DETERMINING THE EFFECTS OF LAND USE AND LAND COVER CHANGES ON SIZE OF LAKE BOGORIA USING GIS AND REMOTE SENSING

BY

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DECLARATION

DECLARATION BY CANDIDATE

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This thesis has been submitted with our approval as University supervisors.

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DEDICATION

This work is dedicated to my Parents Mr/Mrs Kurgat and Husband Raymond Mwangata; you are the source of my inspiration.

ABSTRACT

Land cover and land use changes in the Lake Bogoria catchment area have had diverse influence on the lake. The aim of this study was to determine the land use and land cover changes that have affected the size of Lake Bogoria using GIS and Remote Sensing**.** Data was obtained from LANDSAT (1986 and 2000) and ASTER images (2008). A combination of geographic information systems and digital image processing software were used to process the images and determine the percentage change in the identified land use/land cover classes. IDRISI-software was used to create the change maps. Spatial data analyses covering the period of 1986 and 2008 indicated an extensive change of land cover characters that have really affected the lake. The study showed decrease in the size of the lake from 32.76 km^2 (1986), 32.07 km^2 (2000) to 30.59 km^2 (2008). A significant correlation in the change map between the increase of cultivated area from 610.27 km^2, 624.82 km^2 to 734.17 km^2 (1986, 2000 and 2008), built up area from 56.80 km^2, 58.65 km^2 to 63.97 km^2 (1986, 2000 and 2008) and the size of the lake was obtained. Increase in the two land cover types had negative effect on the size of the Lake as a result of over abstraction of water by farmers for irrigation. Results showed fluctuations in shrub (551 km^2, 225.37 km^2 and 620.57 km^2), Forest (74.21 km^2, 70.50 km^2 and 146.34 km^2) and grassland (138.55 km^2, 465.39 km^2 and 637.84 km^2) in the three years respectively. There was general decrease in bare ground (231.7 km^2, 214.35 km^2 to 21.30 km^2) as a result of increased infrastructure and farming. The study recommends the need of Intergrated River Basin Management Approach for long-term conservation of rapidly declining natural resources and development of a framework for decision makers who can promote conservation of such threatened and unprotected habitats.

Keywords: Land use/Land cover, GIS and Remote Sensing and Catchment Area.

DEFINITION OF WORKING TERMS

Land use refers to the human use of land for instance grazing and agriculture.

Land cover represents biophysical cover for instance woodland, forest and grassland.

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LIST OF ACRONYMS

WWF	World Wide Fund for Nature
GIS	Geographic Information Systems
LBNR	Lake Bogoria National Reserve
GPS	Geographic Position System
U.S.G.S	United States Geological Survey
IBA	Important Bird Area

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CHAPTER ONE

INTRODUCTION TO THE STUDY

1.1 Introduction

Lakes and other water bodies such as rivers are dying world over. Africa's lakes are reducing in size rapidly (Sharma *et al.,* 2001). Rapid land cover changes occurring in the Rift Valley of Kenya are altering the hydrologic characteristic of critical watersheds. Land cover change affects hydrologic response at a watershed scale (Calder, 1993; Krhoda, 1988; Miller et al., 2002; Sharma *et al.,* 2001). Over time, these can lead to water shortages, desertification, and habitat destruction (Cirone and Duncan, 2000; King and Hood, 1999; Krhoda, 1988; Mathooko and Kariuki, 2000; Mathooko et al., 2001; Mistry, 2000; Navrud and Mungatana, 1994; Patz, 2001).

Lakes in the rift valley region of Kenya, including Bogoria, Turkana, Baringo and Nakuru have been reported to have shrunk significantly. Many reasons have been advanced to explain these shrinkages. These include climate change, excessive water abstraction for irrigation, reduced river inflow due to catchment degradation, siltation and increased outflow from newly formed underground rivers.

Lake Bogoria National Reserve is an important conservation area in Kenya holding regionally and nationally endangered species. The reserve has unique physiographic features and geothermal manifestations due to its geological history (Renaut and Tiercelin 1993). The combination of landforms, biodiversity content, availability of water and forage makes this site important at community, national and global levels. It was designated as a national reserve in 1974 and in 2001 it was listed as a wetland of international importance under the Ramsar convention. Revenue from tourism, related activities and other natural resources in the reserve can play an important role in the socioeconomic development of the area.

The National reserve is at risk from environmental degradation arising from unsustainable resource exploitation and ecologically negative catchment-wide processes. The root causes of these problems are poverty, poor land use, overstocking and unsustainable farming systems. These socioeconomic circumstances of the populace and the environmental impacts are threatening Lake Bogoria National Reserve and its wider catchment (WWF, 2007 plan).

1.2 Statement of the Problem

Land use/cover studies using GIS which is a set of tools that captures, stores, analyzes, manages, and presents data that are linked to location(s) and remote sensing data have received immense attention worldwide due to their importance in global change analysis (Chilar, 2000). Observations from satellite imagery and information from the local communities seem to confirm the fact that Lake Bogoria is actually shrinking. These observations indicate that the shrinkage is not uniform around the lake; some parts seem to be shrinking faster than others. Further, there is no empirical data showing the patterns and extent of shrinkage of the lake. It is also not known whether the factors causing this shrinkage are global such as climate changes or local including reduced inflow and siltation arising from catchment degradation.

This study aims at establishing the linkages between the changes in landcover and landuse activities around the lake and its wider catchment and the patterns of the lake shrinkage over the years using satellite imagery and GIS analysis.

1.3 Objectives and Hypothesis of the Study

Overall objective

1. To determine the effects of land use and land cover changes on size of Lake Bogoria.

Objectives

1. To determine the changes in size of lake Bogoria between 1986 and 2008.
2. To determine the changes in land use/land cover in lake Bogoria catchment area between 1986 and 2008.
3. To establish the relationship between landuse/landcover changes in the catchment and patterns of Lake Bogoria size changes.

1.4 Research Questions

1. What changes have occurred in size of Lake Bogoria between 1986 and 2008?
2. How are these changes distributed around the lake?
3. What land use/land cover changes have occurred in Lake Bogoria catchment?
4. What is the relationship between the change in land use/land cover and the reduction in the size of the Lake?

1.5 Assumptions

Lake Bogoria is characterised by steep shoreline and has a trough basin morphometry which is assumed to have no effect on the water level change.

1.6 Justification Of The Study

Land use and land cover information is significant in the management of natural resources. Campbell (2007) asserts that almost all governmental units have a continuing requirement to form and implement laws and policies that directly or indirectly influence existing or future land use. There is increasing recognition that sensible use of finite or possibly shrinking resources requires comprehensive planning of private and public facilities with amounts and locations of human resources. Uncoordinated development can lead to inefficient and undesirable environment, social and economic conditions.

Land use information forms an important part of decisions made at state level. State legislation must address issues regarding allocation of land to alternative uses, either in specific geographic regions, or through general policies tailored for specific statewide goals. In either context the availability of accurate information regarding existing uses of the states land is an important element in formal decisions (Cambell, 1996).

Land use information at national level is an important element in forming policies regarding economic, demographic and environmental issues. International requirement for land use data also focuses upon many of today's major changes in land use within the world biomes may have generated effects upon global biochemical cycles and energy balance. Other issues that require world-wide perspective include changes in global patterns of agriculture and forestlands, settlement pattern and to control environmentally questionable practices. Land use is also of great significance in scientific and scholarly research. National and regional land use patterns reflect the characteristics of the interaction between people and environment and influence of distance and resources base upon human economic activities. As a result geographers, economists, and others have long recognized knowledge of regional land use patterns as a fundamental element in the studies of economic system. Land use pattern are also recognised as influential elements in hydrological and meteorological processes. The importance of land use theory developed by Johann Heinrich Von Thunen, August Losch, and others working in the disciplines of regional sciences, economics, and geography is evidence of the fundamental nature of land use in both theoretical and application (Cambell, 1989). Therefore this study aims at determining the effects of land use and land cover changes on size of lake bogoria

1.7 Scope and Limitation of The Study

The study covered Lake Bogoria Catchment Area. It concentrated on determining change in size of the lake and analyzing land use/landcover change over specified period of time (1986 to 2008). In subject matter the study explored the nature and extent of land use and land cover changes in the area. The study limited itself to gather data on; landuse/landcover change in terms of location and size. Data was collected by conducting field surveys, extracting information from existing topographical maps and images. The study brought out the changes in each land use category and implication of each land use type on the environment.

1.8 Study Area

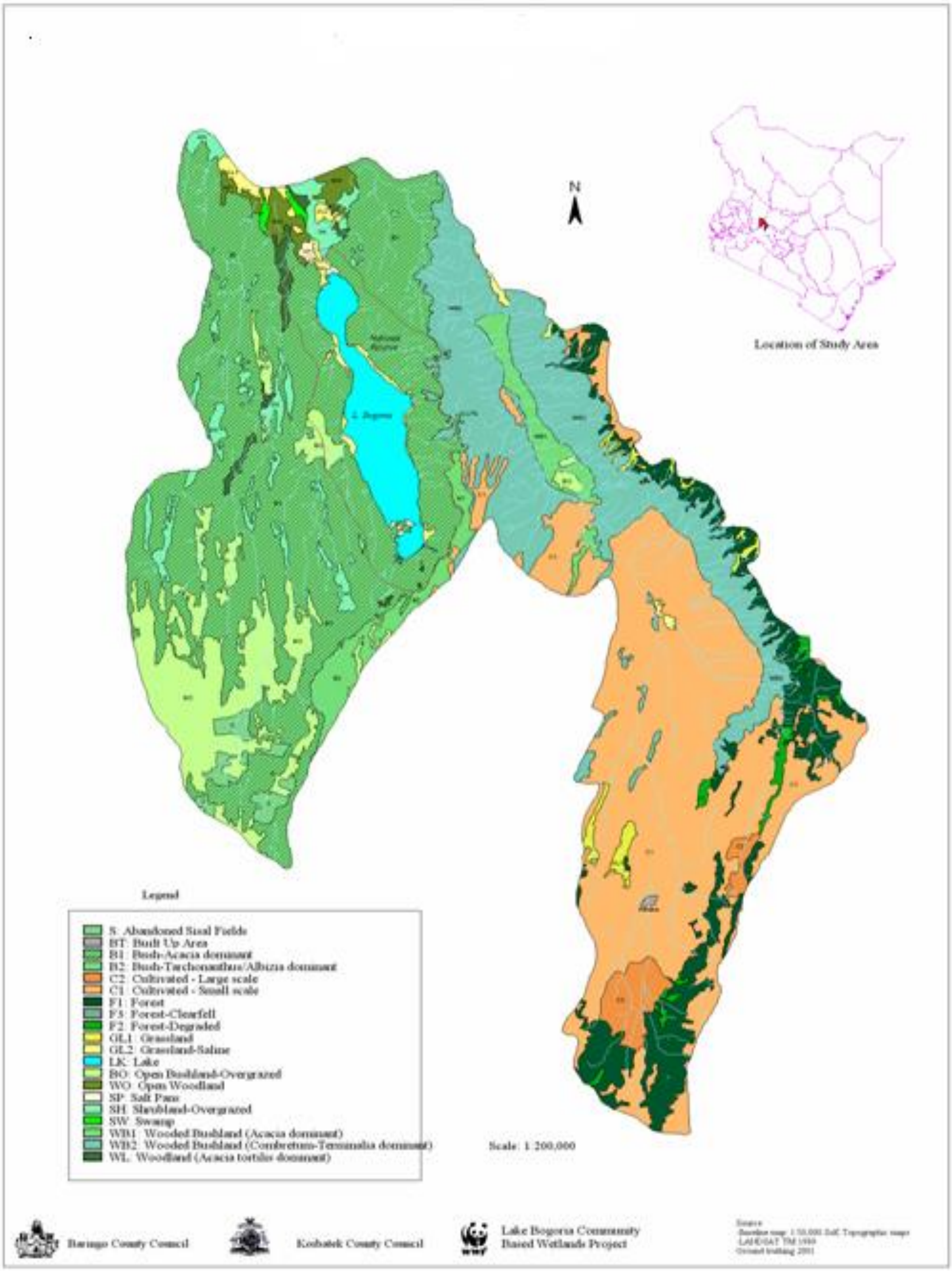

Figure 1.1: Location of the Study Area (LBNR Sub Catchment Plan)

Source: (Author, 2014)

1.8. 1 Physiography, Geology and soils

Lake Bogoria and its catchment have been affected by past tectonic events of faulting, warping, and volcanic eruptions associated with the formation of the Rift Valley (Renaut and Tiercelin, 1994). The area has geologic manifestations of ongoing volcanic processes in the form of fumaroles, hot springs and geysers within the lake, along the lakeshores and various points in the surrounding areas (North Lewis, 1998). The lake is located along one of the major blocks defining faults in the Rift Valley, the Solai-Subukia fault block, which includes the Solai, Iguamiti and South Arabel fault scarps. Lake Bogoria is partially separated from this main fault block by the Kisanana- Chemasa-Emsos fault that merges into Lake Bogoria fault along the Emsos fault structure at Sirken Hill. These fault lines are aligned in the north - south direction with Sandai deposition pans infilling a large portion of the graben north of the lake and stretching to Lake Baringo (Renaut and Tiercelin, 1994).

The area is characterised by volcanic rocks and sediments overlying metamorphic substrata, which belong to the Pleistocene and Miocene geological eras. The area is highly faulted and fissured with the major rivers flowing north along the fault-lines. Close to the Lake and its surroundings are stratified deltaic silts and saline deposits (Mulwa *et al.,* 2006). The western section of the Lake comprises of analcitic phonolites and porphyritic trachytes. The Eastern section beyond the deltaic silts comprises of sedimentary deposits, volcanic soils, screes and alluvium. Porphyritic olivine basalts are also found along the eastern faults bounding Lake Bogoria (Renaut and Tiercelin, 1994).

Lake Bogoria drainage basin has three major soil types; clay soil, clay loam and silt loam. Soil texture is not variable and most soils are categorized as loamy with exceptions of clay loams restricted to riverine areas. The riverine soils are complex with varied textures depending on the drainage conditions and are composed of eroded volcanic sediments and alluvial deposits. They consist of diverse types of granulomites, conglomerates, silts and gravels (Renaut et al.,1997).

Clay soils are found on the upper part of the catchment, lowlands. The middle part is dominated by clay loam while a small portion at the mouth of river Waseges to Lake Bogoria was identified as silt loam (Renaut *et al.*, 1998).

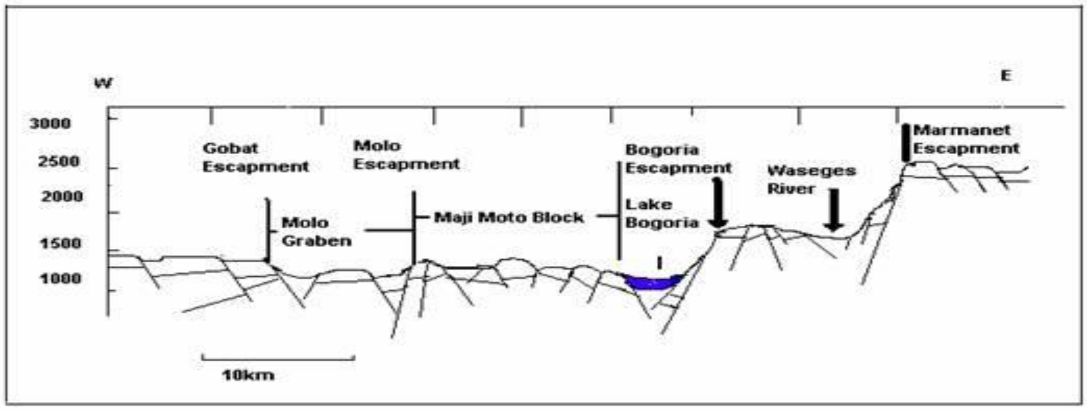

Figure 1.2: A cross section of the lake Baringo-Bogoria half-graben (Renaut and Tiercelin, 1994)

The soils around the lake have high pH ranging from 6.8 to 9.0, with high sodium bicarbonate levels ranging from 0.5 to 9.92 meql^{-1}. The salinity and sodicity are attributed to the parent rock material. Highly alkaline soils are found along the shoreline fringes, but those close to permanent water sources have intermediate values, while soils in the ridges and scarps have the lowest pH values (Tiercelin and Vincens (Eds) 1987).

Soil nutrient availability indices are high indicating high fertility levels with mean phosphorous concentrations of 80 ppm in the riverine soils. Kaolinites constitute 70–80% of silt while illionites are inter-stratified with the rest 10–20%. Potassium, magnesium and manganese concentrations are generally low. Calcium concentrations are high and exhibit wide variation between 10.37 and 37.26 meql^{-1} (Mwangi, 1992).

1.8.2 Climate and rainfall

The climate in the area is arid to semi arid regimes except in the moist highlands around Subukia. The climatic conditions are strongly influenced by the ITCZ (Inter Tropical Convergence Zone) and there are two distinct wet and dry seasons (Mwangi, 1992).

Within the reserve and adjacent areas, the climatic conditions are harsh with temperatures at the Lake ranging from 18^0C-39^0C with a daily mean of 25^0C. Mean annual precipitation varies from 500-1000mm and falls in two seasons April- May and October-November. The physiographic location of the reserve in a graben places is in the rain shadow of the surrounding fault scarps and highlands. The combination of weather variables and physiographic location give the lake basin a hot, semi arid climate (LaVigne & Ashley, 2002).

Lake Bogoria and its surroundings are categorized under agro-ecological climatic zone E. Rainfall reliability is low (Mwangi, 1992), and daily sunshine hours average 10 making the area hot for most of the year (WWF, 2003 annual report). There is a marked hot spell from January to March when temperatures in excess of 34^0C are experienced. Cold spells occur in the months of July and August.

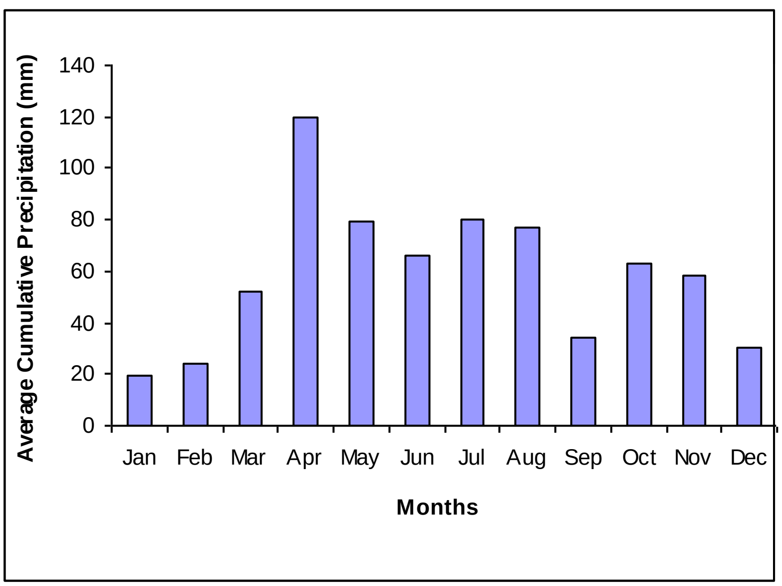

Figure 1.3: Average monthly rainfall for the period 1977-2001 (LaVigne and Ashley, 2001).

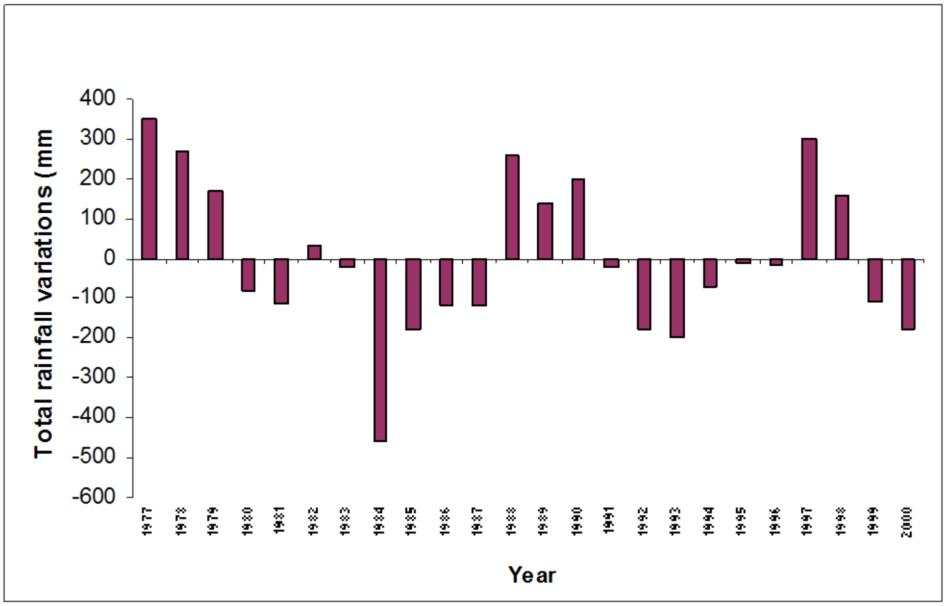

Figure 1.4: Departures of annual total rainfall (mm) from the 25-year mean. (LaVigne & Ashley, 2002).

1977-1979, 1988-1990 and 1997-1998   El Nino years

1984-1986 La Nina years

El Nino and *La Nina* events are interpreted from analyses of the 25-year record from the Lake Bogoria National Reserve weather station. The deviation of the average annual rainfall from the 25-year mean reveals 5-7 year cycles of inter-annular variability in precipitation.

1.8.3 Hydrology

Lake Bogoria area has a trellis drainage pattern and rivers flow northwards along fault lines. The lake's catchment is 1693 km^2 drained by river Sandai-Waseges, which flows northwards towards Lake Baringo but deviates to the south at Sandai to drain into Lake Bogoria (Renaut and Owen 2005). The river flow is seasonal and occasionally dries up between January and March. In the long rainy season, the river brings in large volumes of silt, eroded from the degraded rangelands. River Loboi that drains into Lake Baringo diverts its course in the wet season to drain into Lake Bogoria due to clogging of its channel by sediments (Renaut *et al.,* 1997).. This has turned out to be a normal flow pattern during the wet season, greatly increasing the amount of surface inflows and silt loads into Lake Bogoria. The area has several dry wadis that are characterized by flash flood flows in the wet season. In the south River Emsos and a few perennial springs discharge fresh water into the lake (Renaut and Owen 2005).

1.8.4 Lake Bogoria

The lake is one of a series of saline lakes within the Great Rift Valley and has an area of 34 km^2. The Lake is surrounded by Lake Bogoria National Reserve, which covers an area of 109 km^2 Lake Bogoria is characterised by steep shoreline and has a trough basin morphometry comprising of three semi-distinct but interconnected basins consisting of; the northern, central and southern basins (Renaut and Tiercelin (1994).. The southern basin, a relict volcanic crater is the deepest part (14 m), joined to the rest of the lake by a narrow isthmus. The Lake has a high alkalinity with pH ranging between 9.8-10.6, alkalinity between 480-800 $meql^{-1}$ and an electrical conductivity of 45,000-85,000 μScm^{-1}. Phosphorus levels are extremely high and occur in the form of orthophosphates. Total phosphate and nitrogen concentrations of 3.5 mgl^{-1} and 32 mgl^{-1}, respectively, have been measured in the lake (Renaut, R. W. & J.J. Tiercelin (1994).

The open water is dominated by phytoplankton species such as *Spirulina platensis, Microcystis flos-aquae, Anabaenopsis arnoldii* and bacteria extremophiles. The shoreline vegetation is characterised by plant species such as *Cyperus laevigatus, Sporoblus spicatus* and *Cynodon dactylon* among others (Beentje, 1994).

1.8.5 Hot Springs, Geysers and springs

The hot springs have high temperatures and are highly mineralized and are sourced from shallow aquifers in contact with lava intrusions. They have an estimated discharge of 900 l sec^{-1} (28.38 mm^3) to the lake (Renaut and Owen 2005). The springs are found in three main clusters, Loburu, Chemurkeu and Mwanasis-Kibwu-Losaramat areas (Renaut *et al*., 1998). The hot spring at the Loburu and Chemurkeu have a shallow aquifer with temperatures of about 100^0C, while the southern Mwanasis-Kibwu-Losaramat hot springs have a deeper lying aquifer with temperatures of about 170^0C (Cioni *et al*., 1992). All the springs are alkaline with a pH above 8.0. There are numerous other smaller hot springs, geysers and fumaroles in the plan area.

1.8.6 Flora

Within the reserve, biodiversity inventories have identified approximately 210 plant species belonging to 53 plant families in the reserve and neighbouring wetlands. Amongst these, are 38 species of Graminae and 15 of Acanthaceae. These species are distributed in six broad vegetation types (Mwangi, 1992). These are; riverine forests, wooded bush land, bushed thicket, bush land, bushed grassland and swamps (Collar, 1988).. These are further described into ten vegetation communities on the basis of dominance. Dominant grasses include; *Sporobolus ioclados, Dactyolectenium aegyptium, Chlonis virgata and Digitaria velutina.* Shrubs include; *Grewia tenax, G. bicolor, Acalypha fruticosa and Acacia mellifora*. The most dominant tree species is *Acacia tortilis*. Other community types include mixtures of *Balanites aegyptica, Combretum spp., Ficus spp.,* and *Terminalia spp* Evergreen and semi deciduous bush land cover large areas along stream valley and other inhospitable areas (Beentje, 1994).

1.8.7 Fauna

Wildlife

The area is rich in wildlife species characteristic by a high diversity at low densities. Animals found in the plan area include the Greater Kudu and others shown in Appendix II. There are several reptiles that include monitor lizard, lizards, tortoise, crocodiles and various species of snakes (Harper *et al.,* 2003).

Bird life

Over 373 species of birds have been recorded in the plan area (Appendix 3) including over 50 migratory species, making it one of the richest birdlife areas (IBA) in Kenya. The zoogeographical location of the reserve between the Ethiopian and the Masai zoo-regions contributes to the areas high species diversity (Mathooko and Kariuki 2000)

The lake holds huge congregations of lesser flamingo that feed on the high production of blue-green algae dominated by *Spirulina platensis*. The lake shore configuration and fresh water points provide favourable environment for these assemblages and at times more than 1.5 million flamingos can be counted. Lake Bogoria supports the highest population of greater flamingos in the rift valley alkaline lakes (Goss-custard, 1990).

1.8.8 Human–wildlife conflict

Human –wildlife conflict has increased due to grazing in the reserve and the adjacent forest area in the upper catchment, settlement in wildlife dispersal areas and destruction of crops and property by wildlife. The conflicts have intensified with time due to poor management of natural resources outside protected area and it is strongly correlated with increased poverty.

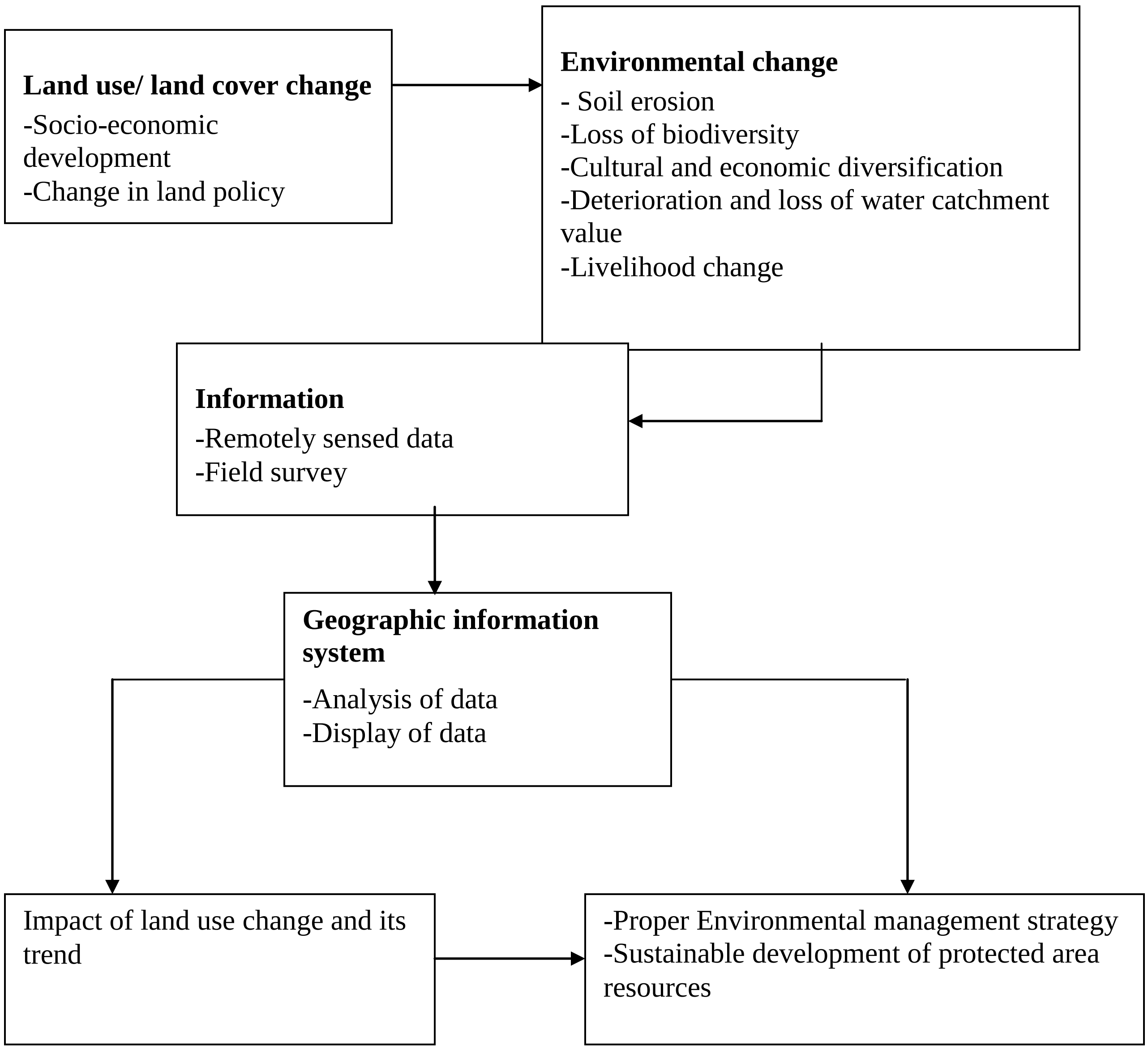

Figure 1.5: Conceptual Model of Natural Resource Management (Kessler, W.B., 1992)

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Remote sensing is becoming increasingly important for mapping land use and land cover due to specific characteristics of remotely sensed data e.g. large area coverage, good spatial resolution, accessibility to remote areas and faster interpretation with higher degree of objectivity and reproducibility (Sabins, 1996, Dafalla and Csaplovics, 2005). There are two broad types of image classification methods; namely, supervised and unsupervised classifications. In supervised classification approach, training samples for information classes are selected with aid of ground truth points and then are used to train the classifier, where in unsupervised classification approach the classifier determines dependently the spectral classes with the image and finally the image analyst determines the related information classes to these spectral classes.However, combined hybrid (supervised and unsupervised) classification approach is also used for land use and land cover classification (Sabins, 1996, Dafalla and Csaplovics, 2005). The difficulties concerning land use / land cover classification by means of remote sensing in arid and semi-arid regions are well known. Since vegetation-soil-patterns in arid and semi-arid zones are characterized by a sparse distribution of non-photo synthesising vegetation (NPV) its spectral behaviour interferes with spectral signatures of bare soil patterns (Schmidt and Karnieli, 2000, Khiry et. al., 2006). Moreover, the spatial heterogeneity at pixel level strongly affects systematic separation between dominant land uses. Therefore, many studies have recommended subpixel unmixing analysis as a suitable method to overcome such constrains (Elmore, et al.,2000), but still there are many difficulties to be overcome such as unavailability of spectral libraries for dominant plant species and soil types.

2.2 Remote sensing in land use and land cover studies

Remote sensing has been widely used in studies and activities related to land use and land cover. Lillesand and Kiefer (1994) noted that this application especially the use of panchromatic, medium scale aerial photographs in mapping land use has been accepted practice since the 1940s'. Alphan (2003) added that, this historical application stemmed from the development of the techniques for the purpose of military reconnaissance in 1915-1918. The technique has been used in assessing a rapidly changing of agricultural area (Odenyo and Pettry, 1977). In the generation of map of land use-use at the national level and in the development of systems of land use and land cover classification and land evaluation (Anderson et al ; 1976). Rostom and Mortimore (1991) reported that sequential aerial photograph interpretation is potentially a powerful, method of evaluating environmental change; subject to satisfactory interpretation, it can generate accurate land use statistic.

Land use/land cover (LULC) changes play a major role in the study of global change. Land use/land cover and human/natural modifications have largely resulted in deforestation biodiversity loss, global warming and increase of natural disaster-flooding (Dwivedi, 2005) These environmental problems are often related to LULC changes. Therefore, available data on LULC changes can provide critical input to decision-making of environmental management and planning the future (Prenzel, 2004)

The growing population and increasing socio-economic necessities creates a pressure on land use/land cover. This pressure results in unplanned and uncontrolled changes in LULC (Prenzel, 2004). The LULC alterations are generally caused by mismanagement of agricultural, urban, range and forest lands which lead to severe environmental problems such as landslides, floods etc (Atasoy *et al.,* 2006).

Remote sensing and Geographical Information Systems (GIS) are powerful tools to derive accurate and timely information on the spatial distribution of land use/land cover changes over large areas (Carlson, 1999). Past and present studies conducted by organizations and institutions around the world, mostly, has concentrated on the application of LULC changes. GIS provides a flexible environment for collecting, storing, displaying and analyzing digital data necessary for change detection (Demers, 2005). Remote sensing imagery is the most important data resources of GIS. Satellite imagery is used for recognition of synoptic data of earth's surface (Ulbricht, 1998) Landsat Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic

Mapper Plus (ETM+) data have been broadly employed in studies towards the determination of land cover since 1972, the starting year of Landsat program, mainly in forest and agricultural areas (Campbell, 2005). The rich archive and spectral resolution of satellite images are the most important reasons for their use.

The aim of change detection process is to recognize LULC on digital images that change features of interest between two or more dates (Muttitanon, 2005). There are many techniques developed in literature using post classification comparison, conventional image differentiation, using image ratio, image regression, and manual on-screen digitization of change principal components analysis and multi date image classification (Lu D., 2005). A variety of studies have addressed that post-classification comparison was found to be the most accurate procedure and presented the advantage of indicating the nature of the changes (Mas, 1999). In this study, change detection comparison (pixel by pixel) technique was applied to the Land use\land cover maps derived from satellite imagery.

2.3 Land-use, land-cover change

Destruction of natural habitat due to increased human population is quite common in the developing world. Clear felled expanses of indigenous trees are usually replaced with mono-culture plantations (Geiser, 1982). Forest clearance and degradation is the single most important threat to the birds of Africa and related islands (Collar and Stuart, 1988). This is an increasingly important threat to biodiversity particularly where the largest concentration occurs Human population growth and economic activity convert vast areas for settlement, agriculture, and forestry.

This results in the ecological effects of habitat destruction, degradation, and fragmentation, which are among the most important causes of species declines and extinctions (Landweber and Dobson, 1999). Land-use/land-cover changes affect the environmental factors that in turn influence the rates of species survival and population size (Gosscustard and Durell, 1990).With the disappearance of natural habitats, biodiversity also disappears (Geiser, 1982). Inadequately regulated competition among resource extractors, especially in open access forestry, is one of the major causes of resource overexploitation and depletion (Luong, 1994). Food limitations are another common problem that can result from human-caused habitat changes. Changes in land-use patterns can eliminate or reduce any species chances of survival.

The use of GIS and spatial tools is useful in production of a detailed inventory of existing resources for socio-economic exploitation, detection of changes in both available resources' quantity and quality. It enables recognition of vegetation patterns less easily perceived from the ground over large areas and fairly long time scales. For planning, ecosystem management and integrated conservation projects to succeed, then patterns of harvesting and land use have to be taken into account at a landscape level. Majority of the landscapes are affected by natural disturbances. Anthropogenic factors also play a crucial role in influencing the natural coexistence of these landscapes. It is widely recognized now that protected areas have to be seen in the context of land use and land cover (Anderson et al., 1976)

2.4 Land use and cover mapping

Knowledge of land use and land cover is important for many planning and management activities and is considered an essential element for modeling and understanding the earth as a system (Lillesand and Kiefer, 1999). Remote sensed images lend themselves to accurate land use and land cover mapping in part because land cover information can be interpreted more directly from evidence directly visible on aerial images. According to Campbell (1996) land-use and land cover information is important for all decisions made at the regional level, national level, and international level. Presentation of this information is best done by the use of maps derived from aerial photographs or satellite imageries.

The process of generating maps from aerial photographs and satellite imageries requires skills to delineate and correctly identify various features on the image or photographs. They can be done manually especially with the use of analogue aerial photographs or electronically in the case of digital data. Various software have been developed for handling digital data and compiling maps. In addition, the digital data from satellite imagery or digitized aerial photograph could be integrated into GIS to produce quality maps. GIS is recent computer based technology used in capturing, storing, retrieving, analyzing and displaying digital data. It has hastened the process of generating statistics for land use and land cover.

2.5 Land use change detection

Land use patterns change in response to economic, social and environmental forces. For planners and administrators they reveal the areas that require greatest attention if communities have to develop in a harmonious and orderly manner. From a conceptual perspective, the study of land use change permits identification of long term trends in time and space and provide information of policy in anticipation of the problems that accompany changes in land use (Estes and Singer, 1974)

Two basic methods are frequently employed in the detection of land use change. The first method is pixel to pixel combination of multi-date images without classifying the data. The data are then classified after pixel to pixel comparison has been carried out. Pixels can be compared by image differencing, image ratioing and principal component analysis. Classification errors in this method can be avoided. Although these methods are sensitive in determining a pixel that has changed. It is often difficult to construct a land use conversion from them (Houghton, 1994).

The second method compares two or more images of different dates after their classification (post – classification comparison). The advantages of this method is that the land use type for each pixel of both or several dates is identified. The post classification comparison can be used to identify not only the amount and location of change, but also the nature of change. However the comparison is subject to the error originating in the misclassification of two or more independent classified images (Houghton, 1994).

Another method is "masking detection", which is the combination of pixel-to-pixel comparison and post-classification comparison. It attempts to minimize classification error as much as possible. Changes detected by comparison of classified images are often over estimated and unsatisfactory. The analysis is easily affected by misclassification and mis-registration error that may be present in each classification (Howarth and Wickware, 1981).

2.6 Land use classification

Land use map prepared from remotely sensed data is in essence a process of segmenting the image into parcels assigned to a land use class. Because of unpredictable interplay between image detail, classification and map scale, the interpreter must find a balance between the precision of the classification systems and the sizes of the parcel that can be interpreted, then portrayed legibly on a map. Although many land use and land cover classification systems have been used, the United States Geographical Survey (USGS) classification as reported by Anderson *et al.,* (1976) has been widely used in remote sensing applications.

Land use and land cover can be successfully mapped by digital classification of satellite images. The classification may be either supervised or unsupervised. In supervised classification, the user develops spectral signatures of unknown categories e.g. Urban and forest and then software assigns each pixel in the image to the cover type to which it's signature is most similar. On the other hand, in unsupervised classification, the software groups pixels into categories of like signatures and then the user identifies what cover types they represent (Jensen, 1996)

CHAPTER THREE

MATERIALS AND METHODS

3.0 Introduction

In recent years, researchers have developed a sophisticated way of judging the quantity and quality of vegetation by using computers to analyze satellite images. This technique has the potential to show changes in land use/land cover changes, estimate the quantity over varying time periods and distribution. Aerial photographs and satellite images are both extremely useful in any inventory of harvested plant resources, and enable recognition of vegetation patterns less easily perceived from the ground (Cunningham, 2001). This chapter describes the data used, how they were obtained and the analyses that were carried on them. The study seeks to establish the changes in size of the lake and landcover over the past 22 years based on the availability of the images. The chapter is structured as follows. The first section identifies the data and their sources. This is followed by description of how these data were processed, data analysis and finally change detection.

3.1 Sources of data

Satellite images were the main data source for the study which were acquired from Regional Centre for Mapping of Resources for Development, Kasarani, Nairobi. The data used included: multi-temporal satellite data i.e., LANDSAT Thematic Mapper 1986 path 169 row 60, LANDSAT Enhanced Thematic Mapper 2000 path 169 row 60 and five ASTER (2008) satellite imagery, topographic map and field data e.g. Global Positioning System (GPS) points of different land uses. The catchment area has a total coverage of 1693.7 $km^{2.}$

3.2 Data Processing

Image processing was done in all the images and maps that were used in the study. It involved image georeferencing, digitization and image registration.

3.2.1 Georeferencing

The area of study used was adopted from WWF on Lake Bogoria catchment map of scale 1:250,000 which had been defined with the use of contours to come up with the boundary. This map was in JPEG format and not georeferenced. The topographic map was then georeferenced using the coordinates of the extent. This process involved entering the four coordinates to mark the control points, rectified and confirmed the accuracy using the Root Mean Square (RMS) which was 0.0001.

3.2.2 Digitization

Georeferenced Lake Bogoria catchment map was digitized and the catchment polygon (boundary) was then rasterized for it to be used to clip the catchment area from the LANDSAT images as well as mosaiced ASTER image for 2008.

3.2.3 Mosaicking and Registration

Five Aster image scenes used for 2008 were all mosaicked. It was also noticed that there were some shifts between the satellite images for different years. Images were therefore georectified to ensure that features appearing on any of the satellite images (1986, 2000 and 2008) used are in the same corresponding position as in the topographic map. The topo map was used as the reference for the image registration.

3.2.4 Image Clipping (Sub-setting)

Polygon bounding the catchment boundary was created by digitizing the Georeferenced Lake Bogoria catchment image map. This polygon was then rasterized for it to be used to clip single image bands as well as mosaiced image bands for 2008 images based on the catchment boundary.

After clipping all image bands for the images used the clipped images were windowed to reduce the big background on the image bands. Arbitrary row and column values covering the area of study on the images were picked at the upper left and lower right corners to be used in windowing.

3.3 Data analysis

3.3.1 Image Compositing (Layer Stacking)

This involved combination of three bands of LANDSAT 1986 and 2000 images that were used. Bands 2, 3 and 4 were combined to give a false color composite for identification of different land cover and land use types (band 2 as blue, band 3 as green and band 4 as red).

3.3.2 Land use land cover Classification

Reconnaissance in the field had been done to identify land cover/land use classes by taking their GPS points. Eight different land cover/land use classes were identified on the satellite images. U.S.G.S scheme was adopted for classification (Anderson *et al.*, 1976). These were: forest, shrubs, grassland, cultivated area, bare ground, built up area, lake and dams. A layer called training sites was created in for the land cover and land use classes. **P**olygons were digitized around different homogeneous pixels, referred to as signatures on the images with similar areas being assigned same ID or value. Various random sites for each land cover were chosen to maximize on spectral variabilities. The classes captured were given IDs as shown below:

Table 3.1 Land use and land cover classification (Pratt and Gwynne 1977).

NAME	DESCRIPTION
Forest	Deciduous, woodland and evergreen mixed forest lands
Shrubs	Dominated by shrubs
Grassland	Area covered with grass
Cultivated area	Cropland
Bare Ground	Bare exposed area
Built Up Area	Residential commercial structures
Lake	Large body of water surrounded by land
Dam	A lowland area, such as a marsh or swamp, that is saturated with moisture.

Supervised Classification

Images were classified based on the signatures developed. Maxlike (maximum likelihood) supervised classification tool was used under Image Processing-Hard Classifiers in Idrisi. The training sites layer was input under group signature on the maximum likelihood classification window and output image name assigned before running the classification.

Ground truthing' in the field was done for further clarification on features of which there was no much difference. This involved verification of data in the field. Any changes noted on the boundaries and fields were drawn on the maps while in the field. GPS (Global Positioning System) device was used to record co-ordinates of location and distribution of features. Notes were made on vegetation changes, land uses and human impacts. Ground truthing was used in the final refinement process. The importance of ground truthing was that due to limited information discernable from remotely sensed imagery and errors made during interpretation, it helped in providing supplemental details of actual information in the field.

3.4 Land Cover and Land Use Change Detection

Land cover/land use change detection was derived from the areas of different land cover/land use classes obtained from images of different years. This involved area computation and subtraction between different year images.

3.4.1 Land use/Land covers Area Computation

Computation of areas of different land cover/land use classes was done in Idrisi software using Area tool under GIS Analysis-Database Query tools. On the area calculation window tabular output was selected and classified image inserted as input image. Square kilometers were chosen as the option for area calculation before running the computation.

Area values for same land cover/land use classes from different year images were subtracted to get the differences. The differences obtained indicated the changes in areas covered by different land cover/land use classes. The differences also showed the trend of land cover/land use change. To determine the changes of the lake only, the classified images for 1986, 2000 and 2008 was used. This involved point mode digitization of the extent of the lake which were then overlaid.

Land use/land cover change analysis [1986, 2000 and 2008]

To develop land cover changes that had taken place over the varying time span (between 1986 and 2000, 2000 and 2008, and 1986 to 2008), GIS Analysis tools Database query was used.

A land use/land cover mapping exercise was undertaken to identify, interpret and analyze land use/land cover changes within Lake Bogoria Catchment. The interpretation of the change maps provided accurate rendition of the location and distribution of land use and land cover types. This information was important in examination of the relationship existing between changes in vegetative classes, human impacts and changes in the size of the Lake.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results

Land use/land cover changes

Land use/land cover changes reflect the dynamics observed in the socio-economic processes of a given area. Methodologies developed in calculating Landcover change in this study were useful in production of detailed land use/land cover information between 1986 and 2008. This information allowed for the identification of land use/land cover changes, which was significant in predicting the future of the catchment and the lake.

The land use/land cover changes of different time periods summarized in the maps and tables below indicate how land use and land cover has had rapid changes in the study sites within the 22 years span of time. This has been quantitatively extracted and presented both in square meters and percentages. The changes have been documented in the maps and figures below.

4.1.1 Changes In Shore Line

Lake Bogoria showed a decrease of the area from 32.76 km^2 (1.93%) 32.07km^2 (1.87%) to 30.60 km^2 (1.81%) in the years 1986, 2000 and 2008 respectively. The reduction is seen in the northern part of the lake which is the area where the Waseges River drains into the lake (Figure 4.1).

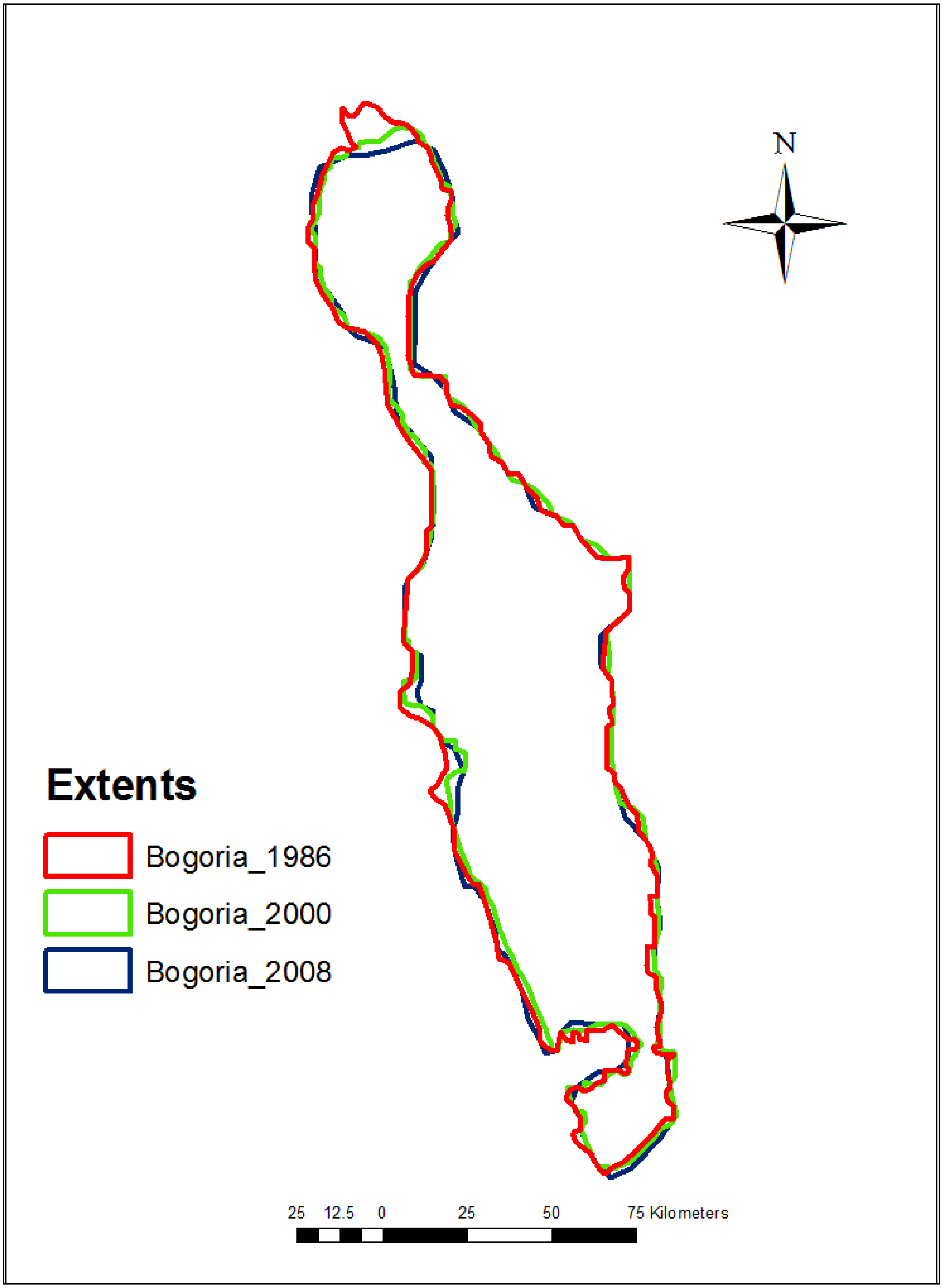

Figure 4.1: Map of Lake Bogoria Extent (1986, 2000 and 2008)
Source: (Author, 2014)

4.1.2 Changes In Land Cover

The forests cover analysis showed percentage decrease and increase over the years between 1986-2008. The changes calculated showed a decrease from 74.21 km^2 (4.38%) to 70.50 km^2 (4.16%) to increase of 146.35 km^2 (8.64%) in the years 1986, 2000 and 2008 respectively as demonstrated in the maps (Figure 4.2, 4.3 and 4.4). In the lower catchment where there is high shrubland, as seen in the maps (Figure 4.2, 4.3 and 4.4) it showed reduction from 551.00 km^2 (32.53%) to 225.37 km^2 (13.31%) then increase to 620.57 km^2 (36.64%) Table 4.1. In grassland there was an increase from 138.55 km^2 (8.18%) to 465.39 km^2 (27.48%) between 1986-2000 (Table 4.1). However, there was a decrease in this class between 2000 and 2008 (465.39 km^2 (27.48%) to 637.84 km^2 (3.77%)). There was gradual increase in dam from 0.57 km^2 (0.03%) to 1.87 km^2 (0.11%) then 11.48 km^2 (0.68%) in 1986, 2000 and 2008 respectively. Cultivated area increased from 610.27 km^2 (35.92%) 624.82 km^2 (36.95%) to 734.17 km^2 (43.42%) in 1986, 2000 and 2008 respectively (Table 4.1). Bare ground showed a drastic decrease in area from 231.7 km^2 (13.68%), 214.35 km^2 (12.66%) to 21.30km^2 (1.26%) in the years 1986, 2000 and 2008 respectively. There was a gradual increase in built up area from 56.80km^2 3.35% (1986), 58.65 km^2 3.46% (2000) to 63.97 km^2 3.78% (2008).

Table 4.1: Landuse/landcover classes in 1986, 2000 and 2008

	1989		**2000**		**2008**	
LANDCOVER/ AND USE CATEGORIES	**Area(km^2)**	**% Area coverage**	**Area(km^2)**	**% Area coverage**	**Area(km^2)**	**% Area coverage**
Forest	74.21	4.38	70.50	4.16	146.35	8.64
Shrub	551.00	32.53	225.37	13.31	620.57	36.64
Grassland	138.55	8.18	465.39	27.48	637.84	3.77
Cultivated Area	610.27	35.92	624.82	36.95	734.17	43.42
Bare Ground	231.70	13.68	214.35	12.66	21.30	1.26
Built Up Area	56.80	3.35	58.65	3.46	63.97	3.78
Lake Bogoria	32.76	1.93	32.07	1.87	30.59	1.81
Dams	0.57	0.03	1.87	0.11	11.48	0.68

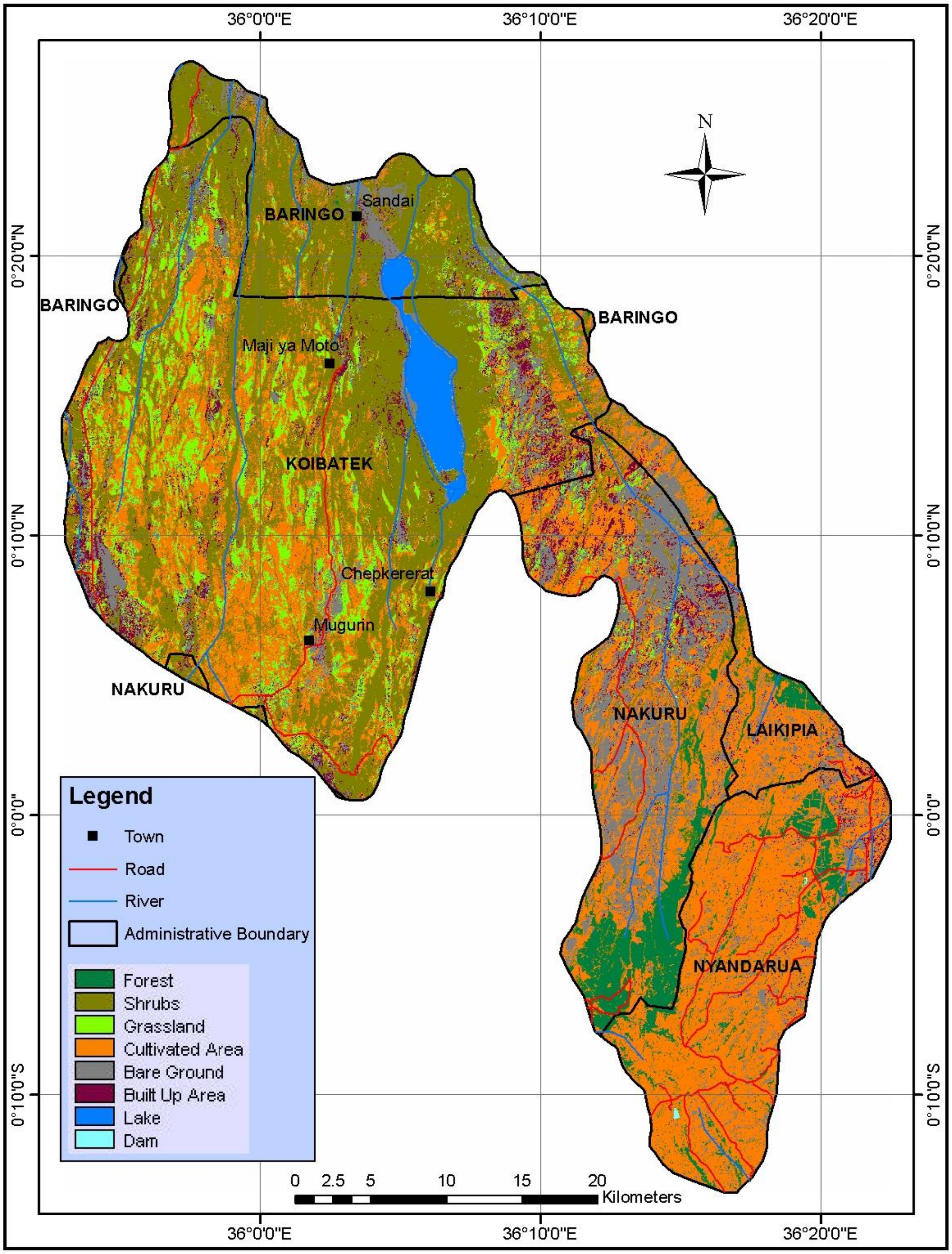

Figure 4.2: Map of Landcover/Landuse from the image 1986.
Source: (Author, 2014)

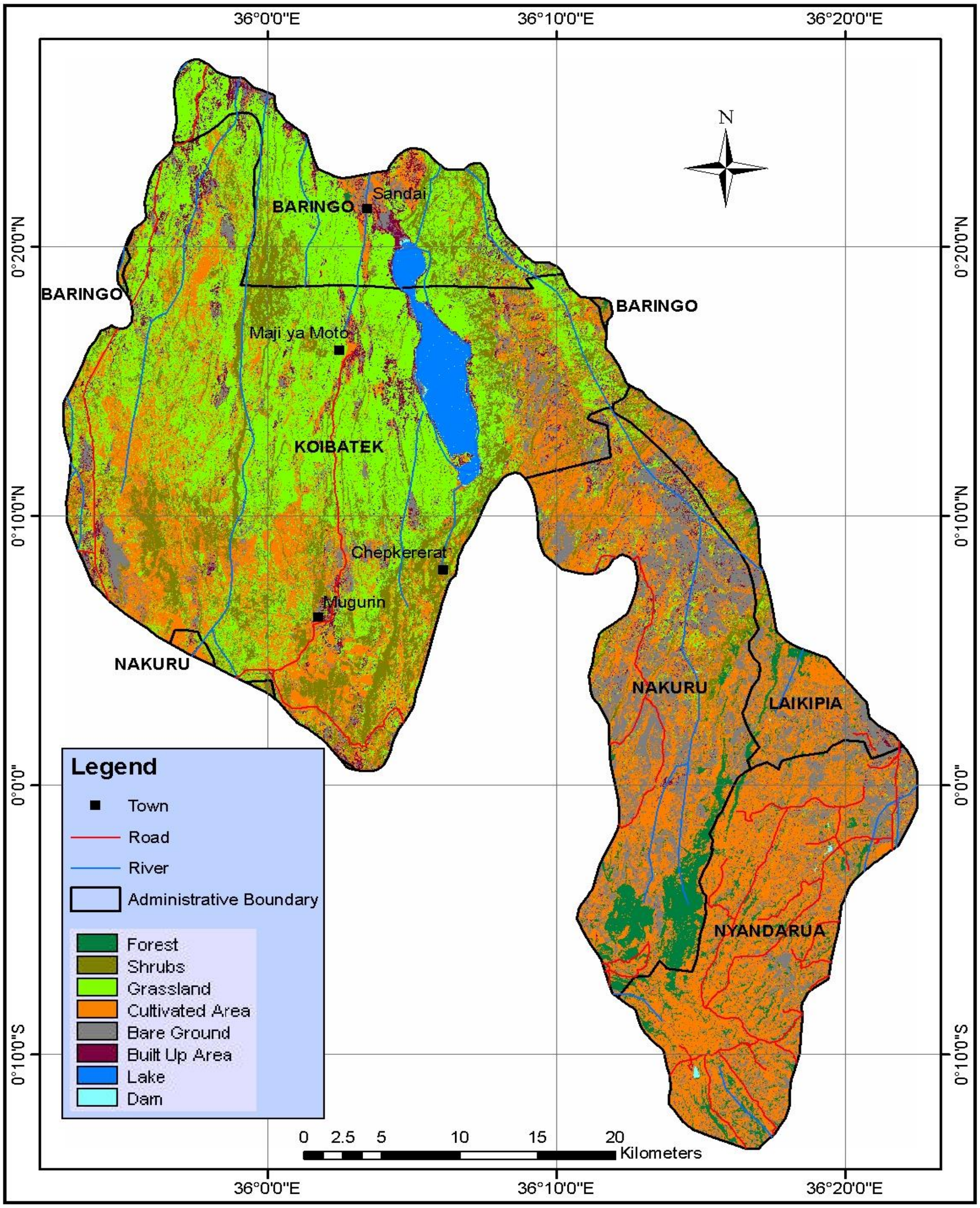

Figure 4.3: Map of landcover/landuse from the image 2000.

Source: (Author, 2014)

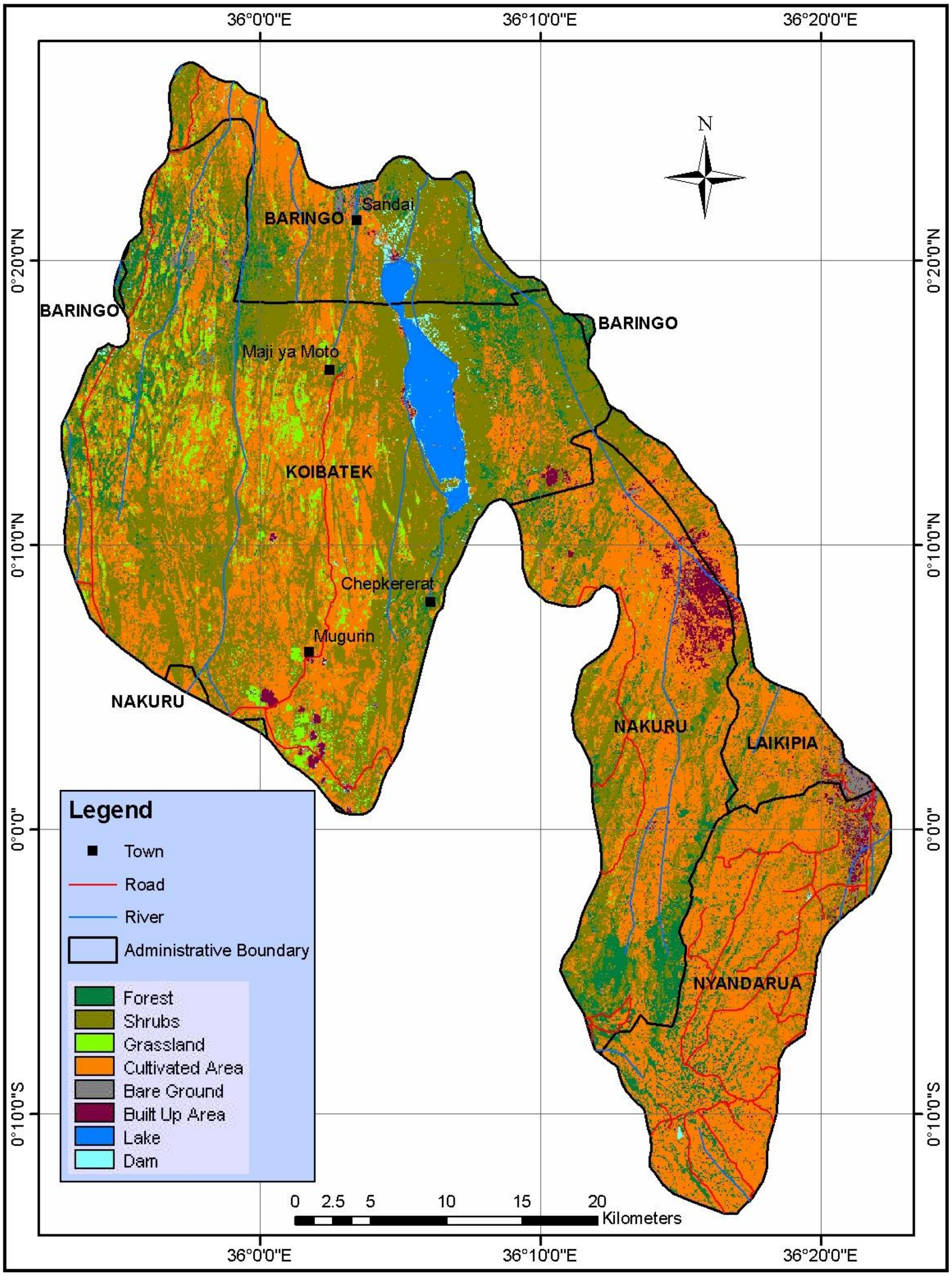

Figure 4.4: Map of landcover/landuse from the image 2008.

Source: (Author, 2014)

4.1.3 Relationships Between Shore Line Changes And Land Use/Land Cover Changes

The land use/land cover changes of different time periods summarized in the table below indicate how land use and land cover had changes in the study sites within the 22 years span of time

Table 4.2 land use land cover change for 1986-2000, 2000-2008 and 1986-2008

LANDCOVERL/LANDUSE TYPE	**1986-2000 CHANGE**	**2000-2008 CHANGE**	**1986-2008 CHANGE**
FOREST	Shrub, Built up area, Cultivation, Bareground, Grassland	Shrub Grassland Dam Cultivation Buildings Bareground	Shrub Cultivation Buildings Bareground
LAKE	Bareground	Bareground	Bareground
SHRUB	Forest Grassland Dam Cultivation Buildings Bareground	Forest Grassland Dam Cultivation Buildings Bareground	Cultivation Buildings Bareground Grassland
GRASSLAND	Shrub Buildings Bareground Cultivation Dam	Shrub Dam Cultivation Buildings Forest Bareground	Shrub Cultivation Buildings Bareground forest Dam

BAREGROUND	Shrub Buildings Cultivation Lake Dam Forest	Shrub Grassland Dam Cultivation Buildings Forest	Shrub Cultivation Buildings Grassland Dam Forest
CULTIVATED AREA	Shrub Buildings Grassland Dam Forest Bareground	Shrub Grassland Dam forest Buildings Bareground	Buildings Shrub Bareground Grassland Dam
BUILT UP AREA	Cultivation Shrub forest Bareground	Shrub Grassland forest Cultivation Bareground	Shrub Grassland Dam Cultivation Bareground

Table 4.3: Landcover change matrix from 1986-2008 in Lake Bogoria Catchment Areas.

Change in years	**1986-2000**	**2000-2008**	**1986-2008**	
LULC Thematic class	Amount and type of change in (m^2)	Amount and type of change in (m^2)	Amount and type of change in (m^2)	Remarks
Forest	3717668.30	-75853720.10	-72136051.80	Increase in cover
Shrub	325629368.70	-395196670.20	-69567301.50	Increase in cover
Grassland	-326837638.30	401602486.70	74764848.40	Increase in cover
Cultivated Area	-14550372.00	-109351971.40	-123902343.40	Increase in cover
Bare Ground	17354079.80	193047282.70	210401362.50	Decrease in cover
Built Up Area	-1852921.50	-5320830.50	-7173752.00	Increase in cover
Lake Bogoria	685201.30	1477008.20	2162209.50	Decrease in cover
Dams	-1297975.50	-9611778.50	-10909754.00	Increase in cover

4.2 Discussion

The entire catchment has multiple land use types that have undergone major changes in the last 100 years. The upper catchment has changed from pastoralism to large- scale commercial farms and ranches, later subdivided into small- scale holdings. The lower catchment has changed from nomadic livestock production to a sedentary livestock production system (Ellis *et al.*, 1999).

4.2.1 Forest

This represents the natural forests mainly composed of mature trees and other plants growing close together (Collar, 1988). The issues affecting forest cover are; Logging, Charcoal burning, Cultivation in riparian areas and Encroachment into gazetted forests, riverine forests and other fragile microhabitats (WWF, 2007 plan). There has been extensive deforestation in the upland forests with consequences on downstream ecosystems and water availability. The drastic increase in the forest cover in 2008 is as a result of afforestation in the individual farms in the upper catchment and the reforestation of the Shamanek and Subukia forest as a result of the Community Forest Association and riverine forests along river courses around the border between Baringo and Koibatek District; this area is also a communal land with low population allowing the rejuvenation of the forest. The distribution of the vegetation types strongly correlates to combinations of topography, soil types, elevation, drainage systems and soil moisture content (Appendix 1). In the upper parts of the catchment, mountane forests are found around Subukia, Olrara Bel, Mchongoi and Marmanet areas. These areas are the catchment for River Sandai/Waseges (WWF, 2007 plan).

4.2.2 Lake

In the catchment there are moist upland forests around Subukia that are the major sources of surface inflows into the lake and are rich in forest products and biodiversity. Reduction in the size of the Lake is as a result of the destruction of its water catchment through encroachment and over abstraction of water for irrigation in the catchment and poor farming method causing siltation (WWF, 2007 plan). Trends in the lower basin show that the area experiences acute water shortage for at least five months each year. There is also serious silt deposition brought in by flash floods from upstream. These results into rivers changing course, family's displacement and farm flooding in the lower catchment near L. Bogoria (Mathooko and Kariuki 2000).

The lake level fluctuates between 11 and 14 meters with precipitation but does not exhibit extreme surface area variations compared to other shallow rift valley lakes. Its trough basin morphometry prevent major surface area variations, while discharge from all the springs counterbalance evaporative losses considerably (Tiercellin et al, 1987).

A study carried out to determine the water budget for Lake Bogoria quantified inflows and outflows to the lake. The inflows include, river flows, direct rainfall into the lake and flow from springs into the lake of 31 Mm^3, 24.29 Mm^3 and 28.38 Mm^3 (Million cubic meters) respectively. The outflows are mainly through direct evaporation from the lake surface, domestic and livestock abstractions at 75 Mm^3, 0.7 Mm^3 and 1.2 Mm^3, respectively. Total inflows are 83.67 Mm^3 while total outflows are 70.65 Mm^3 resulting in a difference of 13.02 Mm^3, which is accounted for by abstractions for irrigation upstream (Onyando and Musila, 2004).

The major source of fresh water is R. Waseges, which emerges from the Bahati and Marmanet Forests in the upper catchment which is facing a lot of destruction. River Waseges is a river that drains into Lake Bogoria and is a major source of water for communities within the Lake Bogoria Basin. In the upper catchment the river is referred to as R. Subukia and as Waseges after joining with R. Igwamiti. Several streams including Subukia River, Igwamiti River, and Fitzgerald stream and all tributaries of river Subukia among others drain the area and flow into Waseges River. The river flows through settled areas and finally into Lake Bogoria (WWF, 2007 plan).

Since 1990s the two rivers (Igwamiti & Subukia) have experienced over abstraction by an ever-growing number of farmers. This has resulted to depletion of water leading to serious confrontations and conflicts between various water users within the basin.

The rivers and riverine ecosystems lower catchment arid and semi-arid plan area are critical habitats and provide refuge for wildlife. The riverine ecosystems have distinct ecological characteristics that allow them to support wildlife, invertebrates and plant species that cannot thrive in the arid areas (Kessler *et al.,* 1992). The world-renowned flamingo congregations in L. Bogoria rely on fresh water supplies for drinking and bathing. Without which they migrate to other lakes during the dry months. This affects income from gate collection at the reserve hence; the community which is entitled to 6% of the revenue is then affected (Renaut and Tiercelin 1993).

4.2.3 Shrub

Outside LBNR and the forest areas the vegetation comprises of bushlands, shrublands, scrublands and woodlands. These vegetation types are associated with unconsolidated soils, rock outcrops and riverine plains in the arid parts of the area. These are the community land, which are communally grazed (Beentje, 1994).

Shrubs happens to be the principal sources of fuel, medicine, animal pasture, charcoal sales and logging. The population increase in the area also resulted in clearing of the shrubs to pave way for cultivation and upcoming of settlements (Beentje, 1994). The increase in this cover is because the main forest cover and grassland was depleted over the years giving way to the shrubs. Since the area is not productive the cultivated areas paved way for the shrubs (Foran *et al.,* 1999).

4.2.4 Grassland

Scattered trees and grasses mainly constitute this type of land cover. The lower catchment was initially under nomadic livestock production, which changed over time to a relatively sedentary mode of livestock production (Pratt *et al.,* 1977). Livestock numbers in this area have increased over time and are restricted to a smaller range compared to the past herding system (Mathooko and Kariuki 2000). This indicates that most of the natural trees and shrubs in the semi desert area around Lake Bogoria national reserve with deeper roots that may not depend on seasonal rainfall could have been cut down by the community. The negative change mainly occurred as a result of cultivation, increase in built up areas, upcoming of shrubland and bare ground since Livestock densities increased beyond the lands carrying capacity leading to over grazing (Schmidt, 2000). The cumulative effect of overgrazing, and sustained pressure on forage has led to:

- Soil erosion with sheet and gully formation
- Loss of soil fertility
- Sparse vegetation cover with soil exposure
- Reduced forage availability
- Increase in invader plant species
- Intensification of dust storms
- Flash flooding
- Increased pressure on fragile microhabitats
- Encroachment into swamps
- Prevalence of animal diseases
- Human – wildlife conflict

4.2.5 Dam

It comprised of the dams and swamps. Several dams and swamps occurred in the area and they differed in size, water chemistry, biota and hydrology. The Loboi swamp is the largest and constituted a key ecosystem component in the area as a water reservoir for livestock, agricultural and domestic supply. Swamps along Waseges River play an important role in nutrient removal, agro-chemical retention and sediments filtration. There were also other numerous small marshes fed by fault related springs. The wetlands especially those outside the reserve were important to the local communities for water and food production. The swamps are also rich in bird life.

The decrease in forest, shrub and grassland in Loboi swamp and other swamps in the catchment led to the increase in these class (Figure 4.1).

4.2.6 Cultivated Area

Increase in this class had adverse effect on the upper catchment. This is as a result of the, encroachment and intensification of agriculture in the upper catchment arising from numerous financial needs and decreasing land sizes thus farmers have resorted to small-scale irrigation (WWF, 2007 plan).

In the upper Subukia basin, many farmers rely on irrigated high value horticultural crops such as tomatoes, cabbages and cut flowers for both the local markets and export. In the lower Subukia basin (Waseges) where rainfall is scarce, irrigation is used after the rains production of food crops like maize and beans. There are only two legal irrigation schemes in the basin; i.e. Lari Wendani Irrigation Scheme in lower Subukia and the Sandai Irrigation Scheme near Lake Bogoria. There are other hundreds of small-scale farmers who operate individually or in small group all over the villages along the river and its tributaries (WWF, 2007 plan). .

4.2.7 Bare Ground

It is a class that resulted from both human and climatic processes of the environment. This was commonly seen in the upper catchment. This was as a result of increased built up areas, cultivation, and planted forests in people's farms.

4.2.8 Built up area

This class represented roads, towns and villages. The increase in this class had an adverse effect on the forest, bareground and grassland. This was because anthropogenic interference like infrastructure development and settlement in this area was not that intense in 1986 and had consistently increased over the years (WWF, 2007 plan). . This was also due to population increase in the catchment which was estimated at 40,000 (1999 census), and continues to increase due to immigration. The total human population adjacent to LBNR is estimated at 10,000 inhabitants (GOK, *1999)*.

Owing to the increase in population, there was a dramatic increase in the built up area over the past 22 years.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The land cover has been extensively modified and converted into various land use systems to meet human needs and this has precipitated severe adverse environmental impacts, with far reaching ecological and socio-economic consequence. Farming, settlement, overgrazing, charcoal burning and tree logging were the main driving forces responsible for the changes in land cover types in the area. Irrigation is an essential tool for stability and an increase of agricultural production but has had adverse negative effects on the Lake. There is need for Integrated River Basin Management Approach that takes into consideration the diverse needs of water users and aims at sustainable utilization of water and other natural resources within the basin. The other sub-sectors therefore require to be developed under close co-coordination with the irrigation sub-sector, to achieve a significant increase of agricultural production. However, Efforts by all stakeholders need to be taken to ensure wise use of resources is employed to assist in solving the problem in an effective way.

5.2 Recommendations

- Educate community on better land husbandry, soil and water conservation.
- Train and mobilize communities through extension programs to manage land cover.
- Rehabilitate and protect degraded areas.
- Improve livestock quality and create links to livestock markets to manage stocking rates.
- Explore and promote alternative sources of livelihood (game farming).
- Demarcate and acquire title deeds for the forestland.
- Enhance capacity within Government department to deal with land cover loss.
- Enforce polices, laws and indigenous management systems.
- Undertake education and awareness, sensitisation and appropriate action on riverbank, steep slope farming.
- Advocate integrated pest management and wise use of agro-chemicals.

- Introduce drip irrigation and regulate community irrigation schemes
- Enforce and implement the water Act, through formation of a water apportionment board and water users association to resolve conflicts.
- Undertake riverine vegetation rehabilitation and river bank protection.
- Encourage alternative water harvesting technologies
- Adopt water conserving irrigation technologies

REFERENCES

Alphan, H. (2003) Land use change and urbanization in Adana, Turkey. *Land Degradation and Development*, 14, pp. 575-586.

Anderson J.R., Hardy E.E., Roch J.T. and Witmer R.E. (1976). 'A Land use and land cover classification system for use with remote sensor data', In: U.S.Geological Survey Professional Paper 964, p. 28.

Atasoy M., Karslı F., Bıyık C., Demir O (2006). *Determining Land Use Changes with Digital Photogrammetric Techniques*. Environmental Engineering Science;23(4):712–721.

Beentje, H.J. (1994). *Kenya Trees, Shrubs and Lianas.* Nairobi: National Museums of Kenya. 722 p

Calder, I.R. (1993). *Hydrologic effects of land-use chang*e. Chapter 13 in *Handbook of Hydrology* (Maidment, D.R. Ed). McGraw-Hill, New York, 13.1-13.50. Campbell J.B (1987) Introduction to remote sensing. The Guilford Press, USA.

Campbell J.B. (2007). *Introduction to Remote Sensing.* Fourth edition, The Guilford Press; New York, USA.

Campbell, J. (1996) Understanding Risk and Return, Journal of Political Economy 104(2), 298-345.

Carlson T.N and Azofeifa S.G.A (1999). Satellite Remote Sensing of land Use changes in and around San José, Costa Rica. Remote Sensing of Environment;70:247–256.

Chilar, J. (2000). Land cover mapping of large areas from satellites: status and research priorities. *International Journal of Remote Sensing*, 21 (6&7), pp. 1093-1114.

Cioni, R., Fanelli, G., Guidi, M., Kinyariro, J.K., and Marini, L. (1992). Lake Bogoria hot springs (Kenya): geochemical features and geothermal implications. *Journal of Volcanology and Geothermal Research*, v. 50, p. 231–246.

Cirone, P.A. and P.B. Duncan (2000). Integrating human health and ecological concerns in risk assessments. *Journal of Hazardous Materials*, 78:1-17.

Collar, N. J. and Stuart, S. N. (1988). *Key forests for threatened birds in Africa*. ICBP Monograph No 3. Cambridge, UK: International Council for Bird Preservation.

Dafalla, M.S. and Csaplovics, E. (2005). Applicability and limitations of land use / land cover classification using high resolution satellite imagery in arid and semi-arid areas of the Northern

Demers M. N. (2005). Fundamentals of Geographic Information Systems. John Wiley&Sons, Inc.; Newyork, USA.

Dwivedi R.S., Sreenivas K., Ramana K.V(2005). Land-use/land-cover change analysis in part of Ethiopia using Landsat Thematic Mapper data. International Journal of Remote Sensing. 26(7):1285–1287.

Elmore, A.J., Mustard, J.F., Manning, S. and Lobell, D. (2000). *Quantifying percent live cover in multitemporal data of a semi-arid region: Comparison between spectral mixture analysis and NDVI*. Remote Sensing of Environment 73, 87-102.

Estes, J.E. and L.W. Singer (1974). *Remote Sensing for Environmental Analysis*, Santa Barbara CA; Hamilton publishing CO; 340PP.

Geiser U., Sommer J., Haefner H. and Itten K.J. (1982). 'Multistage land use mapping and change monitoring Sri Lanka' : paper presented to EARS el/ESA Symposium on satellite Remote Sensing from Developing Countries, 20-21 April, Austria.

GOK (Government of Kenya). 2001b (*1999). Population and housing census. Counting our people for development. Population distribution by administrative areas and urban centres.* Ministry of Finance and Planning, Nairobi, Kenya. 446 pp.

Goss-Custard, J.D. & Durell, S.E.A. (1990). Bird behaviour and environmental planning: approaches in the study of wader populations. Ibis 132: 273-289.

Harper, D.M., Childress, R.B.. Harper, M.M., Boar, R.R., Hickley, P., Mills, S.C., Otieno, N., Drane, T., Vareschi, E., Nasirwa, O.1, Mwatha, W.E., Darlington, J.P.E.C., and Escuté-Gasulla, X. (2003). Aquatic biodiversity and saline lakes: Lake Bogoria National Reserve, Kenya. *Hydrobiologia*, v. 500, p. 259-276.

Howarth, J. P. and Wickware, G. M. (1981). Procedure for change detection using Landsat King, Ecosystem Health, 5(1):49-57.

Jensen J.R (1996) *Introductory Digital Image Processing*. Second Edition. Prentice-hall Press; New Jersey.

Kessler, W.B., H. Salwasser, C.W. Cartwright Jr., and J.A. Caplan (1992). *New perspectives for sustainable natural resources management.* Ecological Applications 2:221-225. Overbay, J.C.1992. Ecosystem management. Paper at national work-shop on taking an ecological approach to management. (Reprint available from USDA Forest Service, Washington, D.C.) 8 pp.

Khiry, M.A., Dafalla, M.S., and Csaplovics, E. (2006). M*apping and assessment of sand encroachment by spectral mixture analysis in arid and semi-arid areas*: Case study North Kordofan, Sudan. Proceeding of the 6th International Conference on "Earth Observation & Geoinformation Sciences in Support of Africa's Development" (AARSE2006). 30th Nov.-2nd Oct. 2006, Cairo, Egypt.

Krhoda, G.O., (1988). *The impact of resource utilization on the hydrology of the Mau Hills forest in Kenya*. Mountain Research and Development, 8(2-3):193-200.

Landweber, L. F. and Dobson, A. P., eds. (1999). *Genetics and the Extinction of Species:* DNA and the Conservation of Biodiversity Princeton University Press.

LaVigne, M. & G.M. Ashley (2001). *Climatology and rainfall patterns: Lake Bogoria National Reserve (1976-2001)*. Rutgers University, New Brunswick, NJ, USA, unpublished report.

Lillesand, T.M. and R.W. Kiefer (1994). *Remote Sensing and Photo Interpretation, 3rd. ed.* John Wiley & Sons: New York. 750 p.

Lu D., Mausel P., Batistella M., Moran E (2005). Land-cover binary change detection methods for use in the moist tropical region of the Amazon: a comparative study. *International Journal of Remote Sensing* ;26(1):101–114.

Ludwig, D., R. Hilborn and C. Walters (1993). Uncertainty, resource exploitation, and conservation: lessons from history. Science 260: 17, 36.

Luong P.T. (1994). 'The detection of landuse/landcover changes using remote sensing and GIS in vietnam', *Asian-Pacific Remote Sensing Journal,* No.5, Vol. 2, pp. 63-66. machine processing of Landsat 1 data', Photogrammetric Engineering & Remote Sensing, Vol. 43, pp. 515-523.

Whitby, M.C and Ollerenshaw J. (1988*). Land use and the European Environment*. Belhaven Press

Mas J.F. (1999) Monitoring land-cover changes: a comparison of change detection techniques. International Journal of Remote Sensing. 20(1):139–152.

Mathooko and Kariuki (2000). Disturbances and species distribution of the riparian vegetation of a Rift Valley stream. African Journal of Ecology, 38:123-129.

Mathooko, J.M, Morara G.O and Leichtfried M (2001). The effect of different anthropogenic disturbances on benthic plant coarse particulate matter in a tropical Rift Valley stream. African Journal of Ecology, 39:310-312.

Miller, S.N, Kepner W.G, Mehaffey M.H, Hernandez M, Miller R.C, Goodrich D.C, Devonhold K.K., Heggem D. T., and Miller W. P. (2002). Integrating landscape assessment and hydrologic modeling for land cover change analysis. Journal of the American Water Resources Association, 38(4):915-929.

Mistry, J., (2000). *Savannas.* Progress in Physical Geography, 24(2):273-279.

Mulwa, J., Barongo, P. and Patel, J. (2006). *Preliminary magnetotelluric survey results of Arus-Bogoria geothermal prospect*, Kenya. *IAGA 18th Workshop on Electromagnetic Induction in the Earth, El Vendrell, Spain, September 17-23, 2006, Extended Abstracts*, S7-E5, p. 1-5.

Muttitanon W., Tiıpathi N.K. (2005) Land use/land cover changes in the coastal zone of Ban Don Bay, Thailand using Landsat 5 TM data. *International Journal of Remote Sensing.* 26(11):2311–2323.

Mwangi, C. (1992). *The vegetation of Lake Bogoria National Reserve*: Composition, structure and distribution. Moi University, Eldoret, Kenya.

Navrud, S. and Mungatana E.D. (1994). Environmental valuation in developing countries: the recreational value of wildlife viewing. Ecological Economics, 11:135-151.

North Lewis, M. (1998). *A Guide to Lake Baringo and Lake Bogoria*. Horizon Books. (ISBN 9966-868-17-8)

Odenyo V.A.O. and Pettry D.E. (1977), 'Land use mapping by machine processing of Landsat 1 data', Photogrammetric Engineering & Remote Sensing, Vol. 43, pp. 515-523.

Owen, R.A., Owen, R.B., Renaut, R.W., Scott, J.J., Jones, B. and Ashley, G.M. (2008). Mineralogy and origin of rhizoliths on the margins of saline, alkaline Lake Bogoria, Kenya Rift Valley. *Sedimentary Geology*, v. 203, p. 143-163.

Patz, J. A., (2001). Public health risk assessment linked to climatic and ecological change. Human and ecological risk assessment, 7(5):1317-1327.

Pratt, D. J. and Gwynne, M. D., editors, (1977). Rangeland management and ecology in East Africa. London: Hodder and Stoughton. x + 310 pp. 7.50 cloth

Prenzel B. (2004). Remote sensing-based quantification of land-cover and land-use change for planning. Progress in Planning. 61:281–299.

Renaut, R. W. and Tiercelin J.J. (1994). Lake Bogoria, Kenya Rift Valley- a sedimentological overview in Renaut R. W & Last W. M. (eds.), *Sedimentology and Geochemistry of Modern and Ancient Saline Lakes*. SEPM (Society for Sedimentary Geology) Tulsa, OK, USA. Special Publication 50. Pp.101–123.

Renaut, R. W., Jones, B. and Tiercelin, J. J. (1998). Rapid *in situ* silicification of microbes at Loburu hot springs, Lake Bogoria, Kenya Rift Valley. *Sedimentology*, v. 45, p. 1083-1103

Renaut, R.W. and Jones, B. (1997). Controls of aragonite and calcite precipitation in hot spring travertines at Chemurkeu, Lake Bogoria, Kenya. *Canadian Journal of Earth Sciences*, v. 34, p. 801-818.

Renaut, R.W. and Owen, R.B. (2005). T*he geysers of Lake Bogoria, Kenya Rift Valley, Africa. GOSA Transactions*, v. 9, 4–18.

Renaut, R.W. and Tiercelin, J.-J. (1993). Lake Bogoria, Kenya: soda, hot springs and about a million flamingoes. *Geology Today*, v. 9, p. 56-61.

Renaut, R.W., Tiercelin J.J., & Owen R.B. (1986). Mineral precipitation and diagenesis in the sediments of the Lake Bogoria basin, Kenya Rift Valley. In L.E. Frostick, R.W. Renaut, I.Reid & J.J. Tiercelin (eds), *Sedimentation in the African Rifts*. Geological Society Special Publication No. 25, Oxford. Pp. 159–175.

Sabins, F.F. (1996). *Remote Sensing Principles and Interpretation*. 3rd Ed. W. H. Freeman. New York

Schmidt, H. and Karnieli, A. (2000). R*emote sensing of the seasonal variability of vegetation in a semi-arid environment*. Journal of Arid Environments 45: 43–59.

Sharma, T., Satya Kiran P.V., Singh T.P., Trivedi A.V. and Navalgund R.R. (2001). Hydrologic response of a watershed to land use changes: a remote sensing and GIS approach. International Journal of Remote Sensing, 22(11):2095-2108.

Tiercelin, J.J. and Vincens, A. (Eds) (1987). Le demi–graben de Baringo–Bogoria, Rift Gregory, Kenya: 30,000 ans d'histoire hydrologique et sédimentaire. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, v. 11, p. 249–540.

Ulbricht K.A. and Heckendorf W.D. (1998) *Satellite images for recognition of landscape and land use changes.* ISPRS Journal of Photogrammetry & Remote Sensing.

Walsh, J. (1969). Geology of the Eldama Ravine-Kabarnet area. *Report of the Geological Survey of Kenya*, No. 83, 48 pp.

Appendix I: Trees and Shrubs of Lake Bogoria National Reserve and its Environs

Scientific Name	Common Name	Local (Turgen Name)	*Scientific Name*	Common Name	Local (Turgen Name)
Boscia angustifolia		Linto	*Opuntia opuntia*	Prickly cactus	Matunchiate
Acacia milliner	Hook thorn	Ngorore	*Warbugia ugandesis*		Soke
Grecian villas		Mokuywe	*Grevia bicolor*		Sitewe
Casaba farinose		Imbirikwo	*Rrhus natalensis*	Red currant	Siriande
Varies glomeration		Chepkoriande	*Acacia tortilis*	Umbrella thorn	Sesia
Acacia militia	Egyptian thorn	Chepiywe	*Aloe secundiflora*	aloe	Tangaretwe
Acacia deficient		Barsule	*Maema angolense*		Cheboskewe
Cumbersome aculeate		Kamsalawa	*Kigelia africana*	sausage	Rotinwo
Grecian tuna		Toronwe	*Calotropis procera*	Elephant apple	Lopusakii
Cappers trascularis		Korobuywe	*Cordial ovalis*	cordia	Temdererwe
Cumbersome hereroense		Miskitwe	*Acalypha indica*		Walbeyon/jepnondos
Salvadora persica	Toothbrush tree	Sokotoiwo	*Aclyrantha aspera*		Chesirim
Balanite aegyptiaca	Desert date	Ngoswe	*Albublin spp.*		Kipnyali/kiptulwa
Acacia brevispiza	Wait-a-bit thorn	Gornista	*Boscia salicifolia*		Kurionde
Casaba edulis		Eidumeitolyon	*Cucumis spp*		Solopchesiny
Alchornea fruticosa		Lokurwe	*Euphorbia tirucalli*	Finger euphorbia	Kormotwo
Cissus rotundifolia		Rorowe	*Maerua triphylla*		Roson
Berchemioa discolor	Wild almond	Muchukwe	*Ludwigia spp.*		Chepchorusion
Commiphora samharansis		Kelepmoi	*Lycium europaeum*		Kipyambatia /kipnaget
Euphorbia scartina		Ele	*Gardenia ternifolia*		Kipbulwo
Commiphora edulis		Masian	*Albizia amara*		Kotutwo
Croton dischogamus		Kelelwe	*Commifora africana*		Tolginy
Sterculia stenocapa		Mukoywo	*Acacia gerrardii*		Sibeldi
Adenum venenata		Sotoplekech	*Olea europaea*	Brown olive	Temtit
Adenum obesum somalensis		Simbalwe	*Pappea capensis*		Kibiriokwo
Lannea triphylla		Tabuye	*Solanum nignum*		Sojonte
Albizia anthelmintica		Barmukunte	*Syzygium gguineense/cordata*		Lomoiwo
Terminalia brownee		Koloswo	*Lanea fulua*		Lelit
Aspragus africana		Tobororwe	*Dodonaea*	hopbush	Tibilibkwo

			angustifolia/viscosa		
Cumbersome molle	Cumbersome	Chepchopoiwo	*Ocorea kenyesis*		Kipnaget
Acacia senegalis	Gum Arabic thorn	Chemange	*Tarchonanthus comphoratus*		Lelekwet
Dichrostachy cinerea		Tinet	*Carrisa edulis*	Legetetwet	
Ziziphus macronata	Buffalo thorn	Noiwet	*Pisticia aethopica*		tulda
Euphorbia candlebrum		Kunes	*Ficus thonningii*	Strangler fig	Simotwe
Ormocarpum kenieuse		Chemoyukobil	*Phyllantus zepialis*		Ariab lakwa
Acacia ceyal	White thorn	Lengne	*Crateva adansonii*		Kolewon
Haplocoelum foliotosum		Kokonte	*Lantana camara*		Ketip
Diospyros scabra		Tuwetye	*Meyna tetraphyila*		Tilingwo
Cissus quadringularis		Sungurtutwe	*Terminalia spinosa*		Tukuwemet
Zanthoxylum chalybeum	Knob wood	Kokchante	*Acacia drepanolobium*	Whistling thorn	Ngowe
Maema subcordata		Chepuluswo	*Premna resinosa*		Britapta/kekech
Maema decumbens		Monogwo	*Arundinalia alpina*	Mountain bamboo	Tegande
Acacia hockii		Tilatilie	*Vanguemia madagascarensis*		Komolwe
Tarmarindus indica	Tarmarind	Orwe	*Ficus sycomorus*	Sycomore fig	Lokoywe

Appendix II: Lake Bogoria National Reserve Mammal checklist

Common name	**Scientific name**	**Remark**
Greater kudu	*Tragelaphus strepsiceros*	Threatened
Cape buffalo	*Syncerus caffer*	Rarely seen
Impala	*Aepyceros melampus rendilis*	Common
Grants gazelle	*Gazella granti*	Common
Dikdik	*Rhynchotragus kirki*	Common
Klipspringer	*Oreotragus oreotragus*	Rare
Blue duiker	*Cephalophus caeruleus*	Rare
Yellow – backed duiker	*Cephalophus silvicultor*	Rare
Anubis baboon	*Papio Anubis*	Common
Leopard	*Panthera pardus*	Rare
Serval cat	*Felis (Leptailurus) serval*	Very rare
Wildcat	*Felis (Sylvestris) libyca*	Very rare
Common waterbuck	*Kobus ellipsiprymnus*	Rare
Warthog	*Phacochoerus aethiopicus*	Common
Bush pig	*Potamochoerus porcus*	Common
Common jackal	*Canis aureus*	Common
Spotted hyena	*Crocuta crocuta*	Rare
Stripped hyena	*Hyaena hyaena*	Rare
Bat – eared fox	*Otocyon megalotis*	Rare
Burchell's zebra	*Equus (Hippotigris) burchelli*	Common
Patas monkey	*Erythrocebus patas*	Rare
Vervet monkey	*Cercopithecus pygerythrus*	Common
Cheetah	*Acinonyx jubatus*	Rare
Aardvark	*Orycteropus afer*	Rare

Appendix III: Lake Bogoria National Reserve Birds Checklist

Common Name	**Scientific Name**	**Common Name**	**Scientific Name**
Common Ostrich	*Struthio camelus*	Jackson's Francolin	*Francolinus jacksoni*
Little Grebe	*Tachibuptus ruficollis*	Crested Francolin	*Francolinus saphaena*
Black necked Grebe	*Podiceps nigricollis*	Black Crake	*Amaurornis flavirostris*
Greate- white pelican	*Pelecanus onocrotalus*	Grey Crown Crane	*Balearica regulorum*
Cattle Egret	*bubulcus ibis*	Black-winged Stilt	*Himantopujsn himantopus*
Striaed(Green-backed)Heron s	*butorides striatu*	Pied Avocet	*Recurviurosta avosetta*
Litle Egret	*Egretta garzeta*	Spur winged Lapwing	*Vanellus spinosus*
Gredy Heron	*Ardea cinerea*	Crowned Lapwing	*Vanellus coronatus*
Black heade Heron	*Ardea malanocephala*	Black-headed lapwing	*Vanellus tectus*
Hamerkop	*scopus umbretta*	Kittlitz's plover	*Charadrius pecuarius*
Yellow-billed stork	*Mycteria ibis*	Three-banded plover	*Charadrius tricollaris*
Wooly-necked Stork	*Ciconia episcopus*	Common ringed plover	*Charadrius hiaticula*
Marabou stork	*Leptoptilos crumeniferus*	Lesser sandpiper	*Chandarius mongolus*
Sacred ibis	*Threskiornis aethiopicus*	Little Bee-eater	*Merops pasillius*
Hadada ibis	*Bostrychia hagedash*	Cinammon-chested Bee-eater	*Meros oreobates*
Glossy ibis	*Bostrychia falcinellus*	European Bee-eater	*Merops apiaster*
Greater flamingo	*Phoenicopterus rubber*	Madagascar Bee-eater	*Merops superiliosus*
Lesser flamingoe	*Phoenicopterus minor*	Lilac breasted Roller	*Coraciass caudate*
Egyptian Goose	*Alopochen aegyptiacus*	Green Wood Hoopoe	*Phoeniculus purpureus*
Spur- winged goose	*Plectopterus gambensis*	African Hoopoe	*Upupa Africana*
Knobed –billed duck	*Sarkidiornis melanotos*	Red- billed Hornbill	*Tockus erythrorhynchus*
White –faced Whistling Duck	*Dendrocygna viduata*	Von der Deckens Hornbill	*Tockus deckeni*
Cape Teal	Anas capensis	Jackson's Hornbill	*Tockus jacksoni*
Yellow-billed Kite	*Milvus parasiticus*	African Grey Hornbill	*Tockus nasutus*
African fish eagle	*Haliaeetus vocifer*	Red-fronted Tinkerbird	*Pogoniulus pusillus*
African Harrier-Hawk	*Polyboroides typus*	Red-fronted Barbet	*Tricholaema diademata*
Augar buzzard	*Buteo augur*	Black throated Barbet	*Tricholaema melanocephala*
Common buzzard	*Buteo buteo*	White -headed Barbet	*Lybius leucocephalus*
Montangu's Harrier	*Circus ranivorus*	d'Arnaud's Barbet	*Trachyphonus darnaudii*
Dark Chantineg Goshhawk	*Melierax metabates*	Red and Yellow Barbet	*Trachyphonus erythrophalus*
Gabar Goshhawk	*Micronisus gabar*	Lesser Honeyguide	*Indicator minor*

Tawny Eagle	*Aquila rapax*	Nubian Woodpecker	*Campethera nubica*
Steppe Eagle	*Aquila nipalensis orientalis*	Cardinal Woodpecker	*Dendropicos fuscescns*
Verreaux Eagle	*Aquila verreauxii*	Bearded Woodpecker	*Dendropicos namaquus*
Martial Eagle	*Polemaetus bellicosdus*	Grey Woodpecker	*Dendropicos goertae*
Pygmy Falcon	*Polihierax semitorquatus*	Fischer's Sparrow Lark	*Eremopterix leucopareia*
Peregrine Falcon	*Falco peregrinus*	Rock Martin	*Hirundo filigula*
Helmeted Guinea fowl	*Numida meleagris*	Plain Martin	*Riparia paludicola*
Red-rumped Swallow	*Hirundo fuligula*	Sand Martin	*Riparia riparia*
Lesser striped swallow	*Hirundo abyssinica*	African scops-owl	*Otus senegalensis*
Barn swallow	*Hirundo rustica*	Verreaux's eagle-owl	*Bubo lacteus*
Wire-tailed swallow	*Hirundo smithii*	Pearl-spotted owlet	*Glaucidium perlatum*
African pied wagtail	*Motacilla lutea*	Little swift	*Apus affinis*
Common bulbul	*Pycnonotus barbatus*	White-rumped swift	*Apus caffer*
African thrush	*Turdus pelios*	Mottled swift	*Apus aequatorialis*
Isabelline wheatear	*Oenanthe pleschanka*	Nyanza swift	*Apus niansae*
Sported morning Thrush	*Cichladusa guttata*	Eurasian swift	*Apus apus*
Grey-baked camaroptera	*Camaptera brachyuran*	Speckled mousebird	*Colias striatus*
Southern black flycatcher	*Melaenornis pammelaina*	Blue-naped mouse bird	*Urocolias macrourus*
African grey flycatcher	*Bradornis microrhynchus*	Red-faced mouse bird	*Urocolias indicus*
Silverbird	*Empidornis semipartitus*	Grey-headed kingfisher	*Halcyon leucocephala*
Rufous chatterer	*Turdoides rubiginosus*	Woodland kingfisher	*Halcyon senegalensis*
Northern pied babbler	*Turdoides hypoleucus*	Malachite kingfisher	*Alcedo cristata*
White-bellied tit	*Parus albiventris*	African pigmy kingfisher	*Ispidina picta*
Northern grey tit	*Parus thruppi*	Beautiful sunbird	*Cinnyris pulchella*
Red-throated tit	*Parus fringillinus*	Eastern violet-backed sunbird	*Anthreptes orientalis*
Ruff	*Philomanchus pugnax*	Common fiscal	*Lanius collaris*
Common sandpiper	*Actitis hypoleucos*	Long-tailed fiscal	*Lanius cabanisi*
Wood sandpiper	*Tringa glareola*	Grey-backed fiscal	*Lanius excubitoroides*
Green sandpiper	*Tringer ochropus*	Slate-coloured boubou	*Laniarius funebris*
Common greenshank	*Tringa nebularis*	Brubru	*Nilaus afer*
Marsh sandpiper	*Tringa stagnatilis*	Black-backed puffback	*Dryoscopus cubia*
Spotted redshank	*Tringa erythropus*	Nothern White-crowned shrike	*Eurocephalus rueppelli*
Little stint	*Calidris minuta*	Fork-tailed drongo	*Dicrurus adsimilis*
Curlew sandpiper	*Calidris ferriginea*	Pied crow	*Corvus albus*
Common snipe	*Gallinago gallinago*	African black-headed oriole	*Oriolus larvatus*
Lichtenstein's sandgrouse	*Pterocles lichtensteinii*	African golden oriole	*Oriolus auratus*

Africa green-pigeon	*Treron calva*	Red-billed oxpecker	*Buphagus erythrorhynchus*
Speckled pigeon	*Columba guinea*	Ashy starling	*Cosmopsarus unicolor*
Emerald-spotted wood-dove	*Turtur chalcospilos*	Ruppell's long-tailed starling	*Lamprotornis purpuropterus*
Namaqua dove	*Oena capensis*	Magpie starling	*Speculipastor bicolar*
Ring-necked dove	*Streptopelia capicola*	Supurb starling	*Lamprotornis superbus*
Red-eyed dove	*Streptopelia semitorquata*	Wattled starling	*Creatophora cinerea*
African mourning dove	*Streptopelia decipiens*	House sparrow	*Passer domestica*
Laughing dove	*Streptopelia senegalensis*	Chestnut sparrow	*Passer eminibey*
White-belied go-away-bird	*Corythaixoides leucogaster*	Grey-headed sparrow	*Passer griseus*
White-browed coucal	*Centropus superciliosus*	White-browed sparrow-weaver	*Plocepasser mahali*
White-billed buffalo-weaver	*Bubalornis albirostris*	White-headed buffalo-weaver	*Dinemellia dinemelli*
Northern masked weaver	*Ploceus taeniopterus*	Pin-tailed whydah	*Vidua macroura*
Speke's weaver	*Ploceus spekei*	Straw-tailed whydah	*Vidua fischeri*
Jackson's Golden-backed weaver	*Ploceus jacksoni*	Steel-blue whydah	*Vidua hypocherina*
Red-headed weaver	*Anaplectes rubriceps*	Village indigobird	*Vidua chalybeate*
Red-cheeked cordon-bleu	*Uraeginthus bengalus*	African citril	*Serinus citrinelloides*
Blue-capped cordon-bleu	*Uraeginthus cyanocephalus*	Streaky seedeater	*Serinus striolatus*
Red-billed firefinch	*Lagonosticta senegala*		