EFFECTS OF CLIMATE CHANGE AND HUMAN ACTIVITY ON LAKE LEVELS IN THE KENYAN RIFT (CASE STUDY NAIVASHA)

MUTUNGWA DAVID MWAI

I13/2357/2007

This Is a Research Project Submitted in Partial Fulfillment of the Bachelor's Degree.

University of Nairobi

JUNE 2011

DECLARATION

This Research Project is a result of my original work and has not been submitted for a degree in any other university

Mutungwa David Mwai

I13/2357/2007

Signatuture …………………………….

Date………………………………..…...

This research project has been submitted with my approval as the advisor

Prof. E. Odada

Signature ………………………………

Date ……………………………………

This Research Project has been submitted with our approval as the university supervisors

1) **Dr. Daniel Olago**

Signature ………………………………

Date ……………………………………

2) **Dr. Charles Gichaba**

Signature ………………………………

Date ……………………………………

ABSTRACT

Lake Naivasha, (0. 45ºS, 36. 26ºE) lies in the Kenyan rift approximately 80km NW of Nairobi. It lies at 1,890m (a.s.l) and an average depth of 6m with the deepest part being the crescent island crater at a maximum depth of 30m. There are two smaller lakes within the vicinity of Lake Naivasha; Oloiden and Sonachi. The lake is a fresh water lake situated within that part of Eastern Africa that is influenced by the monsoonal systems of Asia and Indian Ocean with Rainfall averaging from 450-900mmy^{-1}. The lake is underlain by flood basalts (Miocene), phonolites (Pleistocene), trachytes (Quaternary), volcaniclastics, Quaternary deposits , and their weathering products (Olago *et al.*, 2009).

Lake Naivasha and aquifer surrounding the lake are important water resources in the area and they are used extensively for agriculture mainly in the booming flower industry and domestic water supplies. However in the last 100 years, there have been large variations in the lake level with the past four decades indicating a steady decline of the lake waters. This has been attributed in part to climate variations as well as the vast human activities taking place at the shores of the lake. Studies in the lake of the past millennium (Verschuren *et al.*, 2000; Olago *et al.*, 2009; Olaka *et al.*, 2010) have showed climatic induced fluctuations in the lake level associating the fluctuations with periods of lowstands (Medival Warm Period ~AD 900-1300) and periods highstands (Little Ice Age ~1300-1900). More studies on the anthropogenic impacts in the lake (Odada *et al*., 2005) have showed a steady decline in the lake waters. Therefore the research reveals that collective impacts of both climate change and human activities have exerted profound effects to the declining waters of Lake Naivasha.

Key words: climate change, human activities/anthropogenic activities, lake level

DEDICATION

This report is dedicated to my beloved family and friends.

TABLE OF CONTENTS

List of Figures

List of Tables

1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

Climatic variations in the past played a role in determining the levels in water bodies, yet climatic conditions and climate variations are still not well known. Paleoclimatic records in the tropics are scarce compared to the data available for higher latitudes despite the fact that the tropics are well endowed with paleoclimate archives. Wetlands including lakes and swamps provide longterm past changes in climate change and hence can help in understanding the impacts of climate changes on these water bodies.

Often a core is taken from the sediment of a limnological system, fossils and geologic signals that are preserved in the cores are clues to revealing the history of the lake or swamp. This can help in the reconstruction of the lake or swamp level in the past and the prevailing climate at the time.

Anthropogenic activities around the lake over the past century are not quite well known but in the last century abstraction of large volumes of water from the lake, this has also been attributed to the decline in lake level.

1.1.1 The study area

Lake Naivasha is a shallow basin lake, situated 80km northwest of Nairobi in the Kenyan rift valley. The lake (0. 45ºS, 36. 26ºE), altitude 1890m, lies in the Eastern Rift Valley and currently covers approximately 100 km^2. It is the second-largest freshwater lake in Kenya (after Lake Victoria). The lake is situated within the Gregory Rift Valley system that extends northward from Lake Malawi through Tanzania, Kenya, and Ethiopia, and is considered part of the valley that contains the Red Sea, and the Jordan valley. The lake is fresh, in a linear series of soda lakes north-south along the Rift floor and is situated in a semi-arid climate. Lake Naivasha gets its water from the Aberdare and Nyandarua highlands to the east and the Rift Valley, via two main rivers: the Malewa and the Gilgil Rivers, contributing 80 and 20 percent, respectively, to the surface inflow of the lake (Becht *et al*., 2005). The lake remains fresh due to a significant exchange of groundwater.

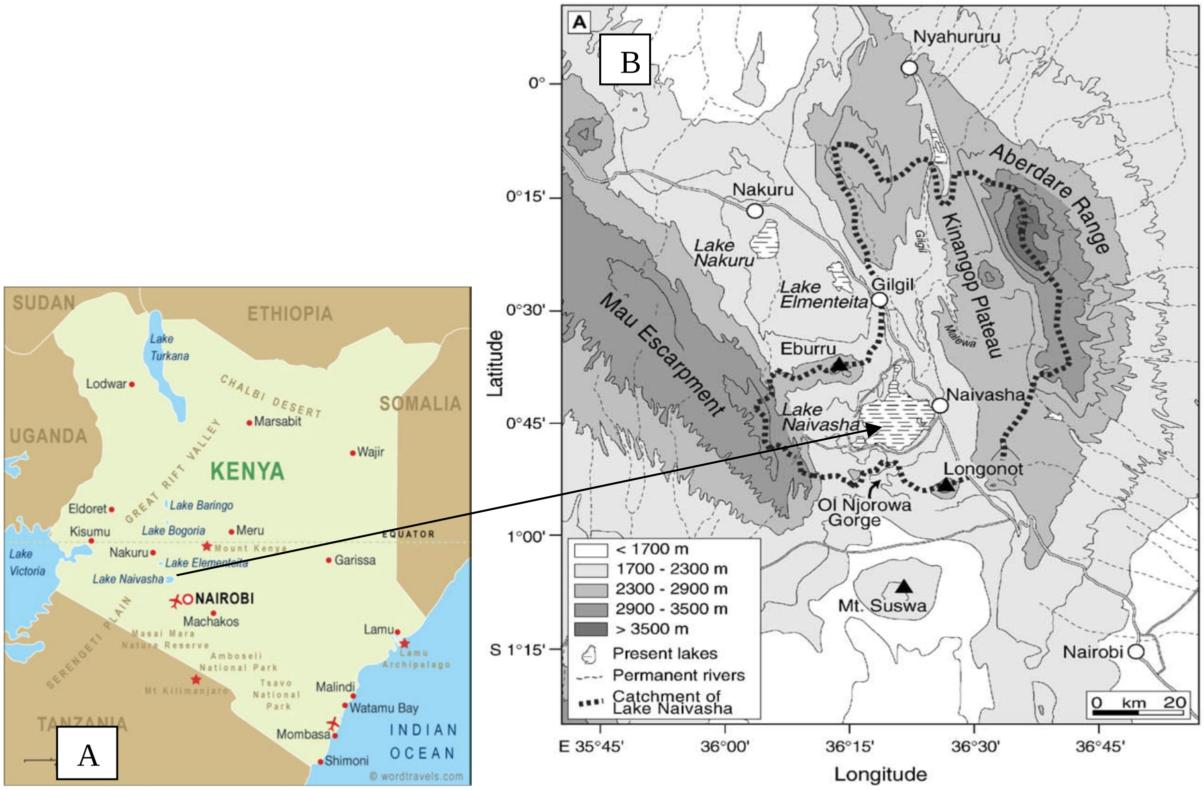


Fig1.1: (A) the study area in a map of Kenya, (source: Becht, 2007). (B) Lake Naivasha basin (source: Bergner et al., 2003)

1.2 Literature review

Richardson and Richardson, (1972), as they studied East Africa Quaternary climatic changes, they noted that lacustrine sediments reflect changes in water level and chemistry. They used this observation to reconstruct the past climatic changes in the area.

Abiya, (1996), in his study `Towards sustainable utilization of lake Naivasha, Kenya,' stated that Lake Naivasha has experienced level changes of more than 12m in the last 100 years.

A study conducted by Maitima, 1991, in Lake Naivasha on diatom, ostracod and pollen record suggests a high lake level, although it is the only record in the region to record the LGM (Late Glacial Maximum) as being a relatively wet period.

Verschuren *et al*., (2000), as they tried to reconstruct the fluctuations in the water levels in lake naivasha in the last 1800yrs, they noted that sediment records contain clear lithological evidence of an episode of complete desiccation in East African Lakes in the relatively recent past.

Trauth, *et al*., (2003), studied diatom and stromatolite sediments within the Rift Lakes and used various levels of salinities recorded on their shell to reconstruct past lake level and hence climate changes.

Jonson *et al*., (2001), studied a sediment record from Lake Naivasha, from this they provided a history of inferred lake level for the past 1100 yr. They indicate that Lake Naivasha reflects a relatively dry Medieval Warm Period from about A.D. 1000 to 1270 and a relatively wet Little Ice Age from A.D. 1270 to 1850.

Due to insufficient geographical coverage and partly due to the difficulty of extracting past patterns in rainfall and temperature, Muzuka *et al*., (2004) studied diatoms, chironomids and ostracods in lake-sediment sequence as proxy indicators of fluctuations in water level and chemistry as he conducted a research in the Rift Valley lakes. From their analysis they noted periods of highstands and lowstands in the past within the lake.

Olago *et al*., (2009) investigated the sensitivity of the east African lake to climate changes and they noted that the Medieval Warm Period and the Little Ice Age affected the water level in the lake.

Mavuti and Harper, (2005) in their study, `The ecological state of Lake Naivasha' noted that human activities have greatly affected the water level in the lake, this is strongly supported by Odada *et al*., (2005) when they document an estimate of water consumed from the lake by horticulture per year.

.

1.3 Problem Statement

Over past (1000yrs BP) Lake Naivasha has observed fluctuations in water levels, recent studies have indicated a steady decline of water in the lake of about 12m or more within just a few months causing a shift of the shoreline of several kilometers (Mavuti and Harper, 2005), human activities have impinged on the lake basin causing further decline of the lake. These dynamics add an extra dimension to the riparian ecosystem as well as complicating the water resource management issues. Therefore, the intent of this review is to address some of the key contributors (climate change and anthropogenic activities) of the observed ebb and flow.

1.4 Objectives

The main objective of the study is to determine how climate change and anthropogenic activities have affected the fluctuating water levels in Lake Naivasha.

Specific objectives;

- To study how lake levels have changed naturally over the past millennia.
- To study the impacts of human activities on Lake levels in the past 100 years.

1.5 Research Questions

Research questions were built up from the objectives and they included;

- How has lake level varied naturally over the past millennia?
- What human activities have taken place in Lake Naivasha and how have they affected the lake levels?

1.6 Methodology

The study is a literature review on;

- Palaeolimnological (sediment stratigraphy) and palynological data record done in African tropics and Lake Naivasha basin.
- Data on human activities in Lake Naivasha basin over the past.
- Data on the past climatic changes and water level variations in Lake Naivasha.

1.7 Rationale of the project

Lake Naivasha is the backbone of Naivasha town; its waters support major industries like fishing, horticulture, and tourism that bring substantial income to the locals and the country at large. The lake also creates a good microclimate in the rather hot semi arid area. However, in the recent past major fluctuations in the lake levels have been observed. Speculations to the principal factors responsible for these variations are subject to debate. Therefore the research intends to pinpoint some of the key issues causing the fluctuations and further defines measures that can be employed for sustainable management of the lake level.

2.2 GENERAL PHYSICAL CHARACTERISTICS OF THE AREA

2.1 Geology of the area

Geologically Lake Naivasha is situated at the highest elevation of the central Kenyan Rift. It is underlain by flood basalts (Miocene), phonolites (Pleistocene), trachytes (Quaternary), volcaniclastics, Quaternary deposits , and their weathering products (Olago *et al.*, 2009). Step faulting which produced the Rift Valley has led to extensive, and often intense, volcanic activity.

The valley floor is composed of a complex stratigraphy of volcanic and fluvio-lacustrine deposits laid down in Pleistocene times from a larger lake (Richardson, 1972; Butzer *et al*., 1972). The underlying rocks are a complex of fractured mosaics as a consequence of this tectonic activity, and include a deep and wide aquifer. Water from the lake seeps into this (Gaudet and Melack, 1981) and moves through it, probably both southwards towards Longonot and northwards towards Gilgil (Clarke *et al*., 1990).

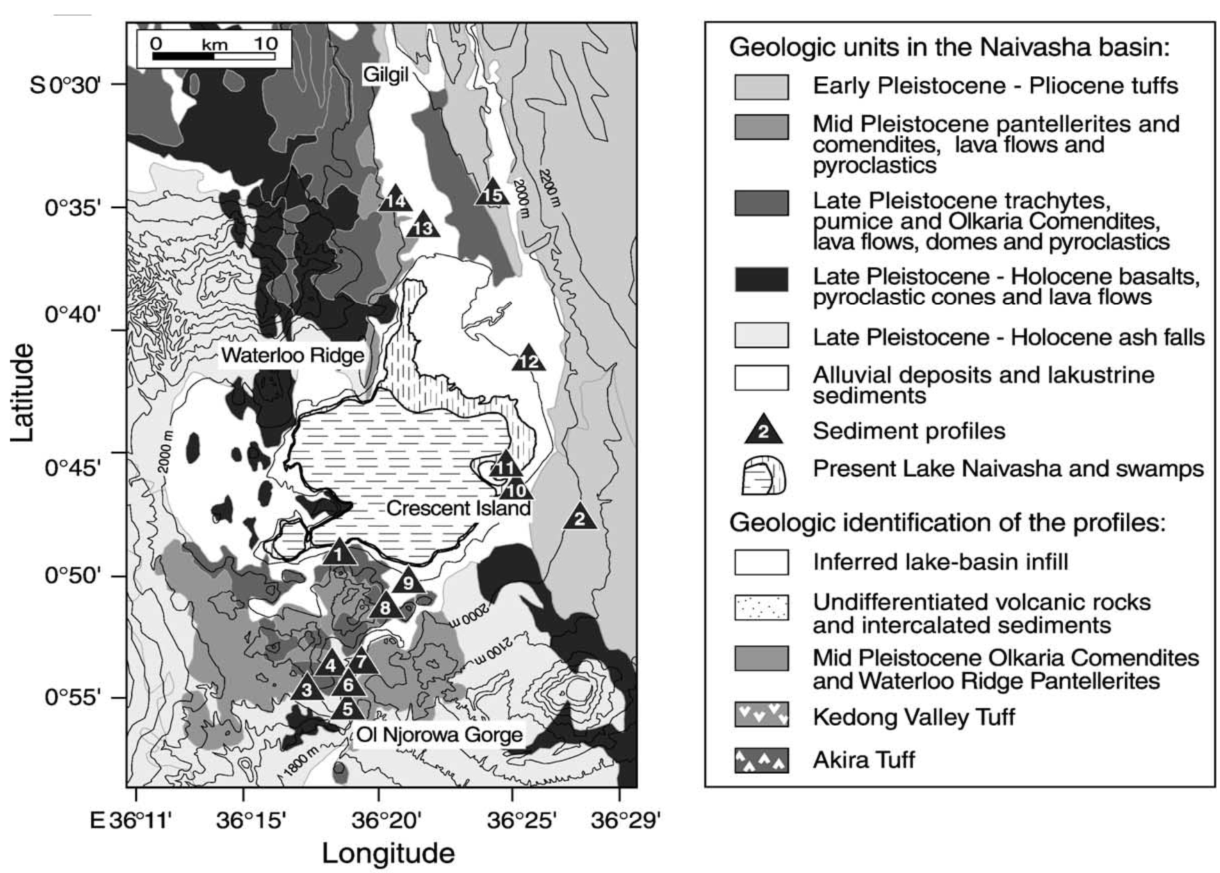


Fig1.: Lithological units in Naivasha basin (map after Clarke et al., 1990)

2.2 Climate

The climatic patterns in East Africa are very complex and change rapidly over short distances. This is attributed to large-scale climatic controls that include major convergence zones which are superimposed upon regional factors associated with lakes, topography, and maritime influences (Nicholson, 2000).

The climate of Lake Naivasha basin is governed by air streams and convergence zones that are linked to the seasonal shifts of the subtropical high-pressure cells situated about 20–30° north and south of the equator (Nicholson, 1996). The basin lies within the range of the Intertropical Convergence Zone (ITCZ). The rainfall distribution has a bi-modal character- The long rains from April to June and the short rains during October and November. Mt. Kenya and the Nyandarua range capture moisture from the easterly monsoon winds casting a significant rain shadow over the Lake Naivasha Basin.

The inter-annual variability of rainfall is high with a mean of 600 mm/year, but 10% of all years receive more than 900 mm or less than 450 mm. Lake Naivasha basin lies in the rain shadow of the highlands and experiences high daytime temperatures with an estimated evapotranspiration of 1865 mm/yr (Lamb *et al.*, 2002), making the region a semi-arid area. Strong correlations between inter-annual lake-level change and rainfall at seven nearby weather stations indicate that lake level is strongly influenced by annual rainfall (Vincent *et al.*, 1989).

Below (Fig 1.3) is a graph showing yearly rainfall distribution

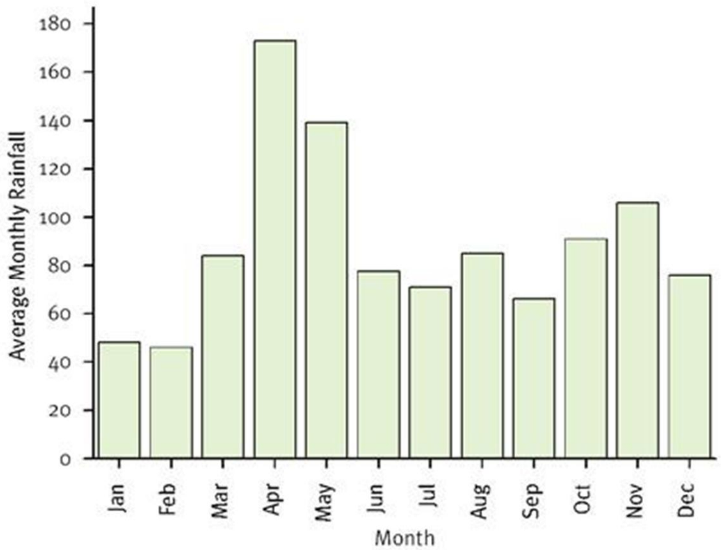


Fig1.2: Average monthly rainfall distribution in lake naivasha basin (source; Kenya meteorological department)

2.3 Hydrogeology and Water balance

Lake Naivasha is a freshwater lake, which has three associated satellite lakes that are hydrologically connected by either surface water or groundwater flow, namely, Crescent Island, Oloiden and Sonachi. The Malewa and Gilgil rivers account for 80 and 20%, respectively, of the river inflows to the lake (Becht *et al*., 2005). The Malewa River rises from the western slopes of the Aberdare range.

The lake fills a shallow water basin with gentle slopes, thus both the area and the water evaporation increases with rising lake levels. Groundwater in the volcanic regions of Kenya occurs at varying depths and several aquifers may exist on top of each other (IEA, 2006). The aquifers around Lake Naivasha are composed of lacustrine deposits derived from erosion and redepositions of the local volcanic rocks, and are characterized by relatively high discharge yields and transmissivities (Bwire-Ojiambo *et al*., 2003. Rare earth element (REE) studies suggest that a significant amount of the groundwater south of Lake Naivasha (50–85%) consists of lake water recharge to the aquifer system; indeed, mixing calculations conducted using REE data of Lake Naivasha water and groundwaters indicate that 70–85% of the groundwater in that area is likely lake water (Bwire-Ojiambo *et al*., 2003).

The water balance of the lake has been calculated for the period 1934-1983 (table 1) representing the period before large scale water abstractions began.

Table 2. 1: Lake naivasha water balance ($10^6 m^3$ / month). (Source: Mmbuie, 1999)

Rain	Surface water inflow	Evaporation	Groundwater flow
95	220	260	55

From the table it is notable that the inflow equalled outflow in the last 50 years but this has greatly altered by large water abstraction.

2.4 Vegetation within the basin

The fresh, shallow waters of Lake Naivasha support abundant aquatic macrophytes (Lamb *et al.*, 2002). Large areas of littoral *Cyperus papyrus* swamp have been cleared over the last 80 years, but it still occupied 54% of the lake shore in 1968 (Harper, 1992; Gaudet, 1977). It is less abundant around Cresent Island Crater (CIC) where the steeply shelving margins support a narrower macrophyte zone. The deep zones of CIC supports a relatively abundant phytoplankton community, with periodic blooms of green algae such as *Botryococcus braunii* (Richardson and Richardson, 1972). On Crescent Island, dense bushland is found close to the shore, dominated by *Rhus natalensis*. Some areas have a more open vegetation dominated by *Senecio hadiensis* and *Cynodon dactylon,* grazed by zebra and antelope. The natural riparian vegetation is dominated by *Acacia xanthophloea,* the characteristic riparian tree in southern Kenya (Lind and Morrison, 1974).

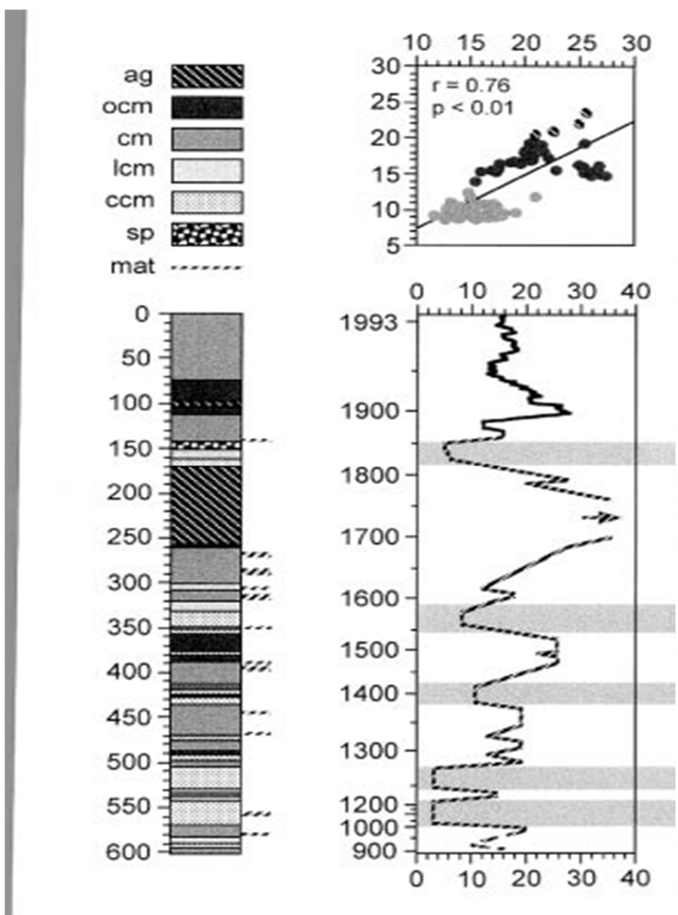
More dense *A. xanthophloea* woodland with a thicker undergrowth of herbaceous taxa including *Urtica massaica* occurs on the southern shores of Naivasha. Much of the riparian vegetation has been cleared to make way for agricultural production of alfalfa (*Medicago sativa*), cereals, and vegetables and flowers (Morgan, 1963; Richardson and Richardson, 1972; Gaudet, 1977). Away from the lake, the arid Rift Valley supports dry savanna grassland with scattered *Acacia* bushland and *Euphorbia* woodland. Large areas around Naivasha have been disturbed by cultivation and ranching, resulting in the expansion of a secondary bushland with *Tarchonanthus* *camphoratus*, *Dodonaea angustifolia*, *Acacia* and *Euclea* (White, 1983). *Tarchonanthus* bushland is particularly abundant on the Rift margins where, with *Olea europaea* ssp. *africana*, it may form an ecotone between the savanna and the upland forest (Maitima, 1991). Plantations of exotic trees, mainly *Eucalyptus*, are locally common in the Rift Valley. *Schinus molle* has been widely planted around Naivasha town.

3.0 CLIMATE CHANGE OVER THE PAST MILLENNIA

Meteorological records and written observations are limited to the very recent past (often only the past few decades); thus data on longer-term cyclical fluctuations is very limited, so geologists have opted to study climate proxies such as sediments and pollen in order to understand past climate variations and their impacts on water bodies. Some of the proxies are discussed below include pollen and sediments deposited over long geologic periods.

3.1 changes in the lake level over the past millennia

Verschuren *et al.*, (2001) studied sediments from cores raised from Lake Naivasha and its two satellite lakes (Oloiden and Sonachi). From the cores he identified six different lithological units representing different depositional times. Fig 3.1 below shows the lithological units derived from the lake.



Lithological units

Inferred Lake Levels

Key

ag- algal gyttja

ocm- organic clayey mud

icm-

ccm- calcerous clayey mud

sp- silty peat

mat- diatoms

Fig 3. 1: Sedimentological evidence (from CIC), of past lake depth. (Modified from Verschuren, 2000)

The six units reflect variations in bottom dynamics, clastic input, and water chemistry related to the depth of the lake and its degree of hydrologic closure at the time of deposition. Analyses of modern and historical sedimentation patterns in CIC and neighboring lakes revealed strong and consistent relationships between sediment composition and lake depth; these relationships can be used to reconstruct former fluctuations in lake depth. Variation in organic-carbon content in the lithological sequence from clayey mud to gelatinous algal gyttja is positively correlated with lake depth because its dilution by relatively coarse-grained, inorganic littoral sediments is reduced during highstands. Deposition of calcareous clayey mud reflects biogenic carbonate precipitation following the evaporative concentration of dissolved salts. This, (concentration of salts) also indicates prolonged hydrologic closure of the crater basin during lowstands below the elevation of the sill connecting it to Lake Naivasha. Deposition of silty peat with abundant remains of the aquatic plant Ceratophyllum is interpreted to reflect a freshwater lowstand when submerged macrophytes grew across the bottom of the crater (5 m depth), while the shallow basin of Lake Naivasha stood dry.

Analysis

From the fig 3.1 above it can be noted that CIC experienced a long saline lowstand from about AD 1000 to 1270, a similar occurrence is documented in Loboi plain (between lakes Bogoria and Baringo) by Olago *et al*., (2009), where abrupt wetland formation is related to a climate shift from the previous drier conditions (MWP ~AD 800-1270). This lowstand was followed from, AD 1270 to 1550 by a mostly positive water balance and establishment of freshwater conditions, which is correlated with the increase in *Podocarpus* pollen by Lamb *et al*., (2002). After a second pronounced lowstand dated to, AD 1560-1590, CIC rose to a highstand that lasted from about AD 1670 to 1770, with lake level continuously above the historical maximum reached in 1894.

The prominent eighteenth-century highstand ended with strong lake-level decline culminating in a third lowstand during ~AD 1810-1850. Renewed lake filling in the mid nineteenth century achieved the intermediate levels that preceded the historic highstand of the late 1880s and 1890s, which is correlated with high levels in Lake Turkana (Olago *et al*., 2009)

From this data it can be noted that East Africa was generally drier than today during the Mediaeval Warm Period (MWP ¬AD 1000 to 1270), and that fairly wet conditions during the

Little Ice Age (LIA ¬AD 1270-1850) were interrupted around AD 1380-1420, 1560-1620 and 1760-1840 by episodes of persistent aridity more severe than any recorded drought of the twentieth century. This period of aridity and the first occurrence of *Zea mays* (maize) pollen together with peak abundances of *Ricinus communis*, (~AD 1650), is interpreted as movement of humans to the shorelines in search of water, (Lamb, *et al*., 2002). This pronounced lowstand agrees with historical sources indicating severe aridity in East Africa from the late 1700s to the 1820s and 1830s, followed by a return to wetter conditions by the mid-19th century (Nicholson, 1995). A sharp rise in the lake level in the mid 1990s is also correlated with highstands during the same time in Lakes Victoria, Turkana, Elementeita, Nakuru, Edward, Albert and Tanganyika, (Richardson & Richardson, 1972; Vincent *et al.*, 1989).

Richardson & Richardson, (1972), reported that Lake Naivasha was nearly twice as extensive in the early 1920s as in 1960 but thereafter a steady decline has been observed which is interpreted as reflecting, in part, a decreasing rainfall trend averaging about 5 mm year^{-1} over the basin between 1920–1949 (Sansome, 1952), as well as perhaps increasing human consumption from river influents and borehole pumping (Richardson & Richardson, 1972), though recent research suggests that human impacts on lake level began to be felt only about 30 years ago (Becht & Harper, 2002).

4.0 ANTHROPOGENIC ACTIVITIES IN THE LAKE BASIN IN THE PAST CENTURY

4.1 Introduction

Many scientists believe that global warming is likely, in many regions to alter the distribution of freshwater, an important resource that supports human activities and ecosystems. Increased temperatures will mean that evaporation will occur at a higher rate promoting cycles of intense drought and floods (Long, 2005). Droughts on the other hand will drive human population to seek alternative sources of freshwater for survival as noted by Sutton, (1993); the abundance of pasture within Amboseli basin encouraged movement of pastoralists into the area and primarily near Namelok catchment during dry periods.

Mavuti and Harper, (2005) indicates that human activities started way long ago with only small areas under cultivation of vegetables and fodder crops. However, in 1929, Lake Naivasha Riparian Owners Association (LNROA) was formed to resolve the disputes adjacent land owners over their use of this riparian lake bed (Eniskellen, 2002), this is correlated with a steady decline observed by Richardson & Richardson, (1972), reflecting in part, a decreasing rainfall trend averaging about 5mm $year^{-1}$ over the basin between 1920–1949 (Sansome, 1952), as well as perhaps increasing human consumption from river influents and borehole pumping.

Anthropogenic activities affecting the lake levels the past century are enormous, some of the dominant ones are:

4.1.1 Population pressure

Global population projection indicates that world population will increase by 20% from 6 billion in 2000 to 7 billion by 2015 and 7.8 billion by 2025 totaling to 30% increase, (UNEP, 2003)

In Kenya, UNDP, (2000), indicate that the population in 1998 was 29 million and the expected population by 2015 is 37.6 million. These figures indicate the annual growth rate of 3.8% for 1975-1998 and anticipated annual growth rate for 1998-2015 to be 1.5%, projecting the increase in water for consumption. The total population in Lake Naivasha basin in the early 1900s is not quite well documented but population census during the mid 20^{th} century indicates a steady rise in population. The 1999 population census report indicates that both Naivasha and Nakuru areas have witnessed an increase in population between 1979 and 1989, and a noticeable decrease in

Naivasha urban core in 1999 (table 2.1 below). However the whole of Naivasha municipality harbors 115,000 persons as per the bureau of statistics.

Table 4. 1: Population of towns (source: 1999 census report, www.citypopulation.de)

Town	Province	Population in year 1979	Population in year 1989	Population in year 1999
Naivasha	Rift valley	11,491	34,519	32,222
Nakuru	Rift valley	92,851	163,927	219,366

In the nearby Nakuru area (get's its water from lake Naivasha), acute water shortages have been reported, (Odada, *et al*., 2005) with demand being 45000 to 5000m^3/day resulting to a shortfall of about 1000m^3/day, this figure indicates that chances of Naivasha basin to experience the same is high but at a slightly lower margin.

4.1.2 Industrialization

Much of the worlds is concentrated in developing and rapid emergent economies, third world countries account for only about 14% of the world's industries Kenya included, (UNEP, 2003).

Over the last 100 years several industries have come up in the lake basin and have used the water either directly by abstraction or indirectly through tapping geothermal power.

.

4.1.3 Agriculture

Agriculture has been the main stay of local livelihoods and the major national GDP in Kenya and other African countries. UNEP, (2003) indicates that irrigated land produces 40% of the world's freshwater withdrawals, this sheds light on the amount of water agriculture consumes. In Naivasha, for example, horticulture industry commenced in 1982 and since then there has been tremendous increase in the industry causing a decline of about 10m in the lake level (Abdul, 2006)

Betcher and Harper (2002) noted that abstraction rates in Naivasha area constantly increasing over the last 15 years to occupy about 4,000 ha due to expanding area under irrigation. Boateng, (2001), extensively studied soils in assessment of the use of groundwater for irrigation in

Naivasha where he noticed that the weathered soils from volcanic and basement rocks are highly infiltrative and absorptive indicating that irrigation of crops in the basin consumes a lot of water.

The figure below shows some of the horticulture industries around the lake.

Fig 4. 1: Horticultural farms along the shores of Lake Naivasha

From the figure, the extent of human activities is very evident with horticultural farms covering most of the lakeshores. These horticultural farms draw a lot of water for irrigation from the lake.

5.0 SYNTHESIS AND DISCUSSIONS

Synthesis falls on two folds;

1. Impacts of climate change (by studying the lake sediments) on lake levels.
2. Anthropogenic impacts on lake levels.

5.1 Impacts of climate change over the past millennia

The palaeoclimate records of North and East Africa, and the Americas, indicate with high confidence that droughts lasting decades or longer were a recurrent feature of climate over the last two millennia, and that under gradual climate forcings the periods can be abrupt as indicated by fluctuations in the lake levels (Olago *et al.,* 2009).

During the last millennium, decade-scale periods of droughts and intervening wet periods have been documented in Lake Naivasha, and are related to high and low phases of solar radiation, respectively (Verschuren *et al*., 2000). The drier periods in Lake Naivasha basin are associated with the Medieval Warm Period (~AD 1000-1200), while the wet periods are correlated with the Little Ice Age (~AD 1270-1850) (Verschuren *et al*., 2000), which were interrupted around AD 1380-1420, 1560-1620 and 1760-1840 by episodes of persistent aridity more severe than any recorded drought of the twentieth century. These similar lowstands and a highstands are observed in lakes Victoria, Elementeita, Bogoria, Nakuru, Edward, Albert and Tanganyika, (Richardson & Richardson, 1972; Vincent *et al.*, 1989; Kiage and Liu, 2009).

There has been indications that the Indian Monsoon rainfall has been decreasing over the past century and that its variation over the past century is not outside of the range of the past 800 years (Burns *et al*., 2002), this may explain the declining lake levels observed by Richardson and Richardson, (1972) between 1920-1949 and the declining rainfall trend, (Sansome, 1952).

5.2 Anthropogenic impacts on lake levels

Significant anthropogenic activities in Naivasha basin are subject to the quantity of water in the lake. These include population pressure industrialization and agricultural activities.

5.2.1 Population pressure

Evidence of human impacts around the lake started way back in the 1650 AD, where the first appearance of *zea mays* pollen in the cores was noted by lamb *et al*., (2002). Since then there has been a steady increase in extensive cultivation and rapid urbanizing due to the increase in population. A key driver in the substantial increase population has been from the rise in fertility in women and the in-migration. The average number of children per homestead (from each married woman) in 1975 used to be 8.1, but today the figure has decreased to about 4.5 per woman, but still the figure is above the global average of 2.8 (MCN, 1999). Basing on the 1999 population census report (table 2.1) the demand of potable water by the population surrounding the lake is very high outpacing the demand. Due to limited water resources available per person in the region some people have resolved in sinking their own boreholes. Sinking of boreholes has in led to abstraction of water at a rate higher than its natural replenishment causing a decline in groundwater level and lake level, owing that the lake is hydraulically connected to the groundwater system.

5.2.2 Industrialization

Clear impacts of industrialization are observed in last three decades. Deforestation has therefore increased in search for new lands for industries and settlement of worker. Deforestation has caused higher levels of runoff and erosion thereby silting the lake. Siltation causes a major threat to evaporation owing that the lake will have a higher surface area to volume ratio.

Greenhouse gases have increased due to the rapid growth of industries emitting various gases (CO_2, CH4, N_2O and CFCs). These gases will have a significant influence to global temperatures and an increase in the overall evaporation rate.

5.2.3 Agriculture

Agriculture caters for 75% of the GDP of the country, the rift valley being regarded as "farmer capital," is rich in agricultural hinterland and famous for its agro-based industries. Large scale farms include the horticultural farms, and fodder farms. Other agricultural zones include numerous small-scale farms in the peri-urban areas. Subsequent with extensive urban farming, rising demands for water resource is recorded. Amani, (2004) in his research in the area noted that the basin is subject to a cone of depression and lowering of ground water level. Boateng, (2001), extensively studied soils in assessment of the use of groundwater for irrigation in Naivasha where he noticed that the weathered soils from volcanic and basement rocks are highly infiltrative and absorptive indicating that irrigation in the area takes a higher amount of water than normal moderate soils. Cultivation in the upper areas (the highlands and along the feeder rivers of lake Naivasha) has also indicated higher levels of siltation jeopardizing the lake depth and the overall water quality. Some of the crops grown around the lake are summarized in the pie chart below.

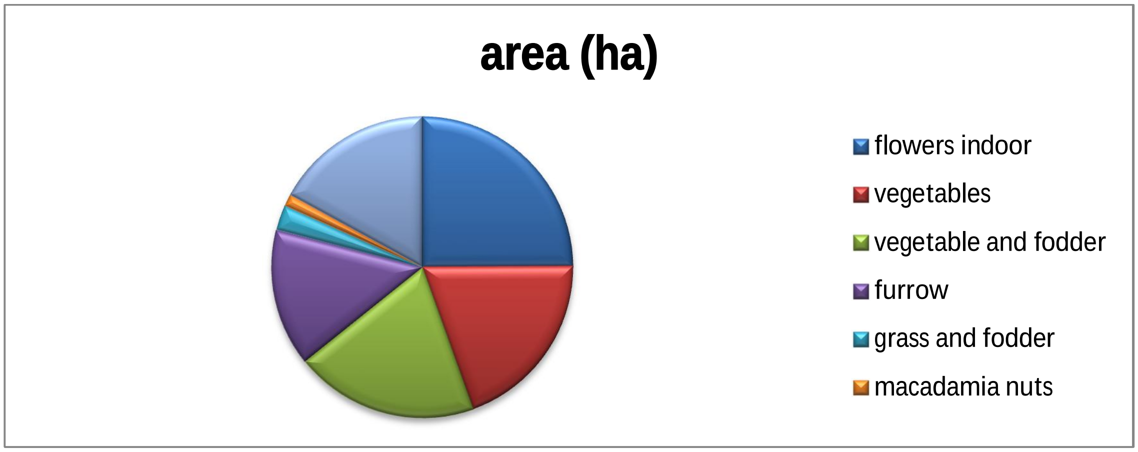


Fig 5. 1: Area under irrigation in the lake basin covering 3966ha. (Modified after Harper, 2003).

Findings

- Both change in climatic patterns and anthropogenic activities have impacts directly and indirectly on the lake level.p
- Due to current climatic changes and the growing human population the lake level is projected to further decline if no measures are put in place.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1Conclusions

Climate, geology, geological structures (faults) and human activities greatly influence the lake level in this area. Sedimentological records from the CIC indicates that, periods of dry and wet climatic conditions are cyclic in the area with extreme dry periods (drier than today) occurring in the Medieval Warm Period (~AD 1000-1200) and wet periods during the Little Ice Age (~1270-1850). Both dry and wet periods have been observed in the East Africa region and they have been correlated with high and low phases solar radiations respectively. Droughts have also been noted as lasting decades or longer and that they are a recurrent feature of climate in the last millennia.

It is apparent that the extend of human influence on lake Naivasha waters started over 70 years ago with the last 3 decades indicating an accelerated demand for portable water. The anthropogenic activities stressing the lake are mainly; population pressure, industrialization, and agriculture, however empirical evidence from sediments and pollen analysis shows that climate is the factor that seems to dominate the fluctuations of water in Lake Naivasha.

6.2 Recommendations

Protection measures on water in the lake should be impacted through;

- Reforming land use management plans leading to controlling activities which can lead to over abstraction of water from the lake or boreholes.
- Preserving the riparian strips.
- Controlling the number of boreholes by registering owners.
- Preventing high rates of siltation by forest conservation and educating farmers on good farming practices.
- Encouraging farmers to use modern farming methods which are both cost effective and have minimal water usage.
- Promoting proper sewage disposal other than dumping in the lake.

Moreover, the lake management authority should define the lake edge and mark a 200m buffer above it where human activities should not reach.

Acknowledgement

My sincere appreciation goes to my advisors Prof. E. O. Odada and Dr. C. Nyamai for their valuable guidance in this research. I would like also to acknowledge Ms. C. Omuombo for her tireless efforts and guidance all through the research work. Lastly my gratitude goes to the entire geological department for their support and motivation.

REFERENCES

Abiya, I.O. (1996) `Towards sustainable utilization of lake Naivasha, Kenya,' Lakes and Reserviors, 231-242

Amani, A. (2004) Modeling of water resource management in Lake Naivasha, Msc Theisis, International Institute for Geo-Information science and Earth observation Nertherlands.

Becht, R., Odada, O., and Higgins, S. (2005) Lake Naivasha: Experience and lessons learned brief. In: ILEC, 2005, Managing lakes and their basins for sustainable use: A report for Lake Basin managers and stakeholders, International Lake Environment Committee Foundation. Kusatsu, Japan.

Bwire-Ojiambo, S., Berry Lyons, W., Welch, K. A., Poreda, R. J. & Johannesson, K. H. (2003) Strontium isotopes and rare earth elements as tracers of groundwater-lake water interactions, Lake Naivasha, Kenya. *Appl. Geochem.* 18, 1789–1805.

Census Report, (1999) Populations of towns and housing census Report. www.citypopulation.de

Clarke, M.C.G., Woodhall, D.G., Allen, D., Darling, G. (1990) Geological, volcanological and hydrogeological controls on the occurrence of geothermal activity in the area surrounding Lake Naivasha, Kenya. British Geological Survey Report and Government of Kenya—Ministry of Energy, Nairobi, Kenya.

Gaudet, J.J. (1977) Natural drawdown on Lake Naivasha, Kenya, and the formation of papyrus swamps. *Aquatic Botany* 3, 1–47.

Gaudet, J.J. and Melack, J.M. (1981) Major ion chemistry in a tropical African lake basin. *Freshwater Biology* 11, 309–33.

Harper, D.M. (1992) The ecological relationships of aquatic plants at Lake Naivasha, Kenya. *Hydrobiologia* 232, 65–71.

Harper, D.M., Mavuti, K.M. and Muchiri, S.M. (1990) Ecology and management of Lake Naivasha, Kenya, in relation to climatic change, alien species introductions and agricultural development. *Environmental Conservation* 17, 328–36.

IEA (Institute of Economic Affairs), (2006) A rapid assessment of Kenya's water, sanitation and sewerage framework. IEA, Nairobi, Kenya.

Kiage,L.M, Liu, K. (2009) Palynological evidence of climate change and land degradation in the Lake Baringo area, Kenya, East Africa, since AD 1650, 60-72

Lamb, H. Derbyshire, L. Verschuren, D., 2002. Vegetation response to rainfall variation and human impact in central Kenya during the past 1100 years, 76

Long, D. (2005) Global Warming, New Delhi: Vinod Vasishtha, 3-5.

Mavuti, K.M., Harper, D.M. (2005) The ecological state of Lake Naivasha, Kenya, 2005: Turning 25 years research into an effective Ramsar monitoring programme, 30-33

MCN, (1999) Strategic Nakuru Structure Plan. Action planfor sustainable development of Nakuru town and its environs. Nakuru. Municipal council of Nakuru (Final Draft).

Morgan, W.T.W. (1963) The 'White Highlands' of Kenya. *The Geographical Journal* 129, 140–55.

Nicholson, S.E. (1996) A review of climate dynamics and climate variability in Eastern Africa. In: Johnson, T.C., Odada, E. (eds.), The Limnology, Climatology and Paleoclimatology of the Eastern African Lakes. Gordon & Breach Publishers, Amsterdam, pp. 549– 557.

Nicholson, S. E., (1995) Environmental change within the historical period. In A. S. Goudie, W. M. Adams & A. Orme (eds), The Physical Geography of Africa. Oxford University Press, Oxford, 60–75.

Nicholson, S. E. (2000) The nature of rainfall variability over Africa on time scales of decades to millennia. *Global Planetary Change* 26, 137–58.

Odada, E.O., Rain, J., and Ndetei, R. (2005) Global experience and African issues. Management of Lake Basin for their sustainable uses. 11th World Lakes Conference. Nov. 2005. Kenya.

Odada, E. O., Onyando, J. O. & Obudho, P. A. (2005) Lake Baringo: experience and lessons learned brief. In: *ILEC 2005: Managing Lakes and their Basins for Sustainable Use: A Report for Lake Basin Managers and Stakeholders*. International Lake Environment Committee Foundation, Kusatsu, Japan.

Olaka, L.A., Odada, E. O., Trauth, M.H., Olago, D. O., 2010. The sensitivity of East African rift lakes to climate fluctuations, 629-644

Richardson, J.L. and Richardson, A.E. (1972) History of an African Rift lake and its climatic implications. *Ecological Monographs* 42, 499–533.

Sansome, H. W. (1952) The trend of rainfall in East Africa. *East Africa Meteorology Dept Tech. Memo. 1.*

Sutton JEG. (1993) Deloraine: Further excavations and the Iron Agesequence of the central Rift. *Azania* 17: 103–125.

Tole, M. P., (1996) Geothermal energy research in Kenya: a review. *J. Afr. Earth Sci.* 23(4), 565–575.

Trauth, M.H., Deino, A., Bergner, A.G.N., Strecker, M.R. (2003) East African climate change and orbital forcing during the last 175 kyr BP. Earth Planet. Sci. Lett. 206, 297-313.

UNDP, (2000) Human Development Report 2000. New York Oxford university press.

UNEP, (2003) Groundwater and its susceptibility to degradation. A global Assesment of the problem and Management.

Verschuren, D., Kathleen, R. L. & Cumming, B. F. (2000) Rainfall and drought in equatorial East Africa during the past 1,100 years. *Nature* 403, 410–413.

Vincent, C. E., Davies, T. D., Brimblecombe, P. & Beresford, A. K. C. (1989) Lake levels and glaciers: indicators of changing rainfall in the mountains of East Africa. In: *Quaternary and Environmental Research on East African Mountains* (ed. by W. C. Mahaney), 199–216. Balkema, Rotterdam, The Netherlands.

White, F. (1983) The vegetation of Africa. *A descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa*. Paris: UNESCO.