoirs are usually formed through construction of dams across rivers, streams or run-off channels resulting in the impoundment of water behind the dam wall. Alternately, they may be formed by river or stream diversion to a suitable depression such as for Lake Qaran in Egypt (Latif, 1984). Reservoir construction is an ancient art: Lake Qaran in Egypt, Itoms in the Orontes valley of Syria and Parakrama-Samuda in Sri- Lanka date back to 4000 BC, 13000 BC and 1300 AD respectively (Beadle, 1981). Since then technological advances have brought about a rapid increase in the number and size of artificially constructed reservoirs (ICOLD, 1998). The number of reservoirs in the world has steadily increased from approximately 5,000 in the 1950's through 30,000 in the 70's to approximately 40,000 in the 80's (ICSU-SCOPE, 1972). Towards the end of the last millennium there were about 845,000 dams worldwide (ICOLD, 1998).

### 2.2.2 Reasons for reservoir construction

According to ICOLD (1998), worldwide irrigation water supply is the main reason for reservoir construction, with 40% of the larger reservoirs being used for irrigation.

Irrigated agriculture accounts for about 40% of the world's agricultural production. The remaining large reservoirs are used as follows; 19% for hydropower production, 13% for flood management and 12% for water supply and 16% are multipurpose (ICOLD, 1998). In Africa, 52% of the large reservoirs are used for irrigation, 20% for water supply, 6% for hydro-power production and 2% for flood control while the rest of the reservoirs, 20%, are multipurpose (ICOLD, 1998). Additional benefits from reservoirs include fishery exploitation, tourist attraction and opening up of new areas for development. Apart from the large reservoirs, most countries have numerous small reservoirs. The small reservoirs have been created mainly for irrigation and water supply. The high utility of reservoirs, especially the small ones, means that greater efforts should be put into the understanding of the existing reservoir systems so as to enhance the benefits from them.

### 2.2.3 Relationship between reservoirs and natural lakes

Reservoirs are formed through impoundment of rivers and therefore they are expected to have characteristics in between those of rivers and lakes. There are many differences between lakes (lentic system) and rivers (lotic system), the most important being current direction and origin of kinetic energy. Whereas water movement in rivers is unidirectional, it is variable in lakes. In rivers and streams, the kinetic energy originates predominantly from the gravitational mass transport of water, while in lakes it is mainly the action of wind upon the surface of the water.

Reservoirs occupy an intermediary position between rivers and lakes. Under natural conditions, reservoirs have got both lacustrine and riverine characteristics with the ideal riverine and lacustrine conditions at both ends of the continuum. Based on relative importance of external nutrient inputs and internal nutrient cycling and significance of

allochthonous relative to autochthonous sources of organic matter to the food web, Bruce *et al.,* (1990) places reservoirs at an intermediate position between natural lakes and rivers. Because of their intermediary position, reservoirs are described as river-lake hybrids, a term that has been used by a number of limnologists (Thornton *et al.,* 1990; Thornton, 1990 and Ryder, 1978) to describe this unique intermediary position.

Although reservoirs have characteristics in between those of rivers and lakes, past studies show that the reservoirs are functionally similar to natural lakes, and have therefore been grouped together as lakes. An early classification of lakes based on the agencies that produced their basins placed reservoirs in the same group as natural lakes born of obstructive processes. A classification scheme put forward by Hutchinson (1957) places reservoirs into a class of lakes produced by the complex activities of higher organisms, such as humans and beavers.

Several studies have also shown that there are some differences between natural lakes and reservoirs (Thornton *et al.,* 1990). Based on a comparison of the geometric mean values of a number of morphologic and hydrologic parameters in 309 natural lakes and 107 reservoirs in North America, Thornton *et al.,* (1990) concluded that comparatively; reservoirs have a larger drainage basin to surface area ratio, larger mean maximum depths, greater areal water loads, shorter hydraulic residence time and greater areal nutrient load.

Reservoirs are usually constructed at the downstream boundary of a drainage basin and this result in the drainage basins being narrow and elongated with a small portion of the drainage basin being contiguous with the reservoir. Most nutrients and water enter the reservoir through a single large tributary located at an upstream point some distance away from the dam wall. This results in the existence of a gradient in environmental conditions from river mouth to the dam wall, which is caused by a decline in the influence of the inflow from river mouth to the dam wall. The spatial gradient in environmental conditions is most pronounced in long, narrow and dendritic reservoirs. The spatial gradient in environmental conditions is not present in lakes as they usually occupy natural depressions in the local topography and inputs enter the lake through several points around the lake.

The spatial gradient in most environmental conditions is characterized by a shift from river-like conditions next to the river mouth to lake like conditions near the dam wall. In reservoirs that are long, narrow and dendritic, three distinct zones can be recognized; the riverine zone, the transition zone and the lacustrine zone (Thornton *et al.,* 1990; Bruce *et al.,* 1990 and Kimmel and Greeger, 1984). The above patterns are not discrete entities with distinct boundaries but are the combined effects of a number of overlapping gradients. Temporally, the zones are usually dynamic, that is they expand and contract in response to inflow rates and quality.

Depending on the extent of development of the three zones (dictated by the hydraulic residence time), reservoirs have been classified into three groups; mainstream, transitional and deep storage reservoirs (Thornton *et al.,* 1990). Mainstream or riverine

reservoirs with very short hydraulic residence time, are wholly characterized by the riverine conditions. The transitional reservoir with moderate residence time has only the riverine and transitional zone conditions formed. Deep storage reservoirs with much longer residence time are characterized by a full development of the lacustrine zone in addition to the riverine and transitional zones.

Existence of differences between reservoirs and natural lakes means that the findings from lake studies may not form the basis of understanding reservoir ecology. Hence the documentation of the reservoir limnology is important for the better understanding of reservoir ecology. Such information forms a vital baseline for the detection of undesirable changes in water quality that may stem from human related activities in the catchment area. Data collected can also guide in the formulation of rational management strategies for reservoir resources.

## 2.3 Reservoir conditions in Africa

### 2.3.1 Historical development of reservoirs

Africa is a continent of plateaus each with marked edges. The plateaus are as a result of several cycles of erosion and uplifts (Church, 1960). The rivers fall over the edges forming suitable dam sites especially for hydropower generation. The continent is therefore rich in hydropower potential, which amounts to one third of the world's prime potential capacity (Smith, 1968). The development of reservoirs in Africa is a recent venture when compared to the temperate regions. In the 1950s, the continent witnessed the appearance of reservoirs comparable in size with some of its large natural lakes (Smith, 1968).

The largest man-made reservoir, Volta with an area of 8730 $km^2$, was commissioned in 1968. The other reservoirs are Kariba (5000 $km^2$), Nasser-Nubia (5000 $km^2$), Kafue Gorge (3100 $km^2$), Lake Cabora Bassa (2700 $km^2$), Lake Kossoli (1700 $km^2$) and Lake Kainji (1280 $km^2$). The presence of reservoirs has altered the fluvial geography and landscape throughout the continent (Talling, 1990). Reservoirs therefore form an important component of Africa's water resource.

In Africa, the principal purpose of the large reservoirs is hydropower generation. The role of the smaller reservoirs in the continent range from hydro-power, domestic, irrigation, water supply, to flood control. Additional benefits include fishery development, tourism promotion, improved communication and opening up of remote places to development. Reservoirs therefore play a crucial role in the economic development of the continent; hence it is important to understand their limnology.

### 2.3.2 The status of reservoirs in Kenya

In Kenya, reservoirs have been developed mainly to meet the country's rapidly expanding electric power needs. Hydroelectric power in Kenya constitutes 75% of the country's total electric power generation (ACRES, 1987). Additional benefits from reservoirs include control the perennial floods, provision of domestic water, irrigation, fishery and improvement of the communication network. The reservoirs built in Kenya for hydropower generation are Turkwel Gorge Reservoir located on Turkwel River, Masinga, Kindaruma, Gitaru, Kiambere and Kamburu reservoirs, all located on the Tana River. Tana River, which is 1000 Km long is in Kenya.

According to the Kenya National Power Development Plan for the period 1986 to 2006 many potential sites for construction of hydropower reservoirs have been identified on a number of Kenya's rivers. These sites include Serewa in Rift Valley Basins and Mutonga, Low Grand falls and Usweni in the lower Tana. However, most have not been developed because they are not cost effective as compared to other power generation options such as geothermal sources (ACRES, 1987).

In the Central Province of Kenya, there are numerous small reservoirs, which were mainly constructed to provide year round water supply for irrigation, domestic use and also fishery development. The small reservoirs are within areas where human population density is high (100-200 individuals per $Km^2$) with average house density of about 100 units per $Km^2$ (Mwaura, 2000). Near market centers; the human population density doubles (Mwaura, 2000). Hence, the reservoirs are not only heavily utilized but are likely to be influenced by reservoir catchment activities. In most parts of Kenya, the period from January to March is the driest and during this time water levels in reservoirs become low.

The Limnological characteristics of most hydropower reservoirs are better known (Pacini, 1994). However, limited attention has been given to the small reservoirs, which are usually multipurpose, and located in areas of intense human activities. Hence an understanding of their limnological conditions is necessary for their sustainable use.

## 2.4 Physico-chemical environmental conditions and their impact on phytoplankton properties

### 2.4.1 Transparency

Transparency varies depending on the amount of suspended substances, such as algae and other buoyant particulate matter. The presence of suspended matter influence the optical properties of water. Quality and quantity of radiant energy, which penetrate to different depths influence the primary production of a water body. In Lake Victoria, transparency fluctuates temporally and spatially mainly due to changes in phytoplankton density (Ochumba, 1993; Ochumba and Kibaara, 1989). Transparency is significantly reduced during algal blooms (Ochumba, 1993 and Muggide, 1993).

Comparative studies of phytoplankton abundance and light availability in lakes have revealed the existence of a positive correlation between phytoplankton standing crop and light availability. For example, a proportional relationship between light availability and chlorophyll *a* concentrations has been reported for Lakes Naivasha and Sonachi (Njuguna, 1982). In Lake Shield, phytoplankton production was proportional to length of the ice-free season (Fee *et al.,* 1992). A 25% increase in ice free season from 6 to 8 months resulted in a 25% increase in phytoplankton production. Other studies by Regier *et al.* (1990) in northern temperate lakes have shown that annual phytoplankton primary production increases with increase in transparency. However, it markedly reduces on cloudy days.

Experimental studies carried out in Lake Okeechobee (Holmgren, 1984a), a large eutrophic lake, on the relationship between light intensity and phytoplankton standing crop have shown that low light availability reduces phytoplankton standing crop and that

phytoplankton growth is restricted by levels of light availability experienced during winter (Philips *et al.,* 1977). Studies in Swedish lakes show that dinoflagellates and coccoid green algae prefer high levels of light and are found at the upper strata of a water body where there is a high light intensity. Chrysophytes become dominant under low light conditions (Rambery, 1977), while cryptomonds were found in extremely poor light conditions (Morgan and Kalff, 1979). In Lake Windermere, the chlorophytes *Staurastrum lunatun* and *Cosmarium abbreviatum* do well under low light intensity (Lund, 1971). Experiments carried out in Lake Windermere showed maximum growth of *Scenedesmus proturbans* at high light intensity whereas *Oscilatoria agardhii* did well at lower light intensities (Mur *et al., 1*979).

### 2.4.2 Temperature

Studies in temperate lakes and reservoirs have shown that changes in temperature may bring about abrupt changes in phytoplankton species composition and diversity (Moss, 1973; Schindler, 1977). Such changes in species composition are said to be due to the fact that each species has a specific temperature tolerance limit. In Lake Kinerret, a temperate reservoir, C*eratium sp.* grows well at temperatures of between 16 $^{O}$C to 23 $^{O}$C but disappear when the temperature becomes higher than 25 $^{O}$C (Hutchinson, 1967; Heaney, 1976). *Ceratium* grows well in culture at 21$^{O}$C (Bruno and McLaughlin, 1977). According to Bowen and Ward (1977), *Chilomonas ovata var. palustris* do well at 25 $^{O}$ C while *Chilomonas erosa* does well at 23.5 $^{O}$C. *Anabaena, Aphanizomenon* and *Microcystis* do well under temperatures of 25 $^{O}$C (Paerl *et al.,* 1983). Increase in temperature results in a decline in *Dinobyron cylindricum* population density in culture (Tilman and Kiesling, 1984).

A study of population dynamics and form variation of *Rhodomonas minuta* and *Rhodomonas lens* in Lakes Malaven and Vattern by Oke *et al.,* (1980), showed that *Rhodomonas minuta* developed well at temperatures of 0.5 $^{O}$C to 1$^{O}$ C but also dominated at temperatures of 16 $^{O}$C in turbulent early autumnal surface waters while *Rhodomonas lens* was absent in late summer when water temperature was in excess of 16 $^{O}$C and at the time when blue green algae were at a maximum (Oke *et al.,* 1980). According to Schindler (1977), blue green algae are found at high temperatures and are succeeded by green algae, flagellates and lastly diatoms as temperature drops. In the Austrian Alps lakes, *Cryptomonas erosa* is found to be dominant under temperatures ranging from 5 $^{O}$ C to 21 $^{O}$C (Findenegg, 1977). Cyanobacteria, pennate diatoms and chrysophytes are found in abundance at 10 $^{O}$C to 20 $^{O}$C but show a decline above 20 $^{O}$C (Seabury *et al.*, 1983).

Tropical reservoirs that exhibit temperature stratification within the water column record the lowest temperature during the wet months and the highest temperature during the dry months (UNESCO, 1992). Changes in temperature alter the physico-chemical environment by reducing water density and oxygen concentration. This may affect the distribution, abundance and density of phytoplankton in the reservoir. For example, an increase in water temperature reduces solubility of dissolved oxygen and these results in abundance of fungi and pathogenic bacteria (Ambasht, 1990).

### 2.4.3 Conductivity

The conductivity of a standing water body is a measure of the ionic concentration of water and is used as an approximation of the total dissolved solids (APHA, 1998). Conductivity is influenced by the amount of dissolved solids in rainfall, amount brought in from the catchment areas and ion exchange equilibrium between the water and

reservoir sediments. Reservoirs vary widely in their conductivity. For example, it ranges from 160 μS $cm^{-1}$ to 200 μS $cm^{-1}$ in the Turkwel Gorge Reservoir (Kotut *et al.,* 1998a), 35 μS $cm^{-1}$ to 54 μS $cm^{-1}$ in Kainji Reservoir, 55 μS $cm^{-1}$ to 81 μS $cm^{-1}$ in Lake Kariba (Latif, 1984) and 113 μS $cm^{-1}$ to 140 μS $cm^{-1}$ in Masinga Reservoir (Pacini, 1994). Conductivity varies with season depending on evaporative concentration during the dry season and dilution during the rainy season (Melack, 1982).

Phytoplankton composition varies with the conductivity of the water body. Lake Naivasha with a conductivity range of 300 μS $cm^{-1}$ to 350 μS $cm^{-1}$ is dominated by *Oocystis lacustris, Cosmarium pseudoproturberans var. alpinum, Cosmarium and Botryococcus* (Njuguna, 1982). In Turkwel Gorge Reservoir with a conductivity range of 160 μS $cm^{-1}$ to 200 μS $cm^{-1}$ *Aphanocapsa koordersi, Achnanthes catenata, Koliella longiseta, Monoraphidium contoritum* are the dominant species (Kotut *et al.,* 1 998). Studies in temperate lakes and reservoirs have also documented a decline in relative importance of chrysophyte algae with increasing conductivity and total ionic content (Hornstrom, 1981; Smol *et al.,* 1984).

### 2.4.4 pH

Water pH is a measure of the concentration of hydrogen ions at a given temperature (Nemerow, 1991). Under natural conditions water pH is controlled by the concentration of carbon dioxide, carbonate and bicarbonate ions. In an aquatic ecosystem, pH is determined by the balance between photosynthesis, respiration and decomposition. The spatial and temporal changes in photosynthesis and respiration combined with the buffered state of water determine the pH range experienced in a water body. Photosynthesis in weakly buffered lakes such as Lake George in Uganda and Lake

Bangweulu in Tanzania results in wide diurnal changes in pH (Howard- Williams and Grant, 1981). Lakes with a strong chemical buffering such as Lake Naivasha (Litterick *et al.,* 1979), Lake Chilwa (Kalk *et al.,* 1979) and Lake Baringo (Patterson and Wilson, 1995) experience little or no diurnal changes in pH.

The importance of pH as a phytoplankton growth regulating factor is in its effects on pH dependent nutrient uptake processes, and metal toxicity on species (Moss, 1973; Peterson *et al*, 1984). Toxicity and availability of metal ions change with changes in pH. All phytoplankton species are not equally effective at obtaining carbon dioxide for photosynthesis at high pH. The utilization of bicarbonate ions, the dominant form of dissolved carbon at high pH as an alternative carbon source requires special adaptation by cells such as ability to convert bicarbonate into carbon dioxide intracellularly or extracellularly. Some green algae and species of cyanobacteria have carbonic anhydrase, an enzyme capable of converting bicarbonate into dissolved carbon dioxide for photosynthesis.

pH plays an important role in water chemistry; it affects the solubility, chemical speciation and hydration of essential nutrients (Stumm and Morgan, 1981). These changes affect availability of nutrients. For example, an increase in pH leads to a corresponding decrease in phosphorus solubility and increase in silicates in water, while pH lower than 5.5 increases the concentration of calcium, aluminum, iron and metal toxicity (Nathashon, 2000).

Changes in pH bring about changes in phytoplankton composition and diversity (Almer *et al.*, 1974; Mavuti, 1976 and Mulholland, 1986). The dinoflagellate genus *Peridinium* tolerates a wide range of pH although its growth is reduced at a pH below 6 while the highest growth rate occurs at a pH above 8 (Lindstrom, 1984). *Peridinium* blooms in Lake Kinneret occurred at a pH range of 8 to 9 (Bermman and Dublinsky, 1985). *Ceratium hirundinella* can tolerate a wide range of pH under experimental conditions but the optimal levels are pH 7.0 to pH 7.5 (Bruno, 1975). *Peridinium pusillum* has been found to bloom in the mineral acidotropic pond of pH below 4 in North Germany (Hickel, 1985). Tolerance is thus species specific.

Chrysophytes as a group have a pH tolerance range of between 4.5 to 8.5 (Moss, 1973; Bretthauer, 1975; Kristiansen 1975; Reynolds, 1986). The absence of chrysophytes species of all types from lakes and reservoirs with a pH value greater than 8.5 is common. In eutrophic lakes with a more neutral pH, chrysophytes are consistently absent from the summer epilimnetic plankton during periods when pH is greater than 8.5. High pH values results from high photosynthetic activities. A decline in chrysophytes population following a reduction in pH has been documented following the artificial acidification of lakes (Schindler *et al.,* 1985).

Reservoirs and lakes with a neutral pH and dominated by chrysophytes throughout the ice free season exhibited a marked decline in the importance of chrysophytes relative to chorophytes, cyanophytes and dinoflagellates when pH reduced to 5 (Findley 1984; Schinder *et al.,* 1985; Findley and Saesura, 1980). Studies have confirmed that chrysophytes are sensitive to pH changes (Smol, 1984; Reynolds, 1986). Sensitivity to

elevated pH could be related to their inability to secrete alkaline phosphatase or to utilize bicarbonate ions as a carbon source during photosynthesis (Patel and Merret, 1986)

A large number of cyanobacteria genera generally show a negative response to acidic pH (Fogg *et al.*, 1973). It has been documented that as a group, cyanobacteria have a distinct preference for neutral to alkaline water (Shapiro, 1973; Fogg *et al.*, 1973). Under acidic conditions, they are replaced by chrysophytes or chlorophytes (Shapiro, 1973). Species composition changes associated with pH change stem from the fact that each species has a specific pH tolerance limit, which results from reduced nutrient uptake and susceptibility to increased metal toxicity (Peterson *et al.,* 1984). Studies carried out in a Canadian reservoir revealed that chlorophytes, cyanophytes and chrysophytes decline in species numbers from 26 to 5, 22 to 5 and 22 to 10 respectively at a pH < 5 (Holmgren 1984b). According to Findley (1984) and Schindler (1985), reservoirs with pH 5 appear to be dominated by chrysophytes, but decline when a pH of 5 is exceeded.

### 2.4.5 Dissolved oxygen

Dissolved oxygen is fundamental to life and health in water. Dissolved oxygen is important for respiration of living organisms, decomposition of biodegradable organic matter and chemical oxidation in water and sediments. The source of dissolved oxygen in water is the atmosphere and its concentration varies depending on pressure and temperature. Photosynthetic production of oxygen is another source of oxygen for photosynthetically active water. Warm tropical water is susceptible to oxygen depletion due to reduced oxygen solubility in warm waters coupled with high rates of microbial metabolism (Hutchinson, 1973). Low solubility of oxygen in warm waters in the tropics is compensated by a high photosynthetic production of oxygen (Townsend, 1999). Large

fluctuations in oxygen concentration are properly more common in tropical water bodies than in their temperate counterparts. Oxygen concentration varies with the tropic state of the reservoir. High photosynthetic production of oxygen is characteristic of eutrophic reservoirs while a low production of oxygen is characteristic of oligotrophic reservoirs (Meybeck and Chapman, 1998).

Studies on phytoplankton distribution and composition in reservoirs have revealed that the phytoplankton composition is influenced by fluctuations in dissolved oxygen concentration. For example, the dinoflagellates thrive well in oxygenated water bodies and are absent in eutropic systems that experience periodic oxygen depletion. According to Harris *et al.* (1979), *Peridinium* in Kinneret reservoir does not reach the anoxic hypolimnion while *Ceratium* rarely penetrates the anoxic hypolimnion of Esthwaite water. In Lake Victoria, studies have shown that with a decline in dissolved oxygen, the phytoplankton community changes towards dominance by cyanobacteria (Hecky, 1993).

### 2.4.6 Alkalinity

Alkalinity is the difference between strong base cations and strong inorganic and organic acid anions (Samson *et al.,* 1994). Water alkalinity is a measure of its capacity to neutralize acids and can be used as an index of the buffered state of a water body. Alkalinity is influenced by the presences of bicarbonate, carbonate and hydroxyl ions that are formed as a result of the interaction between carbon dioxide in water with basic materials such as calcium carbonate from chalk or limestone.

Studies in tropical and temperate water bodies show that alkalinity influences the distribution of phytoplankton. For example, desmids are abundant in lakes of low alkalinity (Talling and Talling, 1965; Hornstrom, 1981; Smol *et al.,* 1984). An inverse relationship between alkalinity and desmids diversity has been reported for natural lakes (Moss, 1973). According to Brook (1981), the greatest species diversity of desmids has been described for waters of low alkalinity. Alkalinity has also been found to restrict the distribution of chrysophytes in reservoirs. A sharp decline in relative importance of chrysophytes occurs above an alkalinity value of 125 mg $L^{-1}$ $CaCO_3$ (Stumm and Morgan, 1981). A unimodal relationship between alkalinity and mean chrysophytes biomass integrated over the euphotic zone with maximal development exists between 10 to 125 mg $L^{-1}$ $CaCO_3$ (Stumm and Morgan, 1981). A survey of chrysophytes siliceous microfossils from sediments of lakes in the north east of North America showed that chrysophytes thrives in low alkalinity (Smol *et al.,* 1984). Species succession has also been shown to be related to alkalinity in most tropical lakes (Hecky and Kilham, 1974).

### 2.4.7 Nitrogen

Nitrogen in water originates from a variety of sources that include point and non-point source pollution, biological fixation of gaseous nitrogen and deposition of nitrogen oxides and ammonium salts (Stoddard, 1994). In cultivated areas, increased fertilizer application makes a significant contribution to nitrogen loading of water bodies (UNESCO, 1992). Municipal and industrial activities also contribute to increased nitrogen loading (Loehr, 1977). Levels of the different forms of nitrogen in water bodies are determined by the nature of inflows and the balance between assimilation, mineralization, nitrification, denitrification and nitrogen fixation. The most common forms of nitrogen in water are combined organic nitrogen, ammonia nitrogen and

oxidized nitrogen (Ellis, 1989). Organic nitrogen exists either as an integral part of protein molecules or as partial breakdown products of these molecules (Tisdale *et al.*, 1993). Total oxidized nitrogen exists in two forms, nitrite nitrogen ($N0_2$-N) and nitrate-nitrogen ($N0_3$-N) (Brady, 1992). It is unusual to find $N0_2$-N in appreciable concentrations in water bodies.

A significant relationship exists between phytoplankton composition, abundance, diversity and nitrogen concentration (Melack and Jellis 1973). In Lake Suwa in Japan, *Microcystis aeruginosa* is dominant at high nitrate nitrogen concentration while *Microcystis viridis* is dominant at a lower concentration of the same. In the same lake, a decrease in *Microcystis aeruginosa* density corresponds well to a decrease in dissolved inorganic nitrogen concentration (Amemiya *et al.*, 1990). In Lake Nakanuni, phytoplankton density and species numbers increased with an increase in total nitrogen concentration (Holmgren, 1984; Seike, 1990).

Studies in tropical African lakes have also shown that nitrogen is a limiting factor for phytoplankton growth (Moss, 1969; Holmgren, 1984). In Lake Naivasha, chlorophyll *a* and phytoplankton biomass decline with a reduction in nitrate nitrogen levels (Njuguna 1982). Similar trends are reported for the Turkwel Gorge Reservoir, where the levels of chlorophyll *a* showed a positive correlation to total nitrogen ($p< 0.001$) and nitrate nitrogen ($p< 0.05$) (Kotut *et al.*, 1998a).

### 2.4.8 Phosphorus

Phosphorus in surface waters is present in forms such as orthophosphate and polyphosphate. Phosphorus is important for formation of cellular organelles. Weathering of phosphorus containing rocks is the initial natural source of phosphorus in surface water (Viner, 1975; Golterman, 1975). Other sources of phosphorus in a water body are anthropogenic activities, atmospheric deposition and any internal recycling (Talling and Talling, 1965; Ansa-Sare, 1996). A preliminary study on phosphorus budget for Lake Victoria has shown that tributaries contribute two thirds of incoming phosphorus with the remaining one third coming from atmospheric deposition (Hecky, 1993). A high loading rate of phosphorus in the Turkwel Gorge reservoir suggests that the reservoir catchment is the principal source of reservoir phosphorus (Kotut *et al.*, 1998a).

A wide variation in phosphorus concentration exists in Africa's reservoirs. This variation is mainly brought about by variations in rainfall frequency and vegetation type (Viner, 1975). In general low reservoir phosphorus concentration is characteristic of areas with a good vegetation cover and a low intensity of rainfall. Changes in adsorption equilibrium occasioned by changes in the oxygen levels of water have also been shown to bring about a seasonal variation in phosphate phosphorus levels (Talling, 1976).

A strong correlation between phytoplankton standing crop biomass and total phosphorus has been reported for both temperate and tropical lakes (Mann and Brylinsky, 1973). According to Gaudet (1981) nitrogen and phosphorus are the main factors controlling primary production in tropical reservoirs. Studies carried out have showed that phosphorus is very important for phytoplankton production (Melack, 1979). According to Njuguna (1982), chlorophyll *a* content in Lake Naivasha increased with an increase in

total phosphorus concentration. In Turkwel George reservoir, chlorophyll *a* and phytoplankton biomass changes showed a positive correlation to changes in total nitrogen and phosphorus (Kotut *et al.*, 1998a).

A negative correlation exists between phosphorus concentration and abundance of chrysophytes algae (Vollenweider, 1976; Schindler, 1977; Nicholls *et al.,* 1986). Experiments carried out in several lakes in the temperate region that included lake Trummen (Cronbery, 1982), Lake Mlaren (Willen, 1984), Lake Hymenjaure (Holmgren, 1984) and Lake Logvatn (Reinertsen, 1982), have demonstrated an inverse linear relationship between chrysophytes abundance and total phosphorus. Similar findings have been reported in a survey of Finnish lakes (Eloranta and Palomaki, 1986). Studies on chrysophytes microfossils have also shown an inverse relationship between chrysophytes and availability of phosphorus (Moss, 1979; Munch, 1980; Smol, 1985). Following the artificial fertilization of Lake Hymenjaure with phosphorus for two growing seasons, there was a decrease in the importance of chrysophytes and an increase in *Ochromonas* species new to the reservoir. (Holmgren, 1984).

The concentration of phosphorus plays an important role in dinoflagllate growth. According to Reynolds and Reynolds (1985), in Cross Mere, *Ceratium* dominates in August (400 cells $ml^{-1}$) when lowest levels of dissolved phosphorus and nitrates are recorded. *Peridinium* in Lake Kinneret blooms when concentration of phosphorus is very low and an increase in concentration of phosphorus delays the appearance of *Peridinium* and intensity of its bloom (Pollingher, 1986). Similarly in Lake Balaton, the abundance of *Ceratium* decreases with an increase in phosphorus concentration (Padisak, 1985).

Experiments carried out in temperate lakes/reservoirs showed that phosphorus influences phytoplankton dominance (Vollenweider, 1976). For example, it has been reported that high phosphorus inputs tend to favor cyanobacterial dominance and bloom formation (Schindler, 1977). Luxuriant growth of *Dinobyron* and chrysophytes at high concentration of phosphorus in nature and in artificial medium has been widely reported (Lehman, 1976; Holmgren, 1984b).

### 2.4.9 Soluble reactive silica

Silica in aquatic bodies is exclusively derived from the weathering of silicate rocks under the influence of dissolved carbon dioxide (Hutchinson, 1957). Silica concentration varies with the underlying geology and its concentration increases from polar latitudes towards the tropics due to more complete chemical weathering at high temperatures. According to Talling (1965) and Kotut *et al.*, (1998) river input plays a primary role in determining the levels of dissolved reactive silica in standing water bodies. Silicon is utilized as a structural component and for chlorophyll synthesis.

Studies carried out in the past have revealed that a change in silica concentration brings about changes in phytoplankton abundance and diversity in temperate lakes (Sommer and Stabel, 1983). More importantly, silica availability influences the distribution and abundance of algae with siliceous frustules (Sommer and Stabel, 1983). According to Amstrong and Holm (1981) and Tilman and Kiesling (1984), lack of silica results in the dominance by cyanobacteria or green algae in temperate lakes. When silica is present in

sufficient amounts, the diatoms became dominant. In Constance reservoir, peaks of diatoms were ended by silica depletion (Somer, 1986). Silica enrichment of African lakes increases diatom abundance (Kilham, 1985).

# CHAPTER THREE: STUDY AREA, MATERIALS AND METHODS

## 3.1 Introduction

This chapter introduces the reservoirs studied, data collection procedures in the field, sample collection and processing, and the methods used in the analysis of water samples. Methods used in phytoplankton investigations and the analytical procedures employed are also described.

## 3.2 The study area

### 3.2.1 Introduction

Five reservoirs namely, Uhuru, Ruiru, Ngewa, Comte and Kianjjibbe were investigated (Fig. 3.1).

### 3.2.2 Uhuru reservoir

Uhuru is situated in Nairobi city close to the Central Business District and within Uhuru Park. It lies between latitude 36° 57' E and 36° 58' E, longitude 1° 58'S and 1° 57' S at an altitude of 1800 m above sea level. Rainfall in the area is bimodal with long rains occurring between March and May while the short rains fall in October to November; with a total annual mean of 900 mm. High temperatures are experienced during the day and low temperatures during the night. July is the month with the lowest temperature while the hottest months are January and February. Uhuru reservoir receives its water from an underground drain from Nairobi dam. The reservoir is a regular tourist destination and a recreation point for all groups of people living in Nairobi.

### 3.2.3 Ruiru, Ngewa, Comte and Kianjjibbe reservoirs

Ruiru, Comte and Kianjjibbe reservoirs are located in Githunguri division, Kiambu district. Ngewa reservoir is located in Thika district. The two districts are located in

Central Province. Kiambu district lies between latitudes 0° 75' and 1° 20' south of the equator and longitudes 36° 54' and 36° 85' east. Githunguri division is in the lower highlands of Kiambu district. It lies between altitude of 1500 m and 1800 m above sea. Plateaus and high-level structural plains characterize the division.

Ruiru reservoir lies between latitudes 1° 85' S, 1° 85 S and longitudes 36° 65' E, 36° 66' E. Comte reservoir is located between latitude 1° 76' S, 1° 75' S and longitudes 36° 63' E, 36° 64' E' and Kianjjibbe lies between latitudes and 1° 76' S, 1° 75' S and longitudes 36° 63' E, 36° 64' E. Ngewa reservoir in Thika district lies between latitudes 1° 78' S, 1°, 77' S, longitudes 36° 65' E 36° 66' E. Ruiru, Ngewa, Comte and Kianjjibbe are located approximately 15 to 25 km away north east of Nairobi.

### 3.2.4 Climate and soils in Kiambu and Thika Districts

The climate of the area is influenced by altitude and latitude. The amount of rainfall received varies from 843 mm at 1555 m above sea level to 1375 mm at altitude 2438 m. Rainfall is bimodal with long rains occurring between April and May with short rains from October to November (Appendix 1). Temperatures vary from 20.4 to 34 °C in the upper and lower highlands respectively. July and August are the months with the lowest temperatures ranging from 20.4 °C to 22.1°C while the hottest months are January through March with temperatures of between 28 °C and 34 °C (Appendix 3). The soils are developed on tertiary basic igneous rocks basalt, nepheline, phonolites and basic tufts (Jaetzold and Schmidt, 1983). The soils are well drained, extremely deep dark reddish brown friable clay with humic topsoil.

### 3.2.5 Drainage

Ruiru reservoir receives its water through Rivers Kimaiti, Ruiru, Ngeteti, and Gitindo. Ngewa receives its water from Gaia, which has two tributaries, Ngewa River and Choomba River. Comte and Kianjjibbe reservoirs receive their water through Kianjjibbe River.

### 3.2.6 Economic activities

In the two districts 97% of total area of the catchment is arable land, out of which 90% is under smallholdings while the rest is under large-scale farms. The smallholdings are intensively cultivated. Intensive small-scale crop production and small scale dairy farming is carried out in the area (GOK, 2008). A large number of quarries for extraction of building materials are also present in the area (GOK, 2008).

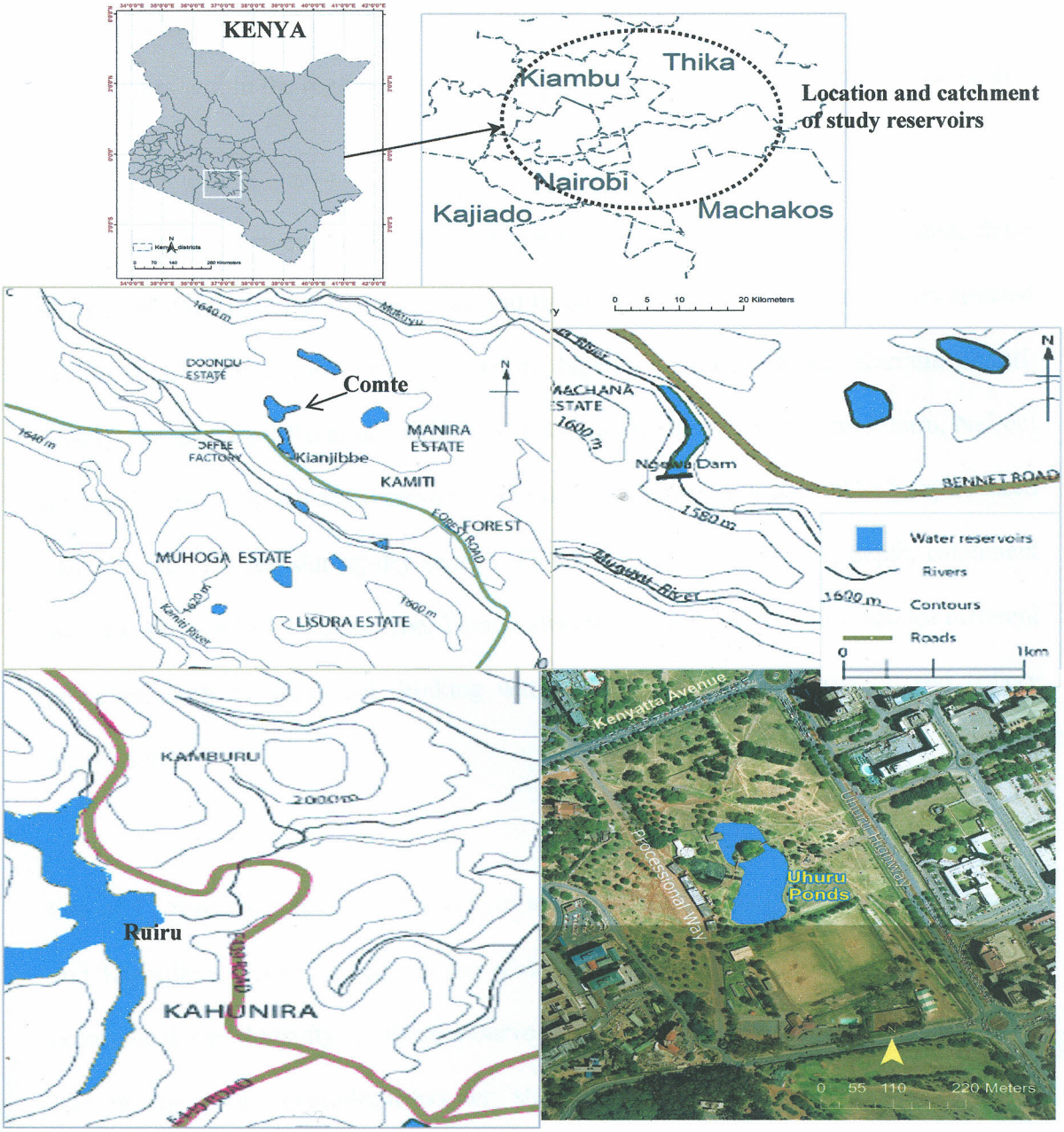


**Fig.3. 1 Maps showing the location and catchment of the study reservoirs; Uhuru, Ruiru, Ngewa, Comte and Kianjjibbe reservoirs, in Kenya**

## 3.3 Selection of the reservoirs

The actual study was preceded by a preliminary survey between the months of August 2000 and January 2001. The aims of the preliminary study were to: (i) assess the

accessibility of reservoirs, (ii) collect background information such as construction dates, uses of the reservoirs, (iii) establish the diversity in the physico-chemical characteristics of reservoirs within the region and (iv) test the instruments to be used in the actual study.

The preliminary survey identified two types of reservoirs within the study area; those situated within rural agricultural areas and those in urban areas. The reservoirs situated within rural agricultural areas were Ruiru, Ngewa, Comte, Manira, Karimu, Sukari, Kianjjibbe, Gitindiri, Rumera and Twiga. Those in the urban areas were Uhuru, Nairobi dam and Athi Dam. All the reservoirs were more than twenty years old and experienced low volume of water during dry season. The reservoirs differ in size, depth, catchment area and surrounding landuse type. Their waters were observed to be utilized for different purposes, such as municipal drinking water supply, irrigation, recreation and fishery exploitation.

Out of 11 reservoirs found in the agricultural area, four; namely Ruiru, Ngewa, Comte and Kianjjibbe were selected for the study because their physico-chemical properties represented the diversity of these reservoirs and were the most accessible. Although Manira was more accessible, it has very steep dam wall and it is dangerous to get water samples even near the dam wall. Others like Karimu and Sukari reservoirs are completely

Surrounded by thick vegetation and access is very difficult. Twiga, Rumera and Gintindiri are located within a coffee farms where access was restricted. From the 3 urban reservoirs, Uhuru reservoir was purposely selected because of its proximity to a commercial/industrial center and also its usage (recreation). Nairobi dam was completely

covered by the water hyacinth and Athi Dam is located in a protected area where access is restricted.

### 3.4 Sampling points and frequency

Sampling points were established within the reservoirs. At Ruiru and Uhuru reservoirs, a sampling point was established close to the centre of the reservoir as the center is far from influence by inflow and human activities. It was possible to get to the site as a boat was available at the two sites. In the other reservoirs, sampling points were established near the dam wall as there were no influences by inflows and human activities. At each of these sites, water samples were collected some three meters away from the dam wall using a water scooper with a 3 m extendable handle. Each water sample was collected from 30 cm below the water surface. Sampling was carried out once every month for 18 months. A monthly sampling frequency was to allow for the detection of seasonal changes in the selected physico- chemical and biological properties of the reservoirs.

### 3.5 Sample processing and storage

Using a water scooper, water samples for laboratory analysis were collected and transferred into 1 litre plastic bottles and capped. Since sample analysis commenced within a period of four hours, sample preservation was on most occasions not necessary. When it was not possible to analyze the sample within four hours, the samples were deep stored at 4 °C. Samples for phytoplankton enumeration were collected in 250 ml plastic bottles and fixed with Lugol iodine solution (APHA, 1998). Sample concentration for phytoplankton identification was carried out using 20 μm diameter plankton net. The concentrate was then transferred into 15 ml plastic tube and preserved with formalin (APHA, 1998). At the laboratory, samples for the analyses of nitrite-nitrogen, nitrate-

nitrogen, ortho-phosphate phosphorus and soluble reactive silica were filtered through pre-washed 47 mm diameter GF/C filters (APHA, 1998).

## 3.6 Analytical procedures

### 3.6.1 Secchi depth (transparency, m)

Secchi depth determination was carried out using a 21 cm diameter disc with alternating black and white quadrants. Secchi depth transparency value was computed as the average of the depth at which the disc disappeared on being lowered and the depth of reappearance on being raised (APHA, 1998).

### 3.6.2 Temperature (°C)

Water temperature was determined with the temperature sensor of the dissolved oxygen probe (Type Cello X 325) of a multiline meter (WTW, Weilheim-Germany). The probe was immersed in water to a depth of 30 cm allowed to stabilize for a few minutes before the temperature reading was taken.

### 3.6.3 Electrical conductivity (μS $cm^{-1}$)

Electrical conductivity (μS $cm^{-1}$) was measured with a conductivity probe (Type TetraCon 325) of a multiline meter (WTW, Weilheim-Germany) with automatic temperature compensation to 25 $^{O}$ C. The conductivity probe was lowered into the water to a depth of 30 cm, allowed to stabilize before taking the conductivity readings.

### 3.6.4 pH

Water pH was measured with a pH probe (Type SenTix 41-3) of a multiline meter (WTW, Weilheim-Germany) with automatic temperature compensation to 25 °C. The probe was lowered directly into the water to a depth of about 30 cm, allowed to stabilize before the pH value was taken.

### 3.6.5 Dissolved oxygen (mg $L^{-1}$)

Dissolved oxygen was established with an oxygen probe (Type Cello X 325) of a multiline meter (WTW, Weilheim-Germany) with automatic temperature compensation to 25 ° C. The probe was lowered into the water to a depth of 30 cm and while gently stirring the water with the oxygen probe, the readings were allowed to stabilize and dissolved oxygen read in mg $L^{-1}$ and % saturation.

### 3.6.6 Total alkalinity (mg $L^{-1}$ $CaCO_3$)

Phenolphthalein alkalinity was first determined by titrating 50 ml volume of a water sample with standard hydrochloric acid (0.02N) using phenolphthalein indicator to determine the titration end point. To establish the total alkalinity, a mixed bromocressol green indicator was next added and titrated to its end point (APHA, 1998). Alkalinity values were calculated as mg $L^{-1}$ $CaCO_3$ (APHA, 1998).

### 3.6.7 Nitrite- nitrogen ($NO_2$-N)

Nitrite nitrogen concentration was determined by the colorimetric diazotization technique (APHA, 1998). An amount of 1 ml sulphanilamide and 1 ml of concentrated sulphuric acid was added to 25 ml water sample and then coupled with N- (1-napthyl) - ethylenediamine dihydrochloride to form a reddish purple azo dye (APHA, 1998). Colour intensity was measured colorimetrically using digital grating spectrophotometer (Model, CE 2343D). Standards of known $NO_2$-N concentration were subjected to the same treatment as the water samples and their readings used to determine actual concentration of nitrite-nitrogen.

### 3.6.8 Nitrate- nitrogen ($NO_3$-N)

Nitrate nitrogen concentration was determined by the modified sodium salicylate procedure (Scheiner, 1974). Nitrate nitrogen reacts with sodium salicylate in an acidic medium to form nitrosalicylic acid. The salicylic acid turns yellow under alkaline conditions (APHA, 1998). Color intensity was measured colorimetrically using a digital grating spectrophotometer (Model, CE 2343D).

An amount of 5 ml of filtered sample was transferred to a clean Nessler tube and 2 ml sodium salicylate added and evaporated to complete dryness at 98 °C in an oven. Once dried, the samples were removed from the oven and 1.0 ml of concentrated sulphuric acid added and allowed to dissolve for at least 10 minutes. An amount of 25 ml distilled water was next added followed by 5 ml Rochelle salt solution. Absorbance was read in 1 cm plastic cuvettes at 420 nm. Standards of known $NO_3$-N concentration were subjected to the same treatment as the water samples and their readings used to determine actual concentration of nitrate nitrogen in the sample.

### 3.6.9 Total nitrogen (TN)

Total nitrogen concentration was determined by the modified sodium salicylate procedure (APHA, 1998). All forms of nitrogen in unfiltered water samples were oxidized to nitrates by autoclaving the samples at 120 °C at 15 psi for 40 minutes with ammonium persulfate oxidizing agent. The nitrate nitrogen concentration of the oxidized sample was determined colorimetrically as in the case of $NO_3$-N above. Standards of known $NO_3$-N concentration were subjected to the same treatment as the water samples and their readings used to determine sample concentration of total nitrogen.

### 3.6.10 Orthophosphate phosphorus ($PO_4$-P)

Glassware for phosphorus determination was cleaned following the procedure outlined in APHA (1998). $PO_4$-P was determined by the ascorbic acid reduction procedure using filtered water samples (APHA, 1998). Phosphate ions combine with ammonium molybdate to form a molybdophosphate complex. The molybdophosphate complex is readily reduced by ascorbic acid to an intensely blue phosphomolybdenum complex. Color intensity was measured colorimetrically at a wavelength of 690 nm (APHA, 1998) using a digital grating spectrophotometer (CE 2343D). To reduce loss due to uptake or adsorption to polyethylene bottles, analysis was carried within 2 hours of sample collection (APHA, 1998). Standards of known phosphate readings were subjected to the same treatment as the samples and their final readings used to determine the actual $P0_4$-P concentration.

### 3.6.11 Total phosphorus (TP)

Total phosphorus determination was similarly carried out by the ascorbic acid reduction procedure (APHA, 1998). Unfiltered water samples were oxidized to $P0_4$-P by autoclaving samples at 120 °C under 15 psi for 40 minutes using ammonium persulfate oxidizing agent (APHA, 1998). Orthophosphate phosphorus concentration was then determined following the $PO_4$-P procedure outlined above. Standards of known $PO_4$-P phosphate concentration readings were subjected to the same treatment as the TP samples and their final readings used to determine actual total phosphorus concentrations.

### 3.6.12 Soluble reactive silica (SRS)

Soluble reactive silica was determined by the molybdosilicate method (APHA, 1998). Molybdate ions react with silica to form a yellow complex (APHA, 1998). The intensity of the yellow complex was then measured colorimetrically using a digital grating spectrophotometer (Model, CE 2343D). Standards of known silica concentration were subjected to the same treatment as the samples and their absorbance readings used to compute actual concentration.

## 3.7 Phytoplankton characteristics

### 3.7.1 Phytoplankton composition

Phytoplankton composition was determined microscopically (APHA, 1998) using preserved and fresh phytoplankton samples. The phytoplankton samples were examined microscopically using a binocular microscope (Nikon Eclipse TS 100). Confirmation of species identity was carried out with the aid of appropriate taxonomic keys that included Hutchinson (1967), Chapman (1973), Prescott (1978) and Entwisele *et al.*, (1997).

### 3.7.2 Phytoplankton diversity

Phytoplankton diversity was computed using Shannon Weiner index (H') based on the results of phytoplankton enumeration.

$$H^{1} = \frac{N \ln N - \sum_{i=n}^{i=k} fi \ln fi}{n}$$

Where $H^{I}$ is Shannon Weiner Diversity Index, n is individual counts, ln is the logarithm to base e, $fi$ is the frequency (total counts) of species or taxon i, k is the total number of taxa counted and N is the total count of individuals in all taxa (Zar, 1976).

### 3.7.3 Phytoplankton biomass

Phytoplankton biomass (unit counts and wet weight) was determined microscopically using samples preserved with Lugol iodine solution. The preserved samples were first gently mixed and an aliquot was immediately transferred to a 10 ml counting chamber (Utermhol counting chambers) and allowed to settle for at least 24 hours before counting. Counting was carried out under an inverted microscope equipped with an ocular micrometer for cell dimension determination. Enumeration was done in 4 transects of equal lengths (APHA, 1998). The recording and conversion of count data to biomass was done with the aid of a phytoplankton enumeration program KIP 6PA (Hamilton, 1990) assuming a specific gravity of 1.

# CHAPTER FOUR: RESULTS AND DISCUSSIONS

## 4.1 Introduction

This chapter presents findings on the physico-chemical conditions and phytoplankton properties of the reservoirs investigated. The physico-chemical properties of the different reservoirs and a comparison of levels recorded in the reservoirs is presented. Phytoplankton composition and biomass in each reservoir as well as a comparison of the phytoplankton characteristics of the study reservoirs are also presented. Finally, conclusions drawn from the study and recommendations on the way forward are given at the end of the chapter.

## 4.2 Physico-chemical parameters

### 4.2.1 Secchi depth

Secchi depth (m) in Uhuru reservoir showed modest variation throughout the study period (Fig. 4.1). The shallowest depth of 0.3 m was recorded during the wet season month of November 2002 (total rainfall received; 337.5 mm) while the deepest transparency of 0.7 m was recorded in the dry season month of February 2002 and January 2003 (Fig. 4.1) (Total rainfall received; February 2002 - 19.1 mm, January 2003- no rainfall). Overall, a mean Secchi depth of 0.57 ± 0.09 m was computed for Uhuru reservoir (Table 4.1, Fig. 4.2, Appendix 3).

At the Ruiru reservoir, Secchi depth (m) varied widely with a range from 0.3 m to 1.9 m (Fig. 4.1). The shallowest measurement was made at the beginning of the wet season month of May 2002 (when a total rainfall of 114.9 mm was recorded). A maximum depth of 1.9 m was observed in the dry season month of February 2002 (Fig. 4.1) when no

rainfall was recorded. Overall a mean Secchi depth of 0.88 ± 0.43 m was recorded for the reservoir (Table. 4.1, Fig. 4.2, Appendix 3).

Ngewa reservoir showed a limited variation in Secchi depth throughout the study period with a range of 0.1m to 0.2 m (Fig. 4.1). The shallowest depth was recorded in April 2002 (when a total rainfall of 231.5 mm was recorded). The deepest Secchi depth of 0.2 m was recorded in February 2002 (when no rainfall was recorded). A mean Secchi depth of 0.1 ± 0.4 m was computed for the reservoir (Table 4.1, Fig. 4.2, Appendix 3).

In Comte reservoir, Secchi depth recorded showed a small variation throughout the study period (Fig. 4.1). The lowest depth of a few centimeters was observed in April and October 2002 (when total rainfall of 231.5 and 148.1 mm was recorded in the two months respectively). The deepest Secchi depth of 0.2 m was recorded in January 2003 (Fig. 4.1), a month in which no rainfall was recorded. Mean Secchi depth for the reservoir was 0.1 ± 0.6 m (Table 4.1, Fig. 4.2, Appendix, 3)

Secchi depth at Kianjjibbe reservoir showed modest variation throughout the study period with a range from 0.2 m to 0.6 m (Fig. 4.1). The deepest Secchi depth of 0.6 m was recorded in February 2002 when no rainfall was recorded. The shallowest Secchi depth of of 0.2 was recorded in June, July, October and November 2002 (Fig, 4.1, Appendix 3). The total rainfall received in these months was 18 mm, 38 mm, 148 mm and 313 mm respectively. A mean depth of 0.34 ± 1.3 m was recorded for the reservoir (Table 4.1, Fig. 4.2, Appendix, 3).

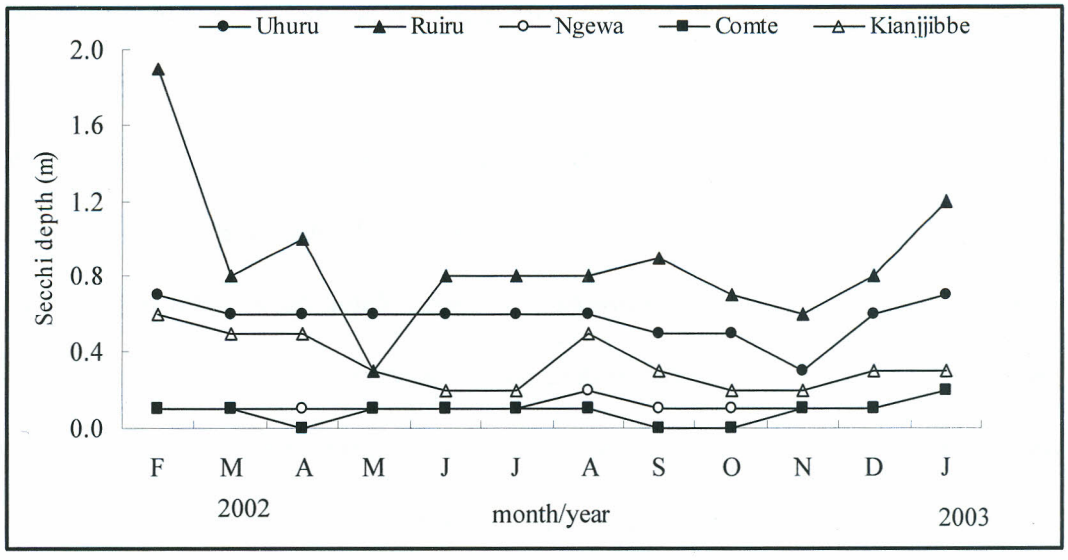


**Fig. 4. 1 Temporal variations in Secchi depth values in the reservoirs studied between February 2002 and January 2003**

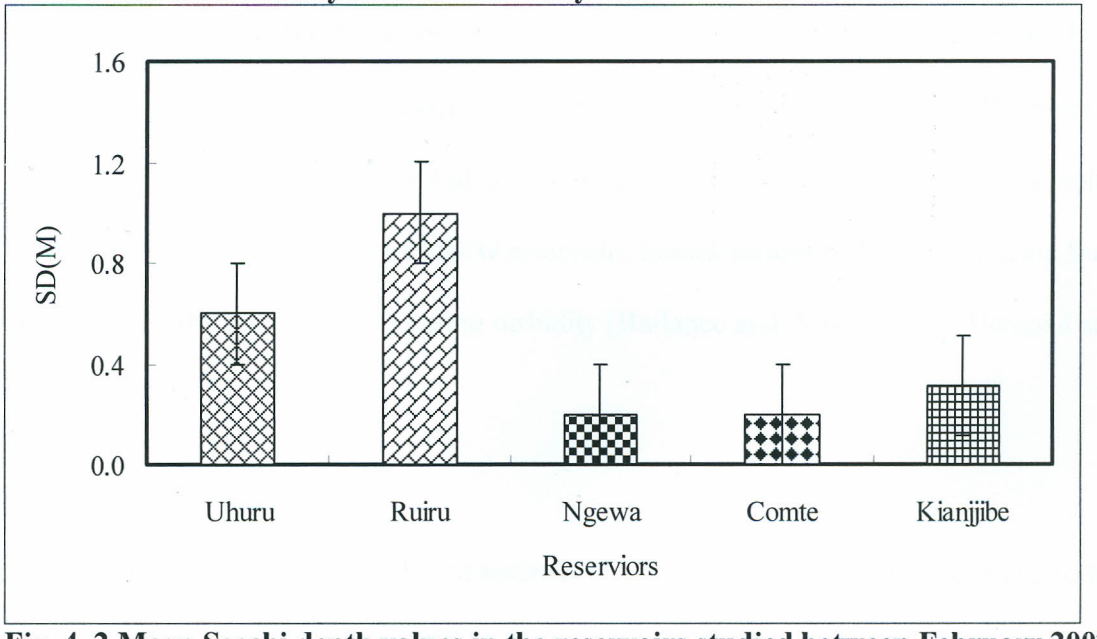


**Fig. 4. 2 Mean Secchi depth values in the reservoirs studied between February 2002 and January 2003. Vertical bars indicate ± 1SE**

Using the one way ANOVA test, mean Secchi depth values of the reservoirs investigated were significantly different ($P < 0.000$, df =59). Mean separation using Tukey's test revealed that mean Secchi depth at Ruiru and Uhuru were significantly greater than the mean values of the other reservoirs investigated (Table 4.1).

Differences in Secchi depth at the reservoirs is largely influenced by seasonal changes in the amount of rainfall received in the area. Low Secchi depth (Fig. 4.1) during the wet season months can be attributed to increased discharge characterized by high surface runoff and flooding. Flood inflows during the wet season have been reported to contribute to low Secchi depth values in Turkwel George reservoir (Kotut *et al.*, 1998) and in a number of small reservoirs in the eastern rift valley (Mwaura, 2000). The large volumes of inflows bring large amounts of suspended particles and coloured compounds that reduce water transparency (Bronmark and Hansson, 2005).

Variation in Secchi depth values among the study reservoirs can be as a result of variation in the amount of substances in suspension and solution caused by differences in the origin of the reservoirs, river and stream input and the trophic state of the reservoirs. Water turbulence, especially in shallow reservoirs causes resuspension of sediments from the bottom of the reservoirs increasing turbidity (Ballance and Batram 1996; Hemond and Fechner, 1994).

The high mean Secchi depth at Ruiru reservoir (0.9 m, Table 4.1) can be attributed to the greater depth of the reservoir, which is approximately 17 m and its narrow and elongated shape that allows sediments to settle quickly. Once settled, wind acting on reservoir surface cannot stir up the sediments. The shoreline of Ruiru reservoir also has vegetation cover and this reduces shore erosion and also helps to bind the soil from being carried into the reservoir during floods. Reduced inflows in the month of February 2002 and January 2003 caused by the low rainfall received in the area resulted in the high Secchi depth values for the Ruiru reservoir.

Low mean Secchi depths at Ngewa and Comte (0.1 m), (Table 4.1) can be attributed to the shallow depths of both reservoirs. Owing to their shallow depths, it takes only a slight breeze to stir up the bottom sediments leading to an increase in the amount of substances in suspension. The lowest Secchi depth recorded at Comte in the months of April 2002 and October 2002 (Fig. 4.1) can be attributed to the high rainfall amount received in the two months (231.5 mm and 148.1 mm respectively).

Secchi depth ranges from 0.6 m to 1.9 m in Ruiru, 0.3 m to 0.7 m in Uhuru, 0.2 m to 0.45 m in Ngewa, 0.0 m to 0.2 m in Comte and 0.2 m to 0.6 m in Kianjjibbe is slightly lower than a range of 0.9 m to 2.2 m recorded in Turkwel reservoir in Kenya (Kotut *et al.*, 1998), 1.0 to 1.7 m in Weija reservoir in Ghana and 1.0 to 1.5 m in Kpong reservoir also in Ghana (Ansare, 1996). The difference can be attributed to the smaller size of the study reservoirs.

### 4.2.2 Temperature (°C)

Water temperature at Ruiru showed a wide variation with a range from 18.1 °C (June, 2002) to 24.8 °C (May 2002) (Fig. 4.3). A mean temperature of 21.5 ± 2.25 °C was noted. In Ngewa, water temperature ranged from 20.2 °C (June, 2002) to 31.0 °C (May, 2002) (Fig. 4.3) with a mean value of 24.3 ± 2.89 °C (Table 4.1, Fig. 4.4, Appendix 4). Overall, Ruiru had a comparatively lower temperature while Ngewa had the highest value.

Water temperatures (°C) at Uhuru, Comte and Kianjjibbe reservoirs varied slightly during the study period (Fig. 4.3). Water temperature values ranged from 20.6 °C (June,

2002) to 27.2 °C (May 2002) at Uhuru, 21.7 °C (August 2002) to 26.0 °C (March 2002) at Comte and from 21.8 °C (June and August 2002) to 28.3 °C (March, 2002) at Kianjjibbe reservoirs. The mean water temperatures over the study period for the 3 reservoirs were 23.8 ± 1.88 °C, 23.4 ± 1.60 °C and 24.0 ± 1.83 °C for Uhuru, Comte and Kianjjibbe reservoirs respectively (Fig. 4.4, Appendix 4).

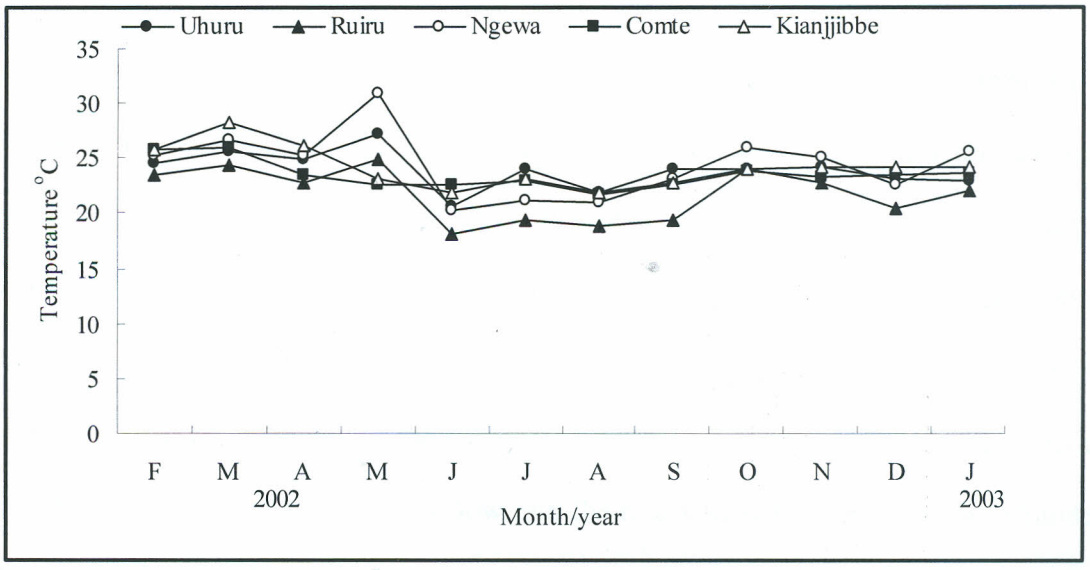


**Fig. 4. 3 Temporal variations in temperature values in the reservoirs studied between February 2002 and January 2003.**

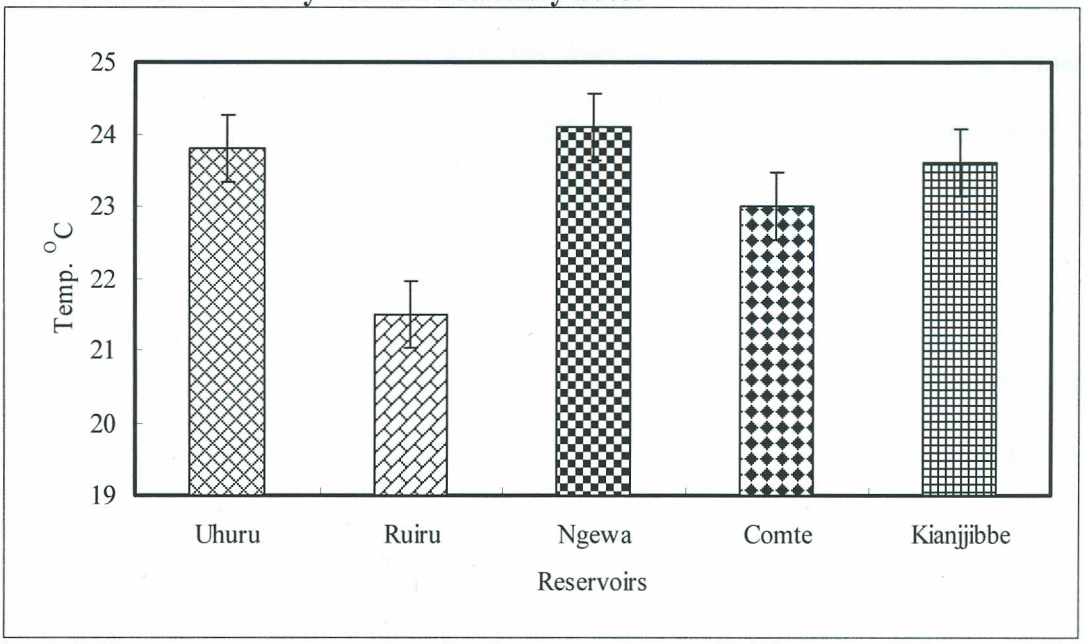


**Fig. 4. 4 Mean temperature values in the reservoirs studied between February 2002 and January 2003. Vertical bars indicate ± 1SE.**

Using the one way ANOVA test, mean water temperature values of the reservoirs investigated were significantly different ($P<0.02$, $df=59$). Mean separation using Tukey's test revealed that Ngewa and Kianjjibbe reservoirs were significantly different from each other and from the other reservoirs investigated.

Temperature differences among the reservoirs investigated can be explained by a difference in weather conditions of the reservoir localities as well as variation in ambient conditions during the time of sampling, which ranged from a clear sky to 100% cloud cover. Surface water temperature has been reported to follow the ambient air temperature closely (Breen *et al,* 1981). A low mean water temperature at Ruiru reservoir of 21.6 °C (Table 4.1) can be attributed to the location of the reservoirs at a high altitude of about 1850 m above sea level and river inflow into the reservoir is from even higher altitudes (1980 m to 2000 m above sea level). On the other hand, a high mean temperature of 24.3 °C in Ngewa (Table 4.1, Appendix 4) is due to the fact that Ngewa is located at a lower altitude of 1600 m above sea level. It was also observed that the reservoir receives limited inflow mostly in the form of surface run-off and also has a limited outflow hence there is progressive warming of the water.

Water temperatures at the selected reservoirs are within the range of better studied tropical reservoirs. A water temperature of 20.6 °C to 27.2 °C (Fig. 4.3) in Uhuru reservoir puts the reservoir in about the same range with Turkwel Gorge reservoir with a temperature range from 23.6 °C to 26.0 °C (Kotut *et al.*, 1998a). Kianjjibbe reservoir with a temperature range of 21.8 °C to 28.3 °C is within the same range with Kanji reservoir with a temperature range of 23 °C to 31°C (Latif, 1984) and Abwa reservoir in

Nigeria with a temperature range of 24 °C to 30 °C (Oriola, 2003). A temperature range of 18.1 °C to 24.8 °C in Ruiru and 21.7 °C to 26°C in Comte is within or about the same range as that of Kamburu reservoir in Kenya with a temperature range of 22 °C to 27 °C (Pacini, 1994) but higher than that of Nasser Nubia with a range of 15 °C to 24 °C (Latif, 1984) and Masinga reservoir with a range from 15 °C to 21°C (Mwaura, 2000).

### 4.2.3 Conductivity

A modest variation in conductivity was recorded at Uhuru and Comte reservoirs (Fig. 4.5). Conductivity ranged from 72 μS $cm^{-1}$ in May 2002, to 95 μS $cm^{-1}$ in April 2002, and from 94 μS $cm^{-1}$ in August 2002 to 166 μS $cm^{-1}$ in February 2002 in Uhuru and Comte reservoirs respectively (Fig. 4.5). The mean conductivity for the two reservoirs for the one year cycle were 90.4 ± 23.8 μS $cm^{-1}$ and 113.4 ± 20.54 μS $cm^{-1}$ respectively (Table 4.1, Fig. 4.6 Appendix 5).

Conductivity recorded at Ruiru was the lowest with the least variation throughout the measurement period (Fig. 4.5). The lowest value of 42 μS $cm^{-1}$ was recorded in July 2002 and January 2003 while the highest value of 60 μS $cm^{-1}$ was recorded in May, 2002 (Fig. 4.5). The mean conductivity for the reservoir over a one year cycle was 45.8 ± 5.71μS $cm^{-1}$ (Table 4.1, Fig. 4.6, Appendix 5).

Higher and wider variation in conductivity were recorded at Ngewa and Kianjjibbe reservoirs (Fig. 4.5) with conductivity ranges from 154 μS $cm^{-1}$ in November and December 2002 to 310 μS $cm^{-1}$ in February 2002 for Ngewa and from 232 μS $cm^{-1}$ in November, 2002 to 356 μS $cm^{-1}$ in August 2002 for Kianjjibbe reservoir. Mean

conductivity over the one year period for the two reservoirs were 195.9 ± 37.28 μS $cm^{-1}$ for Ngewa and 298.4. ± 41.5 μS $cm^{-1}$ for Kianjjibbe (Table 4.1, Fig. 4.6, Appendix 5).

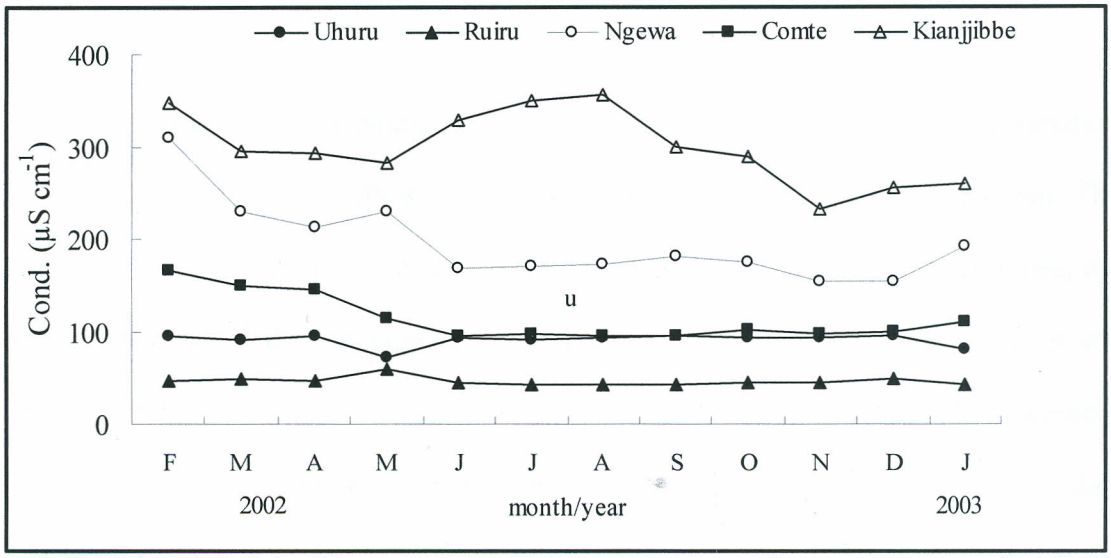


**Fig. 4. 5 Temporal variations in conductivity values in the reservoirs studied between February 2002 and January 2003.**

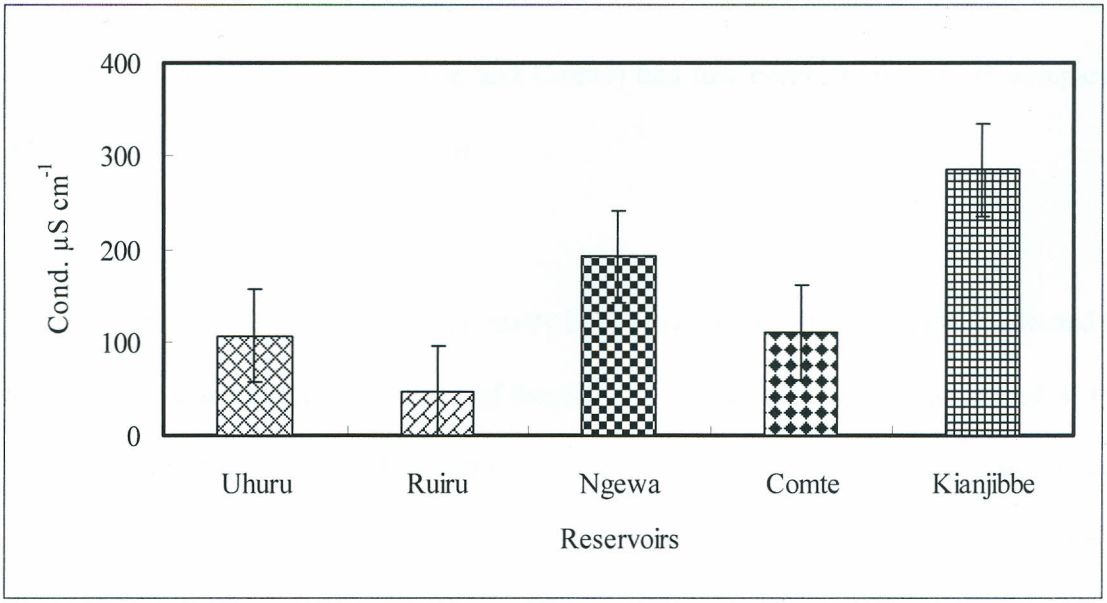


**Fig. 4. 6 Mean conductivity values in the reservoir studied between February 2002 and January 2003. Vertical bars indicate ± 1SE.**

A one way ANOVA test showed that mean conductivity values for the reservoirs investigated were significantly different ($P< 0.001$, df=59). Mean separation using

Tukey's test revealed that Kianjjibbe and Ngewa reservoirs were significantly different from each other and from other reservoirs investigated (Table 4.1).

Conductivity values and variations in water bodies are influenced by levels and variation of total dissolved solids in inflowing water and water residence time in the reservoir. The load of total dissolved solids is determined by the type of soils at the catchments area, the geological nature of the drainage basin and human activities (Payne, 1986; Adeniji and Mbagwu, 1990; Maitland; 1994, Ansare, 1996). In tropical waters, marked seasonal variation in temperature and rainfall influences the conductivity of water bodies (Chapman and Kramer, 1991). According to Maitland (1994), lowland cultivated areas have more total solids than highland cultivated areas. This is in agreement with the observations made in this study, which showed that the reservoirs located in the lowland cultivated areas (Ngewa, Kianjjibbe and Comte) had low conductivity values compared to the highland based Ruiru reservoir.

Seasonal variation in electrical conductivity in the selected reservoirs can be attributed to the seasonal changes in the amount of rainfall and the temperatures experienced in the area. High temperature recorded in the reservoirs towards the end of the dry season are responsible for the high evaporative concentration leading to higher conductivities, while the low conductivities towards the end of the wet season is due to dilution and the short time the water is in contact with the mineral sources. A high mean conductivity at Kianjjibbe reservoir (Table 4.2) possibly resulted from a number of factors that include the location of the reservoir in a rich agricultural area with different human activities. Since its main source of water is surface run-off, after the rains, a large amount of total

solids is carried into the reservoir. As the reservoir is situated at a lower altitude, it receives a rich inflow of dissolved solids. Since its water is retained for irrigation during the dry season, the reservoir water has a longer residence time. This coupled with the high temperatures at low altitudes (800 m above seas level) results in greater evaporative concentration.

Water at the Ruiru reservoir is mainly used to provide municipal water and hence the water has a short residence time. The reservoir also receives water from high altitudes (above 1850 m ASL) with cooler temperatures and therefore limited evaporation. The large volume of discharge from Ruriu, Ngeteti, Rungiki and Gitindo rivers brings about reservoir dilution.

Conductivity ranges at the study reservoirs do not differ appreciably from those of other tropical reservoirs whose conductivity range varies from 35 $\mu S\ cm^{-1}$ to 200 $\mu S\ cm^{-1}$. Kianjjibbe reservoir with conductivity range of 232 $\mu S\ cm^{-1}$ to 356 $\mu S\ cm^{-1}$ is higher than that of most tropical African reservoirs. Ngewa conductivity range from 154 $\mu S\ cm^{-1}$ to 310 $\mu S\ cm^{-1}$ is slightly higher than that of the Turkwel Gorge Reservoir with conductivity range of between 160 $\mu S\ cm^{-1}$ to 200 $\mu S\ cm^{-1}$ (Kotut *et al.*, 1998a). Comte reservoir with a conductivity range from 94 $\mu S\ cm^{-1}$ to 166 $\mu S\ cm^{-1}$ is lower than that of Turkwel Gorge Reservoir (160 $\mu S\ cm^{-1}$ to 200 $\mu S\ cm^{-1}$) but within the same range as that of Masinga dam with a conductivity range of between 113 $\mu S\ cm^{-1}$ to 140 $\mu S\ cm^{-1}$ (Pacini, 1994). Uhuru reservoir with a conductivity range from 72 $\mu S\ cm^{-1}$ to 95 $\mu S\ cm^{-1}$ is nearly the same as that of lake Volta with a range from 65 $\mu S\ cm^{-1}$ to 180 $\mu S\ cm^{-1}$ (Latif, 1984) while Ruiru with a conductivity range from 42 $\mu S\ cm^{-1}$ to 60 $\mu S\ cm^{-1}$ is lower but within

the same range as that of Kariba with a range from 55 μS $cm^{-1}$ to 81 μS $cm^{-1}$ (Latif, 1984).

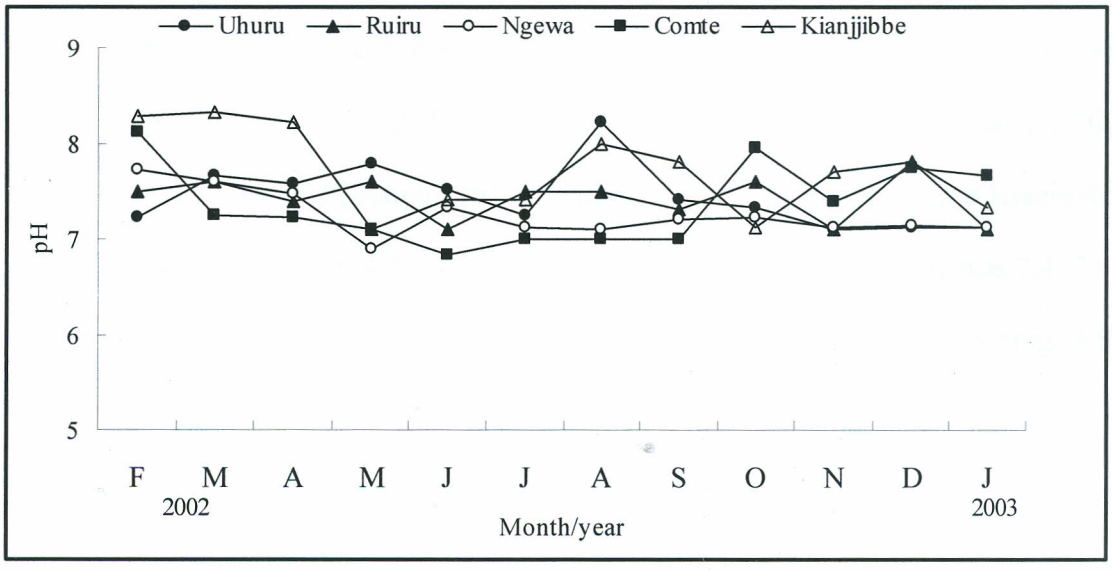


**Fig. 4. 7 Temporal variations in pH values in the reservoirs studied between February 2002 and January 2003.**

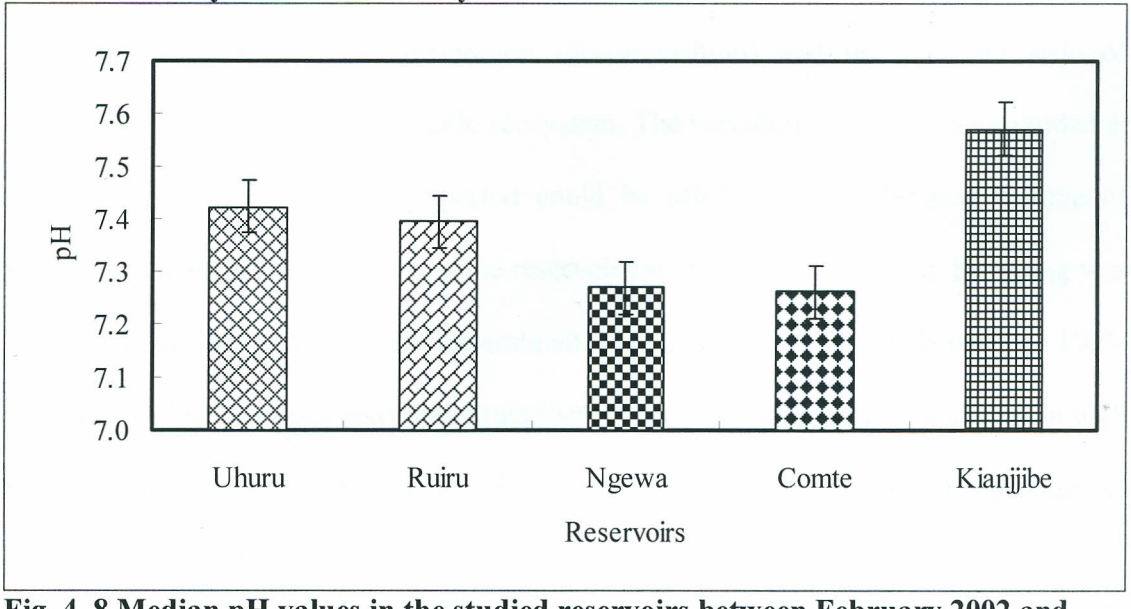


**Fig. 4. 8 Median pH values in the studied reservoirs between February 2002 and January 2003. Vertical bars indicate the pH range.**

### 4.2.4 pH

pH recorded in the reservoirs showed limited variations throughout the one year cycle at all the five reservoirs (Fig. 4.7). pH recorded ranged from 7.1 in November, 2002 to 8.2 (August, 2002), 7.1 (June and November 2002 and January 2003) to 7.8 (December 2002), 6.9 (May 2002) to 7.7 (February 2002), 6.9 (June 2002) to 8.1 (February 2002) and 7.1 (May 2002) to 8.3 (March 2002) at Uhuru, Ruiru, Ngewa, Comte and Kianjjibbe reservoirs respectively (Fig. 4.7). The median pH value for each reservoir was 7.4, 7.4, 7.2, 7.3 and 7.7 for Uhuru, Ruiru, Ngewa, Comte and Kianjjibbe reservoirs (Fig. 4.8, Appendix 6) respectively.

Under natural conditions pH is dependent on the amount of carbonate and bicarbonate alkalinity and carbon dioxide in solution (Talling and Talling, 1965). The balance between photosynthesis and respiration (decomposition) and the buffered state of reservoir determines pH in an aquatic ecosystem. The variations in pH ranges recorded at the reservoirs during the study period could be attributed to difference in time of sampling and ambient conditions at the reservoirs at the time of sampling. Sampling was done between 9 am and 4 pm and the ambient conditions varied from a clear sky to 100% cloudy. On clear days phytosynthetic rate increases rapidly after sunrise and remain high until almost sundown (Harris *et al.,* 1983). Cloudy skies cause a decrease in photosynthetic rates (Romaire and Boyd, 1979).

A high median pH at Kianjjibbe reservoir (Table 4.1) can be attributed to the time of sampling, Kianjjibbe reservoir was sampled between 12 noon and 4 pm, a time when the rate of photosynthesis was high. The reservoir also had a high phytoplankton biomass

(Table 4.5), which may have contributed to the high rate of photosynthesis at the reservoir. The removal of $CO_2$ during algal photosynthesis raises the pH of the reservoir. Similarly at the time of sampling the sky was clear with cloud cover rarely exceeding 10%.

The lower pH at Ngewa and Comte possibly resulted from the time of sampling. The reservoirs were sampled between 9 am and 12 noon a time when the rate of photosynthesis had not picked up. A low phytoplankton biomass recorded at the reservoirs (Table 4.5) meant that uptake of $CO_2$ was lower. Higher temperatures at the reservoirs could have brought about higher rates of decomposition and hence higher levels of carbon dioxide.

Compared to other reservoirs, the pH values recorded at the study reservoirs were within a similar range. A pH range of 7.1 to 8.2 at Uhuru reservoir and 7.1 to 7.8 at Ruiru was higher than that of Weija Reservoir with a pH range of 7.1 to 7.7 (Ansa-sare,1996). Ngewa reservoir with a pH range of 6.7 to 7.0 is nearly within the same range as the Weija Reservoir. Comte and Kianjjibbe with pH ranges of 6.8 to 8.1 and 6.6 to 8.3 respectively are within the same range with Weija but with a lower maximum value when compared to the Turkwel Gorge reservoir with a range from 6.7 to 8.9 (Kotut *et al.*, 1998a).

### 4.2.5 Dissolved oxygen (DO)

At Uhuru and Ruiru reservoirs, dissolved oxygen showed moderate variations throughout the one year period (Fig. 4.9). At Uhuru, DO concentration ranged from of 8.1 mg $L^{-1}$

(October, 2002) to 6.4 mg $L^{-1}$ (February, 2002) while in Ruiru DO concentration ranged from 7.0 mg $L^{-1}$ (February, March, June, October and December 2002 and January, 2003) to 7.2 mg $L^{-1}$ (May, July, August and November 2002) (Fig. 4.9). Overall, mean DO concentration of 7.1 ± 0.75 mg $L^{-1}$ and 7.0 ± 0.26 mg $L^{-1}$ were computed for Uhuru and Ruiru reservoirs respectively (Table 4.1, Fig. 4.10, Appendix 7).

Wide and irregular variations in DO were observed at Ngewa and Comte throughout the one year study period (Fig. 4.9), with ranges from 5.2 mg $L^{-1}$ (December, 2002) to 7.5 mg $L^{-1}$ (April 2002) and from 5.6 mg $L^{-1}$ (September, 2002) to 9.3 mg $L^{-1}$ (February, 2002) at the two reservoirs respectively (Fig. 4.9). Mean DO values at the two reservoirs were 6.2 ± 1.09 mg $L^{-1}$ and 7.6 ± 1.08 mg $L^{-1}$ (Table 4.1, Fig. 4.9) in the same order. At Kianjjibbe, DO concentration varied widely from 8.1mg $L^{-1}$ (December, 2002) to 10.4 mg $L^{-1}$ (February, 2002) with a mean concentration of 9.0 mg $L^{-1}$.

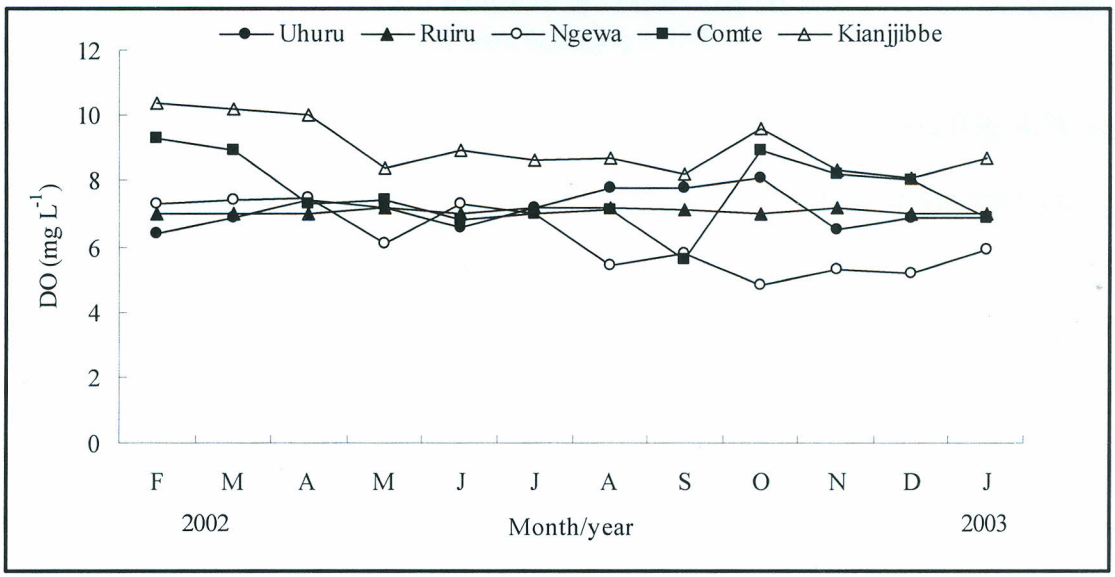


**Fig. 4. 9 Temporal variations in dissolved oxygen values in the studied reservoirs between February 2002 and January 2003**

Using one way ANOVA test, mean dissolved oxygen values at the reservoirs investigated were found to be significantly different ($P<0.001$, $df = 59$). Mean separation using Tukey's test revealed that Kianjjibbe and Comte reservoirs were significantly different from each other and from the other reservoirs.

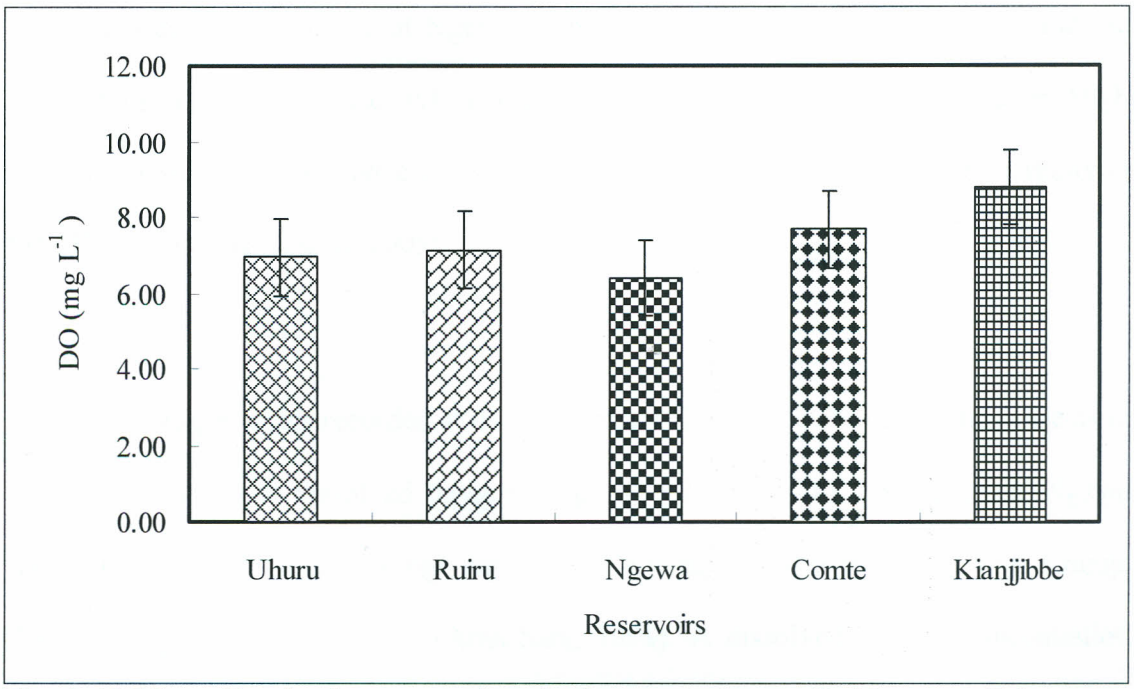


**Fig. 4. 10 Mean dissolved oxygen values in the reservoirs studied between February and January 2003. Vertical bars indicate ± 1SE**

Variations in dissolved oxygen recorded within and between the reservoirs (Fig. 4.9) can be attributed to variations in sampling time and the ambient conditions at the reservoirs at the time of sampling. Ambient conditions e.g. cloud cover, influences the rate of photosynthesis. Low levels of DO are characteristic of cloudy days when the rate of photosynthesis is low. Phytoplankton abundance also influences the rate of photosynthesis.

High mean DO values at Kianjjibbe reservoir (Table 4.1) can be attributed to the time of sampling as well as the phytoplankton abundance. Kianjjibbe reservoir was sampled

between 12 noon and 1 pm, a time when the rate of photosynthesis was high leading to a net accumulation of DO in water on most sampling dates. Similary, the sky was clear with less than 10% cloud cover. A high phytoplankton biomass was also recorded at the reservoir during the study period, and this possibly led to a higher rate of photosynthesis. Low mean dissolved oxygen at Ngewa (Table 4.1) is due to its shallow depth and the higher temperatures recorded, which favor the decomposition of organic matter. High levels of dissolved oxygen have been found to cause gas bubble diseases and mortality in fish (Bronmark and Hassen, 2005).

Dissolved oxygen levels recorded at the study reservoirs were within the same range as in other reservoirs. The dissolved oxygen range of 5.2 mg $L^{-1}$ to 7.5 mg $L^{-1}$ at Ngewa reservoir is within the same range with that of Kpong reservoir in Ghana with a range from 4.6 mg $L^{-1}$ to 9.0 mg $L^{-1}$ (Ansa-Sare, 1996). A dissolved oxygen concentration range of 8.2 mg $L^{-1}$ to 10.4 mg $L^{-1}$ in Kianjjibbe reservoir is within the same range with that of Weija reservoir with a dissolved oxygen concentration range of 7.9 mg $L^{-1}$ to 10 mg $L^{-1}$.

However, a dissolved oxygen range from 5.6 mg $L^{-1}$ to 9.3 mg $L^{-1}$ at Comte is slightly higher than that of Turkwel Gorge Reservoir with a dissolved oxygen range of 4.9 mg $L^{-1}$ to 9.2 mg $L^{-1}$ (Kotut, 1998). Finally a DO range from 6.4 mg $L^{-1}$ to 8.1 mg $L^{-1}$ at Uhuru reservoir is nearly but about the same range with that of Kpong reservoir with a range of 4.6 mg $L^{-1}$ to 9.0 mg $L^{-1}$ (Ansa-Sare, 1996).

### 4.2.6 Total alkalinity (TA)

A narrow variation in total alkalinity (TA) was recorded at Uhuru and Ruiru reservoirs (Fig. 4.11). At Uhuru, the lowest value observed was 27 mg $L^{-1}$ $CaCO_3$ (May, 2002) while the highest value was 44.5 mg $L^{-1}$ $CaCO_3$ (January, 2003) (Fig. 4.11). A mean TA value of 35.3 ± 8.76 mg $L^{-1}$ $CaCO_3$ (Fig. 4.12) was computed for Uhuru. At Ruiru reservoir, total alkalinity ranged from 13.0 mg $L^{-1}$ $CaCO_3$ (May, 2002) to 23.5 mg $L^{-1}$ $CaCO_3$ (March, 2002) with an overall mean value of 18.0 ± 0.24 mg $L^{-1}$ $CaCO_3$ being computed for the year. A modest variation in TA at Comte ranging from 20.5 mg $L^{-1}$ $CaCO_3$ (May, 2002) to 60 mg $L^{-1}$ $CaCO_3$ (February, 2002) was recorded (Fig. 4.11). Overall, mean total alkalinity of 41.1 ± 8.92 mg $L^{-1}$ $CaCO_3$ was recorded for the reservoir (Fig. 4.12, Appendix 8).

A wide variation in TA was recorded at Ngewa and Kianjjibbe reservoirs with ranges from 76 (June, 2002) to 92 mg $L^{-1}$ $CaCO_3$ (April, 2002 and January, 2003) (Fig. 4.11) and from 90 (May, 2002) to 139 mg $L^{-1}$ $CaCO_3$ (February, 2002) in the two reservoirs respectively (Fig. 4.11). Mean total alkalinity for the 2 reservoirs were 83.9 ± 7.88 mg $L^{-1}$ $CaCO_3$ and 110.5 ± 15.9 mg $L^{-1}$ $CaCO_3$ respectively in 2002 (Fig. 4.12).

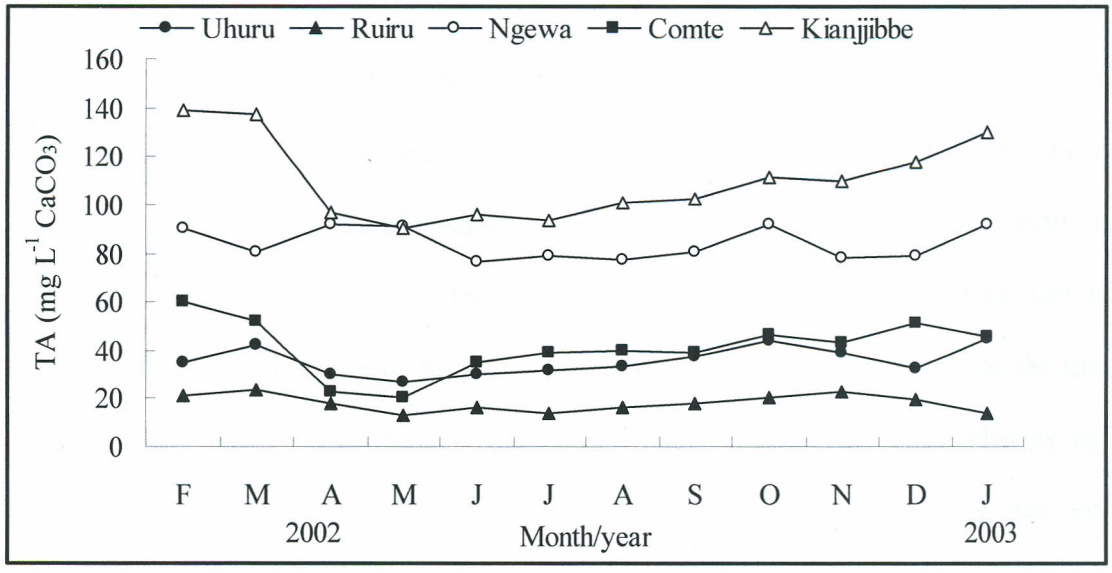


**Fig. 4. 11 Temporal variations in total alkalinity (TA) values in the reservoirs studied between February 2002 and January 2003.**

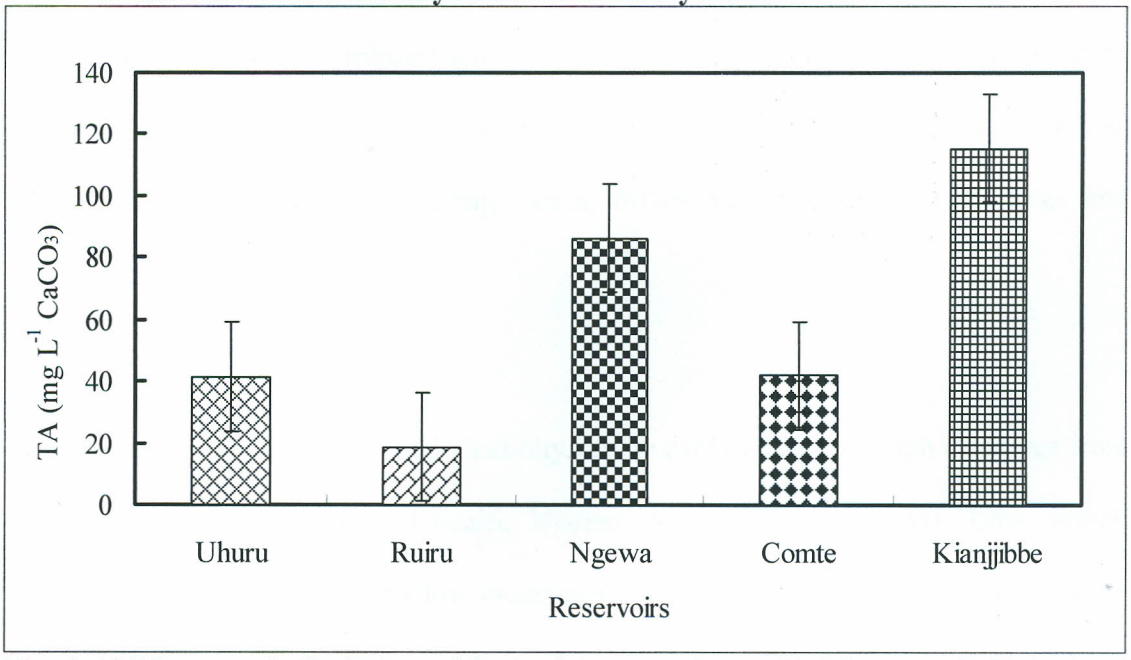


**Fig. 4. 12 Mean total alkalinity values in the reservoirs studied between February 2002 and January 2003. Vertical bars represent ± 1SE**

Using one way ANOVA test, mean total alkalinity values of the reservoirs investigated were significantly different ($P< 0.001$, df =59). Mean separation using Tukey's test revealed that Kianjjibbe and Ngewa reservoirs were significantly different from each and from other reservoirs.

Total alkalinity is determined by the equilibrium between carbon dioxide, bicarbonates and carbonates, and any variation is caused by internal generation of alkalinity (photosynthesis and respiration), watershed weathering processes. Low total alkalinity recorded at the reservoirs during the wet season months of April and May can be attributed to the high velocity of flood water derived from run off, which limits the time the water is in contact with the parent rock and hence a reduction in weathering and hence the low alkalinity. On the other hand, the high alkalinity during the months with low rainfall can be explained by among other reasons, an increase in the length of time the water is in contact with the parent rock that promotes rock weathering. In general, a greater rock weathering combined with increased evaporative concentration brings about a high alkalinity. Total alkalinity variation among the reservoirs can be attributed to variations in the geology of drainage areas, differences in photosynthetic rates and evaporative concentration.

At Ruiru reservoir, low mean total alkalinity can be explained by the high discharge from the inflowing rivers (Ruiru, Kimaiti, Ngeteti, Rungiki and Gitindo). Low overall temperatures also contribute to low evapotranspiration at the reservoir. Absence of an outlet and reliance on run-off may have contributed to a high mean total alkalinity at Kianjjibbe reservoir. In the absence of an outlet evaporation makes an important contribution to water loss from the reservoir. The water collected at the reservoir is retained to be used for irrigation during the dry season. This increases the length of time the water is in contact with the parent rock thus resulting in a greater rock weathering.

**Table 4.1 Mean values ± 1SD of selected physico-chemical properties (median values in case of pH) investigated in the study reservoirs between February 2002 and January 2003.**

| Parameters | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| Secchi depth | 0.6 ± 0.9b | 0.9 ± 0.43a | 0.1± 0.04c | 0.1 ± 0.6c | 0.3 ± 0.13c |
| Temp. °C | 23.8 ± 1.8c | 21.6 ± 2.2c | 24.3 ± 2.9a | 23.4 ± 1.6a | 24.0 ± 1.9b |
| Cond. µS $cm^{-1}$ | 90.4 ± 23.8c | 45.8 ± 5.7c | 195.5 ± 37.3b | 113.3 ± 20.5c | 298.9 ± 41.5a |
| pH | 7.4 | 7.4 | 7.2 | 7.3 | 7.7 |
| DO (mg $L^{-1}$) | 7.1 ± 0.7c | 7.1 ± 0.26c | 6.2 ± 1.1c | 7.6 ± 1.1b | 9.0 ± 0.8a |
| TA (mg $L^{-1}$) | 35.5 ± 8.8c | 18.0 ± 0.24c | 83.9 ± 7.9b | 41.1 ± 8.9c | 110.2 ± 15.9a |

Compared with total alkalinity of other African reservoirs, total alkalinity recorded at the study reservoirs is within and about the same range. An alkalinity range of 76 mg $L^{-1}$ to 92 mg $L^{-1}$ for Ngewa is nearly same with that of Turkwel Gorge reservoir with an alkalinity range of 75 mg $L^{-1}$ to 111 mg $L^{-1}$ (Kotut *et al.*, 1998a). An alkalinity range of 90 mg $L^{-1}$ to 139 mg $L^{-1}$ for Kianjjibbe reservoir is within the same range with Weija reservoir in Ghana with an alkalinity range of 108.3 mg $L^{-1}$ to 130.9 mg $L^{-1}$ (Ansa-Sare, 1996). A low total alkalinity range of 27 mg $L^{-1}$ to 44.5 mg $L^{-1}$ and 20.5 mg $L^{-1}$ to 60 mg $L^{-1}$ in Uhuru and Comte reservoirs respectively is close to the TA range of Kpong in Ghana with a range from 40.3 to 52 mg $L^{-1}$ (Ansa-Sare, 1996).

### 4.2.7 Nitrate –nitrogen ($N0_3$-N)

Nitrate-nitrogen ($N0_3$-N) concentration (µg $l^{-1}$) in Uhuru reservoir exhibited an irregular fluctuation throughout the study period (Fig. 4.13) with a range from 0.1 (March, 2002) to 52.9 µg $L^{-1}$ (November, 2002). Overall, a mean concentration of 9.8 ± 1.37 µg $L^{-1}$ was recorded for the reservoir (Table 4.2, Fig. 4.14). Ruiru reservoir showed wide variations with the lowest concentration of 0.4 µg $L^{-1}$ being recorded in December, while the

highest value of 57.8 μg $L^{-1}$ was recorded in November 2002 (Fig. 4.13). The mean nitrate nitrogen concentration computed for the study was 9.0 ± 12.5 μg $L^{-1}$.

A modest variation in nitrate nitrogen was recorded in Ngewa reservoir with ranges from below the limit of detection in December 2002 (total rainfall recorded -14.5 mm) to 8.0 μg $L^{-1}$ in October 2002. An overall mean reservoir value of 4.2 μg $L^{-1}$ was computed for the study period. A limited variation in nitrate nitrogen was observed at Comte reservoir. Reservoir $NO_3$-N values ranged from 0.3 μg $L^{-1}$ (November 2002) to 23.3 μg $L^{-1}$ (December, 2002). A mean $N0_3$-N concentration of 7.1 ± 5.56 μg $L^{-1}$ was computed for the reservoir. Nitrate nitrogen values at Kianjjibbe reservoir varied widely with a range from below the limit of detection (November, 2002) to 37.3 μg $L^{-1}$ (July, 2002). In general, the highest values were recorded during the wet season months of the year.

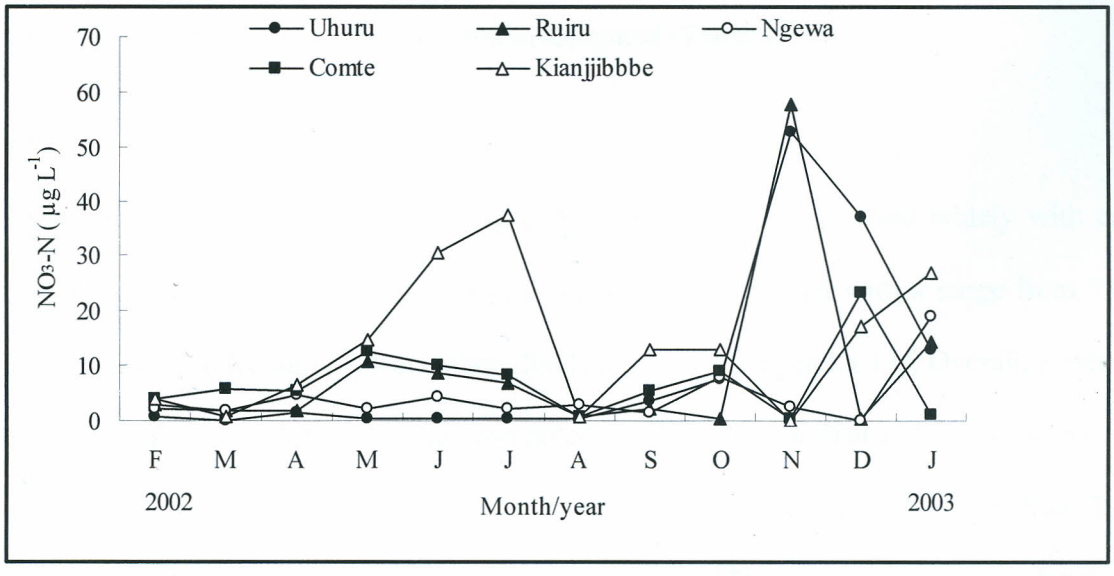


**Fig. 4. 13 Temporal variations in nitrate- nitrogen values in the reservoirs studied between February 2002 and January 2003.**

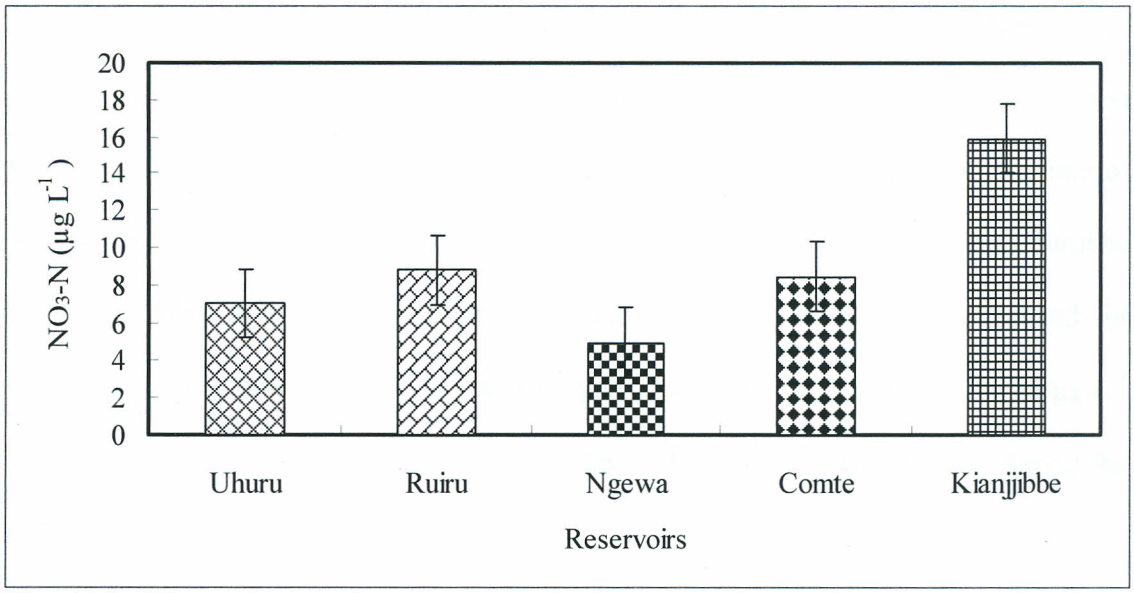


**Fig. 4.14 Mean nitrate nitrogen values in the reservoirs studied between February 2002 and January 2003. Vertical bars represent ± 1SE**

Using the one way ANOVA test, mean nitrate nitrogen values for the reservoirs selected were significantly different ($P < 0.001$, df =59). Mean separation using Tukey's test revealed that Kianjjibbe and Ngewa mean reservoirs were significantly different from each other and from the other reservoirs investigated (Table 4.2).

### 4.2.8 Total nitrogen (TN)

Total nitrogen (TN) concentration (µg $L^{-1}$) in Uhuru reservoir varied widely with an irregular fluctuation throughout the study period (Fig. 4.16) and with a range from 7.0 (August 2002) to 82 µg $L^{-1}$ (November, 2002) (Fig. 4.15, Appendix 11). Overall, a mean TN value of 33.1 ± 22.7 µg $L^{-1}$ was computed for the reservoir (Table 4.2, Fig. 4.16). A modest variation in total nitrogen was recorded in Ngewa reservoir with ranges from 7.0 (October, 2002) to 80 µg $L^{-1}$ (November 2002) (Fig. 4.15). A mean total nitrogen value of 34.3 ± 3.0 µg $L^{-1}$ was noted for the reservoir.

Ruiru and Kianjjibbe reservoirs showed the widest variations with irregular fluctuations, with the lowest concentration of 1.0 μg $L^{-1}$ (recorded in August, 2002) and the highest value of 121 μg $L^{-1}$ (recorded in November, 2002) in Ruiru, and from below the limit of detection (November and December, 2002) to 103 μg $L^{-1}$ (July, 2002) in Kianjjibbe reservoir (Table 4.2, Fig. 4.16). The mean total nitrogen concentration computed for Ruiru and Kianjjibbe reservoirs for the study period were 39.8 ± 3.0 and 31.5 ± 28 μg $L^{-1}$ respectively (Table 4.2, Fig. 4.16). In general the highest values were recorded during the wet season months.

Using the one way ANOVA test, mean total nitrogen values for the reservoirs investigated were significantly different (P>0.5, df =59). Mean separation using Tukey's test revealed that Comte and Ruiru reservoirs were significantly different from each other and from the rest of the reservoirs (Table 4.2).

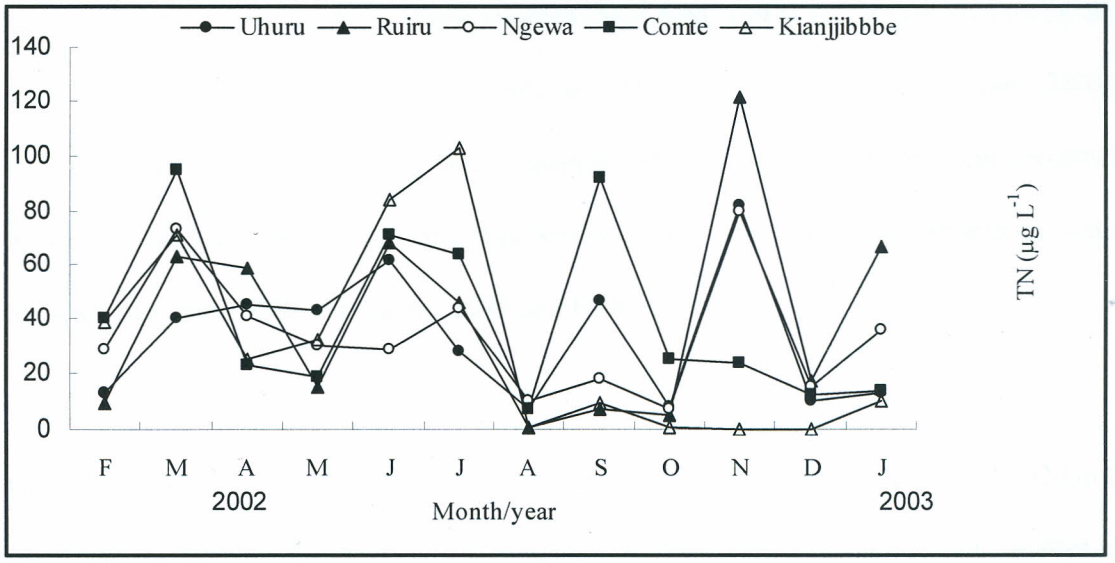


**Fig. 4. 14 Temporal variations in total nitrogen values in the reservoirs studied between February 2002 and January 2003.**

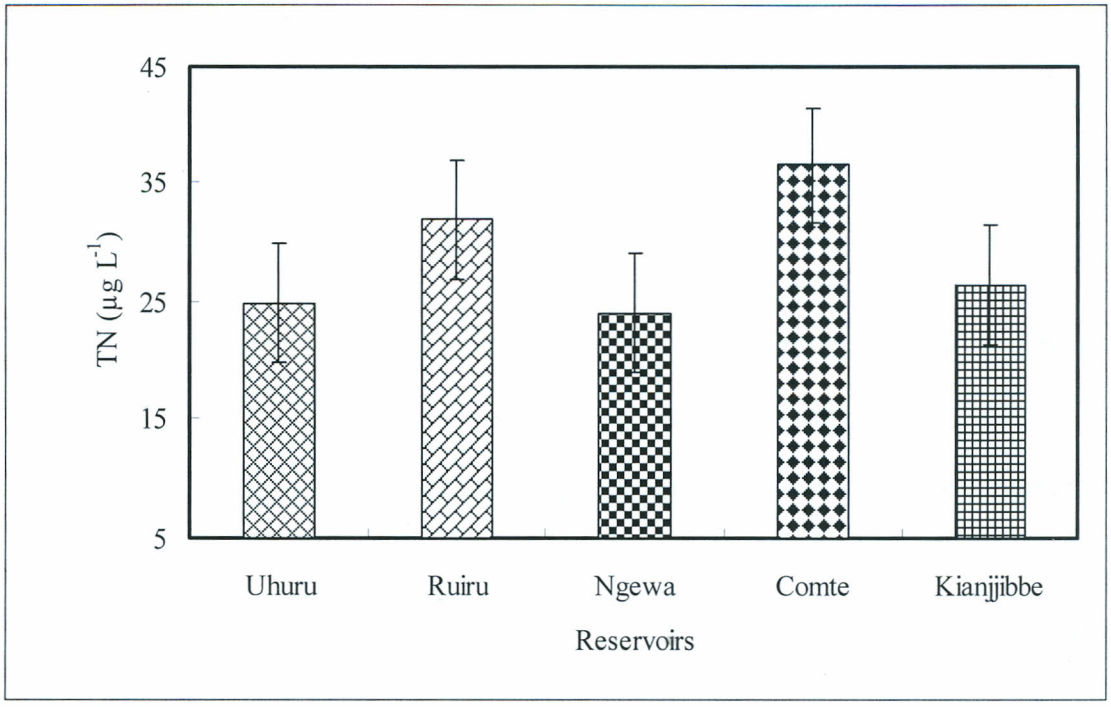


**Fig. 4. 15 Mean total nitrogen values in the reservoirs studied between February 2002 and January 2003. Vertical bars indicate ± 1SE**

Variations in total nitrogen in reservoirs are attributed to agricultural land use practices (Ansa-Sare, 1996), municipal and industrial activities (Ballance and Batram, 1996,), plant decay (Chapman, 1992), atmospheric sources (Stoddard, 1997) and inflow (Kennedy and Walker, 1990), size of the catchment area and presence of vegetation (Hassen., 2005). Run-off from agricultural activities, industrial effluents and manure from livestock operations are rich in nitrogen and this increases the levels of total nitrogen in water bodies (Ana-sare, 1996; Purwanto, 1999 and Dijk, 2002).

High total nitrogen values in all the reservoirs during the wet season months (March, June and November 2002) can be attributed to the high load of organic matter in floodwater from adjacent catchment through run-off and river input. When the river flow resumes after the dry season, the dry season accumulation of portable organic and inorganic matter on the dried river bed and the catchments area is swept downstream by

the first floodwater and this contributes to high values of nitrogen The agricultural activities which use inorganic and organic fertilizers and commercial/ industrial activities around the catchments also contribute to the high levels of total nitrogen.

Although total nitrogen in inflow was not measured, it is likely that an important source of nitrogen is the organic matter load through inlets. Direct organic matter from settlements, agricultural and industrial/commercial activities make a significant impact on levels of total nitrogen at the reservoirs (Tebutt, 1998; Purwanto, 1991and Dijk, 2002). The high nitrogen levels in reservoirs could also be due to increased biological activities during the wet season.

At Ngewa reservoir, low mean total nitrogen (Table 4.2) can be explained by the small size of catchment. Small catchments contribute low amounts of total nitrogen as the run-off water has short distance to gather nutrients before it reaches the reservoir. Similarly, the presence of a fringing vegetation zone helps reservoirs filter the run-off before it gets into the reservoir. This contributed to lower levels of TN in some reservoirs.

High mean total nitrogen values at Kianjjibbe reservoir (Table 4.2) can be attributed to its large catchment area as well as the intense agricultural activities at the catchments. Kianjjibbe reservoir receives surface run-off from a very large catchment's area, about 16,000 $km^2$ and therefore rainfall has a long time to gather the nutrients before it gets to the reservoir. Intense agriculture with the use of organic and inorganic fertilizers contribute high amount of nitrogen to the reservoir. Higher temperatures as a result of the lower altitude (1600 m above sea level) possibly promote faster decomposition of organic

matter at the reservoir. The reservoir also lacks a fringing shore vegetation cover hence during flood periods, most of the flood water ends up in the reservoir. High levels of total nitrogen have the potential of causing frequent blooms of toxic cyanobacteria (Obserholsten, 2006).

### 4.2.9 Total phosphorus (TP)

Total phosphorus concentration recorded in all the reservoirs showed wide variation with irregular fluctuation throughout the one year study period (Fig. 4.17). In Uhuru reservoir, TP ranged from 0.1 μg $L^{-1}$ in February, June, and July 2002 (Total rainfall recorded was 19.1mm, 0.6 mm and no rainfall) to 2.54 μg $L^{-1}$ in November 2002 (total rainfall recorded, 337.5 mm). The mean TP for the period was 0.8 ± 0. 14 μg $L^{-1}$.

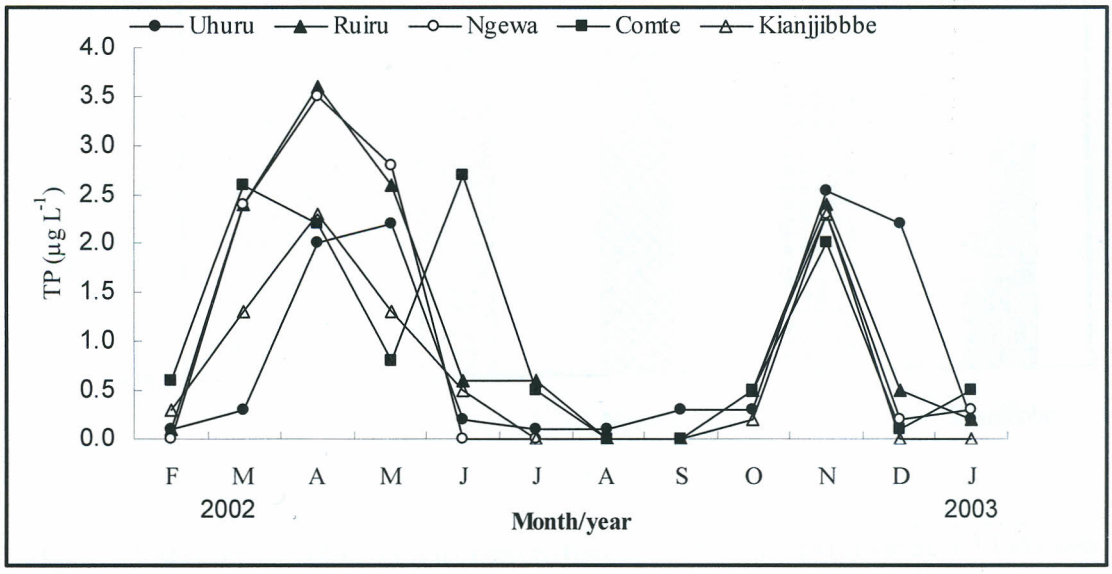


**Fig. 4. 16 Temporal variations total phosphorus values in the reservoirs studied between February 2002 and January 2003.**

In Ruiru, Ngewa Comte and Kianjjibbe reservoirs, total phosphorus showed wide variations with ranges from below the limit of detection to 3.6 μg $L^{-1}$ in Ruiru, 3.5 μg $L^{-1}$ in Ngewa, 2.6 μg $L^{-1}$ in Comte and 2.3 μg $L^{-1}$ in Kianjjibbe reservoirs (Table 4.2, Fig 4.17, Appendix 13). High values were recorded in the months, which recorded the

highest rainfall. Mean total phosphorus values were 1.0 ± 0.01 μg $L^{-1}$, 1.0 ± 0.77 μg $L^{-1}$, 1.0 ± 0.08 μg $L^{-1}$ and 0.7 ± 0.25 μg $L^{-1}$ in Ruiru, Ngewa, Comte and Kianjjibbe reservoirs respectively (Table 4.2, Fig. 4.18, Appendix 13).

Using the one way ANOVA test, mean total phosphorus values for the reservoirs investigated were significantly different (P>0.001, df =59). Mean separation using Tukey's test showed that Ngewa and Ruiru were significantly different from each other and from Comte, Ngewa and Ruiru reservoirs (Table 4.2).

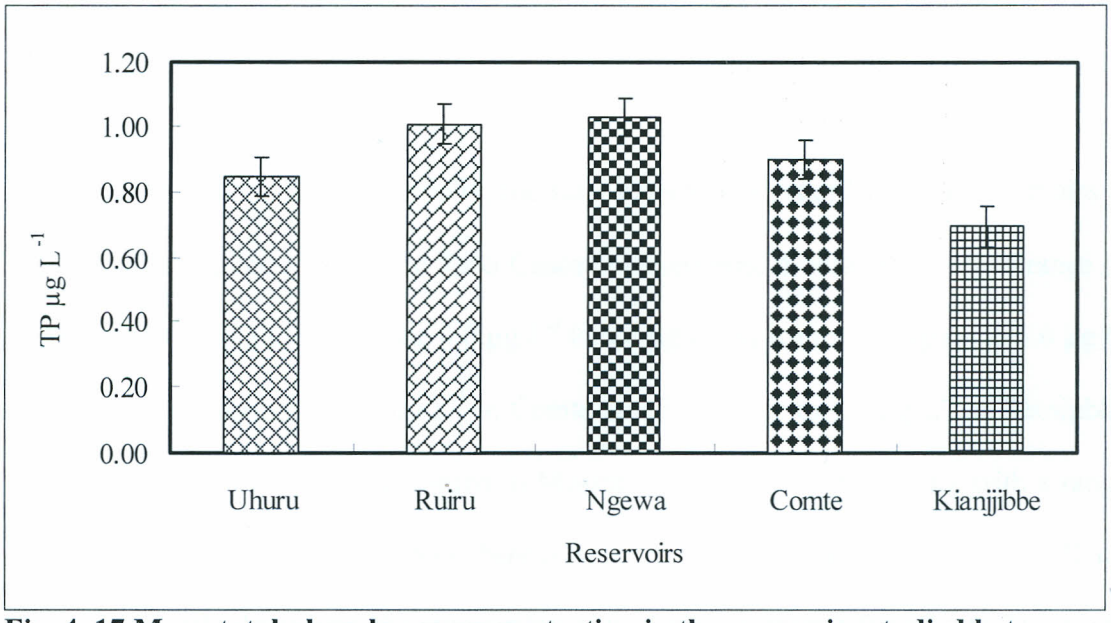


**Fig. 4. 17 Mean total phosphorus concentration in the reservoirs studied between February 2002 and January 2003. Vertical bars indicate ± 1SE**

Variations in total phosphorus concentration in reservoirs can be attributed to differences in geology of the drainage basins (Gotleman, 1973), anthropogenic activities, domestic and industrial inputs of phosphorus such as sewage disposal and soluble polydetergents (Gleick., 2001; Ballance and Batram 1996), agricultural run-off (Ansare, 1996; Chapman, 1992), rainfall frequency and vegetation type at the catchments (Viner, 1975). In general

a low phosphorus concentration in freshwater reservoirs is characteristics of areas with a low rainfall intensity and well developed vegetation cover (Rijsdik *et al.*, 2004).

The high total phosphorus concentration recorded in Ngewa reservoir (Table 4.2) could be attributed to the fact that Ngewa is within a coffee plantation and receives run-off from farms, which uses fertilizers to increase production. It may also be due to the introduction of detergent rich effluents as the water is used for bathing and washing clothes. Low levels of total phosphorus recorded at Uhuru reservoir can be attributed to the fact that Uhuru is far away from the agricultural farms and also receives water from an underground drain.

Compared to other studied reservoirs, the total phosphorus recorded at the reservoirs is higher than those recorded in the Tana Cascade Reservoirs. A total phosphorus range of 0.0 $\mu g\ L^{-1}$ to 0.5 $\mu g\ L^{-1}$ in Uhuru, 0.0 $\mu g\ L^{-1}$ to 0.6 $\mu g\ L^{-1}$ in Ruiru, 0.0 $\mu g\ L^{-1}$ to 3.6 $\mu g\ L^{-1}$ in Ngewa 0.0 $\mu g\ L^{-1}$ to 3.0 $\mu g\ L^{-1}$ in Comte and 0.0 $\mu g\ L^{-1}$ to 1.3 $\mu g\ L^{-1}$ at Kianjjibbe reservoirs is higher than that recorded in Masinga and Kamburu reservoirs with a range of 0.0 $\mu g\ L^{-1}$ to 0.1 $\mu g\ L^{-1}$, and Kiambere reservoir with a range of 0.0 $\mu g\ L^{-1}$ to 0.05 $\mu g\ L^{-1}$ (Pacini, 1994). However, the range is lower than a range from 8.9 $\mu g\ L^{-1}$ to 71.6 $\mu g\ L^{-1}$ recorded at Turkwel Gorge Reservoir (Kotut *et al.*, 1998).

### 4.2.10 Soluble reactive silica (SRS)

A modest variation in soluble reactive silica was recorded in Uhuru and Ruiru reservoir with ranges from 2.4 $mg\ L^{-1}$ in October 2002 (total rainfall received, 58 mm) to 3.8 $mg\ L^{-1}$ November, 2002 (total rainfall, 337.5 mm) and from 3.10 $mg\ L^{-1}$ in October, 2002 (total

rainfall 15.4 mm) to 4.55 mg $L^{-1}$ May, 2002 and November, 2002 (total rainfall, 339.8 mm and 313 mm respectively) (Fig. 4.19, Appendix 14). Mean soluble silica concentration in the two reservoirs were 3.4± 0.47 mg $L^{-1}$ and 4.01 ± 0. 64 mg $L^{-1}$ respectively during the one year cycle (Fig. 4.20, Appendix 14). A limited variation in soluble reactive silica was recorded at Ngewa reservoir with a range from 5.9 mg $L^{-1}$ (October, 2002; Fig. 4.19) to 8.6 mg $L^{-1}$ (March, 2002)). An overall mean SRS value of 7.3 ± 0.74 mg $L^{-1}$ was computed for the reservoir (Table 4.2, Fig. 4. 20).

Soluble reactive silica recorded in Comte and Kianjjibbe showed wide variations with irregular fluctuations pattern and a range from 3.2 mg $L^{-1}$ (June, 2002) to 9.2 mg $L^{-1}$ in (April and November, 2002) and from 3.2 mg $L^{-1}$ (January, 2003) to 8.2 mg $L^{-1}$ (May and September, 2002) (Fig. 4.19). Mean reservoir SRS values for the study period were 5.9 ± 0.154 mg $L^{-1}$ and 6.6 ± 0.199 mg $L^{-1}$ for Comte and Kianjjibbe reservoirs respectively (Fig. 4.20, Appendix 14).

A one way ANOVA test established that SRS values at the reservoirs investigated were significantly different ($P>0.01$, $df=59$). Mean separation using Tukey's procedure revealed that Ngewa and Kianjjibbe reservoirs were significantly different from each other and from the other reservoirs investigated (Table 4.2).

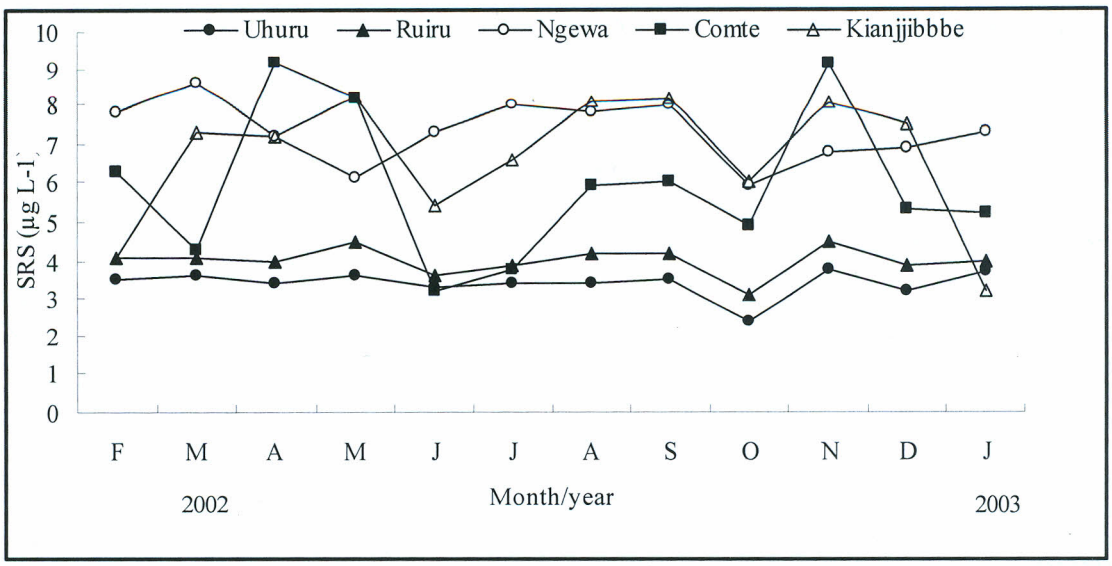


**Fig. 4. 18 Temporal variation in soluble reactive silica values in the reservoirs studied between February 2002 and January 2003.**

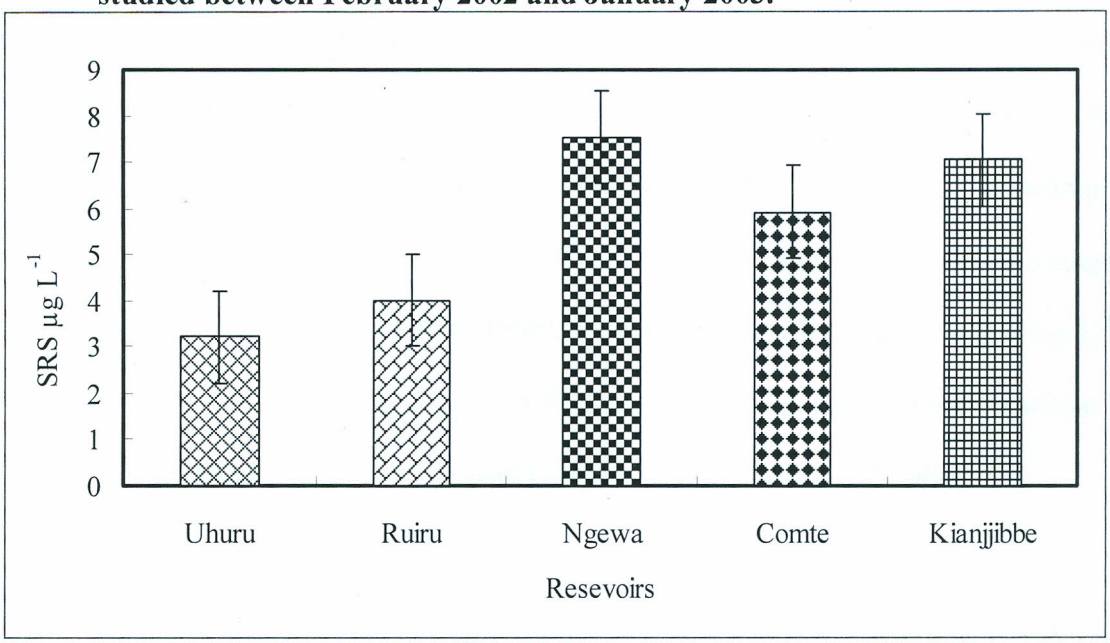


**Fig. 4. 19 Mean soluble reactive silica values in the reservoirs investigated between February 2002 and January 2003. Vertical bars indicate ± 1SE**

Soluble reactive silica (SRS) at the reservoirs is derived from the weathering of silica rocks under the influence of carbon dioxide (Hutchinson, 1994). Variation in SRS soluble in reservoirs is dependent on the rate of weathering (Talling and Talling, 1965). The high concentration of soluble reactive silica at Ruiru can be attributed to the large volume of inflow into the reservoir and the geochemistry of the catchment area. Ruiru catchment

area has a number of quarries some of which have been abandoned. The high concentration of soluble reactive silica can also be due to the low Bacillariophyta biomass at the reservoir during the study period (Table 4.6). Low SRS at Kianjjibbe reservoir can be attributed to the high Bacillariophyta biomass recorded at reservoir (Table 4.9). Silica is used as a structural component of Bacillariophyta and for chlorophyll synthesis (Somer, 1983).

Compared to other reservoirs, the soluble reactive silica recorded at the study reservoirs were much lower. Soluble reactive silica range from 2.2 mg $L^{-1}$ to 4.0 mg $L^{-1}$ and 1.5 mg $L^{-1}$ to 4.5 mg $L^{-1}$ in Uhuru and Ruiru is below the concentration range recorded in Turkwel Gorge reservoir, which had a range of 0.41mg $L^{-1}$ to 9.77 mg $L^{-1}$ (Kotut, 1998). Soluble reactive silica concentration in Comte of 2.5 mg $L^{-1}$ to 9.2 mg $L^{-1}$ is within but above the soluble reactive silica concentration in Turkwel Gorge reservoir with a range of 0.41 mg $L^{-1}$ to 9.77 mg $L^{-1}$ (Kotut, 1998). Soluble reactive silica range of 5.9 mg $L^{-1}$ to 8.6 mg $L^{-1}$ in Ngewa and 3.2 mg $L^{-1}$ to 8.6 mg $L^{-1}$ in Kianjjibbe reservoir is within but slightly below that recorded in Turkwel Gorge reservoir (Kotut *et al.*, 1998).

**Table 4. 1 Results of the mean values of the chemical parameters investigated in the five reservoirs between February 2002 and January 2003**

| Parameters | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| $NO_3$-N (µg $L^{-1}$) | 9.8 ± 1.37b | 9.0 ± 1.25c | 4.2 ± 0.43c | 7.1 ± 5.5 c | 13.6 ± 1.14a |
| TN (µg $L^{-1}$) | 33.1 ± 22.7c | 39.8 ± 3.0b | 34.1 ± 22.5c | 40.5 ± 36.9a | 32.5 ± 28.7c |
| TP (µg $L^{-1}$) | 0.8 ± 0.14c | 1.0 ± 0.02b | 1.0 ± 0.77a | 1.0 ± 0.82c | 0.7 ± 0.25c |
| SRS (mg $L^{-1}$) | 3.4 ± 0.47c | 4.0 ± 0.64c | 7.3 ± 0.74a | 5.9 ± 0.15c | 7.0 ± 199b |

## 4.3 Biological characteristics

### 4.3.1 Phytoplankton Composition

At the five reservoirs investigated a total of 35 phytoplankton species were recorded during the study period (Table 4.3). In Uhuru the dominant species (>500,000 individuals $L^{-1}$) during the period belonged to the genera *Pediastrum* (Plate 4.3), *Staurastrum,* (Plate 4.11) *Selenastrum* (Plate 4. 6), *Crucigenia and Microcystis,* while the common species (<500,000 individual $L^{-1}$) were *Cosmarium (*Plate 4.10*) Scenedesmus (Plate 4.13), Aphanocapsa, Euglena* (Plate 4.14) *and Trachelomonas* (Plate 4.2). The remaining species (<10,000 individual $L^{-1}$) were rare. At Ruiru, *Pediastrum, Ankistrodesmus, Selenastrum* and *Golenkinia* were the dominant species while *Trachelomonas* and *Peridinium* (Plate 4.12) were common. Among the rare species were *Coelastrum* and *Euastrum* species.

At Ngewa, the dominant species were *Cosmarium* and *Pediastrum (*Plate 4.10, 4.3). The common species belonged to the genera Trachelomonas (Plate 4.*2, Euglena* (*Plate* 4.14) *and Peridinium (*Plate 4.12*)*, while the rare species were *Staurastrum* (4.11, *Ankistrodesmus* (Plate 4.5), *Selensatrum (*Plate 4.11*), Goelenkinia, Phacus (*Plate 4.16, *Navicula* and *Dinobryon* (Plate 4.15). In Comte reservoir, the dominant species was *Goelenkinia* while the common species were *Pediastrum, Euglena*, and *Peridinium* (Table 4.3). In Kianjjibbe reservoir, the dominant species identified were *Staurastrum, Microsystis* and *Phacus*. The common species belonged to the genera *Cosmarium, Pediastrum Euglena and Trachelomonas* while the rare species were from the genera *Selenastrum*, *Goelenkenia, Kirchneriella (*Plate 4.9*) Coelasterium, Scenedesmus*

*Ankistrodesmus, Coalastrium, Aphanothece, Aphanocapsa,* and *Merismopedia* (Table 4.3).

Comparatively *Trachelomonas* and *Euglena* were common in Ngewa, Comte, Ruiru and Uhuru reservoir while *Peridinium* was common only in Ngewa, Kianjjibbe and Ruiru reservoirs. *Cosmarium* and *Pediastrum* were common in Kianjjibbe while *Ankistrodesmus* was dominant in Ruiru. *Scenedesmus* (Plate 4.13) was common in all the reservoirs.

**Table 4. 2 Phytoplankton composition and abundance Feb.2002 and January 2003**

| Site | Uhuru | | Ruiru | | Ngewa | | Comte | | Kianjjibbe | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Taxon** | 2002 | 2003 | 2002 | 2003 | 2002 | 2003 | 2002 | 2003 | 2002 | 2003 |
| **Chlorophyceace** | | | | | | | | | | |
| *Cosmarium* | ++ | + | + | + | +++ | + | + | + | ++ | ++ |
| *Pediastrum* | +++ | +++ | +++ | ++ | +++ | ++ | ++ | + | ++ | +++ |
| *Staurastrum* | +++ | +++ | + | + | + | + | + | + | +++ | +++ |
| *Ankistrodemus* | ++ | +++ | +++ | + | + | + | + | + | + | + |
| *Selenastrum* | +++ | - | +++ | + | + | + | - | - | + | + |
| *Golenkinia* | + | ++ | +++ | - | + | - | +++ | +++ | + | - |
| *Kirchneriella* | + | + | ++ | + | - | + | - | + | + | + |
| *Closterium* | + | + | ++ | + | - | - | - | - | + | - |
| *Scenedesmus* | ++ | ++ | ++ | - | ++ | - | + | + | + | ++ |
| *Coelastrum* | - | - | - | - | - | - | - | - | + | + |
| *Dictyosphaerium* | - | - | + | + | - | - | - | - | - | - |
| *Euastrium* | + | - | - | - | - | - | - | - | + | - |
| *Crucigenia* | +++ | + | + | + | - | - | - | ++ | ++ | - |
| **Cyanophyceae** | | | | | | | | | | |
| *Microcystis* | +++ | +++ | - | + | ++ | + | - | + | +++ | + |
| *Aphanothece* | + | + | - | + | - | + | - | - | + | + |
| *Aphanocapsa* | ++ | ++ | - | + | - | + | - | - | + | + |
| *Merismopedia* | + | + | - | + | - | + | - | - | + | + |
| *Monoraphidium* | - | - | - | + | - | - | - | - | + | - |
| **Euglenophyceae** | | | | | | | | | | |
| *Euglena* | ++ | ++ | ++ | +++ | ++ | + | ++ | ++ | ++ | + |
| *Phacus* | + | + | + | + | + | + | + | + | +++ | ++ |
| *Trachelomonass* | ++ | ++ | ++ | +++ | ++ | + | ++ | ++ | ++ | ++ |
| **Dinophyceae** | | | | | | | | | | |
| *Peridinium* | ++ | ++ | ++ | +++ | ++ | +++ | ++ | +++ | ++ | ++ |
| *Ceratium* | + | + | + | ++ | - | ++ | - | ++ | + | +++ |
| **Bacillariophyceae** | | | | | | | | | | |
| *Surirella* | + | + | + | ++ | - | + | - | - | + | ++ |
| *Navicula* | + | + | ++ | + | + | + | + | - | + | + |
| *Pinnularia* | + | ++ | | +++ | ++ | + | ++ | +++ | ++ | ++ |
| *Fragilaria* | + | + | + | + | - | - | - | + | + | + |
| **Chyrsophyceae** | | | | | | | | | | |
| *Dinobryon* | + | + | + | ++ | + | + | - | - | - | + |
| *Mallomonas* | + | + | + | + | - | - | + | - | + | + |
| **Crytophyceae** | | | | | | | | | | |
| *Cryptomonas* | - | + | - | - | - | - | - | + | - | + |

**Key**

- Absent, + Present (<10,000 individuals $L^{-1}$) ++ Common (<500,000 individuals $L^{-1}$) +++ Dominant (>500,000 individual $L^{-1}$).

### 4.3.2. Phytoplankton density

Density changes in individual phytoplankton taxa varied widely during the study period. In general higher individual counts were characteristics of the wet season months. Comparatively, higher individual counts were recorded in Kianjjibbe reservoir while the lowest individual counts were recorded in Ngewa reservoir. Density changes for the common phytoplankton taxa ranged from a nearly uniform density throughout the year through a distinct seasonal pattern with distinct peaks and low count periods to an irregular fluctuation without a distinct seasonal pattern. Although some species showed more than one annual peak, the most common feature was the existence of two main peaks (Fig. 4.20-4.24).

Phytoplankton taxa with two main peaks included *Aphanocapsa* in Uhuru reservoir (Fig. 4.20), *Trachelomonas* in Ruiru reservoir (Fig. 4.21), *Euglena* in both Ngewa and Comte reservoirs (Fig. 4.22 and 4.23) and *Pediastrum* in Kianjjibbe reservoir (Fig. 4.24b). The phytoplankton taxa that showed one main and a small peak were *Ankistrodesmus* in Uhuru (Fig. 4.20), *Peridinium* in both Ruiru and Ngewa reservoirs (Fig. 4.21 and 4.22) and *Navicula* in Kianjjibbe reservoir (Fig. 4.24a). *Cosmaruim* showed a nearly uniform density change throughout the study period (Fig. 4.20 and 4.2b). *Euglena* showed a muted temporal change in Uhuru reservoir during the study (Fig. 4.20). *Trachelomonas* in Comte reservoir showed a muted seasonal change that was characterized by a decline in density at the start of the study, followed by a rapid increase after which it remained constant for three months before it declined steadily to the end of the study period (Fig. 4.23). Comparatively, peak densities for the different phytoplankton taxa were observed

during the wet season months while low counts were recorded during the dry season months in all the reservoirs.

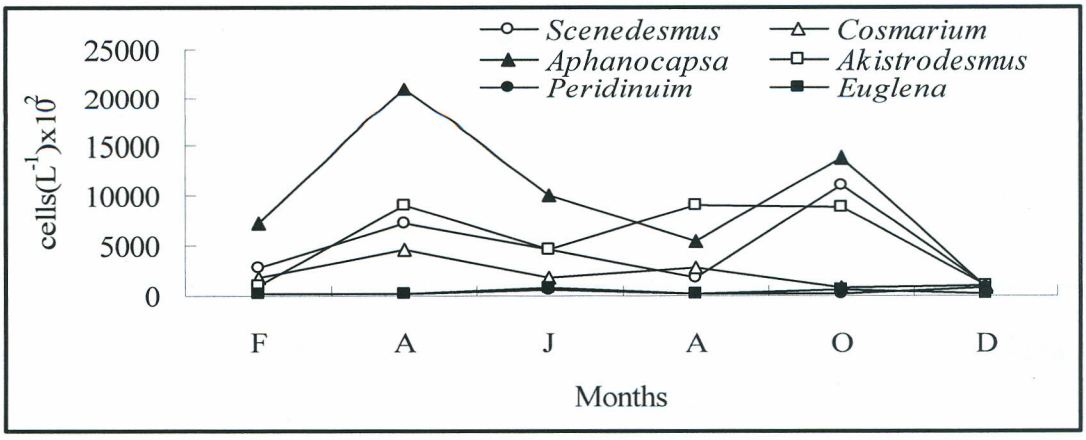


**Fig. 4. 20 Temporal changes in individual counts of common phytoplankton taxa at Uhuru Reservoir in 2002**

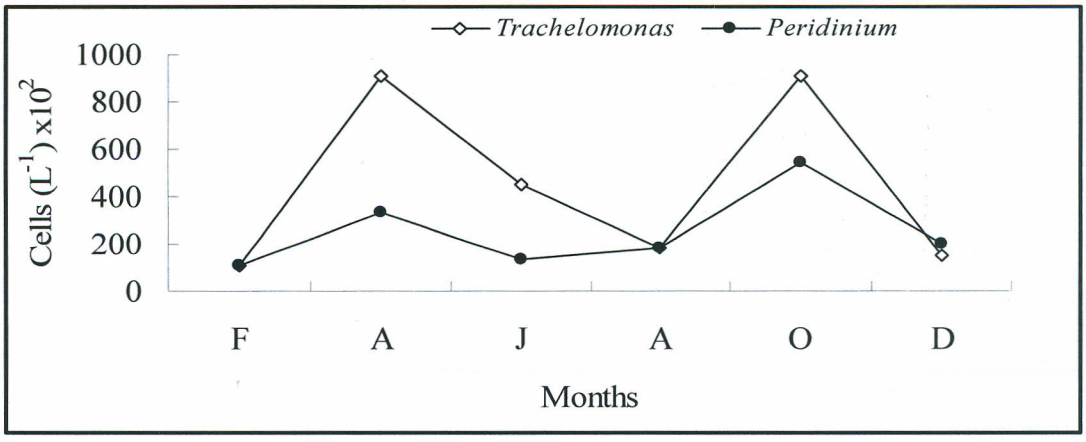


**Fig. 4. 21 Temporal variations in total unit counts of common Euglenophyta and Dinophyta at Ruiru reservoir in 2002.**

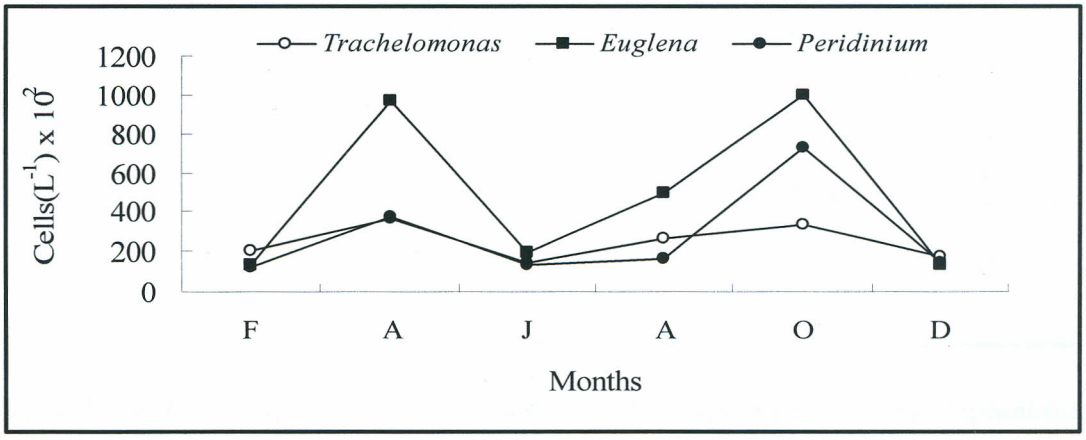


**Fig. 4. 22 Temporal variations in total unit counts of common Euglenophyta and Dinophyta at Ngewa reservoir 2002**

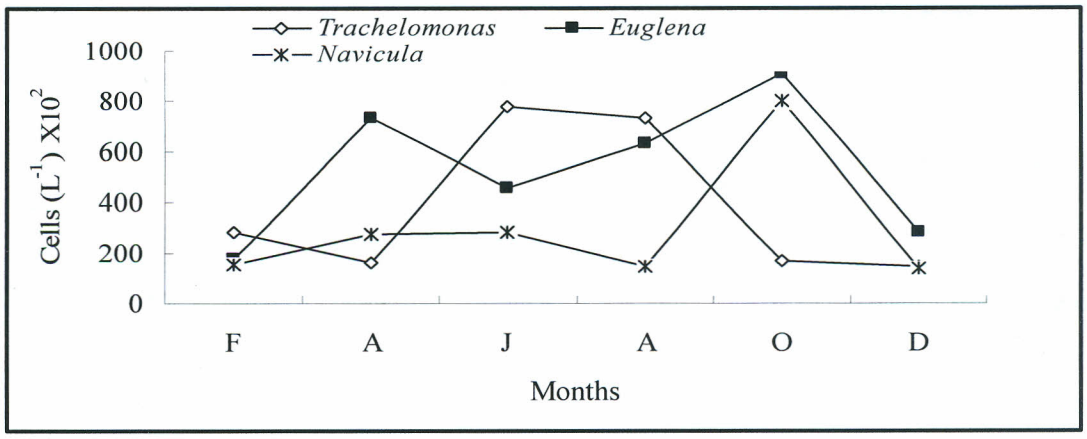


**Fig. 4. 23 Temporal changes in individual counts of common phytoplankton taxa at Comte reservoir 2002.**

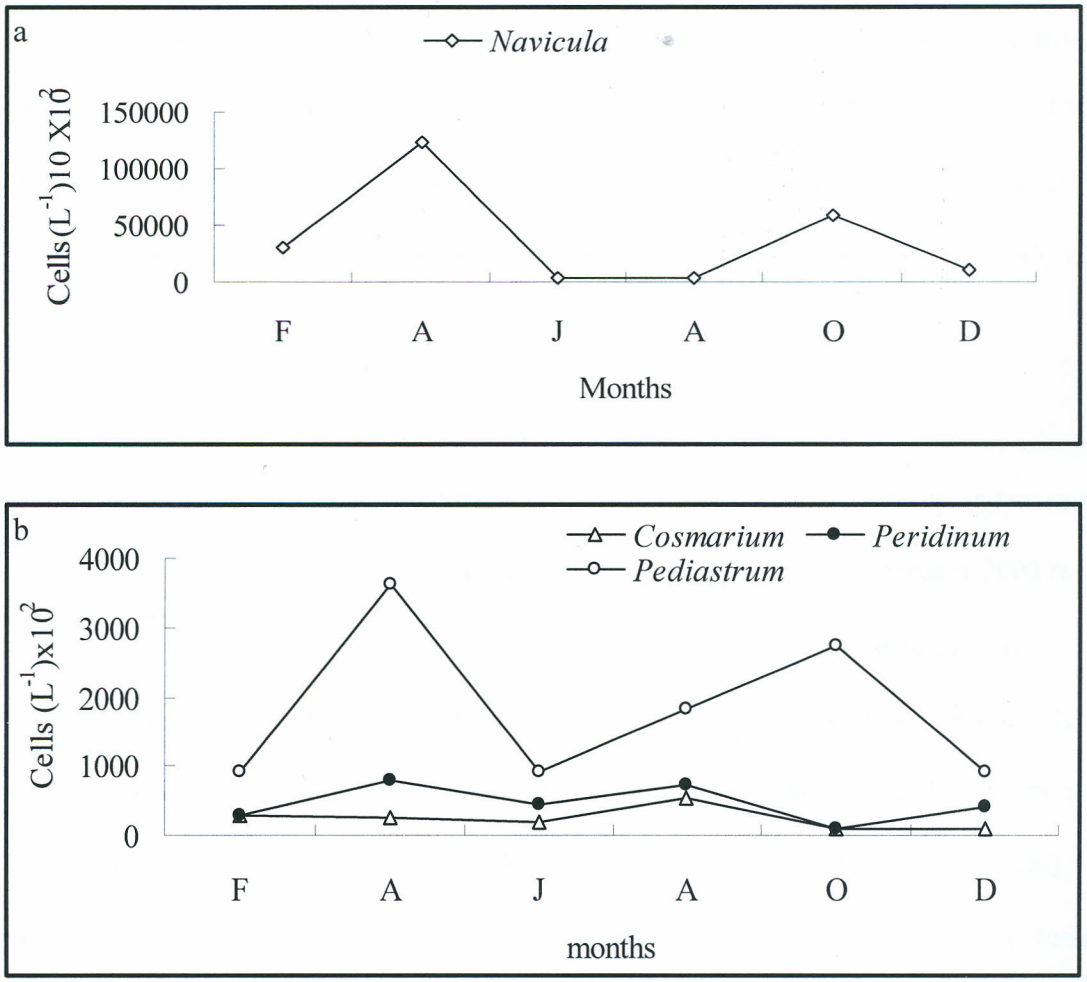


**Fig. 4. 24 (a) (b) Temporal changes in individual counts of common phytoplankton taxa at Kianjjibbe reservoir 2002.**

The two seasons showed different dominance patterns. The driest months were characterized by low individual counts and a high diversity while the wetter months had higher individual counts and low diversity in all the reservoirs. Peak levels following the wet season inflow of water can be attributed to an improved nutrient availability (Lewis 1996). This situation reduces competition and gives way to a mix of species of different growth phases to coexists.

### 4.3.3 Phytoplankton diversity

Phytoplankton diversity index varied slightly throughout the study period in all the five reservoirs investigated (Fig. 4.25, Appendix 26). Uhuru and Kianjjibbe reservoirs had the highest diversity with ranges from 1.7 bits recorded in April 2002 (total rainfall, 100.5 mm) to 2.4 bits observed in February (total rainfall, 12.5 mm) and from 1.8 bits in April (total rainfall received, 339.8 mm) to 2.4 bits in December (total rainfall received, 14.5 mm) in Uhuru and Kianjjibbe reservoirs respectively (Appendix 26).

Ngewa and Comte reservoirs showed modest variations, with a diversity index range from 1.5 bits in October 2002 (total rainfall, 114.9 mm) to 2.1 bits in February 2002 (total rainfall, 19.1mm) in Ngewa and from 1.3 bits in October 2002 (total rainfall received, 148.1mm) to 2.3 bits in February 2002 in Comte (when no rainfall was received). Ruiru reservoir had the lowest diversity index with a range from 1.4 bits in April 2002 (rainfall received was 231.5 mm) to 1.9 bits in August 2002 (rainfall received was 0.6 mm). In general high diversity index was recorded during the dry season months and low diversity was in the wet season months (Fig. 4. 25). Using a one way ANOVA test, biodiversity indices among the reservoirs investigated were significantly different ($P<0.00$, $df=34$).

Seasonal variation in phytoplankton diversity indices in the reservoirs is attributable to the temporal and spatial fluctuations in environmental conditions, differential loss rates of phytoplankton taxa and changes in the quantity of nutrient resources (Capblancy and Catan 1994: Padisak, 1993; Reynolds, 1994 and Lewis 1996). The high diversity in all the reservoirs that coincides with the period of low rainfall is possibly as a result of short term fluctuations in environmental conditions, which affects the availability of nutrients.

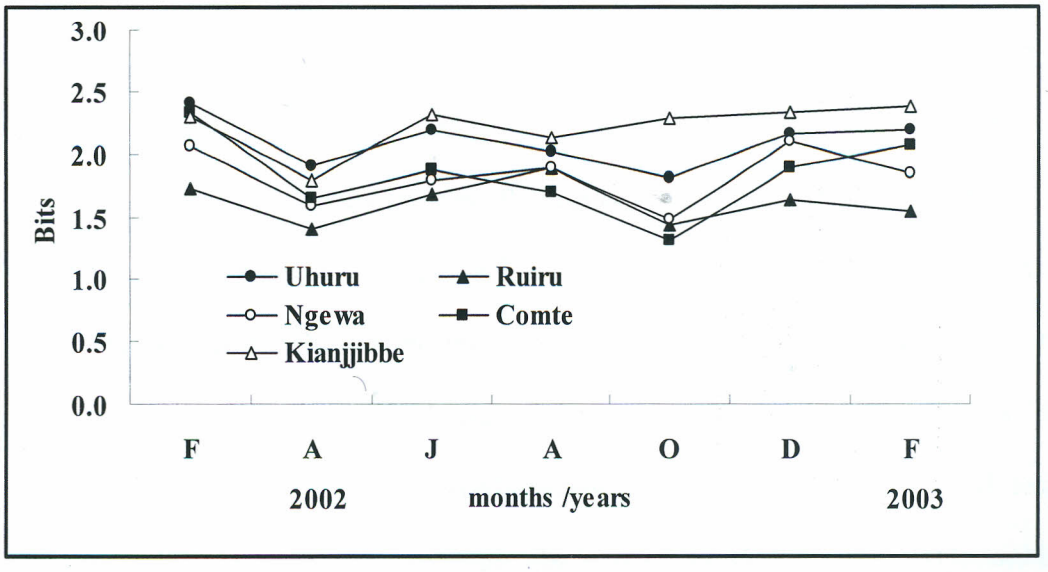


**Fig. 4. 25 Phytoplankton diversity index at the reservoirs during the period February 2002 and February 2003.**

Under a low nutrient regime, a mix of species at different growth phases coexist - with some declining while others are increasing. An improved nutrient supply during the wet season reduces competition for nutrients and allows for progressive succession leading to a greater dominance of a few species. A high diversity index during the dry season can also be attributed to fluctuations in environmental conditions, which increases the depth of the mixed layer. According to Lewis (1996), the depth of the mixed layer alters the physical and chemical environment through improved nutrient conditions and this results in a situation in which a mix of species of different growth phases coexists with some

declining while others are increasing. In Turkwell Gorge Reservoir, reduced inflows in 1995 brought about a lower nutrient supply and this resulted in lower species stability and therefore a relatively high diversity (Kotut *et al.*, 1998b).

### 4.3.4 Total phytoplankton biomass

Total phytoplankton biomass in Ruiru and Ngewa reservoirs showed a muted temporal variation with elevated levels during the wet season (Fig. 4.26, Appendix 28). The total biomass ranged from 90.1 mg $L^{-1}$ (June, 2002) to 762.0 mg $L^{-1}$ (April, 2002) in Ruiru, and from 195.2 mg $L^{-1}$ (August, 2002) to 596 mg $L^{-1}$ (April, 2002) in Ngewa reservoir. In Comte, the variations showed modest fluctuations with ranges from 69.0 mg $L^{-1}$ (June, 2002) to 2758.1 mg $L^{-1}$ (April, 2002). Total phytoplankton biomass at Uhuru and Kianjjibbe reservoirs showed the greatest fluctuations with an irregular variation (Fig. 4.27). The total phytoplankton biomass at Uhuru ranged from 110.2 mg $L^{-1}$ (February when 19.1 mm of rainfall was received) to 5087.5 mg $L^{-1}$ (April - total rainfall recorded, 100 mm) while in Kianjjibbe reservoir, the range was 1202.2 mg $L^{-1}$ (December-total rainfall recorded, 12.5 mm) to 4928.2 mg $L^{-1}$ (November-total rainfall recorded, 337.8 mm) (Fig. 4.26, Appendix 28).

A positive correlation between total nitrogen and total biomass was recorded in Ngewa reservoir (Table 4.4) while a positive correlation with total phosphorus only was noted in Ruiru reservoir in the year 2002 (Table 4.4). The positive correlation between total biomass and both total nitrogen and total phosphorus in Ngewa reservoir suggests both nutrients possibly limit production at the reservoir while a positive correlation with total phosphorus only recorded at Ruiru reservoir suggests that the reservoirs is possibly limited by phosphorus availability only. Absence of a positive correlation between the

two nutrients and biomass in the rest of the reservoirs suggests that primary production in these reservoirs is limited by other factors.

**Table 4. 3 Correlation between total biomass and total nitrogen and phosphorus in the study reservoirs in the year 2002 (df =10).**

| Nutrients | Reservoirs | | | | |
|---|---|---|---|---|---|
| | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
| TN | R=0.40, P=0.24 | R=0.43 P=0.20 | R=0.88, P<0.01 | R=-0.40, P=0.17 | R= -0.11, P=0.74 |
| TP | R=0.53, P=0.11 | R=0.95, P=0.01 | R=0.80, P<0.01 | R=0.02, P=0.94 | R=0.60, P=0.06 |

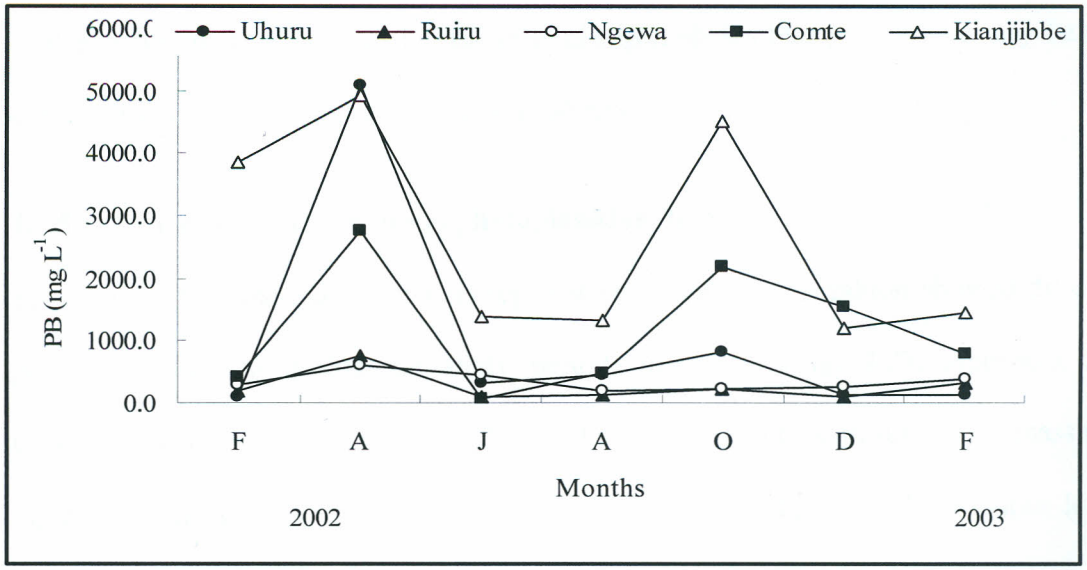


**Fig. 4. 26 Temporal variations in total phytoplankton biomass (PB) between the period February 2002 and February 2003.**

Phytoplankton biomass at the selected reservoirs appears to be largely influenced by the seasonal changes in nutrient levels at the reservoirs. The high total phytoplankton biomass observed during the wet season in all the reservoirs studied (5087.5 mg $L^{-1}$ in Uhuru, 762 mg $L^{-1}$ in Ruiru, 596.4 mg $L^{-1}$ in Ngewa, 2758 mg $L^{-1}$ in Comte and 4928.1 mg $L^{-1}$ in Kianjjibbe) can be attributed to the nutrient increase during the wet season. This position is supported by the positive correlation between total nitrogen and total phosphorus with phytoplankton biomass in Ngewa and Ruiru respectively. High inflows during the wet season resulted in increased nutrients in Weija and Kpong reservoirs in Ghana (Ansare, 1996) and also Abwa Reservoir in Nigeria (Oriola, 2003).

A positive correlation between TN and TP with total phytoplankton biomass suggests that nitrogen and phosphorus may exert a limiting influence on biomass production at different times of the growth period. However, a mean concentration of 0.95 μg $L^{-1}$ for total phosphorus and 35.8 μg $L^{-1}$ for total nitrogen shows that phosphorus may have a greater limiting effect on phytoplankton production.

### 4.3.5 Total biomass of main phytoplankton divisions

Total biomass of the algal divisions represented in the phytoplankton showed different patterns of change during the study period. In Uhuru (Fig. 4.27, Appendix 25), Chlorophyta showed the greatest amplitude of change. Beginning in June its biomass rose rapidly to a maximum in August from whence it declined to about the previous levels towards the end of the study period (Fig. 4.28). Dinophyta and Euglenophyta were the least variable with higher levels at the beginning of the study. Bacillariophyta showed a muted variation throughout the study period. Overall, Chlorophyta contributed 77%,

Euglenophyta 12%, Dinophyta 7%, Cyanophyta, Cryptophyta and Bacillariophyta 1% of the total biomass (Fig. 4.28).

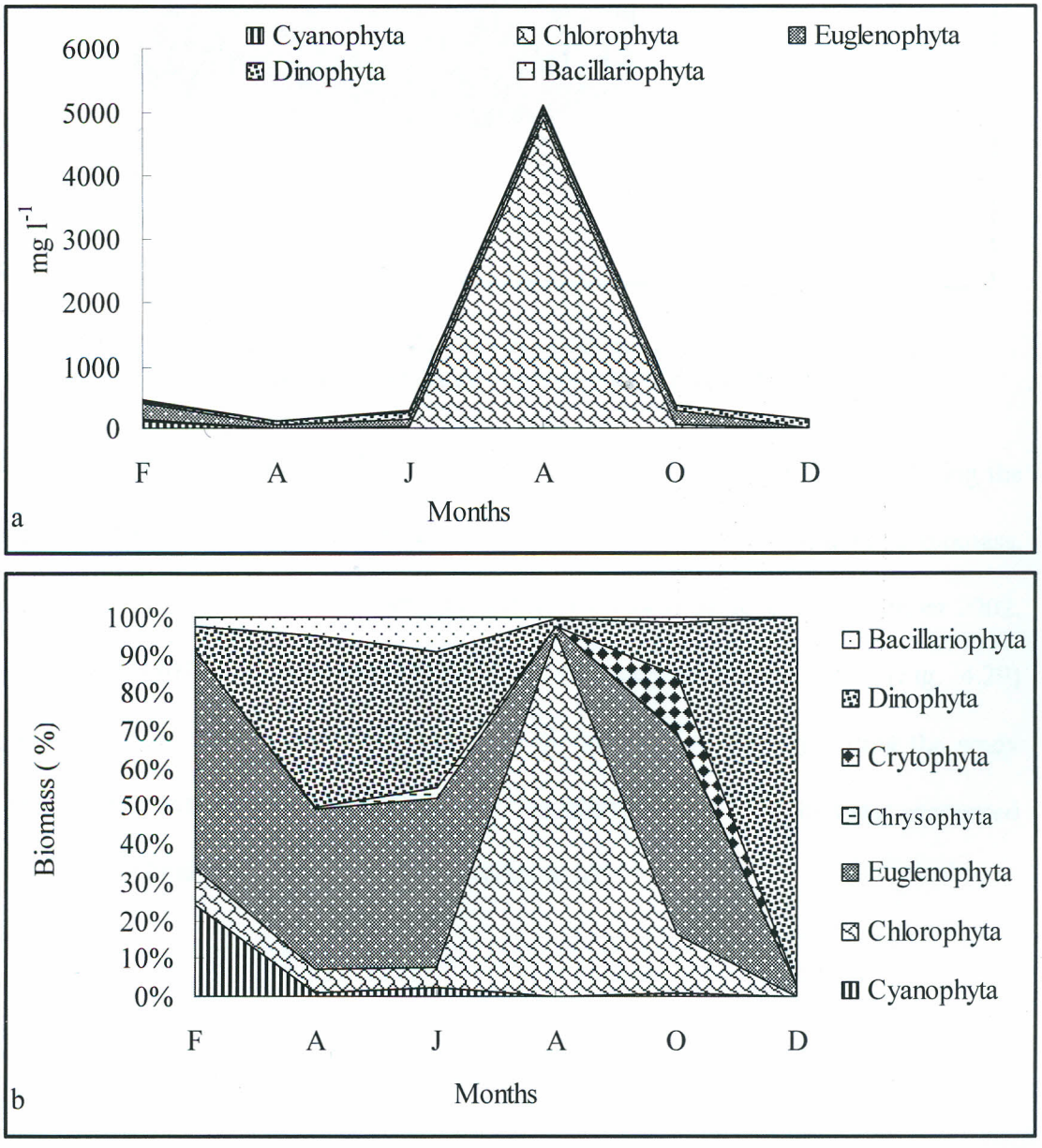


**Fig. 4. 27 Temporal variation in total biomass (a) and the percentage contribution to the total phytoplankton biomass (b) by the main phytoplankton divisions at Uhuru reservoir in the year 2002.**

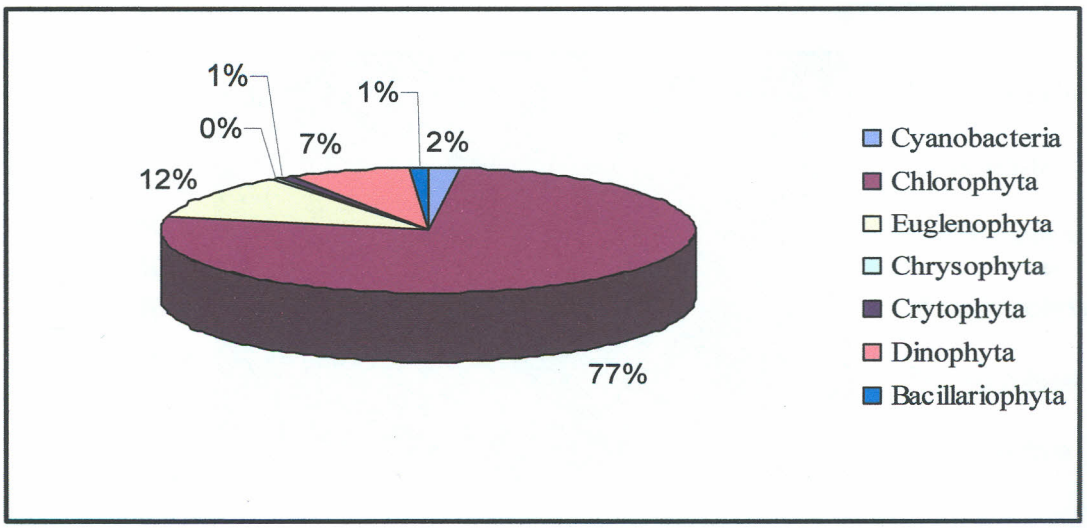


**Fig. 4. 28 Percentage distribution of mean monthly total biomass of the main phytoplankton divisions at Uhuru reservoir in the year 2002**

Total biomass changes of the different algal divisions in Ruiru varied slightly during the study period (Fig. 4.29). An exception to this was in the case of Dinophyta biomass, which showed a steady increase from June 2002 to a maximum level in December 2002. Peak Euglenophyta biomass was recorded in February and June 2002 (Fig. 4.29) Cyanophyta, Chrysophyta and Bacillariophyta biomass varied slightly during the study period. Overall, most biomass was due to the Dinophyta, whose mean biomass accounted for 72% of the total phytoplankton biomass (Fig. 4.30).

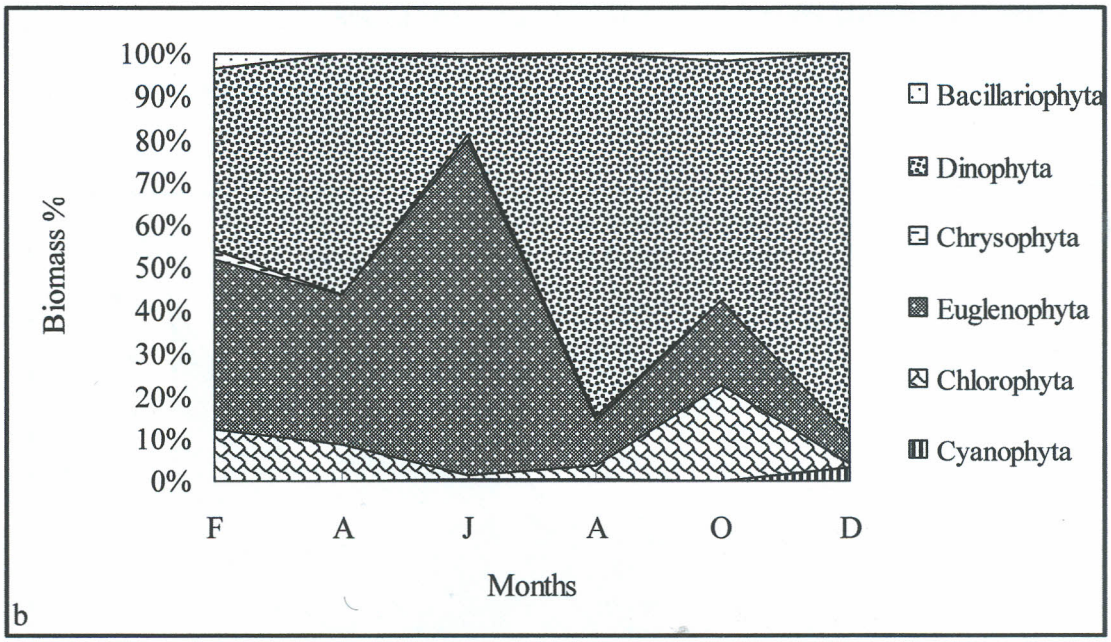


**Fig. 4. 29 Temporal variation in total biomass (a) and the percentage contribution to the total phytoplankton biomass (b) by the main phytoplankton divisions at Ruiru reservoir in the year 2002**

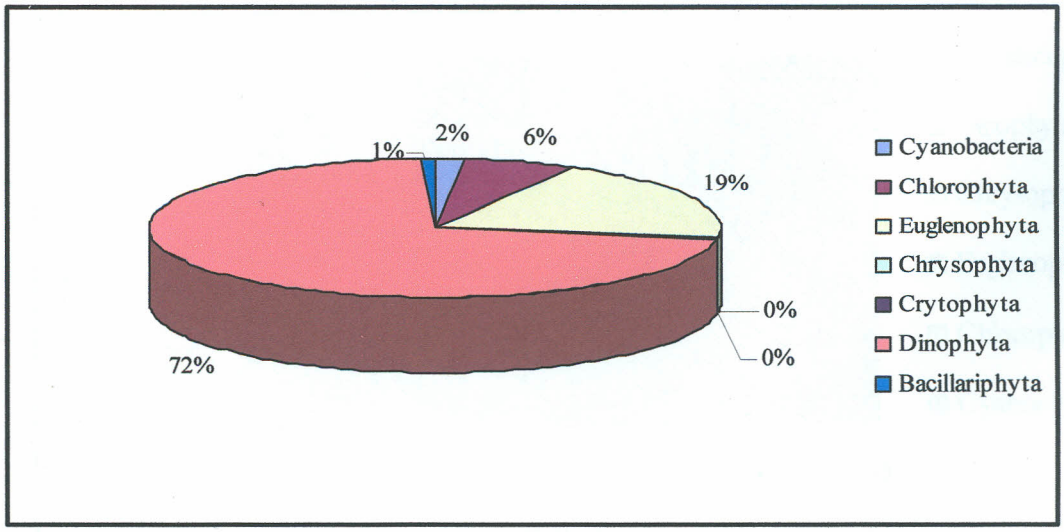


**Fig. 4. 30 Percentage distribution of mean monthly total biomass of the main phytoplankton divisions at Ruiru reservoir in the year 2002.**

Total biomass of different divisions in Ngewa showed different pattern of change during the study period (Fig. 4. 31). Euglenophyta showed the greatest amplitude of change. The lowest Dinophyta biomass was recoded in April while the maximum value was measured in February (Fig. 4.31). Overall, most biomass was due to the Euglenophyta, whose mean

biomass accounted for 68% of the total. The smallest biomass contribution was due to Chrysophyta 1% (Fig. 4.32).

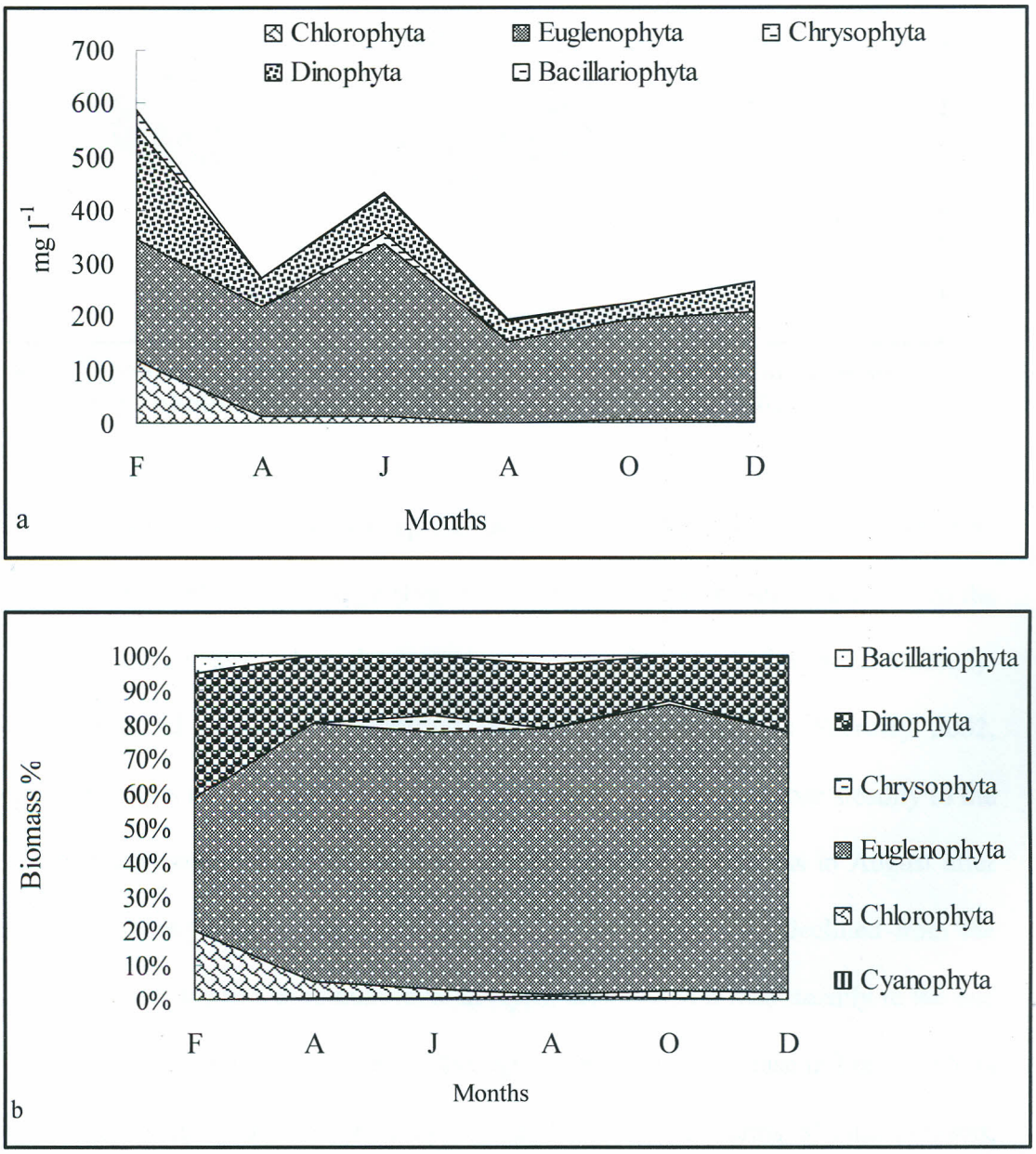


**Fig. 4. 31 Temporal variation in total biomass (a) and the percentage contribution to the total phytoplankton biomass (b) by the main phytoplankton divisions at Ngewa reservoir in the year 2002.**

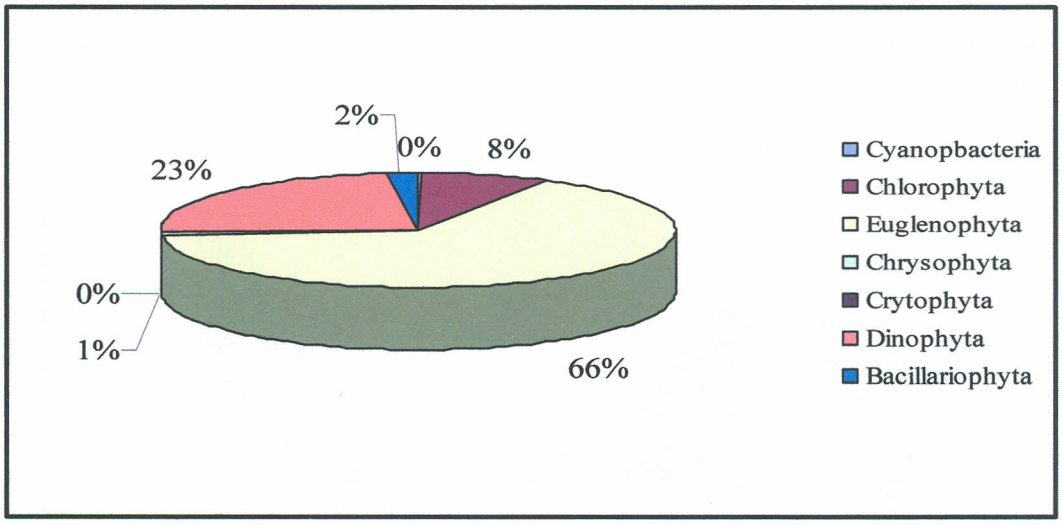


**Fig. 4. 32 Percentage distribution of mean monthly total biomass of the main phytoplankton divisions at Ngewa reservoir in the year 2002.**

Total biomass of the algal divisions represented in the phytoplankton in Comte reservoir showed different patterns of change (Fig. 4.33). Overall, most divisions declined to the lowest values in June after which there was a progressive increase to the end of the study. Dinophyta showed the greatest amplitude of change. Beginning in February 2002, Dinophyta biomass declined rapidly to a minimum level in June, then rose steadily to the end of the study period. Chlorophyta declined to its minimum biomass in August after which the biomass value increased slightly. Bacillariophyta steadily declined from the beginning of the study to a minimum level in April, after which it rose steadily to the end of the study. Cryptophyta had low levels throughout the study. Decrease in Euglenophyta biomass varied slightly during the study period (Fig. 4.33). In terms of total biomass, Dinophyta contributed 61%, Euglenophyta 11%, Bacillariophyta 13% Chlorophyta 8% Cyanophyta 4% (Fig. 4.34).

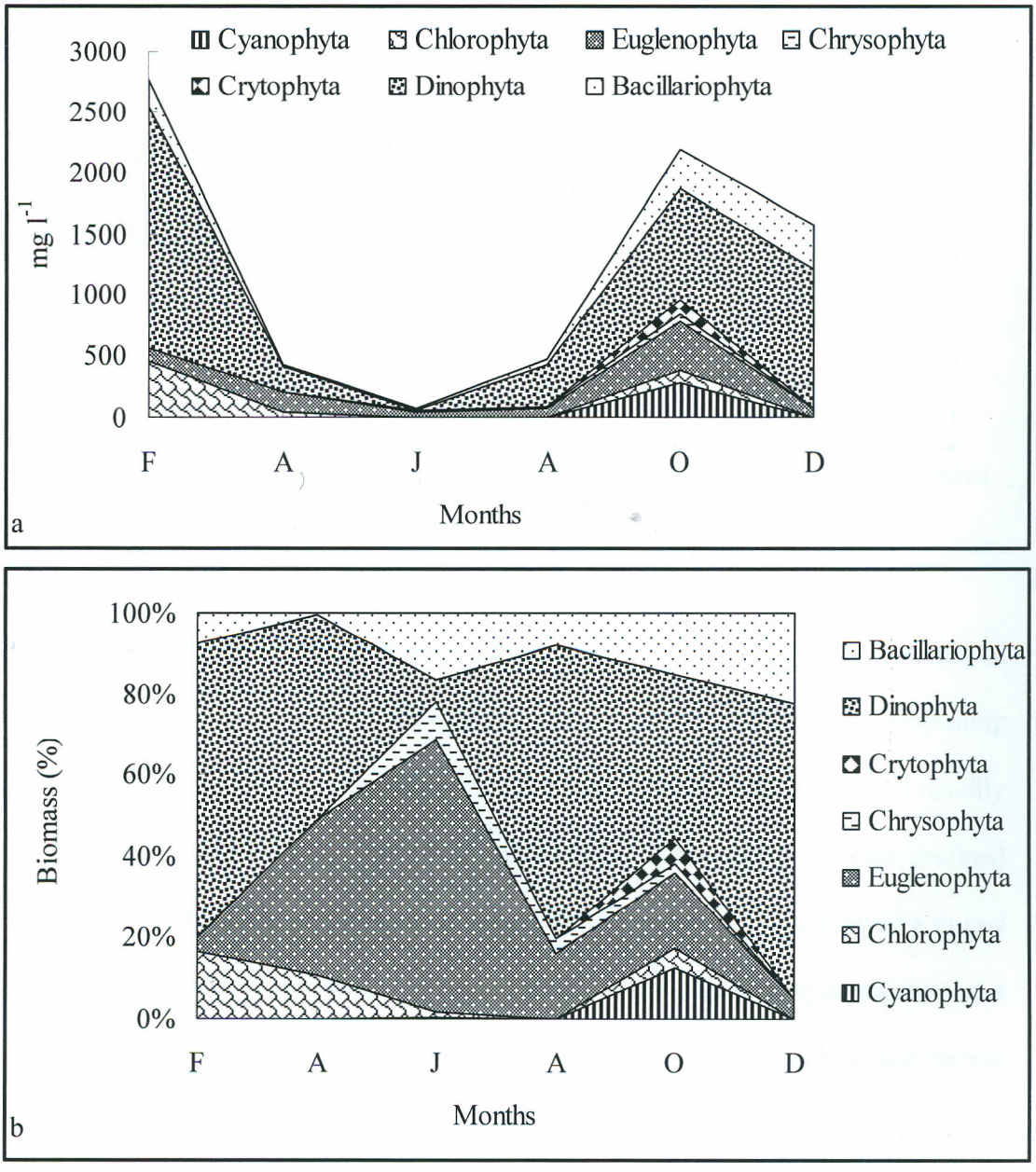


**Fig. 4. 33 Temporal variation in total biomass (a) and the percentage contribution to the total phytoplankton biomass (b) by the main phytoplankton division at Comte reservoir in the year 2002**

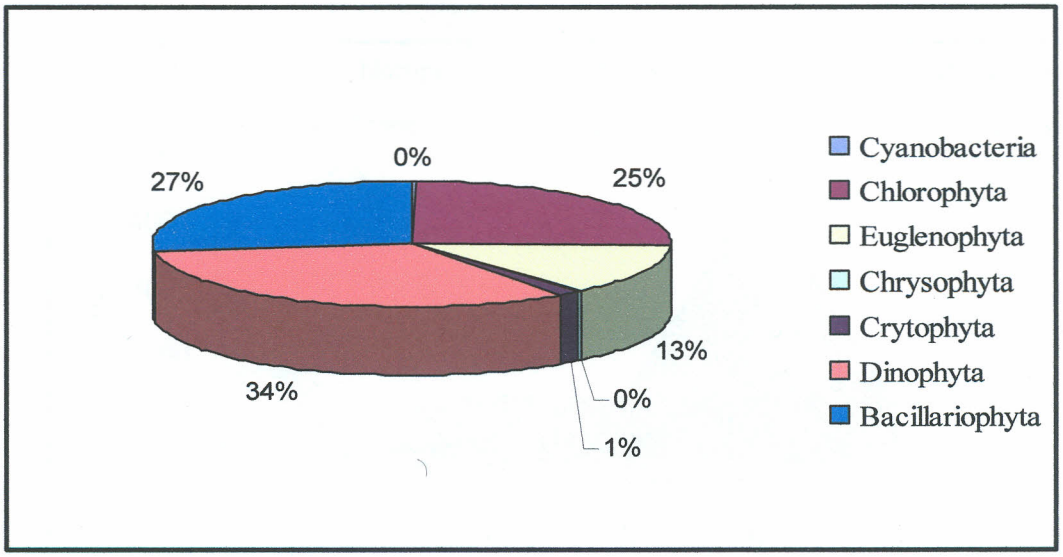


**Fig. 4. 34 Percentage distribution of mean total biomass of the main phytoplankton divisions at Comte reservoir in the year 2002**

Total biomass of algal divisions in Kianjjibbe reservoir showed different patterns of change (Fig. 4.35). Bacillariophyta showed the greatest amplitude of change. Beginning in February, it rose rapidly to a maximum value in April from whence it declined steadily to a minimum level towards the end of the study period. Chlorophyta biomass declined steadily from the beginning of the study period to April from whence it showed a muted appearance to the end of the study period. Dinophyta and Euglenophyta maintained a steady biomass level with a small increase over the study period. Cryptophyta maintained low levels during the study period with a small increase towards the end of the study (Fig. 4.35). In terms of total biomass contribution, Dinophyta contributed 34%, Chlorophyta 25% Bacillariophyta 27%, Euglenophyta 13% and Crytophyta 1% (Fig. 4.36).

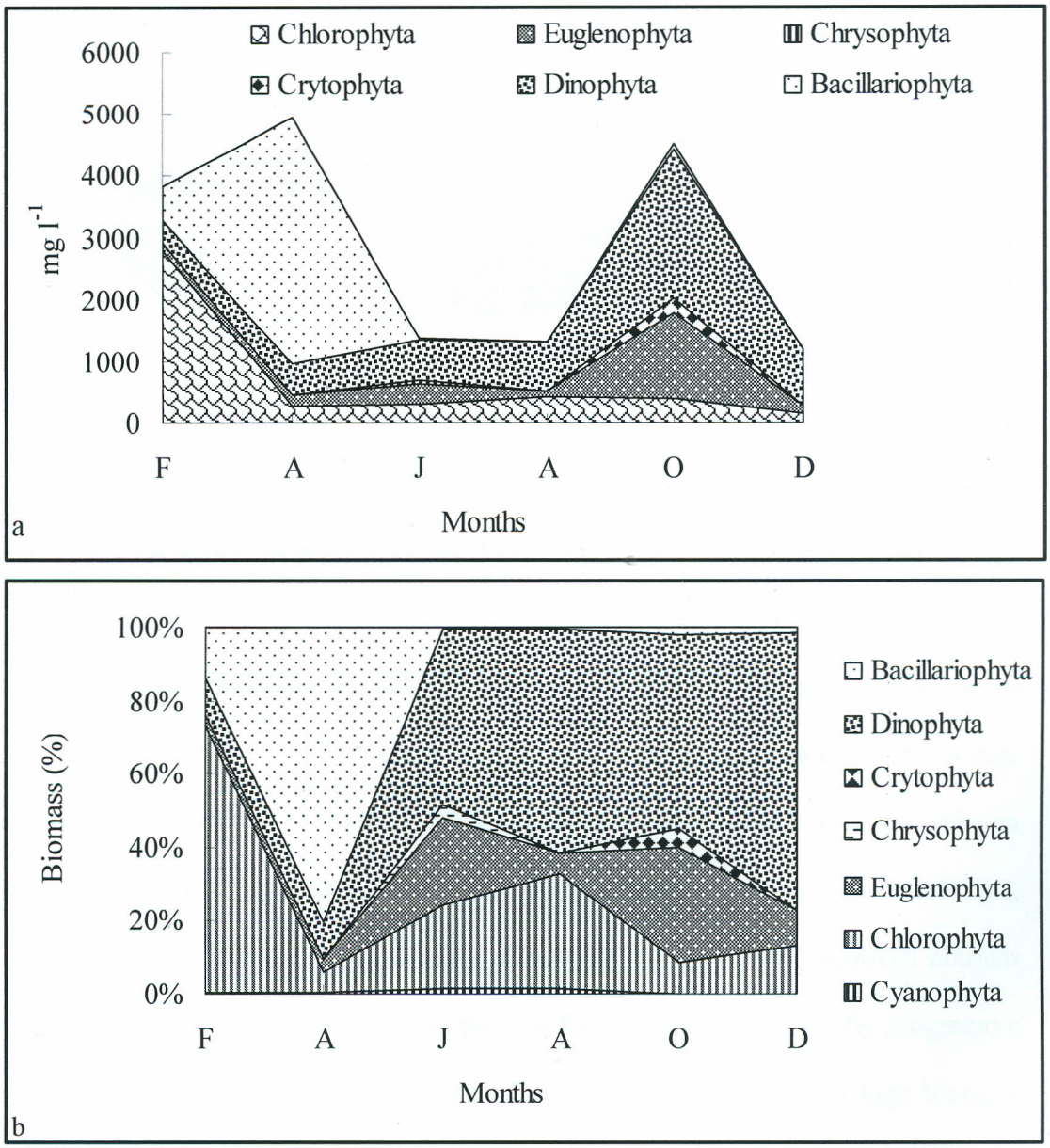


**Fig. 4. 35 Temporal variation in total biomass (a) and the percentage contribution to the total phytoplankton biomass (b) by the main phytoplankton division at Kianjjibbe reservoir in the year 2002**

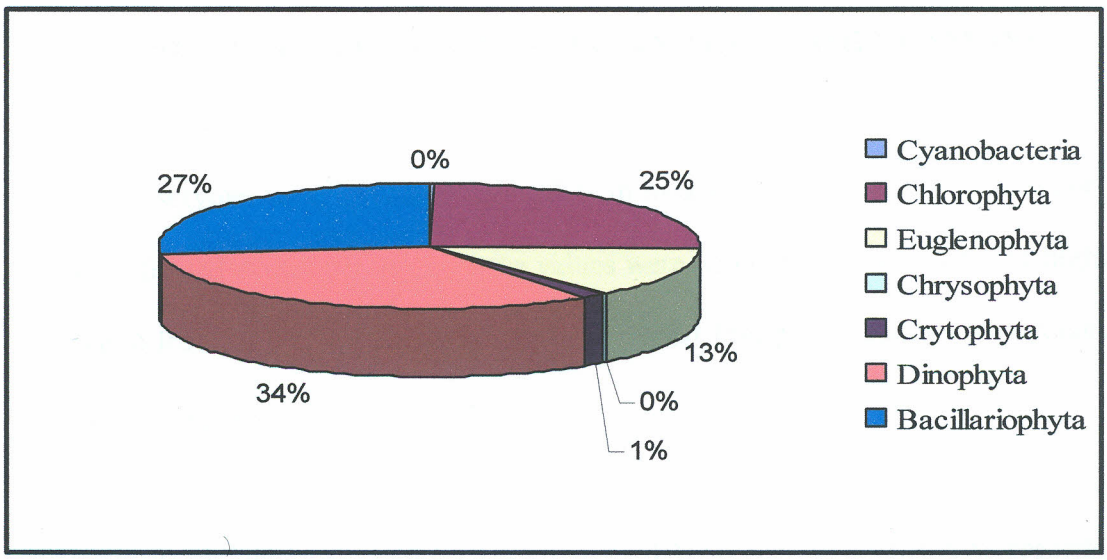


**Fig. 4. 36 Percentage distribution of mean monthly total biomass of the main phytoplankton divisions at Kianjjibbe in the year 2002.**

Variations in the biomass of main phytoplankton divisions during the study period can be attributed to the wind-driven turbulent mixing which entails and transport planktonic algae vertically through light gradient and on occasion beyond photic layer. The variation can also be attributed to temporal and spatial fluctuations in environmental conditions, which bring about changes in the quantity of nutrient resources. An improved nutrient supply during the wet season reduces competition for nutrients and allows for progressive succession leading to a greater dominance of a few species and hence a high biomass while a low nutrient regime during the dry season bring about a mix of species of different growth phases coexisting with some declining while others increase.

# CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

1. The reservoirs investigated varied widely in most of the physico-chemical properties investigated except pH in which the values were within the same range. The highland based Ruiru and Uhuru reservoirs were the most transparent and had comparatively lower temperatures and conductivity.

2. The phytoplankton properties comprising of total biomass, dominant species and biodiversity varied among the reservoirs studied. However, in all the reservoirs, the Chlorophyta was the most diverse and dominant taxon, contributing over 50% of the species identified.

3. A distinct seasonal variation was noted in all the reservoirs investigated. During the wet season, nutrient and phytoplankton biomass values recorded were high while Secchi depth, conductivity, total alkalinity and phytoplankton biodiversity registered were lower as compared to the dry season.

4. A Positive correlation between total phosphorus and phytoplankton biomass was noted in Ngewa and Ruiru reservoirs. In Ngewa reservoir, a positive correlation between total nitrogen and phytoplankton biomass was also recorded. This therefore suggests that changes in nutrient load possibly contributes to variation in phytoplankton biomass in Ruiru and Ngewa reservoirs.

## 5.2 RECOMMENDATIONS

### 5.2.1 Research

- Further research is necessary to find out the sources of the high loads of sediments that get into the reservoir during the wet season

- Owing to the difference in the phytoplankton and physico-chemical characteristics of the reservoirs investigated, it is necessary to carry out further research on other reservoirs within the catchment area so as to obtain a better picture on the magnitude of the diversity.

- The present study focused on the principle primary producers, the phytoplankton, more work needs to be done on the consumer organisms, the zooplankton and the present fishery status.

- Physico-chemical and phytoplankton characteristics are different within and between the reservoirs thus it is important to formulate different management strategies for each reservoir.

- The ecology of the reservoirs is affected by human activities at the catchment area and inflow dynamics. It is therefore important to do research on the ecology of all reservoirs especially those within the agricultural area so that proper management strategy is made for each reservoir instead of transferring the management strategy from one reservoir to another.

### 5.2.2 Management

- The reservoirs studied have modest amounts of phytoplankton biomass. This combined with their permanent nature means that they have a fishery potential. However, further research will be needed to assess the suitable fishery for each water body. Ruiru with its cool and transparent water has the potential to support cold water fishes. However, programs to manage the high turbidity in Ngewa and in most reservoirs during the rainy season will have to be formulated.

- A management plan covering the catchment basins of the rural reservoirs needs to be formulated. Owing to the difference in the physico-chemical and phytoplankton characteristics of the reservoirs investigated, it will be necessary to formulate specific resource use plan for each reservoir.

- The nutrient loading, especially for Ruiru reservoir which is one of the main domestic water source for Nairobi city, should be closely monitored as high levels can lead to blooms of toxic algae and that can cause human health problems. Good farming practices should be encouraged at the catchment area to reduce the nutrient load into the reservoir.

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# APPENDICES

**Appendix 1 Mean monthly rainfall (mm) at the reservoirs between February 2002 and Sept 2003**

| Reservoirs | Year | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Uhuru | 2002 | 33.5 | 19.1 | 154.1 | 100.5 | 91.1 | 0.6 | 0.0 | 57.7 | 81.5 | 58 | 337.5 | 23.1 |
| Uhuru | 2003 | 0.0 | 12.5 | 43.3 | 100.3 | 99.4 | 14.2 | 15 | 19.2 | 7.5 | | | |
| Ruiru | 2002 | 39.5 | 0.0 | 35.1 | 111.5 | 114.9 | 2.5 | 2.4 | 0.6 | 7.6 | 15.4 | 101.4 | 19.5 |
| Ruiru | 2003 | 0.0 | 12.5 | 19.1 | 232.5 | 113.8 | 114 | 18 | 37.7 | 0.6 | | | |
| Ngewa | 2002 | 0.0 | 19.1 | 15.4 | 231.5 | 102.5 | 35.0 | 4.5 | 0.8 | 5.5 | 148 | 69.9 | 49.0 |
| Ngewa | 2003 | 0.0 | 0.0 | 13.8 | 99.2 | 69.8 | 7.5 | 4.5 | 0.25 | 9.8 | | | |
| Comte/ Kianjjibbe | 2002 | 0.5 | 0.0 | 29.7 | 231.1 | 39.5 | 18 | 38 | 2.1 | 11.7 | 148 | 337.8 | 12.5 |
| Comte /Kianjjibbe | 2003 | 0.0 | 0.0 | 32.1 | 339.8 | 148.1 | 17 | 29 | 7.2 | 14.5 | | | |

**Appendix 2 Mean monthly temperature (°C)at the reservoirs between February 2002 and Sept 2003**

| Reservoirs | Year | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Uhuru | 2002 | 25.7 | 25.0 | 25.1 | 26.0 | 27.5 | 20.7 | 23.9 | 21.9 | 24.1 | 24.0 | 24.0 | 23.5 |
| Uhuru | 2003 | 23.0 | 25.9 | 23.9 | 23.2 | 21.9 | 21.0 | 20.0 | 24.9 | 23.0 | | | |
| Ruiru | 2002 | 19.0 | 20.2 | 20.5 | 19.2 | 19.5 | 22.4 | 21.0 | 21.5 | 20.4 | 21.1 | 19.6 | 21.8 |
| Ruiru | 2003 | 21.7 | 23.5 | 22.9 | 22.7 | 20.1 | 19.9 | 20.0 | 20.6 | 20.8 | | | |
| Ngewa | 2002 | 27.0 | 26.2 | 26.5 | 25.9 | 30.0 | 21.9 | 22.8 | 23.0 | 24.0 | 27.0 | 26.1 | 22.9 |
| Ngewa | 2003 | 27.2 | 27.0 | 28.0 | 24.7 | 27.9 | 20.0 | 20.9 | 25.0 | 22.0 | | | |
| Comte/ Kianjjibbee | 2002 | 27.7 | 27.3 | 28.5 | 27.0 | 24.4 | 24.5 | 25.1 | 23.4 | 23.5 | 24.1 | 25.0 | 25.0 |
| Comte/ Kianjjibbe | 2003 | 25.0 | 24.8 | 26.5 | 24.0 | 24.8 | 21.5 | 23.2 | 23.8 | 22.0 | | | |

**Appendix 3 Temporal variation in Secchi depth (m) at the reservoirs between February 2002 and September 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 0.7 | 1.9 | 0.1 | 0.1 | 0.6 |
| M | 0.6 | 0.8 | 0.1 | 0.1 | 0.5 |
| A | 0.6 | 1.0 | 0.1 | NA | 0.5 |
| M | 0.6 | 0.3 | 0.1 | 0.1 | 0.3 |
| J | 0.6 | 0.8 | 0.1 | 0.1 | 0.2 |
| J | 0.6 | 0.8 | 0.1 | 0.1 | 0.2 |
| A | 0.6 | 0.8 | 0.2 | 0.1 | 0.5 |
| S | 0.5 | 0.9 | 0.1 | NA | 0.3 |
| O | 0.5 | 0.7 | 0.1 | NA | 0.2 |
| N | 0.3 | 0.6 | 0.1 | 0.1 | 0.2 |
| D | 0.6 | 0.8 | 0.1 | 0.1 | 0.3 |
| J | 0.7 | 1.2 | 0.2 | 0.2 | 0.3 |
| F | 0.7 | 1.9 | 0.2 | 0.2 | 0.4 |
| M | 0.5 | 1.7 | 0.2 | 0.1 | 0.2 |
| A | 0.6 | 0.9 | 0.1 | 0.1 | 0.2 |
| M | 0.6 | 0.8 | 0.1 | NA | 0.1 |
| J | 0.5 | 0.6 | 0.1 | 0.1 | 0.3 |
| J | 0.6 | 1.1 | 0.1 | 0.2 | 0.3 |
| A | 0.6 | 1.1 | 0.1 | NA | 0.4 |
| S | 0.5 | 1.5 | 0.1 | 0.1 | 0.3 |
| Mean for 2002 | 0.6 | 0.9 | 0.1 | 0.1 | 0.3 |

**Appendix 4 Temporal variation in temperature (oC) at the reservoirs between February 2002 and September 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 24.5 | 23.4 | 25.2 | 25.7 | 25.7 |
| M | 25.6 | 24.4 | 26.7 | 26.0 | 28.3 |
| A | 24.9 | 22.8 | 25.3 | 23.4 | 26.1 |
| M | 27.2 | 24.8 | 31.0 | 22.5 | 23.1 |
| J | 20.6 | 18.1 | 20.2 | 22.6 | 21.8 |
| J | 23.9 | 19.4 | 21.2 | 22.9 | 23.1 |
| A | 21.9 | 18.8 | 20.9 | 21.7 | 21.8 |
| S | 23.9 | 19.4 | 23.1 | 22.6 | 22.8 |
| O | 23.9 | 23.9 | 26.0 | 23.8 | 23.9 |
| N | 24.1 | 22.8 | 25.0 | 23.2 | 24.2 |
| D | 23.1 | 20.5 | 22.6 | 23.5 | 24.1 |
| J | 22.9 | 22.0 | 25.5 | 23.7 | 24.1 |
| F | 25.4 | 23.4 | 25.2 | 22.0 | 23.8 |
| M | 23.0 | 22.0 | 27.0 | 25.5 | 25.4 |
| A | 23.1 | 23.4 | 24.5 | 23.6 | 23.9 |
| M | 21.8 | 23.4 | 27.0 | 22.5 | 24.0 |
| J | 20.2 | 20.1 | 19.2 | 19.7 | 20.4 |
| J | 19.7 | 17.0 | 21.3 | 21.6 | 22.2 |
| A | 24.1 | 20.9 | 24.0 | 21.6 | 22.2 |
| S | 22.0 | 20.0 | 21.2 | 20.5 | 21.4 |
| Mean for 2002 | 23.8 | 21.6 | 24.3 | 23.4 | 24.0 |

**Appendix 5 Temporal variation in conductivity in (µS $cm^{-1}$) between February 2002 and September 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 94 | 46 | 310 | 166 | 348 |
| M | 90 | 48 | 230 | 150 | 295 |
| A | 95 | 46 | 212 | 145 | 293 |
| M | 72 | 60 | 230 | 113 | 282 |
| J | 92 | 44 | 169 | 95 | 329 |
| J | 91 | 42 | 171 | 96 | 350 |
| A | 93 | 43 | 173 | 94 | 356 |
| S | 94 | 43 | 181 | 95 | 298 |
| O | 92 | 44 | 175 | 102 | 288 |
| N | 93 | 44 | 154 | 97 | 232 |
| D | 94 | 48 | 154 | 98 | 255 |
| J | 80 | 42 | 192 | 110 | 260 |
| F | 94 | 46 | 212 | 107 | 344 |
| M | 132 | 48 | 220 | 115 | 232 |
| A | 129 | 48 | 217 | 113 | 240 |
| M | 120 | 49 | 170 | 102 | 230 |
| J | 138 | 51 | 174 | 112 | 257 |
| J | 136 | 33 | 160 | 85 | 259 |
| A | 150 | 37 | 173 | 105 | 275 |
| S | 149 | 54 | 168 | 106 | 274 |
| Mean for 2002 | 90.4 | 45.8 | 195.9 | 113.4 | 298.8 |

**Appendix 6 Temporal variation in pH at the reservoirs between February 2002 and September 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 7.2 | 7.5 | 7.7 | 8.1 | 8.2 |
| M | 7.7 | 7.6 | 7.6 | 7.2 | 8.3 |
| A | 7.5 | 7.4 | 7.4 | 7.2 | 8.2 |
| M | 7.7 | 7.6 | 6.9 | 7.1 | 7.1 |
| J | 7.5 | 7.1 | 7.3 | 6.8 | 7.4 |
| J | 7.2 | 7.5 | 7.1 | 6.9 | 7.4 |
| A | 8.2 | 7.5 | 7.1 | 7.0 | 7.9 |
| S | 7.4 | 7.3 | 7.2 | 7.0 | 7.8 |
| O | 7.3 | 7.6 | 7.2 | 7.9 | 8.1 |
| N | 7.1 | 7.1 | 7.1 | 7.4 | 7.7 |
| D | 7.1 | 7.8 | 7.1 | 7.7 | 7.8 |
| J | 7.1 | 7.1 | 7.1 | 7.6 | 7.3 |
| F | 7.2 | 7.6 | 7.2 | 7.1 | 7.8 |
| M | 7.3 | 7.1 | 7.1 | 7.0 | 7.1 |
| A | 7.7 | 8.0 | 7.2 | 7.4 | 7.6 |
| M | 7.2 | 7.2 | 6.8 | 6.8 | 6.6 |
| J | 7.6 | 7.2 | 7.6 | 7.0 | 6.6 |
| J | 7.1 | 7.1 | 7.5 | 6.9 | 7.1 |
| A | 7.6 | 7.2 | 7.4 | 7.3 | 7.4 |
| S | 7.4 | 7.4 | 7.2 | 7.2 | 7.5 |
| Median 2002 | 7.4 | 7.4 | 7.2 | 7.3 | 7.7 |

**Appendix 7 Temporal variation in dissolved oxygen (mg $L^{-1}$) between February and September 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 6.4 | 7.0 | 7.3 | 9.3 | 10.4 |
| M | 6.9 | 7.0 | 7.4 | 8.9 | 10.2 |
| A | 7.4 | 7.0 | 7.5 | 7.3 | 10.0 |
| M | 7.2 | 7.2 | 6.1 | 7.4 | 8.4 |
| J | 6.6 | 7.0 | 7.3 | 6.8 | 8.9 |
| J | 7.2 | 7.2 | 7.0 | 7.0 | 8.6 |
| A | 7.8 | 7.2 | 5.4 | 7.1 | 8.7 |
| S | 7.8 | 7.1 | 5.8 | 5.6 | 8.2 |
| O | 8.1 | 7.0 | 4.8 | 8.9 | 9.6 |
| N | 6.5 | 7.2 | 5.3 | 8.2 | 8.3 |
| D | 6.9 | 7.0 | 5.2 | 8.0 | 8.1 |
| J | 6.9 | 7.0 | 5.9 | 6.9 | 8.7 |
| F | 6.4 | 7.2 | 7.3 | 6.1 | 8.9 |
| M | 6.0 | 7.0 | 6.1 | 6.0 | 8.9 |
| A | 7.8 | 8.2 | 7.8 | 8.9 | 9.0 |
| M | 7.6 | 7.0 | 7.9 | 8.6 | 8.2 |
| J | 6.2 | 7.0 | 7.8 | 8.7 | 7.9 |
| J | 6.2 | 7.0 | 5.8 | 8.6 | 7.9 |
| A | 7.8 | 7.1 | 5.8 | 7.5 | 9.3 |
| S | 5.2 | 7.0 | 4.4 | 7.5 | 7.2 |
| Mean for 2002 | 7.1 | 7.1 | 6.2 | 7.6 | 9.0 |

**Appendix 8 Temporal variation in total alkalinity (mg $L^{-1}$) at the reservoir between February 2002 and September 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 35.0 | 21.5 | 90.0 | 60.0 | 139.0 |
| M | 42.0 | 23.5 | 80.5 | 52.0 | 137.0 |
| A | 30.0 | 18.0 | 92.0 | 23.0 | 97.0 |
| M | 27.0 | 13.0 | 91.0 | 20.5 | 90.0 |
| J | 30.0 | 16.5 | 76.0 | 35.0 | 95.5 |
| J | 32.0 | 14.0 | 79.0 | 39.0 | 93.0 |
| A | 33.5 | 16.5 | 77.5 | 39.5 | 101.0 |
| S | 37.5 | 17.5 | 80.5 | 39.0 | 102.5 |
| O | 44.0 | 20.5 | 91.5 | 46.0 | 111.5 |
| N | 39.0 | 22.5 | 78.0 | 43.0 | 109.5 |
| D | 32.5 | 19.5 | 79.0 | 51.0 | 117.5 |
| J | 44.5 | 14.0 | 92.0 | 45.5 | 130.0 |
| F | 48.0 | 20.5 | 96.0 | 45.5 | 130.0 |
| M | 50.0 | 20.0 | 100.0 | 43.0 | 136.5 |
| A | 45.5 | 19.5 | 98.0 | 45.5 | 135.5 |
| M | 47.0 | 17.0 | 74.0 | 35.0 | 123.0 |
| J | 55.5 | 19.5 | 83.0 | 41.5 | 108.0 |
| J | 55.0 | 22.0 | 87.0 | 44.5 | 113.5 |
| A | 48.5 | 18.0 | 83.5 | 44.0 | 113.0 |
| S | 50.5 | 21.5 | 92.5 | 41.5 | 126.0 |
| Mean for 2002 | 35.5 | 18.0 | 83.9 | 41.1 | 110.2 |

**Appendix 9 Temporal variation in nitrite nitrogen (µg $L^{-1}$) at the reservoirs between February 2002 and September 2003**

| Months | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | NA | NA | NA | NA | NA |
| M | NA | NA | NA | NA | NA |
| A | NA | 0.I | NA | 0.1 | NA |
| M | NA | 0.I | NA | 0.0 | NA |
| J | NA | NA | NA | NA | NA |
| J | NA | NA | NA | 0.2 | NA |
| A | NA | NA | NA | NA | NA |
| S | NA | NA | NA | NA | NA |
| O | NA | NA | NA | 0.2 | NA |
| N | NA | NA | NA | NA | NA |
| D | NA | NA | NA | NA | NA |
| J | NA | NA | NA | NA | NA |
| F | NA | NA | NA | NA | NA |
| M | NA | NA | NA | NA | NA |
| A | NA | NA | NA | NA | NA |
| M | NA | NA | NA | NA | NA |
| J | NA | NA | NA | NA | NA |
| J | NA | NA | NA | NA | NA |
| A | NA | NA | NA | NA | NA |
| S | NA | NA | NA | NA | NA |
| Mean for 2002 | NA | NA | NA | NA | NA |

**Appendix 10 Temporal variation in nitrate nitrogen (μg $L^{-1}$) at the reservoirs between February 2002 and September 2003**

| Months | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 0.7 | 2.8 | 2.1 | 4.0 | 4.1 |
| M | 0.1 | 1.9 | 1.8 | 5.6 | 0.8 |
| A | 1.5 | 1.9 | 4.5 | 5.4 | 6.3 |
| M | 0.3 | 10.7 | 2.1 | 12.5 | 14.6 |
| J | 0.5 | 8.5 | 4.4 | 10.2 | 30.4 |
| J | 0.3 | 6.9 | 2.1 | 8.1 | 37.3 |
| A | 0.4 | 0.8 | 2.8 | 0.7 | 0.6 |
| S | 3.7 | 2.1 | 1.5 | 5.3 | 13.0 |
| O | 7.6 | 0.4 | 8.0 | 8.9 | 12.9 |
| N | 52.9 | 57.8 | 2.6 | 0.3 | NA |
| D | 36.9 | 0.4 | NA | 23.3 | 17.0 |
| J | 12.9 | 14.3 | 19.0 | 1.2 | 26.9 |
| F | NA | 6.1 | 4.5 | 6.2 | 9.0 |
| M | 4.9 | 5.9 | 2.4 | 7.2 | 9.1 |
| A | 0.3 | 15.1 | 5.5 | 7.1 | 10.8 |
| M | 8.6 | 12.6 | 10.3 | 14.7 | 24.7 |
| J | NA | 0.2 | 8.8 | 12.0 | 33.2 |
| J | 7.4 | 11.8 | 8.4 | 16.0 | 31.3 |
| A | 0.6 | 8.0 | 3.9 | 9.7 | 20.1 |
| S | 0.7 | 7.8 | 4.0 | 10.2 | 16.6 |
| Mean for 2002 | 9.8 | 9.0 | 4.2 | 7.1 | 13.6 |

**Appendix 11 Temporal variation in total nitrogen in (μg $L^{-1}$) at the reservoirs between February 2002 and September 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 13.0 | 9.0 | 29.0 | 40.0 | 39.0 |
| M | 40.0 | 63.0 | 73.0 | 95.0 | 71.0 |
| A | 45.0 | 59.0 | 41.0 | 23.0 | 25.0 |
| M | 43.0 | 15.0 | 30.0 | 19.0 | 32.0 |
| J | 62.0 | 68.0 | 29.0 | 71.0 | 84.0 |
| J | 28.0 | 46.0 | 44.0 | 64.0 | 103.0 |
| A | 7.0 | 1.0 | 10.0 | 7.0 | 1.0 |
| S | 47.0 | 7.0 | 18.0 | 92.0 | 9.0 |
| O | 8.0 | 5.0 | 7.0 | 25.0 | 1.0 |
| N | 2.0 | 121.0 | 80.0 | 24.0 | NA |
| D | 10.0 | 17.0 | 15.0 | 12.0 | NA |
| J | 13.0 | 67.0 | 36.0 | 14.0 | 10.0 |
| F | 4.0 | 32.0 | 4.0 | 11.0 | 11.0 |
| M | 8.0 | 20.0 | 0.7 | 14.0 | 15.0 |
| A | 22.0 | 17.0 | 7.0 | 143.0 | 32.0 |
| M | 22.0 | 28.0 | 29.0 | 15.0 | 22.0 |
| J | 1.0 | 15.0 | 1.0 | 16.0 | 2.0 |
| J | 34.0 | 11.0 | 10.0 | 17.0 | 17.0 |
| A | 1.0 | 11.0 | 7.0 | 14.0 | 28.0 |
| S | 6.0 | 24.0 | 8.0 | 13.0 | 22.0 |
| Mean for 2002 | 33.1 | 39.8 | 34.1 | 40.5 | 32.5 |

**Appendix 12 Temporal variation in orthophosphate phosphorus (μg $L^{-1}$) between February 2002 and January 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | NA | NA | NA | NA | NA |
| M | NA | NA | NA | NA | NA |
| A | NA | NA | NA | NA | NA |
| M | NA | NA | NA | NA | NA |
| J | NA | NA | NA | NA | NA |
| J | NA | NA | NA | NA | NA |
| A | NA | NA | NA | NA | NA |
| S | NA | NA | NA | NA | 0.1 |
| O | NA | NA | 0.1 | NA | NA |
| N | NA | NA | 0.1 | NA | NA |
| D | NA | NA | NA | NA | NA |
| J | NA | NA | NA | NA | NA |
| F | NA | NA | NA | NA | NA |
| M | NA | NA | NA | NA | NA |
| A | NA | NA | NA | NA | NA |
| M | NA | NA | 0.1 | 0.1 | NA |
| J | NA | NA | NA | NA | NA |
| J | NA | NA | NA | NA | NA |
| A | NA | NA | NA | NA | NA |
| S | NA | NA | 0.1 | 0.1 | NA |
| Mean for 2002 | NA | NA | NA | NA | NA |

**Appendix 13 Temporal variations in total phosphorus (µg $L^{-1}$) between February 2002 and September 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 0.1 | 0.1 | NA | 0.6 | 0.3 |
| M | 0.3 | 2.4 | 2.4 | 2.6 | 1.3 |
| A | 2.0 | 3.6 | 3.5 | 2.2 | 2.3 |
| M | 2.2 | 2.6 | 2.8 | 0.8 | 1.3 |
| J | 0.2 | 0.6 | NA | 2.7 | 0.5 |
| J | 0.1 | 0.6 | NA | 0.5 | NA |
| A | 0.1 | NA | NA | NA | NA |
| S | 0.3 | NA | NA | NA | NA |
| O | 0.3 | 0.5 | 0.5 | 0.5 | 0.2 |
| N | 2.5 | 2.4 | 2.3 | 2.0 | 2.3 |
| D | 2.2 | 0.5 | 0.2 | 0.1 | NA |
| J | 0.2 | 0.2 | 0.3 | 0.5 | NA |
| F | 0.1 | 0.1 | 0.2 | 0.3 | 0.2 |
| M | 2.5 | 3.4 | 0.3 | 0.3 | 0.3 |
| A | 2.1 | 2.4 | 2.6 | 1.8 | 2.4 |
| M | 0.9 | 0.2 | 1.5 | 2.3 | 2.2 |
| J | 0.1 | 0.2 | 0.3 | 0.7 | 0.3 |
| J | NA | NA | 3.6 | NA | 0.1 |
| A | 0.6 | 0.2 | NA | 0.1 | 0.1 |
| S | NA | 0.1 | 0.1 | NA | 0.1 |
| Mean for 2002 | 0.8 | 1.0 | 1.0 | 1.0 | 0.7 |

**Appendix 14 Temporal variations in soluble reactive silica (mg $L^{-1}$) between February 2002and September 2003**

| Month | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 3.5 | 4.1 | 7.8 | 6.3 | 4.1 |
| M | 4.0 | 4.1 | 8.6 | 4.3 | 7.3 |
| A | 3.4 | 4.0 | 7.2 | 9.2 | 7.2 |
| M | 3.6 | 4.5 | 6.1 | 8.2 | 8.2 |
| J | 3.3 | 3.6 | 7.3 | 2.5 | 5.4 |
| J | 3.4 | 3.9 | 8.0 | 3.8 | 6.6 |
| A | 3.4 | 4.2 | 7.8 | 5.9 | 8.1 |
| S | 3.5 | 4.2 | 8.0 | 6.0 | 8.2 |
| O | 2.2 | 1.5 | 5.9 | 4.9 | 6.0 |
| N | 3.8 | 4.5 | 6.8 | 9.2 | 8.1 |
| D | 3.2 | 3.9 | 6.9 | 5.3 | 7.5 |
| J | 3.7 | 4.0 | 7.3 | 5.2 | 3.2 |
| F | 3.6 | 4.1 | 7.6 | 6.4 | 4.2 |
| M | 3.6 | 4.1 | 7.9 | 6.4 | 7.9 |
| A | 2.5 | 3.6 | 7.4 | 5.9 | 8.5 |
| M | 3.0 | 3.7 | 7.0 | 3.5 | 7.3 |
| J | 3.1 | 3.6 | 7.6 | 5.1 | 7.9 |
| J | 3.6 | 4.3 | 8.6 | 6.3 | 8.3 |
| A | 3.7 | 4.3 | 8.0 | 6.0 | 8.5 |
| S | 4.0 | 4.3 | 8.6 | 7.0 | 8.3 |
| Mean for 2002 | 3.4 | 4.0 | 7.3 | 5.9 | 7.0 |

**Appendix 15 Biomass of the main phytoplankton division at Uhuru Reservoir in 2002**

| Phylum | Feb | Apr | June | Aug | Oct | Dec | Total |
|---|---|---|---|---|---|---|---|
| Cyanobacteria | 108.583 | 1.244 | 7.294 | 7.153 | 3.226 | 0.227 | 127.727 |
| Chlorophyta | 44.960 | 6.971 | 15.766 | 4862.921 | 68.152 | 0.195 | 4998.964 |
| Euglenophyta | 260.273 | 45.650 | 135.896 | 101.621 | 229.802 | 3.570 | 776.812 |
| Chrysophyta | NA | 0.476 | 7.653 | NA | 2.041 | NA | 10.170 |
| Crytophyta | NA | NA | NA | NA | 64.225 | NA | 64.225 |
| Dinophyta | 29.405 | 50.000 | 110.007 | 99.404 | 62.552 | 137.286 | 488.654 |
| Bacillariophyta | 10.647 | 5.341 | 27.300 | 16.355 | 5.501 | NA | 65.144 |

**Appendix 16 Biomass of the main phytoplankton division at Uhuru Reservoir in 2003**

| Phylum | Feb | Apr | June | Aug | Total |
|---|---|---|---|---|---|
| Cyanobacteria | NA | 18.538 | 26.366 | 33.480 | 78.384 |
| Chlorophyta | 49.127 | 473.253 | 186.631 | 736.064 | 1445.075 |
| Euglenophyta | 37.686 | 63.16 | 517.824 | 14.450 | 633.12 |
| Chrysophyta | NA | NA | NA | NA | NA |
| Crytophyta | 5.466 | NA | NA | NA | 5.466 |
| Dinophyta | 33.908 | 21.568 | 77.429 | 32.356 | 165.261 |
| Bacillariophyta | NA | 12.379 | 20.363 | 7.437 | 40.179 |
| Total | 126.187 | 588.898 | 828.613 | 823.787 | 2367.485 |

**Appendix 17 Biomass of main phytoplankton division at Ruiru Reservoir in 2002**

| Phylum | Feb | Apr | June | Aug | Oct | Dec | Total |
|---|---|---|---|---|---|---|---|
| Cyanobacteria | NA | NA | 0.446 | 0.437 | 0.197 | 25.501 | 26.581 |
| Chlorophyta | 21.366 | 7.665 | 0.707 | 4.157 | 55.823 | 1.281 | 90.999 |
| Euglenophyta | 70.028 | 32.175 | 71.287 | 12.613 | 47.337 | 51.571 | 285.011 |
| Chrysophyta | 3.916 | NA | 0.930 | 0.930 | NA | NA | 5.776 |
| Cryophyta | NA | NA | NA | NA | NA | NA | NA |
| Dinophyta | 74.951 | 51.067 | 15.925 | 100.399 | 136.931 | 683.648 | 1062.921 |
| Bacillariophyta | 6.132 | 0.057 | 0.850 | NA | 4.429 | 0.364 | 11.832 |
| Total | 176.393 | 90.964 | 90.145 | 118.536 | 244.717 | 762.365 | 1483.111 |

**Appendix 18 Biomass of main phytoplankton divisions at Ruiru Reservoir in 2003**

| Phylum | Feb | April | June | August |
|---|---|---|---|---|
| Cyanobacteria | 0.119 | 0.022 | NA | 0.119 |
| Chlorophyta | 6.667 | 0.253 | 1.124 | 91.402 |
| Euglenophyta | 28.348 | 41.964 | 58.780 | 16.906 |
| Chrysophyta | NA | NA | 50.199 | NA |
| Crytophyta | NA | NA | NA | NA |
| Dinophyta | 249.394 | 3008.579 | 125.345 | 106.43 |
| Bacillariophyta | 33.634 | 13.079 | NA | 29.515 |
| Total | 318.162 | 3063.897 | 235.448 | 244.372 |

**Appendix 19 Biomass of main phytoplankton divisions at Ngewa Reservoir in 2002**

| Phylum | Feb | Apr | June | Aug | Oct | Dec | Total |
|---|---|---|---|---|---|---|---|
| Cyanobacteria | 0.2 | 1.1 | 2.2 | 2.0 | 1.0 | 0.2 | 7.0 |
| Chlorophyta | 118.2 | 13.6 | 12.3 | 1.6 | 5.1 | 4.9 | 155.9 |
| Euglenophyta | 226.7 | 203.1 | 323.4 | 151.4 | 187.0 | 202.3 | 1294.2 |
| Chrysophyta | 0.4 | NA | 21.4 | NA | 1.8 | NA | 23.7 |
| Crytophyta | NA | NA | NA | NA | NA | NA | NA |
| Dinophyta | 211.3 | 54.1 | 76.0 | 36.8 | 29.741 | 57.7 | 465.7 |
| Bacillariophyta | 31.6 | 0.1 | 0.5 | 5.2 | 0.2 | 1.4 | 39.2 |
| Total | 588.6 | 272.3 | 436.0 | 197.2 | 225.1 | 266.6 | 1986.1 |

**Appendix 20 Biomass of main phytoplankton division at Ngewa Reservoir in 2003**

| Phylum | Feb | April | June | August | Total |
|---|---|---|---|---|---|
| Cyanobacteria | 0.2 | 2.0 | NA | 0.5 | 2.6 |
| Chlorophyta | 9.3 | 23.4 | 0.1 | 5.9 | 38.9 |
| Euglenophyta | 158.8 | 150.9 | 433.0 | 128.6 | 671.6 |
| Chrysophyta | NA | NA | NA | 3.7 | 3.7 |
| Crytophyta | NA | NA | NA | 21.4 | 21.4 |
| Dinophyta | 211.9 | 31.8 | 12.9 | 49.5 | 306.2 |
| Bacillariophyta | 1.6 | 17.1 | 1.5 | 285 | 48.8 |
| Total | 381.8 | 225.4 | 447.7 | 238.4 | 1293. 5 |

**Appendix 21 Biomass of main phytoplankton divisions at Comte Reservoir in 2002**

| Phylum | Feb | Apr | June | Aug | Oct | Dec | Total |
|---|---|---|---|---|---|---|---|
| Cyanobacteria | 1.8 | NA | 0.3 | 0.4 | 279.0 | NA | 281.7 |
| Chlorophyta | 457.7 | 44.7 | 0.9 | NA | 101.4 | 0.3 | 605.2 |
| Euglenophyta | 99.3 | 160.3 | 46.0 | 74.0 | 399.2 | 78.3 | 857.4 |
| Chrysophyta | NA | NA | 6.4 | 17.0 | 55.4 | NA | 79.0 |
| Crytophyta | NA | NA | NA | NA | 131.7 | NA | 131.7 |
| Dinophyta | 1986.4 | 214.0 | 3.8 | 338.5 | 888.1 | 1133.8 | 4564.9 |
| Bacillariophyta | 212.6 | 1.8 | 11.3 | 36.5 | 330.2 | 349.5 | 942.2 |
| Total | 2758.1 | 421.1 | 68.9 | 466.6 | 2185.4 | 1562.0 | 7462.3 |

**Appendix 22 Biomass of main phytoplankton divisions at Comte Reservoir in 2003**

| Phylum | Feb | April | June | August | Total |
|---|---|---|---|---|---|
| Cyanobacteria | NA | NA | NA | NA | NA |
| Chlorophyta | 57.0 | 44.7 | 0.9 | 300.6 | 403.3 |
| Euglenophyta | 36.2 | 160.3 | 319.3 | 29.9 | 545.9 |
| Chrysophyta | NA | NA | 23.3 | NA | 23.3 |
| Crytophyta | NA | NA | NA | NA | NA |
| Dinophyta | 576.6 | 214.0 | 321.6 | 378.2 | 1490.5 |
| Bacillariophyta | 109.2 | 1.8 | 22.3 | 22.8 | 156.3 |
| Total | 779.0 | 421.1 | 687.7 | 731.7 | 2619.6 |

**Appendix 23. Biomass of main phytoplankton division at Kianjjibbe Reservoir in 2002**

| Phylum | Feb | April | June | Aug | Oct | Dec | Total |
|---|---|---|---|---|---|---|---|
| Cyanobacteria | 10.9 | 15.2 | 22.8 | 18.4 | 3.4 | 0.1 | 71.2 |
| Chlorophyta | 2802.5 | 273.4 | 310.3 | 420.6 | 390.2 | 159.8 | 4357.0 |
| Euglenophyta | 120.5 | 184.9 | 331.1 | 74.8 | 1409.1 | 111.9 | 2232.5 |
| Chrysophyta | NA | NA | 48.0 | NA | NA | NA | 48.0 |
| Crytophyta | NA | NA | 4.7 | NA | 228.9 | NA | 233.6 |
| Dinophyta | 371.1 | 489.1 | 661.9 | 812.8 | 2394.0 | 910.9 | 5640.0 |
| Bacillariophyta | 532.9 | 3965.2 | 9.0 | 6.7 | 81.8 | 19.1 | 4614.9 |
| Total | 3838.0 | 4928.1 | 1388.1 | 1333.4 | 4507.6 | 1202.0 | 17197.5 |

Appendix 23 Biomass of main phytoplankton at Kianjjbbe division Period 2003

| Phylum | Feb | April | June | August | Total |
|---|---|---|---|---|---|
| Cyanobacteria | 20.1 | 5.7 | 1.0 | 0.3 | 27.3 |
| Chlorophyta | 633.2 | 1000.9 | 13.1 | 81.6 | 1729.0 |
| Euglenophyta | 84.0 | 114.0 | 245.8 | 109.4 | 553.4 |
| Chrysophyta | NA | NA | NA | NA | NA |
| Crytophyta | NA | NA | NA | 26.7 | 26.7 |
| Dinophyta | 577.9 | 534.4 | 100.4 | 1283.9 | 2496.8 |
| Bacillariophyta | 129.03 | 112.1 | 40.7 | 32.1 | 314.0 |
| Total | 1444.5 | 1767.3 | 401.2 | 1534.3 | 5147.4 |

**Appendix 24 Biomass of phytoplankton main divisions at the study reservoirs during the period 2002 to 2003**

| Phylum | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| Cyanobacteria | 206.1 | 26.8 | 10.0 | 285.6 | 98.5 |
| Chlorophyta | 6444.0 | 190.4 | 194.8 | 1071.5 | 6086.1 |
| Euglenophyta | 1409.9 | 431.0 | 2165.9 | 1372.1 | 2786.0 |
| Chrysophyta | 10.1 | 55.9 | 27.5 | 102.3 | 48.0 |
| Crytophyta | 69.6 | NA | 21.4 | 131.7 | 260.4 |
| Dinophyta | 653.9 | 4552.6 | 780.0 | 7780.2 | 8156.8 |
| Bacillariophyta | 105.3 | 88.0 | 100.1 | 1138.9 | 4928.7 |

**Appendix 25 Phytoplankton diversity indices at the reservoirs during the period February 2002 to September 2003**

| Months | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 2.4 | 1.7 | 2.1 | 2.3 | 2.3 |
| A | 1.7 | 1.4 | 1.6 | 1.7 | 1.8 |
| J | 2.2 | 1.7 | 1.8 | 1.9 | 2.3 |
| A | 2.0 | 1.9 | 1.9 | 1.7 | 2.1 |
| O | 1.8 | 1.5 | 1.5 | 1.3 | 2.3 |
| D | 2.2 | 1.6 | 2.1 | 1.9 | 2.3 |
| F | 2.2 | 1.5 | 1.5 | 2.0 | 2.4 |
| A | 1.7 | 1.4 | 1.6 | 2.0 | 2.1 |
| J | 2.4 | 1.5 | 1.6 | 1.7 | 1.8 |
| A | 2.3 | 1.7 | 1.7 | 2.1 | 2.2 |

**Appendix 26 Phytoplankton diversity indices at the reservoirs for the period February 2002 to February 2003**

| Months | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| F | 2.4 | 1.7 | 21 | 2.3 | 2.3 |
| A | 1.7 | 1.4 | 1.6 | 1.7 | 1.8 |
| J | 2.2 | 17 | 1.8 | 1.9 | 2.3 |
| A | 2.0 | 1.9 | 1.9 | 1.7 | 2.1 |
| O | 1.8 | 1.5 | 1.5 | 1.3 | 2.3 |
| D | 2.2 | 1.6 | 2.1 | 1.9 | 2.4 |
| F | 2.2 | 1.5 | 1.8 | 2.1 | 2.4 |

**Appendix 27 Total phytoplankton biomass (mg $L^{-1}$) at the study reservoirs over the period 2002-2003**

| Months | Uhuru | Ruiru | Ngewa | Comte | Kianjjibbe |
|---|---|---|---|---|---|
| Feb | 110.2 | 176.4 | 271.1 | 421.1 | 3837.9 |
| Apr | 5087.5 | 762 .0 | 596.4 | 2758.1 | 4928.2 |
| June | 303.9 | 90.1 | 434.8 | 69.0 | 1388.0 |
| Aug | 453.9 | 118.5 | 195.2 | 466.7 | 1333.5 |
| Oct | 828.6 | 225.0 | 224.1 | 2185.4 | 4501.7 |
| Dec | 141.3 | 91.0 | 226.5 | 1562.1 | 1202.1 |
| Feb | 126.2 | 318.2 | 382.2 | 779.2 | 1444.5 |

**Appendix 28 Selected diagrams of the abundant to dominant species observed at the study reservoirs (All diagrams obtained from Lund, 1997)**

**Plate 4.1 *Closterium* a desmid (Chlorophyta) common in Uhuru and Kianjjibbe Reservoirs**

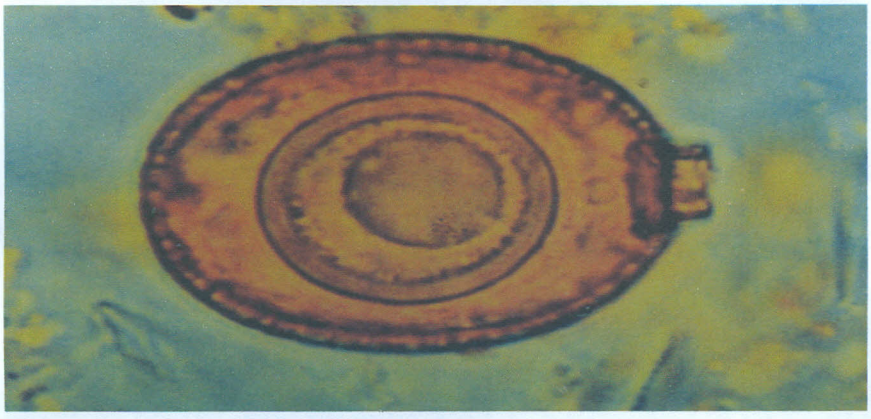

**Plate 4.1 *Trachelomonas*, a Euglenophyta, common in Uhuru, Ruiru, Ngewa and Comte reservoirs.**

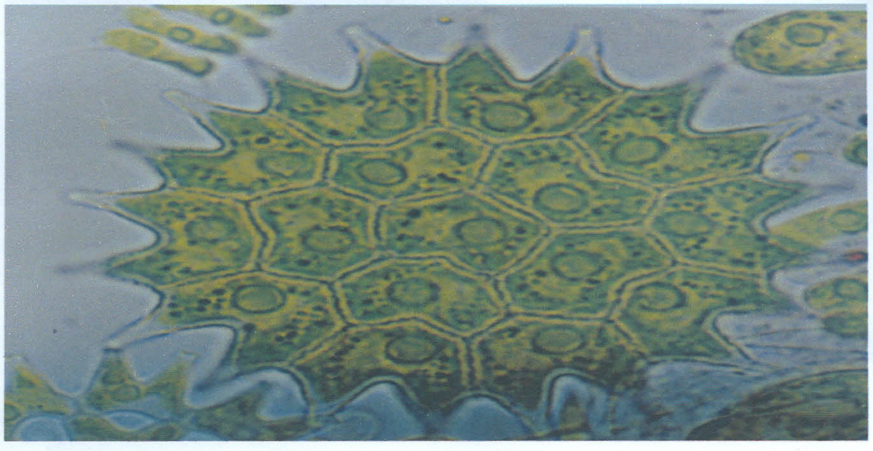

**Plate 4.2 *Pediastrum*, a Chlorophyta dominant in Uhuru, Ruiru, Ngewa and Kianjjibbe reservoir**

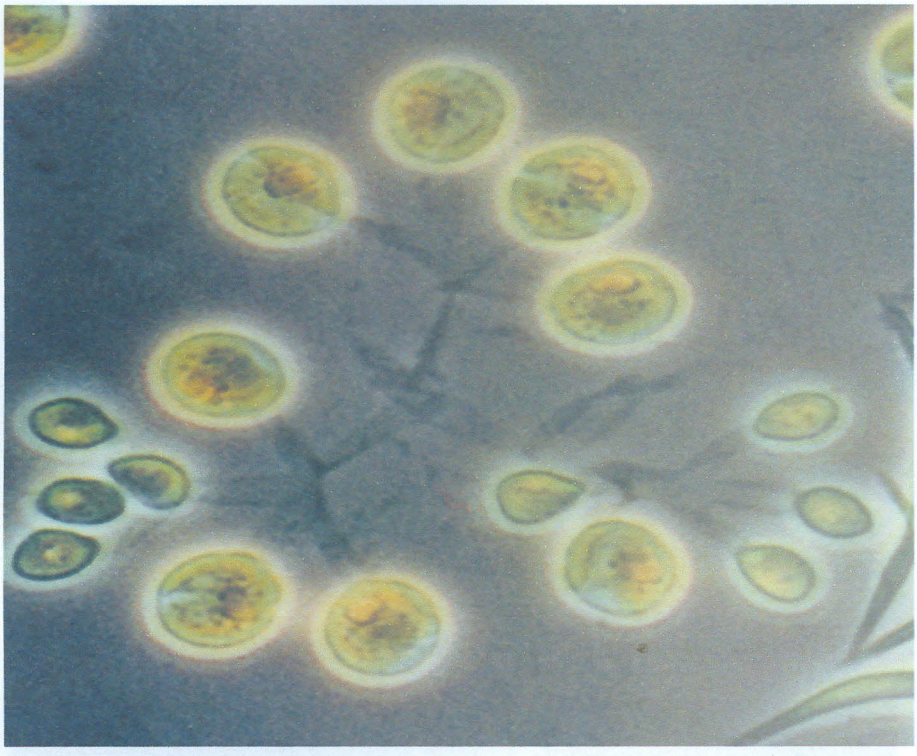

**Plate 4.3 *Dictyosphaerium*, a Chlorophyta, found only in Ruiru reservoir**

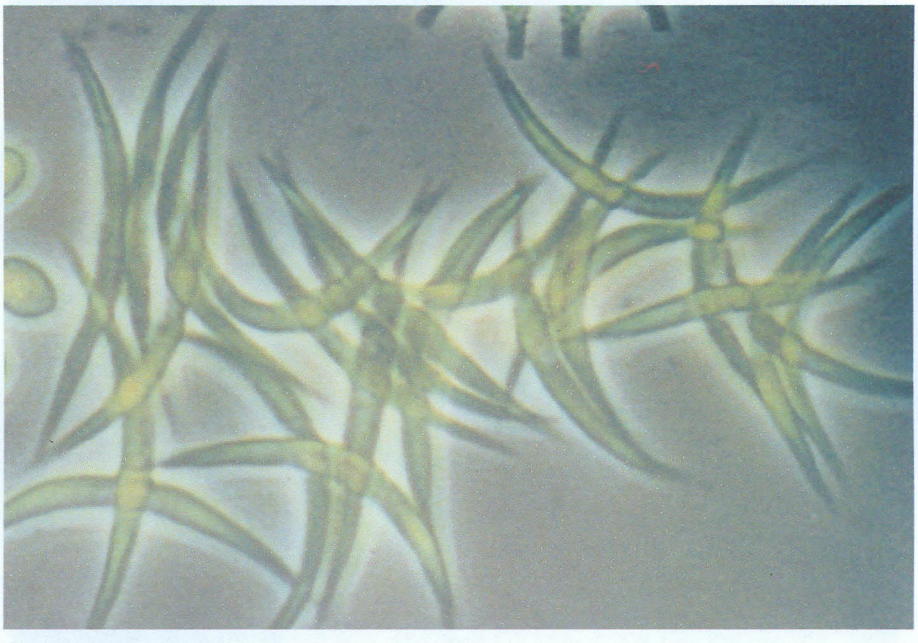

**Plate 4.4 *Ankistrodesmus*, a Chlorophyta common in Uhuru reservoir**

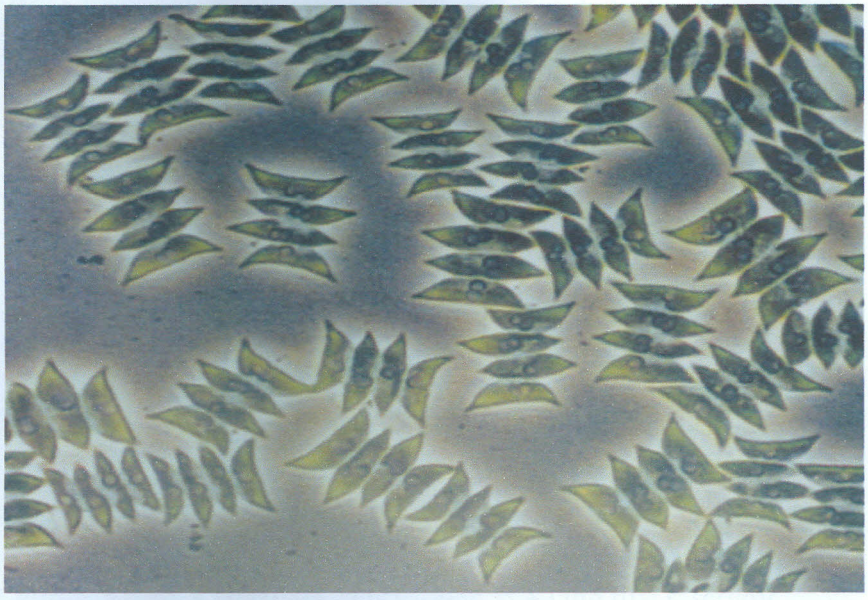

Plate 4.6 *Selenastrum,* a Chlorophyta dominant in Uhuru and Ruiru reservoirs

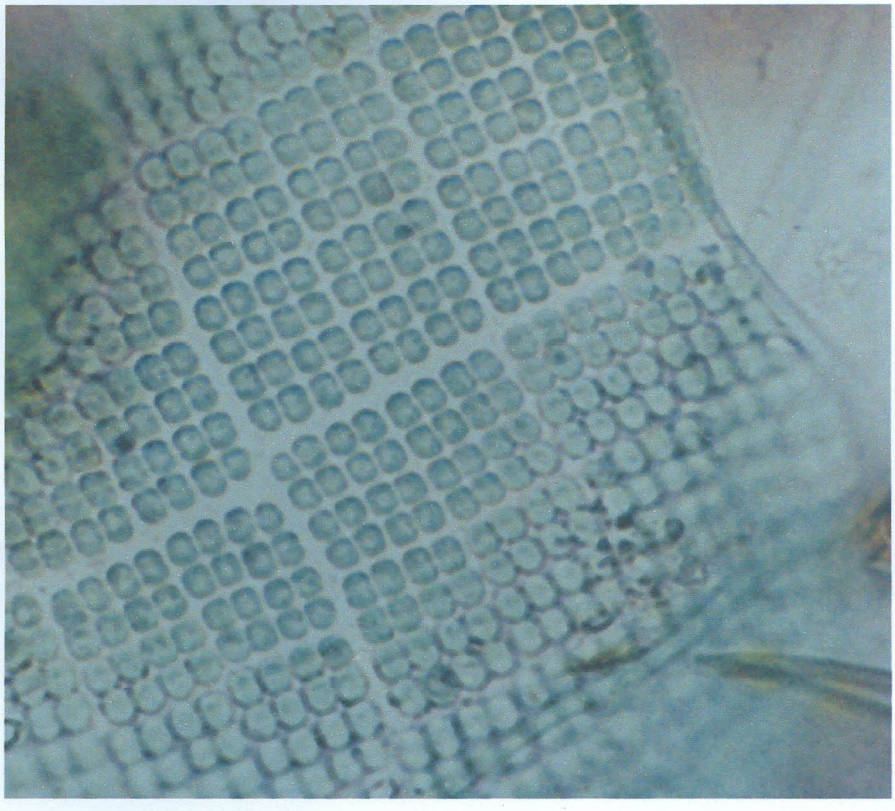

**Plate 4.5 *Merismopedia*; a Cyanophyta, common in Uhuru and Kianjjibbe Reservoirs.**

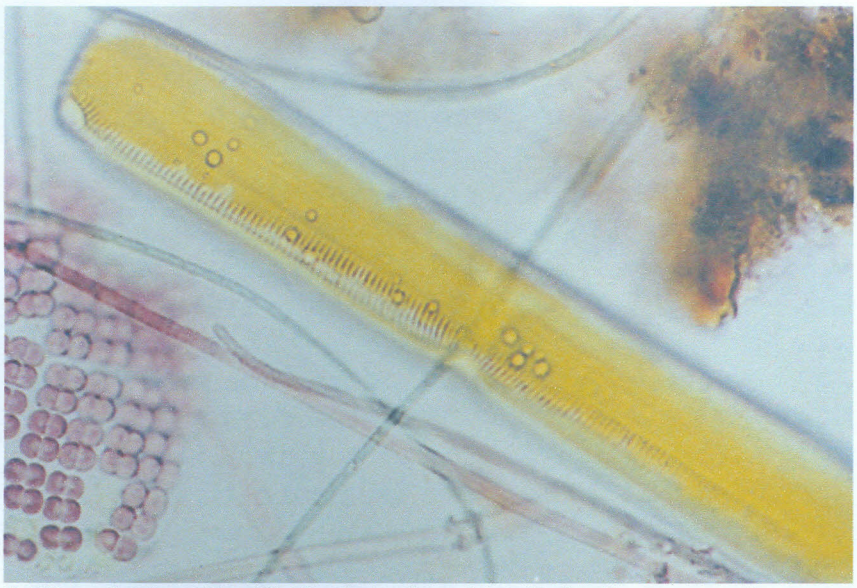

Plate 4.8 ***Pinnularia,*** a Bacillariophyta found in all the five reservoir

Plate 4.6 *Kirchneriella*, a Chlorophyta common in Ruiru reservoir

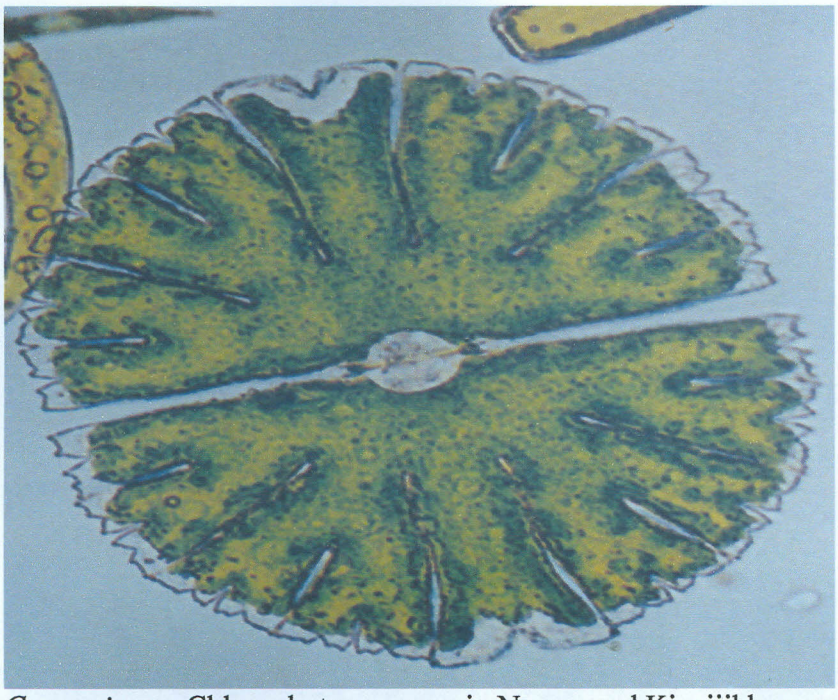

Plate 4.7 *Cosmarium*, a Chlorophyta common in Ngewa and Kianjjibbe reservoirs

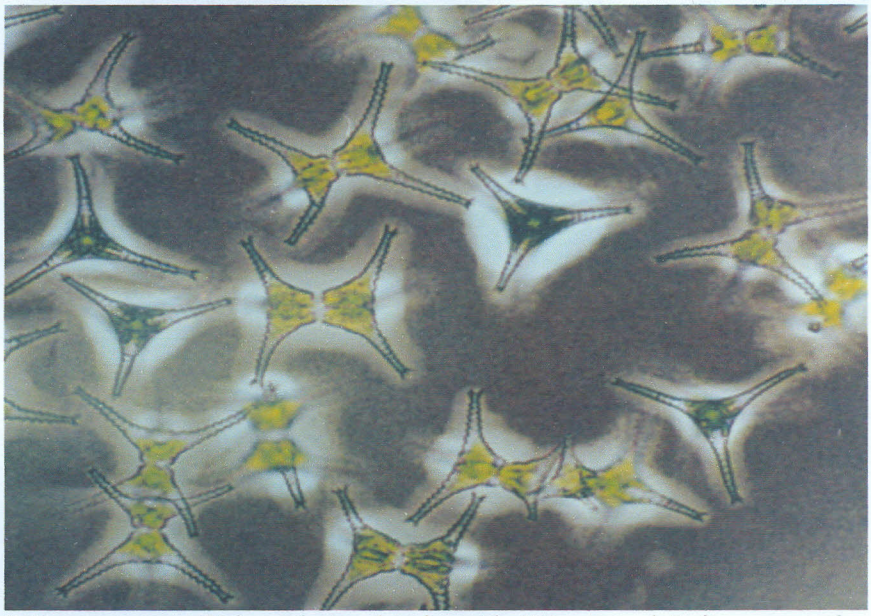

Plate 4.8 *Staurastrum*, Chlorophyta, dominant in Uhuru and Ruiru reservoirs

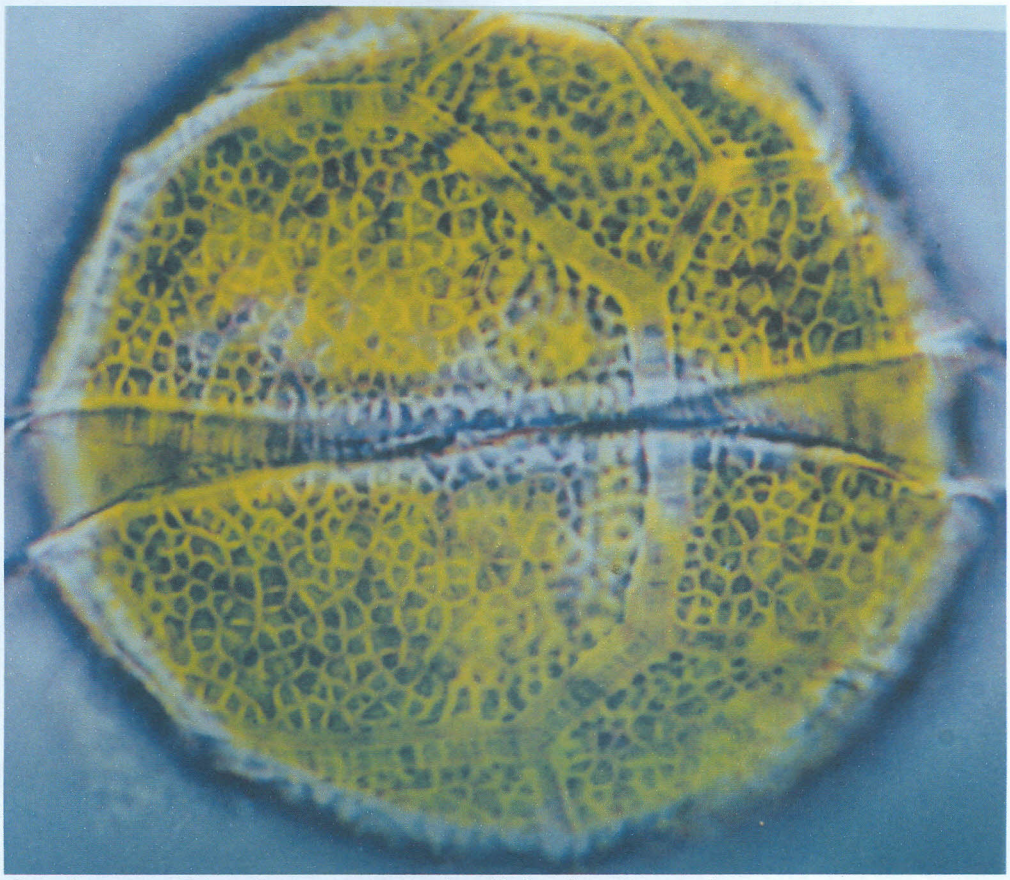

Plate 4.9 *Peridinium*, a Dinophyta, common in all the five reservoirs

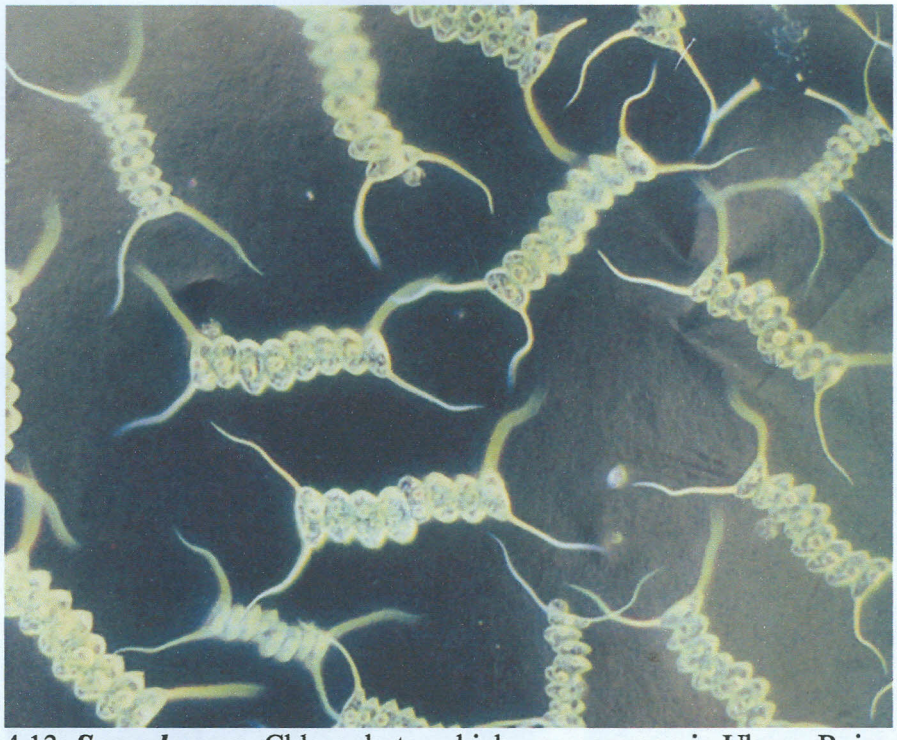

Plate 4.13 ***Scenedesmus;*** Chlorophyta, which was common in Uhuru, Ruiru and Comte reservoirs

Plate 4.10 *Euglena*; Euglenophyta, common in all the five reservoirs

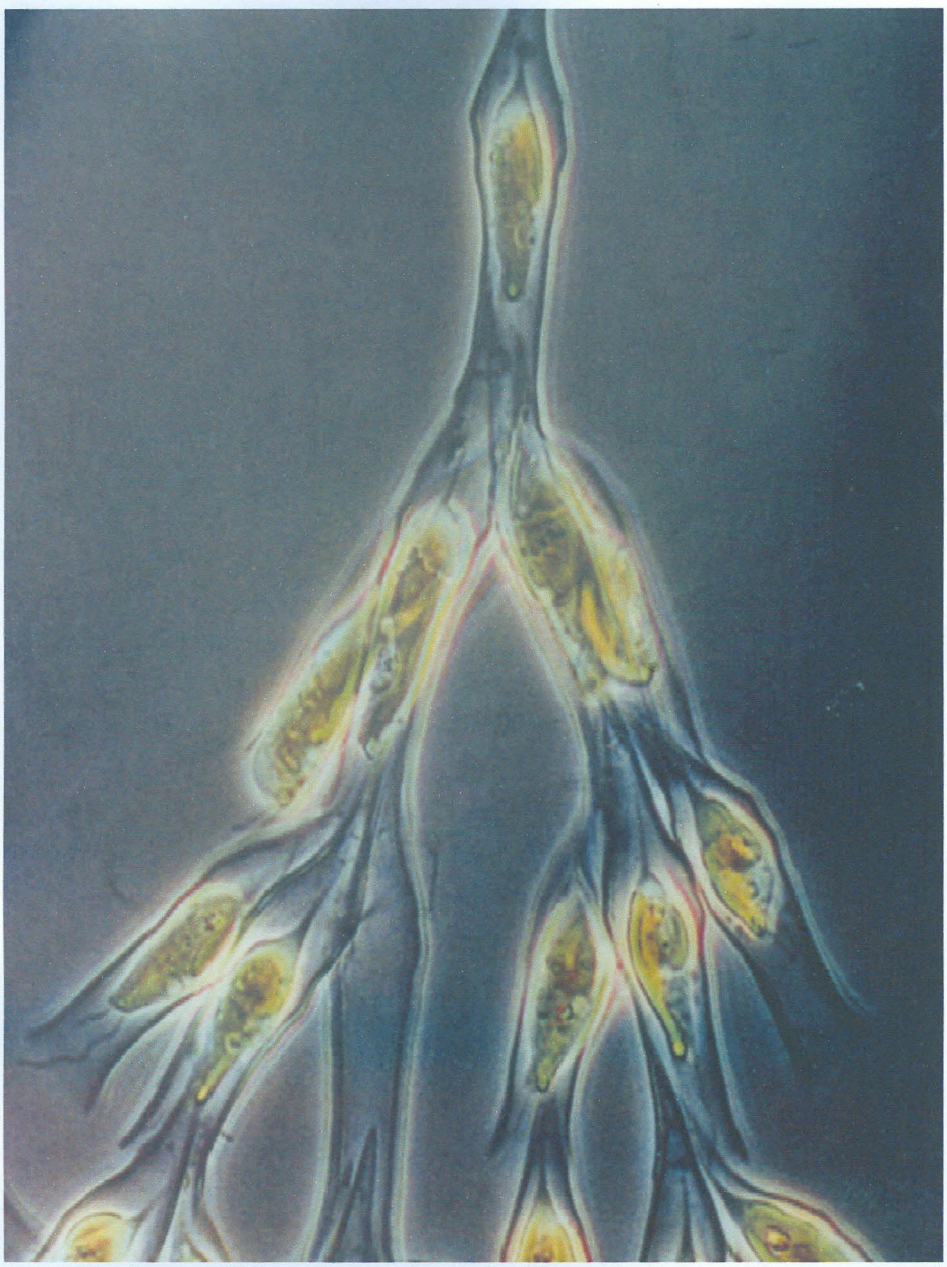

Plate 4.11 *Dinobryon*, Chrysophyta, present in Uhuru, Ruiru and Ngewa reservoirs

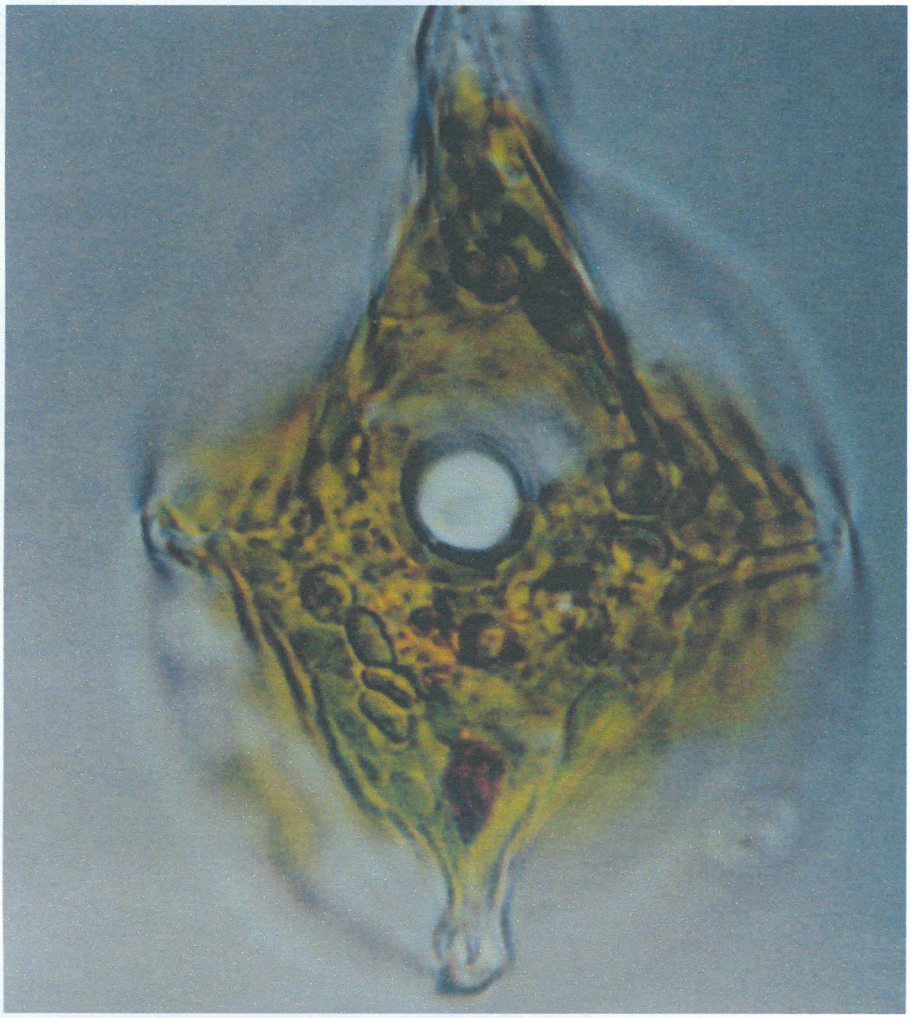

Plate 4.12 *Phacus*, Euglenophyta found in all the five reservoirs.

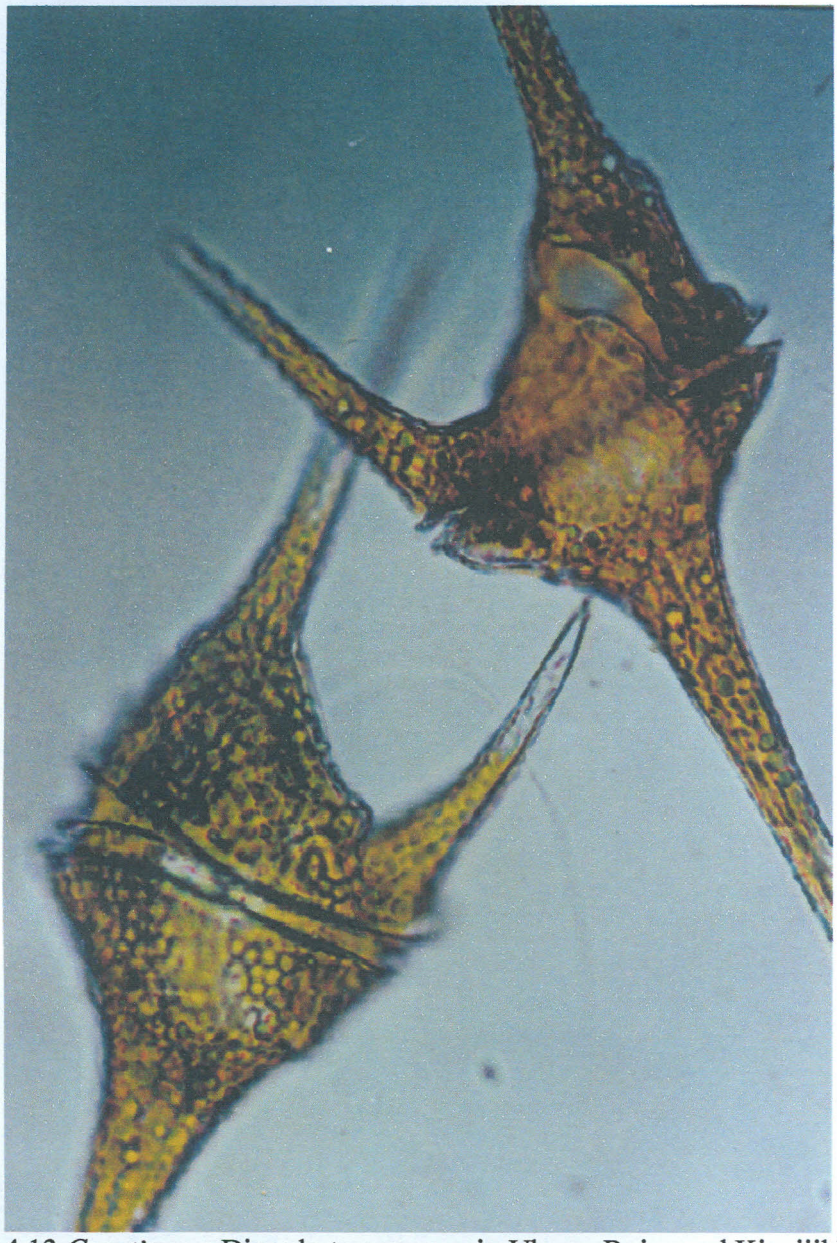

Plate 4.13 *Ceratium*; a Dinophyta common in Uhuru, Ruiru and Kianjjibbe reservoirs