GEOSPATIAL ANALYSIS OF LAND COVER AND LAND USE CHANGE IN THE MAU FOREST COMPLEX OF KENYA

BY

ISAAC ONGONG'A AYUYO

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DECLARATION

This Research Project is my original work and it has never been submitted for approval or examination in any other University.

Isaac O. Ayuyo
(C50/74381/2009)

Date 30/11/2011

This Research Project Report has been submitted for examination with our approval as the University Supervisors

Supervisors:

Date 10/01/2012

Dr. Isaiah Ang'iro Nyandega
Department of Geography
& Environmental Studies

Date 27/01/2012

Dr. Mikalitsa S. Mukhovi
Department of Geography &
Environmental Studies

DEDICATION

This project is dedicated to my late mother, phoebe Ayuyo

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LIST OF ACRONYMS

AVHRR	Advanced Very High Resolution Radiometer.
CBS	Central Bureau of Statistics
ETM	Enhanced Thematic Mapper
DRSRS	Department of Resource Survey and Remote Sensing
FAO	Food and Agricultural Organization
GIS	Geographic Information Systems
GPS	Global Positioning Systems
IFOV	Instantaneous field of view
IGBP	International Geosphere-Biosphere Programme
IHDP	Human Dimensions of Global Environmental Change Programme
KFS	Kenya Forest Service
KFWG	Kenya Forest Working Group
KIFCON	Kenya Indigenous Forest Conservation Programme
KGM	Kenya Greenbelt Movement
KMD	Kenya Meteorological Department
KWS	Kenya Wildlife Service
LACIE	Land Area Crop Inventory Experiment
LULC	Land use and Land cover
MEMR	Ministry of Environment and Mineral Resources
MRLC	Multi-Resolution Land Characteristics
MRS	Mau Rehabilitation Secretariat
MSS	Multi-Spectral Sensor
NASA	National Aeronautical Space Administration
NOAA	National Oceanic and Atmospheric Administration
RCMRD	Regional Centre Mapping of Resources for Development
RS	Remote Sensing
SOK	Survey of Kenya
TM	Thematic Mapper
UN	United Nations
UNEP	United Nations Environmental Programme

ABSTRACT

This study employed the use of Remote Sensing and GIS to evaluate the Land Cover and Land Use Changes that had occurred between 1973 and 2010 in the Mau forest complex, Kenya. The study area is around 400,000 hectares and has the largest montane vegetation in East Africa. The significance of the Mau complex can be viewed in term of the enormous biodiversity of flora and fauna it has and the fact that, it forms upper water catchments to many major rivers. It also sustains many conservation areas and modifies the microclimate in the region. The Mau ecosystem has very high economic potential due to its very fertile soils and high rainfall amounts.

The general objective of this study was to create a geospatial tool for land cover and land use change detection in the Mau forest complex that can be used in decision making. More specifically the study sought to: determine the present status of land cover and land use in the Mau; analyse changes that had occurred over time; determine human activities responsible for the changes; and to determine the environmental impacts associated with these changes.

Multispectral Landsat imageries for 1973, 1986, 2000 and 2010 were analysed using ENVI 4.8 software and applying Supervised Classification to classify the land cover and land use types. To achieve this, the first step involved the development of an appropriate classification scheme in which three classes namely - Forestland, Other Vegetation, and Non-vegetated land were used. After developing classification scheme, the study delineated training sites from each of the cover classes, defined the signatures for each land cover category and finally the software was instructed to use these signatures to classify the remaining pixels.

Post Classification Visual and Area Comparisons were done to get information on the trends, rates and magnitude of land cover and land use changes in the Mau forest complex over time. Overlay operations of the classified images were done under ArcGIS software to detect the changes that had occurred in each cover type over the study period. Overlays determined what actually changed to what, according to the land cover classes used. The process involved a pixel to pixel comparison of the study year images and the information got revealed both the desirable and undesirable changes over time and the classes that were relatively stable. This information was kept in a geo-database and will serve as a vital tool in management decisions.

To detect the variations in the greenness of the vegetation present in the pixel over time, Normalized Difference Vegetation Index (NDVI) was used with density slices ranging from 0.25 μm to 1.00 μm (range of vegetation cover). Time series NDVI analysis was done to detect changes in plant health over time (healthy plants are greener). Field photography was used to capture various human activities taking place in the forest to help in the assigning of training sites and signatures. Integrated analysis in Mount Londiani forest (a case study) used thematic maps of land cover, population densities, slopes, land use, soils and graphs for rainfall distribution for comparative analysis among the variables.

The study established that, changes in Land Use and Land Cover had occurred in all the 22 blocks of Mau forest complex and resulted in the reduction of forest cover. This happened because the rates at which forest cover was converting to other land covers were higher than the rates at which the opposite was taking place. The study also found out that there was relationship between increase in population and decrease in forest cover and that, steep slopes were cleared of their forest as land use changed. The study established that conversion of forest land to agricultural land was the main cause of deforestation in the Mau and resulted in the loss of biodiversity and partly led to reduction in rainfall and subsequent decrease in river discharge.

This study recommends that conservation efforts in the Mau should be continued since they have yielded positive results. Secondly, the Government should enact laws, policies and regulations on land use and forest resource management which should incorporate all stakeholders. Lastly, the Government should develop a good and vibrant geo-database of the Mau forest complex to enhance decision making on conservation while further research on impacts of Land Cover and Land Use Change on livelihoods and on downstream projects, among others needed to be carried out.

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background to the Study

This study was a spatial- temporal analysis of the land cover and land use changes in the Mau forest complex, Kenya. A part from mapping the changes in land cover and land use, it also determined the main human activities that had caused the changes, the trends and patterns thereof, and the resulting environmental impacts. The study created a geospatial tool for land use and land cover change measurement in the Mau forest complex that can be used in decision making for sustainable forest resource uses and management not only in the Mau Complex, but in forests in general.

According to Meyer, (1995), every parcel of land on the earth's surface is unique in the cover it possesses. He asserts that, land use and land cover are distinct yet closely linked characteristics of the earth's surface. Land use is the manner in which human beings employ the land and its resources. Examples of land use include agriculture, urban development, grazing, logging, and mining. In contrast, land cover describes the physical state of the land surface. Land cover categories include cropland, forests, wetlands, pasture, roads, and urban areas. The term land cover originally referred to the kind and state of vegetation, such as forest or grass cover, but it has broadened in subsequent usage to include human structures such as buildings or pavement and other aspects of the natural environment, such as soil type, biodiversity as well as surface and groundwater (Meyer, 1995).

Land use affects land cover and changes in land cover affect land use. A change in either, however, is not necessarily the product of the other. Changes in land cover by land use do not necessarily imply a degradation of the land. However, many shifting land use patterns, driven by a variety of social causes, result in land cover changes that affect biodiversity, water and radiation budgets, trace gas emissions and other processes that, cumulatively, affect global climate and biosphere (Riebsame, Meyer, and Turner, 1994).

Land cover can be altered by forces other than anthropogenic. Natural events such as weather, flooding, fire, climate fluctuations, and ecosystem dynamics may also initiate modifications upon land cover. Globally, land cover today is altered principally by direct human use: by agriculture and livestock raising, forest harvesting and management, and urban and suburban construction and development. There are also incidental impacts on land cover from other human activities such as forests and lakes damaged by acid rain from fossil fuel combustion and crops near cities damaged by tropospheric ozone resulting from automobile exhaust (Meyer, 1995).

Contemporary global change consists of two broad types, systemic and cumulative. Systemic change operates directly on the bio-chemical flows that sustain the biosphere and, depending on its magnitude, can lead to global change, just as fossil fuel consumption increases the concentration of atmospheric carbon dioxide. Systemic change is largely associated with, but not limited to, the Industrial Age and thus has grown especially important over the more recent past (Turner and Butzer, 1992).

Cumulative change has been the most common type of human induced environmental change since antiquity. Cumulative changes are geographically limited, but if repeated sufficiently, become global in magnitude. Changes in landscape, cropland, grasslands, wetlands, or human settlements are examples of cumulative change. Some cumulative changes reached continental and even global proportions long before the 20th Century, including deforestation and the modification of grasslands (Turner and Butzer, 1992).

Changes in land cover driven by land use can be categorized into two types: modification and conversion. Modification is a change of condition within a cover type; for example, unmanaged forest modified to a forest managed by selective cutting. Significant modifications of land cover can occur within these patterns of land cover change. Conversion is a change from one cover type to another, such as deforestation to create cropland or pasture. Such land use and land cover changes have been the focus of many global change research agendas (Riebsame, Meyer and Turner, 1994).

The loss of rainforests throughout the tropical regions of the world as a result of deforestation for timber resources and conversion to agricultural lands has become a topic of global attention with the aid of widespread media coverage. Research specialists such as Skole & Tucker (1993), performed extensive studies in an attempt to bring further attention to this situation by focusing on the social implications and the environmental degradation associated with tropical deforestation in the Amazon of South America and in Southeast Asia. Yet, with all the research, awareness, and attention of the world, this potentially devastating phenomenon continues. It is an unfortunate, but fact of life that deforestation occurs on numerous expanses and at varying scales around the globe.

There were significant historical global changes in land cover and land use which occurred between 1700 and 1990 when the area of cropland expanded from about 3.5 million km^2 to some 16.5 million km^2 (Lambin and Geist, 2006). Much of this expansion occurred at the expense of forest which decreased from 53 million km^2 to 43.5 km^2. Even though the net loss of the global forest area have reduced significantly due to large scale afforestation reported in China and Vietnam, tropical forest deforestation has continued into the 21st century. Between 2002 and 2005, the world experienced about 0.073 million km^2 of net annual deforestation largely due to agricultural expansion (FAO, 2005). Deforestation has essentially been a feature of the poor countries such as Kenya. The average annual deforestation rate between 1990 and 2005 in low-income countries was 0.5 % while that in middle-income countries was 0.2% (World Bank, 2007).

Satellite imageries and topographical maps of the area plus geographical coordinates of selected ground control points were used for registration and image matching, classification and processing. ENVI 4.8 processing software was used for the development of land cover and land use classes and subsequently for change detection analysis of the study area. ArcGIS 9.2 was used for displaying and subsequent processing and enhancement of the images. It was also used for clipping out the area of interest (Mau forest complex) from the images using topographical maps of the area. The whole process thus, applied the use of Remote Sensing and an integrated Geographic Information Systems to evaluate the land cover and land use changes, trends, magnitudes and the emanating environmental impacts in the area for a period of about 37 years.

1.2 Statement of Problem

Loss of forest cover in Kenya has contributed to diminishing livelihoods of many Kenyans caused by reduced land productivity, famine and drought. The recent drought experienced over a couple of years is a case at hand. Large scale livestock deaths were reported and in many places, incidents of conflicts over resources use were witnessed leading to loss of human lives. Though most of Kenya`s forests have been decimated by degradation among other factors, the Mau forest complex and in particular that of the Maasai Mau has been the most affected and has receded drastically over time (UNEP 2005).

The pace and severity of destruction and degradation of Kenya's forests has generated increasing publicity and concern over the last two decades. The cause of this destruction is believed to be change in land use from forest to agriculture and change in ownership from public to private (UNEP, 2005). There has been an extensive encroachment as well as irregular forest land allocation, exacerbating an already serious situation (MFRS, 2009). The report says that, the Mau Complex is a particularly degraded catchment area in Kenya despite its critical role in sustaining current economic development. This degradation of the catchment has been attributed to widespread ill-planned settlements, encroachments, excision and illegal extraction of forest resources.

It is believed that continued destruction of the forests is leading to a water crisis in that, perennial rivers are becoming seasonal, storm flow and downstream flooding are increasing and in some places, the aquifer has dropped by 100 metres while wells and springs are drying up. The impacts are negatively felt on major natural assets and development investments, including Lake Nakuru National Park, Maasai Mara National Reserve, Sondu-Miriu Hydropower Scheme (60MW), Geothermal plants near Naivasha, small hydropower plants in the Kericho tea estates (4MW) and the tea growing areas in Kericho Highlands (MFRS, 2009).

In addition, there are global concerns resulting from loss of the Mau's biodiversity, and increased carbon dioxide emissions as a result of forest cover loss. Poor soil and water conservation practices in the Mau complex is causing soil erosion and decreasing crop yields in an area of high agricultural potential while in the commercial tea estates, yields are being affected by microclimatic changes. With this in mind, much needed to be done to save and or reverse the situation in the country's largest water tower.

Therefore, in order to come up with trends, rates and quantities of change that had come up in the Mau forest complex due to human actions and the resulting environmental impacts and to know how best to plan and manage the forest for sustainable development, this research undertook a spatial temporal analysis of the land cover and land use changes with a view to developing a geo-database for the Mau to enhance decision making. The creation of such a database involved the analysis of the variables like population, rainfall, geology and soils, land use and the slopes data which were processed into thematic maps and graphs alongside land cover classes processed and overlaid.

None of the previous studies had done such kind of analysis, incorporating all these variables. The other gap filled was carrying out land use and land cover change detection in the entire Mau forest complex (all the 22 blocks) since none of the previous studies had done so but had only concentrated in the Eastern Mau, Western Mau, South West and the central blocks leaving out the northern blocks. The northern block was taken care of by choosing Mount Londiani for case study because of its level of degradation and the fact that it had very steep slopes and therefore studying how changes in land use had affected the steep slopes was very necessary. It was assumed that, what happened in Mount Londiani forest happened in the other blocks as well.

This study filled the research gaps and contributed to the policy makers and to knowledge in general. By creating a geo-database, it gave government and those involved in forest management a geo-spatial tool for land use and land cover change detection that could be used to make informed decisions aimed at sustainability in forest use. It contributed to knowledge by coming up with findings that were informative and could help improve the understanding of the subject matter. The study also contributed to knowledge through the methodology used and by coming up with new areas of research that could further add more knowledge when researched and concluded.

The study addressed the following questions:

1. What is the present land cover status of Mau forest complex?
2. What are the land cover and land use changes that have occurred over time?
3. What are the human activities that have contributed to the forest cover changes in the Mau forest complex?
4. What are the environmental impacts of the land cover change in the Mau forest complex?

1.3 Objectives of the Study

1.3.1 General Objective

To create a geospatial tool for land cover and land use change detection for the Mau forest complex that can be used in decision making.

1.3.2 Specific Objectives

The specific objectives of the study were to determine:

1. Present land cover and land use the Mau forest complex
2. Land cover and land use changes in the Mau forest complex overtime.
3. Factors that had contributed to the land cover changes in the Mau
4. Environmental impacts of the land cover and land use changes in the Mau forest complex.

1.4 Research Hypothesis

To achieve the objectives stated above, the study used the hypothesis that, land cover and land use changes were not due to human activities.

1.5 Justification of the Study

Land Use and Land Cover Change is a major driving force in habitat modification and therefore it has implications in the distribution of biodiversity and ecological systems. It was noted that even though there was need to balance the use of forest resources with conservation measures, this tended to be lacking in most developing countries. In Kenya for instance, coexistence between the ecological systems and the biodiversity in relation to their conservation and local use had not been addressed adequately in terms of conditions for environmental, social, and economic sustainability. The lack of coexistence between the ecological systems and conservation was attributed to weak and ineffective policies and/or bad economic strategies and laxity in the implementation of forest protection regulations, resulting in more forest clearance.

Mau forest complex lately became a major discussion point in Climate Change fora due to its international role as one of the major water towers for Lake Victoria and therefore the Nile, as source of livelihood to people in the greater lake region up to the Mediterranean region. This placed a heavy burden on the Kenya government in terms of international obligation to conserve shared resources such as the Mau water resources, in order to reverse the adverse situations that are already being experienced due to degradations.

For the Kenya Government to carry-out the above obligations there was need to create an inventory of the land cover and land use changes that had occurred in the forest cover and to establish their rates, trends and extent in relation to the causal factors. It was also necessary to determine the resulting environmental impacts and all the results kept in a geo-database that could be retrieved by the stakeholders in sustainable forest resources management for decision making.

1.6 Operational Definitions

Afforestation: Is the planting of trees in an area that formally had no forest.

Change Detection: Is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989).

Conversion: Refers to the complete replacement of one cover type by another (Turner et al., 1995).

Deforestation: Is the replacement of forest by any other land cover type. Deforestation may come as a result of converting forest land into farmland or settlement, among many other uses.

Environment: Is the surroundings in which the biosphere, hydrosphere, lithosphere and the atmosphere interact and co-exist in equilibrium.

Forest: A dense growth of trees and under-bush covering a large area.

Geographic Information Systems: Computerized database systems used for capturing, storing, retrieving, and analyzing spatial data so as to generate spatial information (Idrisi 32 guide to GIS and Image processing, volume 1).

Geo-referencing: Is the process of assigning the map coordinates to the imageries to enable the details on the images to have same ground coordinates as the map.

Land Cover: Is the manner in which human beings employ the land and its resources – e.g. agriculture, urban development, grazing, logging, and mining.

Land Use: Is the physical state of the land surface. Land cover categories include cropland, forests, wetlands, pasture, roads, and urban areas.

Land Cover Change: Refers to modification of the existing land cover or complete conversions of the land cover to a new cover type.

Modification: Refers to change in the composition of land cover type without changing its overall classification (Turner et al., 1995).

Proximate (Direct) Causes: Are immediate actions of local people in order to fulfil their needs from the use of the land (Geist and Lambin, 2002).

Reforestation: Means the planting trees in an area of land that at one time had forest but has since been cleared of its forest due to human activities on the land.

Remote Sensing: The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Idrisi 32 guide to GIS and Image processing, volume 1).

Resource: A usable stock or supply that man is capable to utilize for the fulfilment of his needs and wants.

Supervised Image Classification: Is a method in which the analyst defines small areas, called training sites, on the image which are representative of each desired land cover category.

Training Sites: Are small areas representing each known land cover category that appears fairly homogeneous on the image and are used to "train" the classification algorithm to recognize land cover classes based on their spectral signatures, as found in the image.

Underlying (Indirect or Root) Driving Forces: Are fundamental socio-economic and political processes that push proximate causes into immediate action on land use and land cover (Geist and Lambin, 2002).

Unsupervised Image Classification: Is a method in which the image interpreting software separates the pixels in an image based upon their reflectance values into classes or clusters with no direction from the analyst.

Wasteland: Denotes land without scrub, sandy areas, dry grasses, rocky areas and other human induced barren lands.

CHAPTER TWO

2.0 STUDY AREA

2.1 Location and Size

The Mau forest complex is situated in the south western part of Kenya and is found within the Great Rift Valley. It lies between Latitudes 0^0 19' N and 0^0 93' S and Longitudes 35^0 29' and 36^0 10' East. Mau forest complex covers approximately 416,542 hectares and is the largest closed canopy montane forest conservation in East Africa. Prior to its degradation, it was larger than Mt. Kenya and the Aberdare forests combined. Its expanse spreads in seven counties including Nakuru, Kericho, Bomet, Narok, Baringo Uasin Gishu and Nandi (Kenya Forest Service, 2010). All the forest blocks in the Mau Forest Complex are gazetted except the Maasai Mau and are managed by the Kenya Forest Service except the Maasai Mau Forest which is Trust Land and is managed by the Narok County Council (NCC).

The northern blocks comprise Mount Londiani, Tinderet, Northern Tinderet, Timboroa, Nabkoi, Kilombe Hill, Metkei, Maji Mazuri, Chemorogok and Lembus forests while Eburru forest is found to the eastern part of Narok County. Eastern Mau forest lies between Rongai-Njoro plain and the upper slopes of the Mau hills. The south western block occupies parts of Kericho and Bomet counties and include Transmara and Ol Posimoru while the Maasai Mau is in the southern part with its southern boundary 17 km north of Narok Town and is the only ungazetted of the 22 blocks. The central blocks include the Mau Narok and South Molo forests (Kenya Forest Service, 2010).

Figure 2·1: Location of Mau Forest Complex in Kenya.

Source: Kericho D.D. Plan, 1997-2001

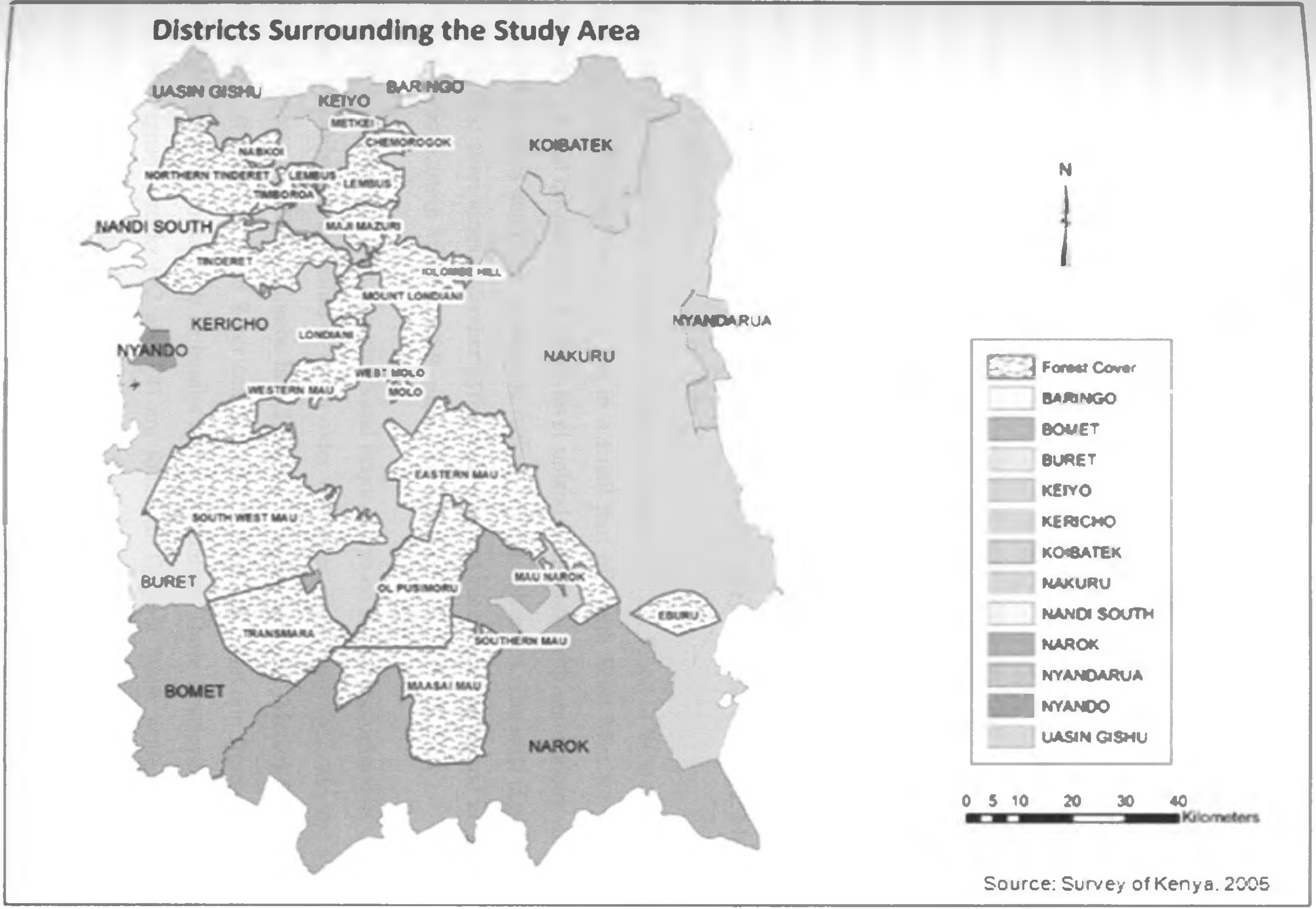


Figure 2.2: Counties and Districts of the Mau Forest Complex

2.2 Geology and Soils

The geology of Mau forest complex is predominantly volcanic in origin making most of the soils to be deep and well drained because of their high nutrient content. This study categorized the geology and soils according to their altitudinal locations and therefore we have the geology and soils found in the bottomlands which comprise soils developed on infill from volcanic ashes and from intermediate igneous rocks. The former (B1) are found in small bits in parts of Londiani, Mount Londiani, Tinderet, Ol Pusimoru and Western Mau forests while the latter (B2) are found in Metkei forest only.

The most common rock formation from which soils were developed in the Mau complex is found on the hills and minor scarps on slopes predominantly over 16%. It comprises basic igneous rocks such as serpentinites, basalts and nepheline pholites; ashes and other pyroclastic rocks of recent volcanoes; intermediate igneous rocks such as syenites and trachytes plus quartzite. Soils developed from basic igneous rocks (H1 and H2) are found in Nabkoi, Tinderet, Northern Tinderet and Londiani forests while those developed from ashes and other pyroclastic rocks of recent volcanoes (H4 and H6) are found in Eburru, Mau Narok and Eastern Mau forests.

The soils developed from intermediate igneous rocks (H7) are found in Western Mau forest while those from quartzite (H16) are in a small part of South West Mau forest. Another category is found on plateau or upper-level upland transitions with undulations and is also composed of ashes and other pyroclastic rocks of recent volcanoes. The soils (Lu1 and Lu2) are developed from ashes and other pyroclastic rocks of recent volcanoes and are found in Southern Mau, Eastern Mau and Ol Pusimoru forests.

The rock formation found on mountains and major scarps on slopes predominantly over 30% include olivine basalts and ashes of major older volcanoes. These soils (M2, M5 and M6) are found in Mount Londiani, Kilombe hill, Tinderet, Western Mau and Metkei forests. On the foot-slopes of between 2 and 8 per cent are soils formed on colluvium from quartzite and from basic igneous rocks such as basalts and serpentinites. Those developed on colluvium from basic igneous rocks (F2 and F4) are found in Tinderet forest while the soils from quartzite (F17) are found in Western Mau forest. At the volcanic foot-ridges including dissected lower slopes of major older volcanoes and mountains, tertiary or basic igneous rocks plus ashes and other pyroclastic rocks of recent volcanoes are found. The soils R2, R5, R9 and R10 are developed on tertiary basic igneous rocks and are found in most parts of

Northern Tinderet, part of Lembus, South West Mau, Western Mau, Transmara and Tinderet forests. The soils developed on ashes and other pyroclastic rocks of recent volcanoes (R13) are found in most parts of Maasai Mau, Transmara and Ol Pusimoru forests.

On the upper-level uplands, usually of rolling to hilly altitudes of 6500 to 11,000 feet and about 4,000 feet above local base level, tertiary or older basic igneous rocks of basalts and nepheline phonolites, among others are found. The soils formed (Uh2, Uh3, Uh3 + Uh4) are found in Maji Mazuri, Mount Londiani, Tinderet, Northern Tinderet, Lembus, Chemorogok and Timboroa forests. At lower middle-level uplands, usually of undulating altitudes of between 3,500 and 65,000 feet and about 1,500 feet above local base level are found basic igneous rocks and biotite gneisses.

The soils developed from basic igneous rocks (Um4) are found in Eastern Mau, Molo and Mount Londiani forest. Those developed on biotite gneisses are found in Northern Tinderet forest. Some soils (Pv9) were developed on Dissected Erosional Plains from various volcanic rocks and ashes and other pyroclastic rocks of recent volcanoes and are found in Kilombe forest. Figure 2.2 shows the main soils found in the Mau forest complex and they are explained here in terms of their location, geology and Soil type.

BOTTOMLANDS (Soils developed on infill from Volcanic Ashes.

B1: Imperfectly drained or poorly drained, moderately deep, dark greyish brown, mottled very firm clay loam, abruptly underlying a top soil of acid humic friable loam (humic PLANOSOLS).

B2: Poorly drained, moderately deep, dark grey to grey, mottled, firm clay, with a humic topsoil, in places over petrolplinthite (mollic GLEYSOLS, partly petroferric phase).

PLATEAU/UPPER-LEVEL UPLAND TRANSITIONS (undulating)

Lu1: Well drained, deep to very deep, dark brown, friable and smeary, very loam with an acid humic topsoil (humic ANDOSOLS)

Lu2: Well drained, deep to very deep, very dark greyish brown, friable and smeary, clay loam with a thick humic top soil (Mollic ANDOSOL)

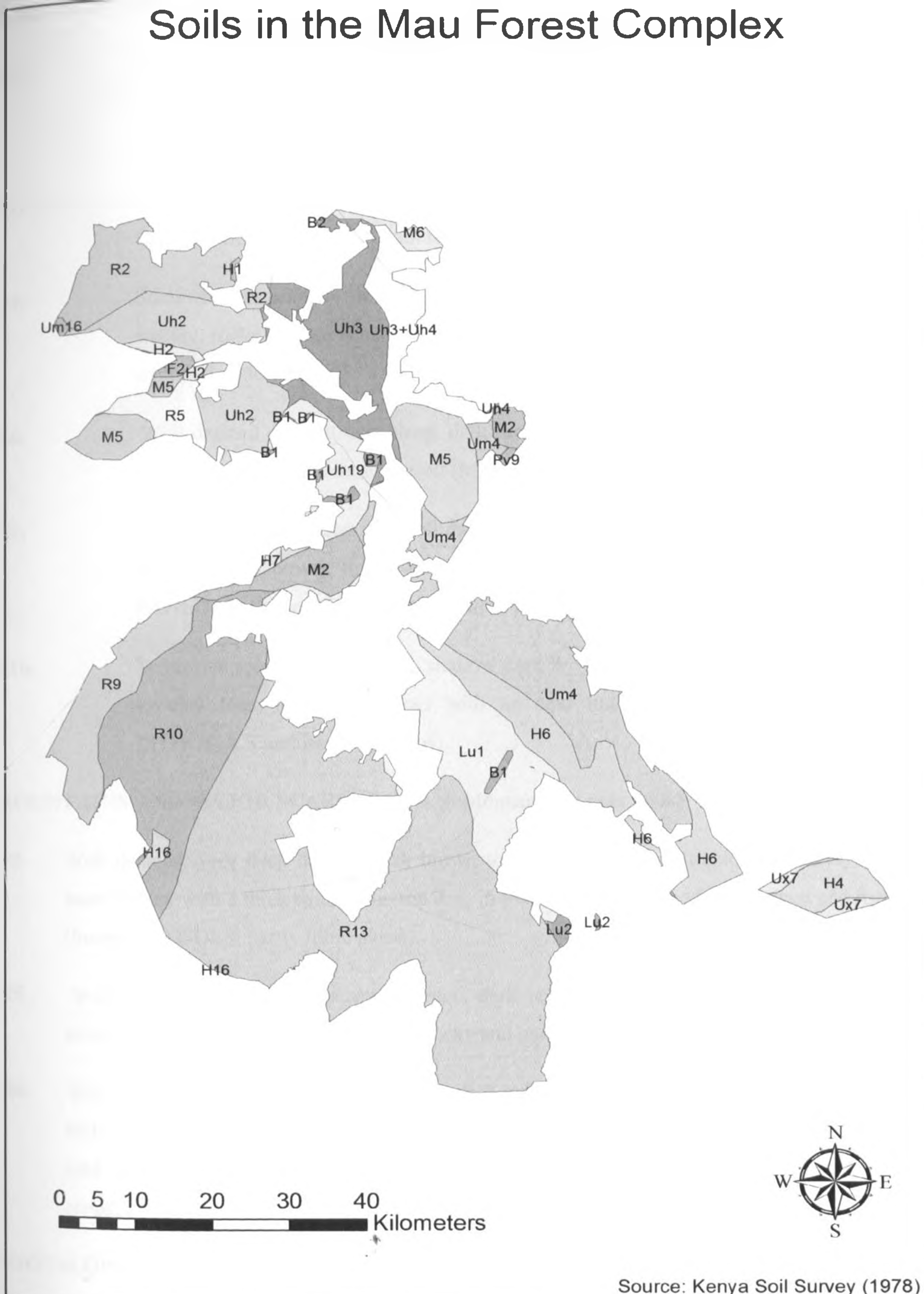


Figure 2.3: Geological and Soils of the Mau forest complex

HILLS AND MINOR SCARPS (slopes predominantly over 16%)

H1: Somewhat excessively drained, shallow to moderately deep, dark reddish brown, friable, gravelly clay with an acid humic topsoil (humic CAMBISOLS, partly paralithic phase)

H2: Well drained, shallow dark reddish brown, friable rocky and stony clay loam (chronic CAMBISOLS, lithic phase with rock outcrops).

H4: Somewhat excessively drained, shallow dark brown to brown, friable and slightly smeary, rocky and stony clay loam (ando-eutric CAMBISOLS, lithic and stony phase with rock outcrops).

H6: Well drained deep to very deep, dark brown to greyish brown, friable and smeary clay loam with thick humic topsoil (Mollic ANDOSOLS).

H7: Well drained to moderately well drained, shallow to moderately deep, dark reddish brown to dark brown, firm, bouldery or stony clay with a humic topsoil (verto-luvic PAHEOZEMS, bouldery and partly lithic phase).

H16: Somewhat excessively drained, shallow dark brown, very friable, rocky, sandy loam to clay loam in many places with an acid humic topsoil (RANKERS; with LITHOSOLS and Rock Outcrops).

MOUNTAINS AND MAJOR SCARPS (slopes predominantly over 30%)

M2- Well drained, very deep dark reddish brown to dark brown, very friable and smeary, clay loam to clay with a thick acid humic top soil, in places shallow to moderately deep and rocky (humic ANDSOLS; partly lithic phase).

M5 - Well drained, shallow to moderately deep, dark reddish brown, friable, humic rocky and stony, clay loam (humic CAMBISOLS, rocky and partly lithic phase).

M6: Well drained, shallow to moderately deep dark reddish brown to dark brown, friable, rocky and bouldery, clay loam to clay; in places with a humic topsoil (nito – chronic CAMBISOLS; with haphic PHAEOZEMS, lithic phase LITHOSOLS, eutric REGOSOLS and Rock Out crops).

FOOTSLOPES (gently sloping to sloping: slopes 2-8%)

F2: Well drained, deep to very deep, dusky red to dark reddish brown, friable clay; in places with a humic (nito-rhodic FERRALSOLS; with verto-mollic NITISOLS)

F4: Well drained to moderately well drained, very deep, dark brown, friable and slightly smeary clay, with a humic topsoil (ando-luvic PHAEOZEMS).

F 17: Well drained, deep to very deep, reddish brown to yellowish red, friable, sandy loam to clay with an acid humic topsoil (humic ACRISOLS; with luvic arenosols)

VOLCANIC FOOTRIDGES (Dissected lower slopes of major older volcanoes and mountains; undulating hilly).

R2: Well drained, extremely deep, dusky red to dark reddish brown, friable clay, with an aid humic topsoil humic NITISOLS).

R5: Well drained, moderately deep to very deep, dark reddish brown, friable to firm clay (nito-ferric LUVISOLS with humic NITISOLS).

R9: Associations of well drained, extremely deep dark reddish brown, friable clay with an acid humic topsoil on interfluves (humic NITISOLS) and humic topsoil (chromo – luvic PHAEOZEMS)

R10: Association of well drained, extremely deep dark reddish brown, friable and slightly smeary clay, with an acid humic topsoil on interfluves (ando- humic NITISOLS) and well drained, shallow to moderately deep, dark brown, friable, clay loam to clay with an acid humic topsoil, on valley sides (humic CAMBISOLS, partly lithic phase).

R13: Association of well drained, very deep, dark reddish brown, very friable and smeary, sandy clay loam to clay with a thick humic topsoil on interfluves (Mollic ANDOSOLS;) well drained, shallow to moderately deep, dark brown to dark reddish brown, very friable and slightly smeary clay loam to clay, on valley sides (ando eutric CAMBISOLS, partly lithic phase).

UPPER-LEVEL UPLANDS (usually rolling to hilly altitudes 6500-11,000ft, approximately 4,000 ft above local base level).

Uh2: Well drained, extremely deep, dark reddish brown, friable clay, with a humic topsoil (Mollic, NITISOLS).

Uh 3: Well drained, extremely deep, dark reddish brown, friable clay (eutric NITISOLS).

Uh 4: Well drained, shallow to moderately deep dark reddish brown, to dark red, friable clay (nito – chronic CAMBISOLS, with chronic CAMBISOLS, lithic phase).

Uh 3 + Uh 4: Complex of soils of units Uh 3 and Uh 4

Uh19: Moderately well drained, moderately deep, reddish brown to red firm clay loam with a humic topsoil (ando-luvic PHAEOZEMS).

Um: **LOWER MIDDLE – LEVEL UPLANDS (usually undulating altitudes 3,500 - 6,500 ft; about 1500 feet above local base level))**

Um 4: Well drained, deep to very deep, dark reddish brown, friable and smeary, silty clay to clay with humic topsoil (Mollic ANDOSOLS).

UM 16: Well drained, deep red, friable clay (rhodic FERRALSOLS; with ferralo – chronic ACROISOLS).

Pd **DISSECTED EROSIONAL PLAINS:** Various volcanic rocks and ashes and other pyroclastic rocks of recent volcanoes

Pv9: Well drained, moderately deep to deep brown, friable loam to sandy clay loam (vitric ANDOSOLS).

2.3 Topography and Drainage

The Mau forest complex is in a mountainous topography and is comprised of hills, valleys, escarpments, plateaus and flat surfaces. Mau Escarpment covers the western and south eastern parts of Nakuru County comprising Molo, Elburgon, Njoro and Olenguruone Divisions and the Naivasha area. These areas generally lie above 2500 metres above sea level. The topography of Kericho County slopes westwards and consequently, the rivers drain in the same direction. These rivers include Kipchorion which originates from Western Mau forest and flows through Londiani, Kipkelion and Chilchila Divisions to join river Nyando on the Kericho-Kisumu border. Rivers Kipturet and Timbilil both flow through Londiani and Chilchila Divisions from Tinderet forest before joining River Nyando (Kericho DDP. 1997-2001).

A hilly shelf is formed between the Mau Escarpment and the lowlands of Kisumu County. To the north – east are the Tinderet hills and Mau Escarpment and between them is the gently rolling land which forms Londiani Division. To the north-west are the hilly areas of Kipkelion and Chilchila Divisions rolling towards Koru. The central parts of Kericho to the east reach 3000 metres high at the Mau Ridge (Kericho DDP. 1997-2001). The Kericho plateau forms the central part of the Kericho County and slopes gently from 2500 metres to about 1800 metres and relief is a major climate factor in Kericho County (Kericho DDP. 1997-2001).

In Narok County, Mau complex covers parts of Upper Mau, Olokurto and Olmotiok Divisions. Included here are the Mau Escarpment and the Suswa Crater which rises over 2300 metres. The lowlands stand between 1000 – 1500 metres above sea level (Narok DDP. 1997-2001). Main rivers are the Mara from Maasai Mau and the Ewaso Nyiro and its tributaries namely Siapei and Narok. The two drain into Tanzania (Narok DDP., 1997-2001).

The topography in Bomet County is generally the same with that of Kericho County. The general altitude varies between 1800metres in the south and 3000 metres to the north. This is the area covered by the South Western Mau forest (Bomet DDP., 1997-2001). The rivers in Bomet generally drain in a parallel fashion -flowing from north-east to south-west. Some of the rivers include Nyangores which flows from South Western Mau forest and proceeds south-wards through Tenwek and Tebenik/Kiptiget which flows along the northern boundary of the county from the Londiani forest (Kericho and Bomet DDP., 1997-2001).

There are both surface and underground water resources in the Mau complex area. In Nakuru County, rivers that originate from the Mau forest complex are Njoro, Nderit, Maka Makalia and Lamriak which drain into Lake Nakuru. The other rivers are Molo, Rongai, Kaumura and Nessuit which drain into Lakes Baringo and Bookie (Nakuru DDP., 1997-2001). Mara River originates from the Mau and drains through Narok County into Lake Victoria basin, covering a distance of 395 km. It discharges into the Mara Bay of Lake Victoria in Tanzania.

The river is easily accessible except in its lower reaches, which falls in the Maasai Mara Game Reserve. The water is used for livestock by the Maasai pastoralists, wildlife in the Maasai Mara Reserve and for domestic purposes. Seyapei River originates from the south-eastern part of Mau Escarpment and drains into Ewaso Nyiro River between Oletukat and Nkuta. Water from this river is used for general irrigation, livestock and domestic purposes (Narok DDP., 1997-2001). Figure 2.3 shows the upper parts of some of the rivers originating from the Mau forest complex and supplying water to Lake Victoria and the inland lakes like Nakuru and Baringo.

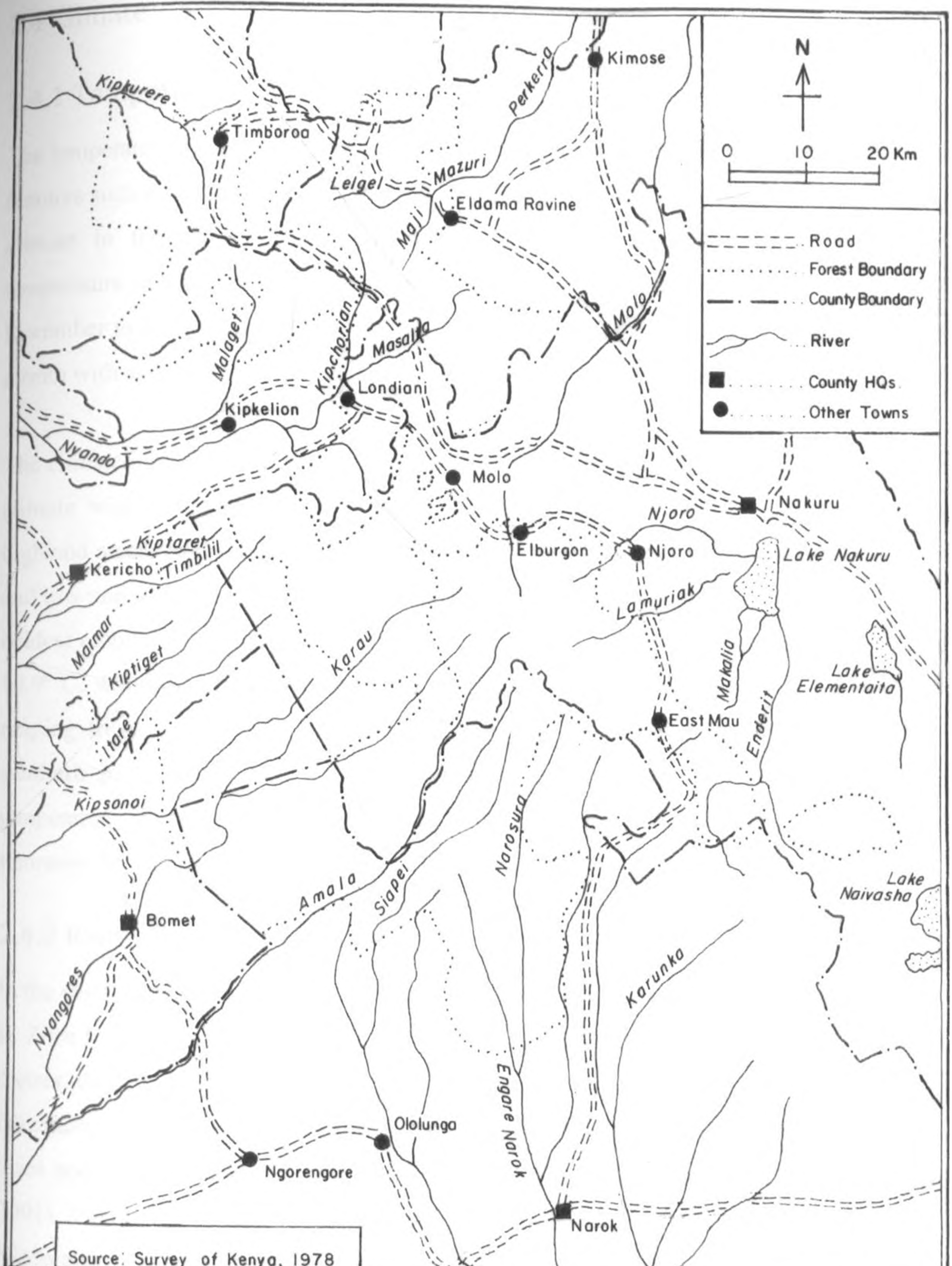


Figure 2.4: Major Rivers (upper parts) originating from the Mau forest complex.

2.4 Climate

2.4.1 Temperature

The temperatures in the Mau forest complex are strongly influenced by altitude and physical features such as forest cover, escarpment and mountains. There are considerable variations in climate in the various parts and counties comprising Mau complex. The maximum temperature in the northern and eastern parts of Mau forests complex is about 30° C with December to March being the hottest months (Nakuru DDP., 1997-2001). July is the coldest month with average temperatures of 23.9° C (Farm Management Handbook of Kenya, 1983).

The climate in the western and south western parts can be described as highland sub-tropical climate with moderate temperatures, low evaporation rates and high rainfall in lower highland areas. At the upper highland areas, the temperatures are high with high evaporation and low rainfall. The temperatures of this region range from about 16° C to about 20° C. The coldest months are usually July and August with mean monthly temperature of 16.6° C and 16.9° C. while the hot season starts from around December to February with temperatures ranging from about 16.9° C to 18.6° C. (Kericho and Bomet DDP., 1997-2001). In the southern parts of the Mau complex, the temperatures range from 8°C - 28°C. Low temperatures in this region reach 8°C in June – September and maximum in November – February Narok DDP., 1997-2001).

2.4.2 Rainfall

In the eastern parts of Mau forest complex, there are two climatic zones known as zones I and II. Zone I receives an average rainfall of 1270 mm per annum and it covers areas above 2,400 metres above the sea level. The areas covered by this zone include Mau Narok, Molo and Olenguruone. Zone II covers altitudes between 1,800 metres and 2,400 metres above sea level and receives rainfall between 760mm and 1270mm per annum (Nakuru DDP., 1997-2001). This is a dry sub-humid equatorial climate and covers the lower parts of Molo and Njoro among others. This region receives very little rainfall in the Months of December to February. The wet Months are from March to May characterized by the long rains while the short rains occur from late August to October. June to August have an average rainfall of 77mm with (Nakuru DDP., 1997-2001). Figure 2.4 shows average annual rainfall of the Mau complex region.

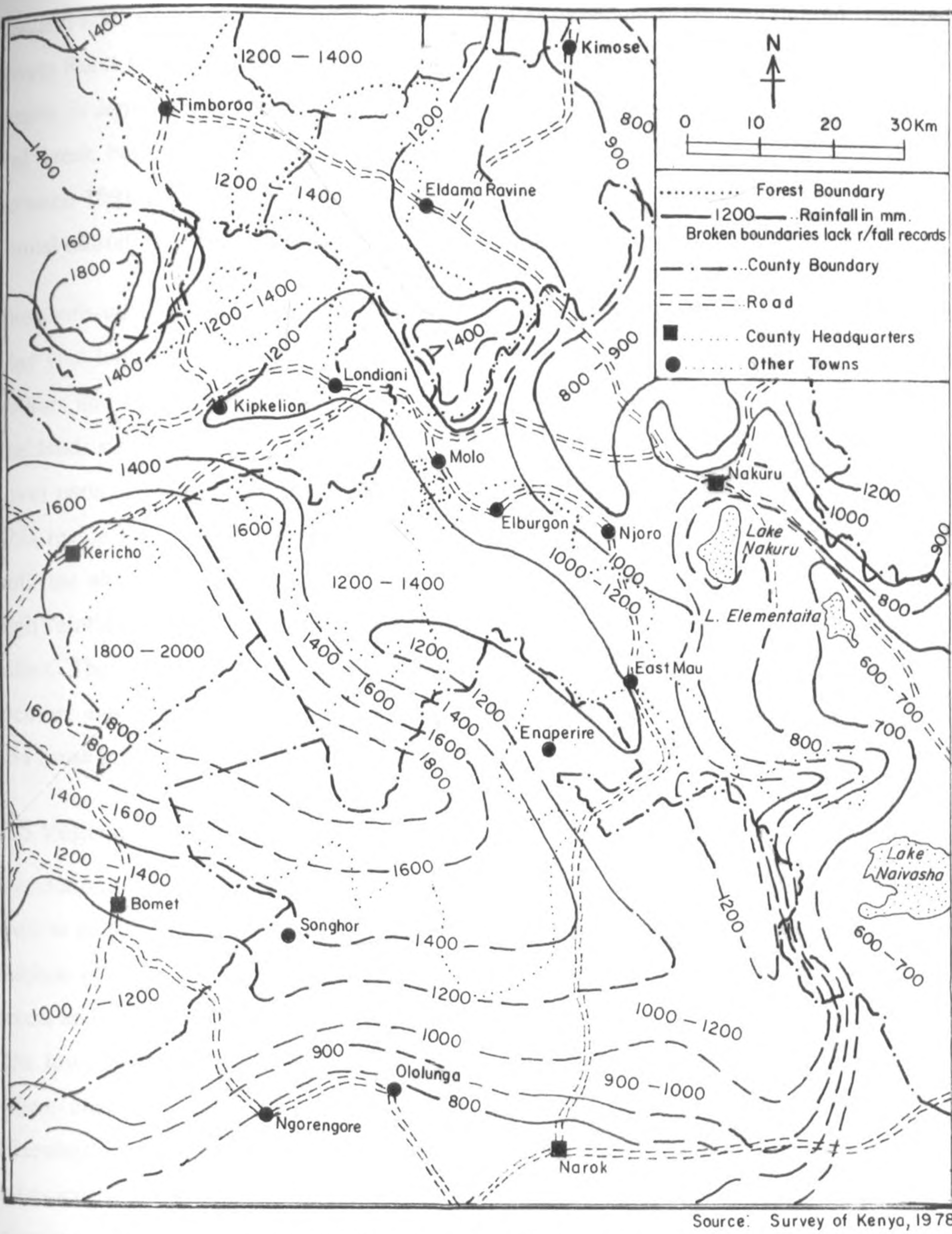


Figure 2.5: Average Annual Rainfall (mm) in the Mau forest complex

Western and north-western parts of Mau complex receive continental type of rainfall which is influenced by altitude. The annual rainfall ranges from 1,700mm to 2020mm per annum (Kericho and Bomet DDP., 1997-2001). Rainfall is highest in the lower highland zone of Ainamoi, Buret and Belgut Divisions while the upper highland zone covering Kipkelion and Londiani which is mainly forest land (the Mau) is drier and receives low rainfall. The upper midland zone which lies to the west of the Rift Valley experiences uniform rainfall. The zone covers Roret Division among other areas. Rainfall is well distribution except for the short dry season in January and February. The wettest months are April and May though there is no real break between short and long rains in the whole area. The average monthly rainfall between 1991 and 1995 were 167.8; 166.4; 142.2; 166.3; and 144.4mm respectively. Total annual rainfall ranges from 1700mm – 2020mm per annum (Kericho DDP., 1997-2001)

The south-western parts of Mau receive rainfall all the year round with the peaks in March to May (the long rains). Apart from December, all the months have mean rainfall of between 100mm and 150mm (Bomet DDP., 2001). The southern parts of the Mau complex consist of highlands rising over 2,300m and lowlands 1000m to 1500m above sea level. The lowlands cover parts of Osupuko, Ololunga and lower Mau areas (transfer this to topography section). This region has a bi-annual passage of the Inter-Tropical Convergence Zone (ITCZ). Thus, both the altitude and ITCZ determine the climatic conditions of the region. It experiences high rainfall caused by south easterly winds between the months of March and June (long rains). The annual average rainfall is 1200 to 1800mm (Narok DDP., 2001). Between October and March, the area is influenced by north easterly winds which are relatively dry and cause low to moderate rainfall.

2.5 Vegetation

Vegetation patterns in the Mau are complex, but there is a broad altitudinal zonation from west to east, with lower montane forest starting below 2,300 m of altitude and giving way to thickets of bamboo *Arundinaria alpina* (now called *Yushania alpine K. Schum*) mixed with forest and grassland, and finally to montane sclerophyllous forest near the escarpment crest. The lower montane forest is in best condition in the South-western Mau Nature Reserve, where characteristic trees include *Aningeria adolfi-friedericii* and *Strombosia scheffleri*. Elsewhere, this zone has been heavily logged, most recently for plywood from *Polyscias kikuyuensis*. Logged-over areas are dominated by pioneer species such as *Tabernaemontana stapfiana, Syzygium guineense* and *Neoboutonia macrocalyx*, while pockets of less-disturbed forest hold *Olea capensis*, *Prunus africana*, *Albizia gummifera* and *Podocarpus latifolius*. Substantial parts of the high *Juniperus-Podocarpus-Olea* forest have been encroached and cleared, although some sections remain in good condition. Large areas of both the Eastern and Western Mau have been converted to plantation forest comprising of cypress, pines and eucalyptus among others.

2.6 Wildlife

The southern forests of the Mau Complex are not only rich in biological diversity in terms of flora but also in fauna. They host ungulates such as the Bongo and the yellow-backed Duiker; carnivores, including the Golden Cat, the Leopard and the forest elephant which are known to occur in Trans Mara and South Western Mau forest reserves, which neighbour the Maasai Mau Forest (KWS, 2003). Some of the animals of special interest that are known to inhabit the higher moist forest zone of the Mau Complex, including the Maasai Mau are Giant Forest Hog, Colombus Monkey, Potto, Sotik Bushbaby and the Greater Galago. In the other forest formations, animals commonly found include lions, leopards and hyenas, Grant Gazelle, Coke's Hartebeest, giraffes, Cape buffalo, hippopotamus, rhinoceros and African elephant

The wildlife earns Kenya a lot of foreign exchange from tourism, the industry which largely dependents on wildlife. In 2006, up to 45% of Kenya's foreign exchange earnings came from tourism and related activities. The sector contributed close to KSh. 100 billion to the country's economy making it the largest contributor to the economy. In Kenya, wildlife based activities comprise a major share of the tourism market, where it is estimated to contribute roughly 70% of the sector's earning.

Table 2.1 Wildlife Populations in the Kenya Rangelands, 2002- 2006

SPECIES					'000 Number
	2002	2003	2004	2005	2006*
Elephant	18.7	18.8	27.5	16.8	16.1
Buffalo	24	24.6	25.1	22.3	22.1
Giraffe	32.1	33.2	34.2	34.4	31.7
Burchell's Zebra	108.6	110.3	112	123.1	110.4
Grevy's Zebra	5.4	5.3	5.1	4.4	4.0
Topi	30.7	31.2	31.6	31	27.3
Kongoni	11.4	11.5	11.6	10	9.1
Wildebeest	288	294.1	300.2	300.3	290.3
Oryx	20.3	20.5	20.6	21.5	21.2
Eland	10.6	10.2	9.8	8.2	8.0
H. Hartbeest Cover	1.3	1.2	1.1	1	0.9
Waterbuck	4.9	4.9	4.8	4.1	4.1
Kudus	13.7	13.6	13.4	13.6	12.1
Gerenuk	27.6	27.5	27.3	27	26.5
Impala	73.5	71.9	70.2	68.7	60.5
Grant's Gazelle	114.6	116	117.3	116	113
Thompson's Gazelle	58.2	55	51.7	48.1	45.1
Warthog	15.1	15	14.8	14.5	13.8
Ostrich	23.3	23.9	24.4	26	25.4

Source: Ministry of Wildlife and Natural Resources, 2008.

2.7 Socio-Economic Activities

The ethnic landscape of Mau Forest Complex is characterized by a diversity of cultures and a variety of livelihood strategies matching the environmental diversity of the region. Among the indigenous communities in the Mau forest complex region are the Kalenjin, Ogiek and the Maasai. The Kalenjin are sedentary in their livelihood and renown farmers who are involved in both crop and livestock farming. The Ogiek are hunters and gatherers and have been relying totally on the Mau ecosystem for their livelihood (shelter and honey plus hunting) although they have started to adopt livestock keeping and some of them have considerably changed towards sedentary and farming oriented livelihood not notably different from the one practiced by other farming communities (MFRS, 2009).

The Maasai have been associated with the Mau forests complex over the years especially the Maasai Mau. Being pastoral community, they have used the Mau in a sustainable manner-going to graze and water their livestock in the forests during drought only. Their love for, and dependent on herbal medicine have always made them to keep and take care of nature. The other category are the immigrants who came from outside Districts and Provinces, mainly the Kikuyu and Kisii. They are farmers and their settling near the Mau forest complex came with a lot of interference to the forest ecosystem through farming. The last group are the recent invaders who were allocated land in the forest illegally and the legally settled people in the land excised by the government of the day to settle the landless. Due to the diverse culture and livelihood strategies of these people and the fact that, Mau complex has high agricultural potential, the region is characterized by all types of activities ranging from agriculture, quarrying, to off farm activities such as business and agricultural industrial production in the urban centres (MFRS, 2009).

2.7.1 Forestry

Forest products and services are estimated to contribute about 7.0 billion shillings to the economy, and provide direct and indirect employment to 50,000 and 30,000 respectively in the country. The forest plantations, so far, remain the main source of raw materials for the forest industries in the country which are in large part located near Mau Forest Complex. The Counties of Nakuru, Kericho, Narok, Bomet, Nandi, Baringo (Koibatek District) and Uasin Gishu are among the counties endowed with forests. Areas covering Molo South, Olenguruone, Keringet and Mau Narok Divisions as well as south east Molo and Siape in the Nakuru County are under forests.

Natural forests are home to biodiversity (flora and fauna), are water catchments, and provide aesthetic values as well as carbon sinks. Increased extraction of forest products and allocation of forest land to non-forest uses have caused negative environmental and social impacts. This trend is expected to change due to advocacy for public awareness to conserve and protect the environment. Kenya has started reafforestation programme in the Mau complex, although this programme can only succeed if there are strong government institutions and informed community participation. Kenya needs to learn from countries like China, Malaysia, Indonesia, India and Brazil which have gone far with reafforestation programmes. Most of these programmes have had varying degrees of success with China being credited to have planted the largest area of forest plantation in the World.

2.7.2 Agriculture

Agriculture plays a very important role in the socio-economic welfare of the people living within the Mau forest complex since the region is endowed with fertile soils and high amounts of rainfall. The main staple food grown are maize, beans, pulses, Irish potatoes, millet and sorghum while the main cash crops grown are tea, coffee, pyrethrum, sugarcane and wheat.

Figure 2.5 shows agro-ecological zones for the areas within the Mau forest complex with Forest Zone (UH0) found in Njoro, Olenguruone, Belgut, Konoin, Olokurto and North Osupuko Divisions; Sheep and Dairy Zone (UH1) covering Elburgon, Molo, Keringet, Belgut and Londiani Divisions; Pyrethrum-Wheat Zone (UH2) in Molo and Elburgon; Wheat-Barley Zone (UH3) in Njoro, Elburgon, Olokurto and Mau Divisions; Tea-Dairy Zone (LH1) in Chilchila, Londiani, Ainamoi and Kipkelion Divisions; Wheat/Maize- Pyrethrum Zone (LH2) in Kipkelion, Londiani Bomet & Chilchila while Wheat/ Maize - Barley Zone (LH3) is found in Njoro, Elburgon, Kipkelion and Bomet Divisions.

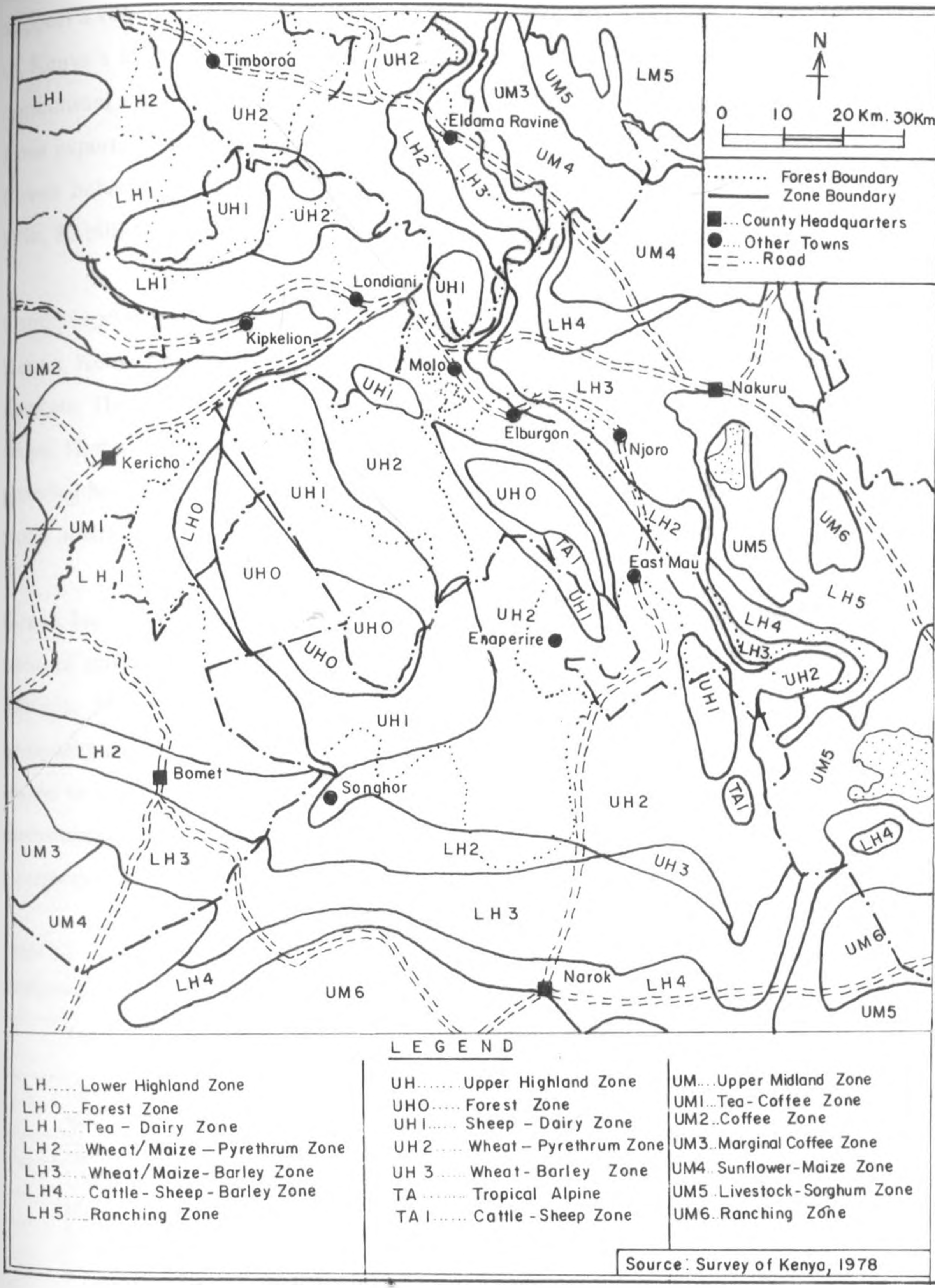


Figure 2.6: Agro- Ecological Zones of the Mau forest complex region

Mau forest complex is very important to the horticultural and cut flower industry in that, the extraction of water from Lake Naivasha which is fed by inflows from Mau forest helps to support a very dynamic horticultural and cut flower industry. The latter produces about 14 % of Kenya's total export earnings. Currently the horticultural industry is the fastest growing agricultural subsector in the country and is ranked third in terms of foreign exchange earnings from exports after tourism and tea. Reports from the Ministry of Agriculture show that Cut flower industry was the highest foreign currency earner in Kenya in 2008, grossing at least KSh. 80 billion.

Fruits, vegetable and cut flower production are the main aspects of horticultural production in Kenya. Kenya has a long history of growing horticultural crops for both domestic and export markets. The climate is highly varied supporting the growth of a wide range of horticultural crops. Horticulture in Kenya is mainly rainfed though a number of farms, especially the ones growing horticultural crops in the Naivasha area for export, but also uses irrigation through water abstraction from mainly Lake Naivasha.

Kenya has seen phenomenal growth in its exports of cut flowers recently even taking into account mounting competition from Colombia, Ecuador, Israel, India, China, Zimbabwe, Zambia, Ethiopia and Uganda (Table 2.3). Cut flowers have spurred great economic prosperity in Kenya- the loss of this industry would create a void in export earnings. While it seems to fit the model of sustainable industry, there are aspects and complications such as unsustainable water extraction from Lake Naivasha that make long-term viability difficult to guarantee.

Table 2.2: Cut flower Export, total horticultural Exports, and Domestic Export from Kenya, 1995- 2003 (Billions of Kenyan Shillings)

Year	Flower exports	Total Horticultural exports	Total domestic exports
1995	3.6	6.5	93.1
1996	4.4	7.7	113.9
1997	4.9	8.7	114.5
1998	4.9	9.7	114.4
1999	7.2	14.2	115.4
2000	7.3	13.9	119.8
2001	10.6	20.2	127.4
2002	14.8	26.7	133.9
2003	16.5	28.8	136.7

Source: HCDA Central Bank of Kenya, "International trade and finance statistics", 2005

2.7.3 Livestock Farming

Livestock industry accounts for about 10 per cent of the country's GDP and over 30 per cent of the farm-gate value of agricultural commodities. Kenya livestock local production depends in large parts from production from the Rift Valley mainly from Nakuru and Kajiado. The production and distribution of livestock in Kenya, especially in Rift Valley is influenced by rainfall patterns. However alteration in the catchments hydrological regime, resulting in increased stream flow seasonality, declining water wells and bore holes and frequent prolonged drought episodes as occurred in 1993, 1994, 1995, and 1996 aggravated by poor land use and deforestation in the Mau ecosystem pose a serious threat to the sector (Ministry of Livestock & Marketing, 1998).

2.8 Scope and Limitations of the Study

This research basically analyzed and mapped the land cover and land use changes in the Mau forest complex covering all the 22 blocks. It mainly relied on digital image processing of the satellite imageries stated above, ground truthing, GPS data and observations made in the field. The study used Mount Londiani forest to analyze the relationship between land cover and land use changes on one hand and population increase, soil types, slopes and rainfall variations on the other hand and inferred the findings to apply to the other forest blocks of Mau complex.

The use of remote sensing and GIS technology for land cover and land use change analysis has had numerous applications and their scope of application is still widening. However, this potential has been hindered by the fact that there are frequently many differences between images other than those indicative of the terrain characteristics to be monitored (Jensen, 2000). For example, differences due to contrast in sun elevation and azimuth and changes in atmospheric conditions such as cloud cover interference would need to be minimized for its effective used.

There are also other changes that occur concurrently with those being monitored causing difficulty and confusion. Such changes may operate over very different time scales from diurnal through seasonal, annual and much longer period. Again, different types of images have different resolution and properties, making them good for specific purposes and not others. This study used Landsat imageries since they are good in vegetation cover change analysis and are a bit affordable pricewise. This property notwithstanding, Landsat imageries used were of different resolutions and image thinning had to be done especially for Landsat MSS of 1973 to give it same resolution as the other two to discriminatively assess the positions and sizes of details from all the imageries with same accuracy and precision. Another problem was that, Landsat is not appropriate for detection of logging and settlement (or built-up) – thus this study avoided using classes like built-up areas, wasteland, etc. Higher resolution imageries like IKONOS and Quick Bird were required for this kind of analysis but the researcher could not afford their prices especially due to the large area of study.

Another limitation was getting two sub-scenes (which were required for this study) taken during similar dates and seasons to enhance mosaicking and classification. Aronoff (2005) suggests that imageries with similar calendar dates acquired at the same time of the day should be used to reduce effects of such changes like change in cloud and surface cover, and help overcome some of these problems – it was not possible to do this in this study.

CHAPTER THREE

3.0. LITERATURE REVIEW

3.1 Introduction

This chapter starts with a review of studies done on land cover and land use Change over time and goes on to review the causes of land cover and land use changes whereby contribution of population growth and other population dynamics on the environment as well as the institutional framework in land cover and land use change are reviewed. The study went ahead to review the consequences of land cover and land use change on forest status, biodiversity and last but not least, its consequences on climate and hydrological cycle.

It went on to review studies that had been done on baseline resources inventory and concluded by reviewing work on change detection and land cover in which the use of Remote Sensing and GIS techniques was done in depth. The chapter ended with a conceptual framework entailing the general overview of the research problem, objectives, hypothesis, methodology and results as well as feedback.

The objectives of literature review in this study were to: have a better understanding of the research under study in terms of the theoretical and empirical concepts and to be current in the study trends and techniques in land cover and land use changes as well as to assist the researcher in identifying gaps that existed in the field of study and the study justification.

3.2 Land Cover and Land Use Change

Human induced changes in land cover and land use are as old as human kind itself (Turner et al., 1993). Lambin reaffirms this when he says that the alteration of the earth's land surface due to human action is unprecedented (Lambin et. al., 2001). Turner and Meyer went on to say that changes in land use and land cover are among the most important human actions to be considered for the understanding of the pace, magnitude, and spatial reach of changes on the earth's surface and immediate sub-surface as a result of human impact (Turner and Meyer, 1994).

Lambin and Geist (2003) in their study on Global Land Use and Land Cover Changes for the Global News Letter state that, land cover changes are not simple processes since there is a functional and structural complexity between types of land cover change, both in spatial and temporal patterns of change. Land cover change can be manifested in the form of conversion or modification according to Turner et al., (1995). It was established in the study by Turner and Meyer in 1994 that land use change leads to change in land cover while land cover may change without the alteration of land use and therefore, simple land cover classifications are not sufficient for the analysis of change (Lambin and Geist, 2003).

3.2.1 Causes of Land Cover and Land Use Change

Land use is never static but constantly changes in response to the dynamic interaction between underlying drivers and proximate causes (Lambin and Geist, 2003). The conceptual understanding of proximate causes and underlying forces has a crucial importance to identifying the causes of land use and land cover changes (Turner and Meyer, 1994).

Proximate causes include agricultural expansion, wood extraction, infrastructural expansion and others that change the physical state of land cover (Turner and Meyer, 1994). At the proximate level, land use and land cover change may be explained by multiple factors rather than a single variable (Geist and Lambin, 2002). Underlying driving forces such as demographic pressure, economic status, technological and institutional factors influence land use and land cover in combination rather than as single causations (Turner and Meyer, 1994).

Proximate causes operate at the local level (individual farms, households, or communities) while underlying causes are at regional and national levels such as districts, provinces or countries. Underlying causes are often external and beyond the control of local communities (Lambin et al., 2003). This study established that both proximate and underlying causes contributed to the land cover and land use change in the Mau complex but the underlying forces, especially political influence contributed most.

3.2.2 Population Growth and Land Cover and Land Use Change

Historically, population was regarded as the most important and the only driving force behind global land use and land cover change. However, currently it is understood that land use and land cover changes have many driving forces that are closely interrelated, population being only one of them (Reindfuss and Adamo, 2004).

Studies conducted at longer time scales show that land cover change had and still has tremendously been influenced by both the increase and decrease of a given population

(Lambin et al., 2003). In contrast, within the time range of a few years, population growth, poverty, and infrastructure are not good indicators of the status of land cover changes. Instead, responses from individual and communities to changing economic conditions and institutional factors often affect land use and land cover change (Lambin and Geist, 2003).

In most developing countries population growth has been a dominant cause of land cover and land use change than other forces (Sege, 1994). There is a significant statistical correlation between population growth and land cover change in most of African, Asian, and Latin American countries (Turner and Meyer, 1994).

Similarly, in Kenya population pressure has been found to have negative effects on forests, especially the Mau (KFWG, UNEP 2005). Akotsi et al. (2003) in their study of natural forest cover in the five water towers in Kenya concluded that population growth really degraded the forests. Unlike these studies, Tiffen et al. (1994) reported for Machakos that population growth was found to have a positive impact on forest cover. They say that, areas occupied by people were found out to have more forest cover than areas with sparse or no population.

The conclusions by the above studies were not based on spatial analysis between population growth on one hand and land cover and land use change on the other. This study closed the gap by comparing time series population density maps with time series land cover changes to ascertain the relationship and therefore did not act on mere increase in population over time. This study is in agreement with the various studies that concluded that increase in population resulted in deforestation and general forest degradation.

3.2.3 Population and Environment

The issues on the theories regarding the impact of population on environment and economic development have been debated between two schools of thought put forward by Thomas Malthus (1798) and Ester Boserup (1965). Neo-Malthusians believe that population growth has a negative impact on economic development and environmental enhancement. According to this view, population growth has a greater power than that in the land itself, to influence food production, and this is because population increases geometrically whereas food production increases arithmetically (Stone, 1993).

In line with the Neo-Malthusians, a report from Robert McNamara, the president of the World Bank, (cited in Muluneh, 2003) states that 'population growth is the greatest single responsible factor for low economic development and poor quality of environment in developing countries'. For instance, in Ecuador population growth with high density resulted in the expansion of rural settlement, afforestation with eucalyptus tree and an accelerated deforestation (Vanacker et al., 2003).

Unlike Neo-Malthusian views, those who support Boserup's ideas have an optimistic vision regarding the link between population growth and food production as well as the quality of the environment (Turner, 2001). According to this school of thought, rapid population growth helps to develop good efficiency and technological innovation instead of hindering the living standards of the people. The case study in Machakos, Kenya, has been taken as an example and helped them develop a model that describes the positive impact of population growth (Tiffen et al., 1994).

The impact of population growth on the environment and poverty is not simple and one directional, since rapid population growth affects the quality of the environment and living standards of the people and the reverse is true where population grows at a slower pace (Woldeamlak, 2004). In line with the sentiments from Woldeamlak, this study found out that the population had grown at very high rates in the study area and had actually resulted in negative environmental impacts which included deforestation, farming on steep slopes and soil loss.

It thus, agrees with Solomon (1994), who states that, land cover and land use changes and socio-economic dynamics have a strong relationship. That is, as population increases the need for cultivated land, grazing land, fuel wood and settlement areas also increase to meet the growing demand for food and energy as well as for increased livestock population. All these put together, resulted in degraded landscape.

3.2.4 Institutional Factors in Land Cover and Land Use Change

Lambin and Geist (2003), state that, the understanding of institutional factors (i.e. political, legal, economic, and traditional) and their interaction with individual decision making are important in explaining land use changes. Institutional factors need to be considered at both micro and macro levels because the implementation of macro policies is practiced at the local level. Land use and land cover changes are influenced significantly when macro policies undermine micro (local) policies (Lambin et al., 2003).

The structure of local and national policies may determine local people's access to land, capital, technology, and information. Lambin and Geist, (2003) noted that, lack of well-defined policies and weak institutional enforcement may facilitate changes of land use. On the other hand, restriction of land use is possible if there are appropriate land use policies in place. In most developing countries, communal (traditional) land holding systems have been shifted to a formal (state) holding system (Lambin et. al., 2003). Policies on price control on agricultural inputs and outputs and emphasis on self-sufficiency in food production have all influenced land use changes (Turner et al., 1993).

The absence of applicable forest policy is cited as a contributing factor for deforestation in different parts of the World. In Brazil, for example, national policies aimed at the transformation of agricultural base and developing the Amazon commercially have caused the deforestation of 1.1-2.1 million hectares annually (Turner et al., 1993). Akotsi et al., (2003) concur with Lambin and Geist when they say that, lack of appropriate land use policies is responsible for decline of forests in the five water towers of Kenya.

To streamline this anomaly in forest management, the Kenya Government enacted the Kenya Forest Act, 2005 which established The Kenya Forest Service charged with the management of forests and water catchments and to enforce conditions and regulations pertaining to logging, charcoal making and other forest utilization activities. The results of the Mau rehabilitation programme are encouraging and with the use of a geo-database such as the one created by this study, there will be more informative and enhanced decisions made in forest management.

3.3 Consequences of Land Cover and Land Use Change

3.3.1 Forest Status and Land Cover and Land Use Change

Globally, about 29 per cent of the land surface was originally under forest cover. Presently, however, it is only a fifth of this original forest cover which remains undisturbed (FAO, 2001). It is estimated that in Kenya, 2.5 per cent of the country was covered with closed forest in 1995 (KIFCON). High- resolution aerial surveys of selected forests in the Aberdares, Mt. Kenya, Mt. Elgon, and the Mau complex revealed that deforestation and general degradation was taking place on a more local scale significantly due to unplanned forest exploitation (Akotsi and Gachanja, 2004). A part from forest clearance due to man's needs and wants, some forests have largely been destroyed by fires. During the year 2000, fires destroyed about 2978 hectares of forest in Kenya. Most of these fires were experienced within Mau and Mt. Kenya areas (Akotsi and Gachanja, 2004).

A study on the changes of forest cover on the five water towers of Kenya (UNEP, KWS, and KFWG, 2005) observed that, a total of 8,266 hectares was destroyed in the Mau, Cherangani and Mt Elgon forests in 2003 alone. The most affected was Mau with 7,084 hectares lost. According to the joint study by UNEP, KFS and KFWG (2005), about 40,000 hectares of land in the heart of Kenyan forests had been excised by 2001 with Mau being most affected.

According to Mau Rehabilitation Secretariat Report (2009), the main causes of forest loss in the Mau Forest Complex were: conversion of forestland into settlements; mismanagement of industrial forest plantations; illegal forest resource extraction; fires and overgrazing. The northern blocks of the Mau Forest Complex have extensive industrial forest plantations which have replaced indigenous forests. Many of the forest plantation blocks are devoid of trees or are not managed properly. In some of the blocks, the surrounding indigenous forests are heavily degraded (MFRS, 2009).

3.3.2 Biodiversity and Land Cover and Land Use Change

A major impact of land use and land cover is on soil and biotic resources. For example, the annual loss of plant species in tropical Africa is as high as 27,000 (Turner et al., 1995). The loss of biodiversity due to land use and land cover changes takes place at multiple levels (landscape, ecosystem and species), and in multiple dimensions (structure and function), (Turner et al., 1995).

The loss of plant biodiversity may lead to the decline of ecosystem integrity and loss of plant genetic resources, which in turn result in hindrance of scientific progress in agriculture and pharmaceutics. According to WHO (1999), 80 per cent of the world population depends on herbal medicine for primary health care needs. The main source of these traditional medicines is the forest ecosystem. Therefore, loss of plant biodiversity would have great influence on the health of the poor who are financially constrained and will not be able to buy modern medicine.

In Kenya, land cover and land use change has significantly affected plant and animal biodiversity (UNEP, KWS and KFS, 2005). The Mau Forest Complex comprises a unique diversity of forest types including the lower montane which is in its best condition in the South Western Mau Forest Reserve but heavily logged in the other forests where it occurs (UNEP, KWS and KFS, 2005).

Large stands of bamboo have been excised or encroached. Substantial parts of the higher altitude Juniperus-Podocarpus-Olea forests have been encroached and cleared while fires have also contributed to enormous loss of both plant and animal species. The Mau Forest Complex together with its diverse animal and plant life forms is currently under threat (ICS, 2009). Thus, loss of biodiversity in the Mau has affected the Maasai and is equally affecting other communities elsewhere who depend on herbal medicine. It has also affected tourism as a sector of Kenya's economy (ICS, 2009).

3.3.3 Impact of Land Cover and Land Use Change on Climate and Hydrological Cycle

Land cover and land use changes have been known to impact on local and regional climate and hydrological balances (Turner et. al., 1995). The release of carbon dioxide to the atmosphere from the global terrestrial biosphere has become a serious problem threatening the health of the environment (Turner et. al., 1995). According to Houghton (1995), in the century we live, deforestation may release 5-53 per cent of the carbon that would be stored in the global atmosphere. Land cover changes caused by both natural and human interventions contribute towards this climate change. The impact of land cover and land use change on hydrological cycle is not yet adequately assessed (Turner et al., 1995). A massive removal of forest in the Amazon has led to a decrease in evaporation and precipitation in the region. Land use and land cover changes, especially vegetation cover, also affect water and energy balances (Houghton, 1995).

Land cover and land use changes represent the largest human source of emission of nitrogen and carbon dioxide which contributes to both greenhouse forcing and atmospheric ozone depletion (Turner et al., 1993). The conversion of different land cover types to cropland has contributed to the release of carbon which is approximately equivalent to 30 per cent of that from fossil fuel combustion (Houghton, 1995). The released amount of carbon and other gases due to the transformation of land cover type into another cover type is partly dependent on the terrestrial characteristics. For instance, forest conversion into cropland or grassland results in much more carbon in humid areas than tropical zone (Turner et al., 1993).

According to Turner et al (1995) certain land use types have significant impacts beyond the proportion of their spatial extent. The expansion of settlement area, for instance, at the expense of other land cover types emit large amount of chemical pollutants which may be dangerous for safe human habitation. In the past 50 years, the construction of dams and reservoirs has become important part of human induced land cover changes. Impacts of land cover changes that occur due to artificial water bodies are beyond their areal proportion in extent.

Land cover characteristics and water cycle have many connections. The type of land cover, obviously, can affect both rate of infiltration and runoff amount (Houghton, 1995). According to Turner et al. (1995), both surface and ground water flows are significantly affected by type of land cover. For example, forest canopy and leaf litter help to reduce the erosive action of rain drops. On the other hand, the formation of sheet, rill and/or gully erosion are common in areas where ground cover is insufficient.

There is evidence that convective currents that increase local precipitation are eliminated when extensive areas of forest cover are removed. However, this does not seem to occur for removal of small areas, and the size of this effect is difficult to establish. Some of the effects of removing forest cover are increased and in some cases, decreased runoff. There is very strong evidence from well conducted, paired catchment studies that the net effect is for mean annual runoff to increase after deforestation, although the size of the increase depends on factors such as the annual rainfall, soil characteristics, and type of replacement vegetation (Zhang et al., 2001).

Stream flows following moderate to large storms also increase in size and flashiness because of the quicker runoff when the forest is replaced with crops and grass. However, removal of tree cover has very little effects on runoff from very large storms. Large enough storms simply overwhelm whatever cover (tree, crops, grass) is present, either because the ground rapidly becomes saturated or the precipitation is so intense that it cannot infiltrate into the ground quickly enough and runs off. The reduction in forest cover in the Mau has resulted in reduced river flows and dryness (MFRS, 2009). This study believes that forest reduction has partly contributed to the above conditions.

3.4 Baseline Resource Inventory

Studies on the Guesselbodi forest in Niger to assess the degree of forest degradation employed the use of aerial photographs and revealed that, large areas had been destroyed by wood-fuel cutting and over-grazing. Wood-fuel was mainly for the majority poor living in the City of Niamey (just next to the forest), who depended entirely on wood for their energy (Kerkhof, 1990).

In a Baseline survey by the Kenya Wood-fuel Development Programme in 1983, the District Resource Analysis both in Kakamega and Kisii Counties employed the use of Aerial photographs and Satellite imageries and developed a classification system based on characteristics such as farm size, crop types and woodlots. Detailed maps were produced showing the land in each district divided into zones in accordance with the classification system. The analysis revealed that, the indigenous trees and shrubs tended to be replaced with exotic species, especially eucalyptus as the population density increased. It also indicated that, the proportion of land with planted trees increased with population density (Kerkhof, 1990).

3.5 Change Detection and Land Cover Analysis

Change detection is an important process in the monitoring, evaluating and managing the natural resources and urban development. Change detection provides quantitative analysis of the spatial-temporal distribution of the population of interest. The basis of using remote sensing for change detection is the fact that, changes in land cover result in changes in radiance values which can be remotely sensed. Macleod and Congation (1998) list four aspects of change detection which are important when monitoring natural resources:

- Detecting the changes that have occurred,
- Identifying the nature of the change,
- Measuring the area extent of the change and,
- Assessing the spatial pattern of the change.

The integration of Remote Sensing and GIS in carrying out monitoring, detection analysis and evaluation of changes has achieved a lot of success in the recent decades. The National Oceanic and Atmospheric Administration (NOAA) satellites have been used by scientists in the preparation of maps and analysis of continental and global scale vegetation cover and vegetation cover change. Justice et al (1985), used image datasets prepared by NOAA to compute global vegetation index to analyse the global area coverage.

Shosheng and Kutiel (1994) investigated the advantages of remote sensing techniques in relation to field surveys in providing a regional description of vegetation cover. The results of their research were used to produce four vegetation cover maps that provided new information on spatial and temporal distributions of vegetation in this area and allowed regional quantitative assessment of the vegetation cover.

Arvind and Nathawat (2006) carried out a study on land use and land cover mapping of Panchkula, Ambala and Yamunanger Districts, Hangana State in India. They observed that the heterogeneous climate and physiographic conditions in these districts has resulted in the development of different land use and land cover in these districts, an evaluation by digital analysis of satellite data indicates that majority of areas in these districts are used for agricultural purpose. The hilly regions exhibit fair development of reserved forests. It is inferred that land use and land cover pattern in the area are generally controlled by agro – climatic conditions, ground water potential and a host of other factors

It has been noted over time through series of studies that Landsat Thematic Mapper is adequate for general extensive synoptic coverage of large areas. As a result, this reduces the need for expensive and time consuming ground surveys conducted for validation of data. Generally, satellite imagery is able to provide more frequent data collection on a regular basis unlike aerial photographs which although may provide more geometrically accurate maps, is limited in respect to its extent of coverage and expensiveness; which means, it is not often used (Arvind and Nathawat, 2006).

In 1985, the U.S Geological Survey carried out a research program to produce 1:250,000 scale land cover maps for Alaska using Landsat MSS data (Fitz Patrick et al, 1987). The State of Maryland Health Resources Planning Commission also used Landsat TM data to create a land cover data set for inclusion in their Maryland Geographic Information (MAGI) database.

All seven TM bands were used to produce a 21 – class land cover map (EOSAT 1992). Also, in 1992, the Georgia Department of Natural Resources completed mapping the entire State of Georgia to identify and quantify wetlands and other land cover types using Landsat Thematic Mapper TM data (ERDAS, 1992). The State of southern Carolina Lands Resources Conservation Commission developed a detailed land cover map composed of 19 classes from TM data (EOSAT, 1994). This mapping effort employed multi-temporal imagery as well as multi-spectral data during classification.

An analysis of land cover and land use changes using the combination of MSS Landsat and land use map of Indonesia (Dimyati, 1995) reveals that land use and land cover change were evaluated by using remote sensing to calculate the index of changes which was done by the superimposition of land use and land cover images of 1972, 1984 and land use maps of 1990. This was done to analyse the pattern of change in the area, which was rather difficult with the traditional method of surveying as noted by Olorunfemi in 1983 when he was using aerial photographic approach to monitor urban land use in developing countries with Ilorin in Nigeria as the case study.

Wilkie and Finn (1996), in detecting change using Remote Sensing, suggested differencing techniques which involved registration of imageries from two dates, subtraction of the pixel values, one from the other and then analyzing and classifying the resultant differenced imageries. Alternatively, imageries from two dates can be expressed as a ratio and size of the deviation from unity used to classify the degree and type of change (Townshend, 1981).

To determine forest cover changes in the five water towers, an assessment was undertaken by DRSRS, UNEP and KFS between the years 2000-2002 where Landsat TM imageries of 1987, 1995, 2000 and 2002 were used. Interpretation of the imageries were based on "true colour" composition of bands 1 (blue), 2(green) and 3(red), and "aerial trudging" was done by low flying to validate results of the satellite imageries. Areas of various cover classes were compared to monitor the cover change, thus achieving its main objective. It finally recommended the use of Geographic Information Systems (GIS) for effective monitoring of changes in ecosystem, using among others aerial survey and satellite imagery (DRSRS, UNEP and KFS, 2003).

Situma et. al., (2005) undertook a project to map land cover and land use changes in Kakamega forest between 1975 and 2005 being necessitated by changes that had occurred in the forest due to several factors such as illegal excision, selective cutting of commercially viable trees, unauthorized settlement and uncontrolled grazing, like in many other forests in the country. They were to provide information on status and to generate database on Kakamega forest resources and its ecological changes to facilitate sustainable management geared towards conservation. The objectives were achieved but the database so provided was not complete in that, it was composed of time series land cover types only. A more vibrant geo-database was required in such a case and this is the gap the present study has fulfilled by bringing on board, such variables like population dynamics, slopes and soils data.

Akotsi et al (2003) in their efforts to examine changes in the five water catchments namely the Cherengani, Aberdare, Mau, Mount Elgon and Mount Kenya utilized image differencing and Normalized Difference Vegetation Index techniques with Landsat imageries to highlight areas where forest cover had been depleted. The study achieved its objective of mapping and showing clearly, the changes in forest cover in the catchments.

Forest cover mapping of Mau forest complex was undertaken by DRSRS in the year 2003, as a priority following the controversial illegal settlements. The forest was about 400,000 hectares and comprised of six blocks. Being a very important catchment area, and source of rivers such as Mara and Rongai, it became of paramount importance to map this forest. The method involved digitizing Landsat satellite imagery of 2003, which had prior been composite using spectral bands 3, 2, and 1 for Red, Green and Blue respectively before performing unsupervised classification.

The classification was aided by data from field sample points and aerial photography. The gazetted forest land boundary was overlaid on classified image to clip the area under study. The whole of Molo forest was found to be under cultivation. However, the most intact of the 22 gazetted forest blocks in this complex, was Chemogorok which had only 0.35% of its original coverage cleared. Through the use of Remote Sensing data the objectives of mapping the forest complex, assessing the status and quantifying the area under different classes in each forest blocks were achieved.

Khamala, (2003), used high resolution Landsat imageries to assess the forest cover change in the Mau forest complex between 1986 and 2000 to illustrate the potential use of high resolution Landsat imageries in vegetation cover analysis. The results gave a good discrimination of changes in cover types, and also showed areas prone to landslides. Although all these studies were purported to have covered all the forests of the Mau, some forests in the northern block were not mapped and therefore were not studied. The present study closed the gap by ensuring that the study incorporated all the 22 block in the Mau. The variables which this study believed were privy to developing a workable geo-database were also used in the analysis, unlike in the previous studies where they were never used.

3.6 The Conceptual Framework

The conceptual framework developed for this study incorporated the Mau complex and the factors of interventions which were both physical and human. Physical interventions were beyond the scope of this study due to their complexity in terms of the variables to be studied and duration of study required, thus only human aspect was looked at. The frame work assumed the position that, increase in population dynamics in the Mau came with increased pressure on the forest cover and this caused changes in land use types which in the end resulted in land cover change.

Remote Sensing software and Geographic Information Systems analytical functions were used to process and analyse Landsat imageries to detect these changes over the 1973 – 2010 study period. The results of the analyses revealed the environmental impacts caused by the changes in land cover and land use over time. Other variables were processed into thematic maps and graphs which, together with the results of the imageries analysis formed a geo-database which was stored.

The geo-database would be used by decision makers in the forest resource management to make key decisions considered appropriate for sustainable forest resource management. In case they make wrong decisions, this would negatively impact on the Mau leading to deforestation while positive or correct decision would lead to rehabilitation hence increase in vegetation cover (Figure 3.1 below).

Conceptual Framework Depicting Human Impacts on Forest Resources

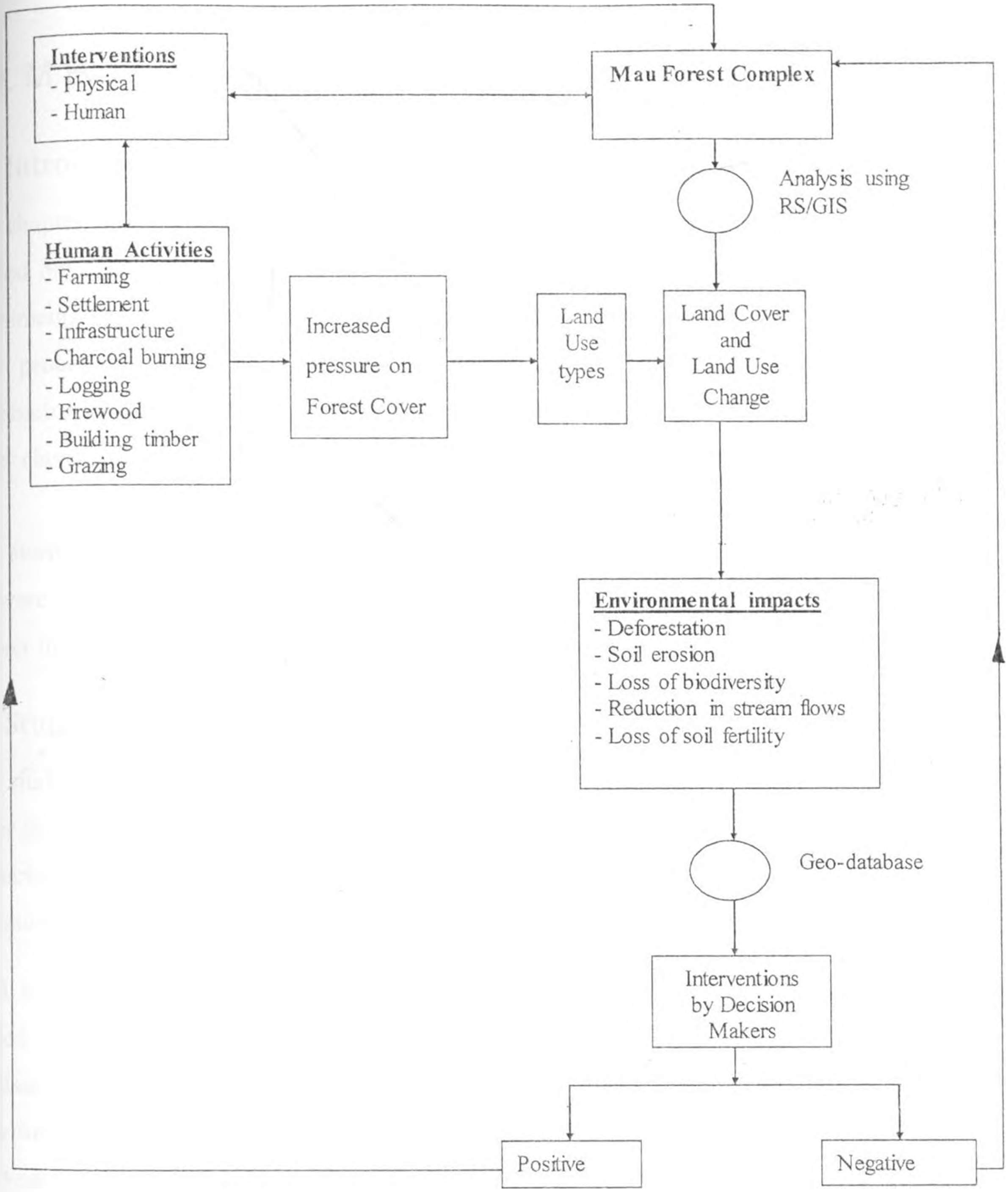


Fig.3·1: Schematic diagram showing the interrelationships between the various components of the study
Source: Researcher, 2010

CHAPTER FOUR

4.0. METHODOLOGY

4.1 Introduction

The chapter starts by giving study design which stated how the whole research was set to be carried out followed by the types and sources of data required for the study, methods and instruments of data collection, spatial data capture and ground truthing. It went on to state the data processing techniques used which included digital image processing and geo-referencing. Data processing was followed by data analysis, involving development of land cover classification scheme, overlay operations, NDVI analysis and digitization.

The study was confined to the analysis of spatial data using Remote Sensing processing software and Geographic Information Systems analysis functions to get results that helped to answer the research questions and the working hypothesis.

4.2 Study Design

The study used both evaluative and comparative techniques in the spatial analysis of land cover and land use changes in the Mau forest complex. All the 22 blocks of the complex were subjected to the land cover and land use analysis in which land cover classification, overlay operations and NDVI analysis were done and results and discussions given in chapter four.

1973 was taken as base year of study because the forest cover had not changed then but started changing thereafter due to anthropogenic processes that set in (KIFCON, 1991). Landsat imageries were used due to their suitability for vegetation cover analysis. They have been found to be good in vegetation discrimination, measurement of chlorophyll absorption and vegetation type and biomass content analysis. The Landsat imageries used were for 1973, 1986, 2000 and 2010, intervals the study believed, were reasonable to give substantial changes in land cover.

Ground control points taken by GPS plus topographical maps of the area were used to geo-reference the images and Supervised Classification was done using ENVI 4.8 remote sensing software which gave three cover classes namely Forest land, Other Vegetation and Non-Vegetated land which were quantified and overlaid spatial-temporally for change detection. Normalized Difference Vegetation Index analysis was done specifically to detect changes in plant health over time. Analyses involving the population, soils, land use, slopes and rainfall data were specifically done for Mount Londiani forest with the assumption that, what happened in Mount Londiani forest happened in the other forest blocks of Mau forest complex

4.3 Data Types and Sources

Both primary and secondary data were used in the spatial analysis of land cover and land use changes together with the associated environmental impacts in the Mau complex. The types of data required for solving the research problem by meeting the research objectives set for the study were as follows:

4.3.1 Primary Data

Primary data consisted of data collected from the field through observations of various features that needed to be included in the study and discussions such as eroded landscapes, burnt areas, timber harvesting, grazing, charcoal burning and fire wood collection. Such information gave at a glance, some of the human activities taking or had taken place in the forest with the resulting impacts. This kind of data was captured through digital photography and field notebook recording. The second primary data was the geographical coordinates of selected ground control points in terms of latitude and longitude values. These coordinates were captured using handheld GPS.

4.3.2. Secondary Data

All secondary data got were in digital form with the satellite imageries as the main secondary data used in this study. The study used Landsat imageries ranging from Multi-Spectral Scanner (MSS) for 1973, Landsat Thematic Mapper (TM) for 1986 to Enhanced Thematic Mapper (ETM+) for 2000 and 2010 to do land cover and land use classification and analysis. They were sourced from Regional Centre for Mapping of Resources for Development (RCMRD), at Kasarani in Nairobi.

The other secondary data were the digital copies of 1: 50,000 topographical maps of Mau forest complex which were sourced from Survey of Kenya, Ruaraka. Others were population, geology and soils, rainfall, digital elevation model and slopes data. Table 4.1 below shows types and sources of secondary data used.

Table 4.1 Types and Sources of Secondary Data

Data type	Year of production	Source
Landsat MSS Landsat TM Landsat TM Landsat ETM+	09/01/1973, Resolution 80x80 Metres 15/11/1986 at 30x30 M. resolution 18/12/2000, 30x30 Metres 11/2/2010, 30x30 Metres	Regional Centre for Mapping of Resources for Development, Kasarani in Nairobi
Topographical maps of Mau region at 1:50,000	1978	Survey of Kenya, Ruaraka in Nairobi
Geology and soils of main	1995	Kenya Soil Survey, Kabete
Slopes of Mau	1995	Kenya Soil Survey, Kabete
Land use	2005	Africover
Population data	1979, 1989, 1999, 2009	Kenya National Bureau of Statistics, Herufi House - Nairobi
Rainfall Data	1977, 1986, 2000, 2010	Kenya Meteorological Department, Dagoretti Corner in Nairobi.
DEM	1995	Kenya Soil Survey, Kabete - Nairobi

Source: Researcher, 2011.

The table below shows monthly rainfall for the years of study which were included in the analysis.

Table 4.2: Monthly Rainfall in Mount Londiani area in Millimetres

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1977	121.7	39	11.1	276.3	209.1	168.4	157.9	190.2	93.2	104.6	272.5	61.7
1986	4.3	19.1	24	142.4	70.2	80.5	151.7	125	107.2	52.2	30	22
2000	12.2	3.1	14.8	42.4	182.4	98.9	90.1	182.6	88.8	150.2	28.11	34.2
2010	22	12	26.8	33.6	29.2	46	89.2	80.8	142	15	4	3.2

Source: Meteorological Department in Dagoretti, Nairobi, 2011.

4.4 Data Collection

Most of the data used were secondary which were acquired from various organizations as listed above, mainly in digital form. Primary data used was mainly got during ground truthing and included selected ground control points, digital photographs and field notebook records.

4.4.1 Instruments of Data Collection

The instruments and equipment that were used in data collection and analysis included:

i. Observation: The investigator did field survey and made observations which were noted down and later included in the report.

ii. Digital camera was used to take photographs of various scenes relevant to this study.

iii. Handheld Global Positioning System (GPS) receiver was used to record the coordinates of the sampled ground control points.

iv. Most of the secondary data acquired were in soft copy and therefore were collected in CDs and flash discs.

4.4.2 Spatial Data Capture

The Landsat imageries were downloaded into the computer directly using imagery downloading software for processing. The field records from the notebook were captured into the computer through the keyboard while the digital photographs and GPS data were downloaded direct into the computer for processing and eventual analysis. The secondary data that were in digital form were also downloaded the same way into the computer while those that were in hard copies were either scanned or captured through the keyboard.

ArcGIS 9.2 was used for displaying and subsequent processing and enhancement of the images. It was also used to clip the Mau forest complex from the larger image and to overlay the images and maps as well as in integrating/interfacing Remote Sensing, Global Positioning System and Geographic Information Systems data.

4.4.3 Ground Truthing

Field reconnaissance was carried out and subsequent field trips followed for ground verifications. GPS receiver was used to collect coordinates of sampled ground control points which had been identified on both the maps and images. These points were verified in the field and were used to give signatures for training sites to help in classification of the land cover. They were also used in geo-referencing the Landsat imageries used in the Supervised Classification applied in this study. Photographic records of features like firewood collection, charcoal burning, grazing of livestock and felling of trees were also taken and used in the report as proof of some of the human activities going on in the forest complex.

4.5 Data Processing and Analysis

4.5.1 Data Processing

Satellite imageries used were already corrected for geometric and radiometric distortions. Data processing involved the preparation of image datasets for spatial analysis which included image resampling/thinning, stacking, and processing of field note book data, digital photographs, population data, rainfall data and soils data among others.

4.5.1.1 Digital Image Processing

Processing of the digital values involved image thinning, image band compositing, standard deviation stretch and geometric registration of the 1973, 1986, 2000 and 2010 Landsat MSS, Landsat TM and Landsat ETM+ imageries respectively. Wavelength bands 4, 3, and 2 (for infra-red, red and green) were used in every imagery to form NIR false colour composite in which red, green and blue colour (RGB) channels were represented by wavelength bands 4, 3 and 2. Spectral resolutions for blue, green, red and infra-red bands were: 0.45-0.52, 0.52-0.60, 0.63-0.69, and 0.76-0.90 micrometres respectively; while the radiometric sensitivity were 0.8, 0.5, 0.5, and 0.5 for blue, green, red and near infra-red bands. Table 3.1 below shows spectral resolutions and key areas of application of bands 2, 3 and 4

Table 4.3: Spectral resolution of Landsat 4 and 5 Thematic Mapper (TM)

Band and Nominal Spectral Location	**Spectral Resolution (μm)**	**Principal Applications**
1. Blue	0. 45 - 0. 52	Useful in forest type & coastal water mapping since it penetrates water body. Also used for soil/vegetation discrimination
2. Green	0. 52- 0. 60	Used to measure green reflectance peak of vegetation for vegetation discrimination & vigour assessment.
3. Red	0. 63-0.69	Designed to sense in a chlorophyll

		absorption region hence good in plant species differentiation.
4. Near infrared	0. 76 - 0. 90	Useful for determining vegetation types, vigour and biomass content, delineating water bodies & for soil moisture discrimination
5. Mid infrared	1. 55 - 1. 75	Indicative of vegetation &, soil moisture content as well as discrimination of snow from clouds.
6. Thermal infrared	10. 40 -12. 4	Useful in Vegetation stress analysis, soil moisture discrimination & thermal mapping
7. Mid infrared	2. 00 -2. 35	Useful for discrimination of mineral & rock types. Also sensitive to moisture content.

Source: Lillesand & Kieffer, 2002.

False colour composite of Landsat TM bands 4 (infra-red), 3 (red), 2 (green) were represented by infra-red, red, green respectively. The combinations of these bands were used in land cover and land use mapping. In addition, true colour composite was also formed to aid in visualization where the false colour composite did not suffice. The composites were in geotiff format for easy display and manipulation by ENVI and ArcGIS software. For better visualization, standard deviation stretch was applied on the image composites.

4.5.1.2 Geo-referencing of the Imageries

Landsat ETM+ image of 2010 was geo-referenced using 1:50, 000 topographic maps of the study area). Seven control points were selected from the unrectified images and associated with their respective geographic coordinates in the topographic maps in order to establish the nature of the geometric coordinate transformation that is needed to relocate every pixel of the unrectified image to its proper geographic position in a rectified image (a process called spatial interpolation). A first order polynomial transformation was applied for this purpose.

The relocation of the brightness values of each pixel in the unrectified image to its appropriate location in the rectified image (a process called intensity interpolation) was performed using the Nearest Neighbour algorithm. The other 3 subsets, one extracted from the Landsat-ETM+ image of January 2000, the Landsat TM for 1986 and the other extracted from the Landsat-MSS image of February 1973, covering the same area, were all-registered to the sub-scene of the Landsat-ETM+ image of October 2010, using an image-to-image registration technique. The Landsat-MSS image of February 1973 which had a resolution of 80 metres was resampled to 30 m pixels using the nearest neighbour algorithm, in order to preserve the integrity of the higher spatial resolution of the Landsat-ETM+ scenes which was used in the change detection analysis.

4.5.2 Data Analysis

Data analysis involved the generation of static forest coverage using Near-infrared false colour composites for each year of study. Thus, there was 1973, 1986, 2000 and 2010 static land coverage (shown in figures 6.1a, 6.1b, 6.1c and 6.1d). It also included the development of land cover classification scheme, generation of actual land cover and land use classes, quantification of cover classes and land cover change detection through overlay operations as well as detection of the changes through Normalized Difference Vegetation Index analysis. Data analysis also involved production of thematic maps (section 4.5.2.7) for integrated analysis in the Mount Londiani forest area.

4.5.2.1 Generating NIR False Colours Using Mau Forest Boundary Of 1973

ENVI 4.8 image processing software was used to stack the various scenes required for the analysis and for mosaicking the images. Clipping the forest extent as at 1973 was done using mask tool in ArcGIS. The forest boundaries of protected forests used in this process were obtained from the KIFCON project (1991-1994) database. This was done in order to come up with the Landsat near infra-red false colour imageries which were then saved in Geo-database. SBQ format imageries to be clipped were opened one at a time on ENVI 4.8 viewer window. On the same viewer, shape file of the area of interest showing Mau complex boundaries was displayed. The SBQ format imagery was then clipped based on Mau forest boundary using ENVI image clip tool, creating an output image file.

This procedure was performed consecutively for all false colour Landsat imageries starting with 1986, 2000 then 2010. Results of the clipped imageries are displayed in Appendix 1 showing the static forest situations in terms of the false colours as at the above dates. The analysis integrated the development of various thematic maps mainly for the integrated analysis in the Mount Londiani Forest which include population density maps, land cover maps, slopes maps, monthly rainfall graphs and land use maps. These maps were put side by side for visual comparison, interpretation and discussion. Any other data, photomechanical or electronic that was captured for this study was analysed here.

4.5.2.2 Development of Image Classification Scheme

This study applied Supervised Classification since it gave the analyst control over selected menu of informational categories tailored to the specifications of the study. The first step involved the development of an appropriate classification scheme. To do this, the study used the Landsat imagery of 2000 and topographical map of 2004 at 1: 50,000 of the Mau complex to identify details that appeared on both the topographical map and on the imagery and recorded them down. During ground truthing, the same details were identified in the field and their coordinates recorded and these were later used by the image analyst to train the ENVI 4.8 software to recognize spectral values or signatures associated with the training sites.

The three classes used for this study were Forestland, Other Vegetation, and Non-vegetated land from which, the researcher delineated training sites after the classification scheme had been developed. After the signatures for each land cover category had been defined, the software used these signatures to classify the remaining pixels. Thus, for each class outlined, mean values and variances of the DNs for each band used to classify them were calculated from all the pixels enclosed in each site.

4.5.2.3 Land Cover and Land Use Classification

In delineating area of interest in order to generate data on spatial changes in the forest, the Landsat Thematic Mapper of 2010 was vectorized under ArcGIS environment. The area of interest (Mau forest extent as at 1973) was then used to clip the Landsat false colour imageries under ENVI 4.8 software environment for every image according to the year of acquisition – 1973, 1986, 2000 and 2010 to give static land cover and land use of the Mau forest complex as at the dates of the imageries.

Starting with the 1973 imagery and using the signatures developed for each land cover category, the software automatically classified all the remaining pixels giving new polygon themes. That is, forestland, other vegetation and non-vegetated land with their quantities. This resulted in Mau forest spatial boundary delineation as at that date of 1973 imagery. The Supervised Classification applied Minimum Distance and the results were refined with smooth kernel size of 3 and Aggregate minimum size of 9 and transferred and stored in a GIS database. Landsat TM for 1986 and Landsat ETM+ for 2000 and 2010 imageries were also analyzed in the same manner. The results of the static classified forest covers and the discussions are given in Chapter 5 (figures 5.1a, 5.1b, 5.1c and 5.1d) with the attribute tables showing quantities of each static forest map according to the Landsat imagery used.

The same interpretations were used to assess the human activities that had contributed to the forest cover change. For instance, when forestland changes to other vegetation, the activity is agriculture or crop farming. When forestland changes to non-vegetated land, the activity could be farming (newly prepared farms), grazing or settlement and the resultant eventuality could be wasteland when these changes are not monitored. The various land cover and land use types were quantified for the entire 22 blocks for every dataset and this enabled this study to come up with the trends and extent to which, each one of them had contributed to the degradation of the forest.

4.5.2.4 Quantification of Cover class Areas

ENVI 4.8 processing software used in the classification of the Landsat imageries generated the three classes and their respective areas in hectares in the attribute table and thematic change showing all areas both that changed and those that did not were indicated. Table 5.1 indicates the areas of thematic classes obtained from classification of 1973, 1986, 2000 and 2010 clipped Landsat imageries. Respective cover class areas in each of the image classification results in the table were later used in quantification of land cover and land use change discussed in chapter 5 of this report.

4.5.2.5 Normalized Difference Vegetation Index (NDVI)

The other instrument used for vegetation cover change detection was the Normalized Difference Vegetation Index (NDVI) for the Mau forest complex got from the same Landsat imageries. NDVI is a ratio often used to determine the density of vegetation in an area based on visible and near infra-red (NIR) sunlight reflected by plants. On the one hand, the pigment in plant leaves (chlorophyll) strongly absorbs visible light in the red spectrum (from 0.4 to 0.7 μm band 3 of Landsat-7) for use in photosynthesis while the cell structure of the leaves strongly reflects near infra-red light (from 0.7 to 1.1 μm – band 4 of Landsat-7). The more leaves a plant has got, the more these wavelengths of light are affected.

The Normalized Difference is preferred to a Simple Index because it compensates for illumination conditions such as surface slope and orientation. Vegetated areas give positive NDVI values due to their high reflectance in NIR and low reflectance in the visible red spectrum, while bare or sparsely vegetated areas have higher reflectance in the visible red spectrum than in NIR, leading to negative or near-zero NDVI values.

The Normalized Difference Vegetation Index values indicate the amount of green vegetation present in the pixel. Thus, higher NDVI values indicate more green vegetation and vice versa. The standard algorithm shown below was used for calculations giving valid results that fell between -1 and +1:

$$NDVI = \frac{NIR - Red}{NIR + Red},$$

Where NIR is band 4 and Red is band 3 of Landsat TM.

For the purpose of this study, density slices were given ranging from 0.25 – 0.50 µm for sparsely vegetated areas to 0.50 – 0.75 µm for areas with reasonably dense vegetation to 0.75 – 1.00 µm for closed canopy forest. The density slices below 0.25 µm represented areas without vegetation and therefore were not included in the NDVI analysis. The NDVI results are presented in appendix 2 while the discussions are presented in chapter 5 (sec. 5.2.2).

4.5.2.6 Land Cover Change Detection

In order to establish the land cover changes that occurred within the study area between 1973 and 2010, a post-classification change detection analysis of the 4 dates of imageries was performed using ENVI 4.8 remote sensing software. For this purpose, the information classes of the 1973, 1986, 2000 and 2010 images were overlaid to get three overlay maps. That is, 1973 was overlaid on 1986, 1986 on 2000 and lastly 2000 on 2010 and the quantities of change in each class for each dataset computed in that sequence and changes in combined into one "change" image (comprising the 1973-1986 -2000 -2010 period) in which each of the "from-to" land cover changes was extracted. Three "from-to" change matrices were obtained for the 1973-1986, 1986-2000 and 2000-2010 periods, in that order.

The main land cover changes that were considered in the analysis were those that corresponded to areas that showed "deforestation" and areas that showed "forest regeneration" and "reforestation". Regenerated forests are forests that were culturally disturbed but have regrown to a state in which they show similar characteristics to undisturbed mature forests, in terms of biomass and canopy structure. These areas constituted the secondary growth forests.

Reforested areas refer to tree planting that has been initiated as a result of the advocacy by various stakeholders which saw the formation of "Mau Complex Rehabilitation Secretariat" to oversee the eviction of the squatters and replanting of trees. The other land cover changes such as farmland and settlements (especially urban) were not considered in the analysis except for the role they play in changing the area under forest.

Having done image classifications, the study went ahead to conduct overlay operations for the same images. But instead of using the thematic classes in the overlay, the study used the unclassified images to change detection in ENVI 4.8 since this approach gave the software a better chance to come up with most appropriate classes than when thematic change detection is done. Overlay operations were performed on all the delineated and clipped Mau forest complex boundaries in ArcGIS environment. First the registered 1973 imagery was overlaid on 1986 image and the changes in land cover produced under ENVI 4.8 processing software.

The exercise was repeated by overlaying 1986 and 2000 imageries followed by the 2000 and 2010 imageries. The results of the above overlay operations were shown in chapter 5 (Figure 5.2a, 5.2b, 5.2c and 5.2d)

4.5.2.7 Digitization and Production of Maps

While the cover classification, change detection analysis, NDVI analysis and most of the integrated analysis done in the Mount Londiani forest were done using Remote Sensing software, a number of variables were digitized on screen using arc Map in ArcGIS . From Mau forest complex land cover map, Mount Londiani forest was clipped using ArcGIS clipping tool after which, the three cover classes were reduced to two, namely, forest land and non-vegetated land. The same forest boundaries were used to clip the perimeter extent of the Sub-locations of Mount Londiani forest, the soils and geology, slopes, land use and agro-ecological zones within Londiani forest area.

Using the population figures and administrative units, this study developed population density maps for the sub-locations for the years 1979, 1989, 1999 and 2009 which gave the patterns and trends of change in population densities over time. The time series density maps were placed side by side with the time series land cover maps to establish the relationship between change in density and change in forest cover. Thus, 1979 population density was compared with 1986 land cover, 1989 with 1986 land cover, 1999 with 2000 land cover, and 2009 with 2010 land cover. Population density maps were again placed and compared with land use map in order to check how change in population densities had influenced the various land use types and the likely consequences.

Geological and Soils thematic map was also produced from soils and geological data through screen digitization using ArcGIS software. This data was necessary because soil types and characteristics such as hardness, compactness, fertility, porosity and erosivity do influence the outcome as the anthropogenic factors intensify on the land cover. Comparisons were done for soils map and slopes, soils and land use as well as for soils and land cover to determine any impacts upon their interactions with each other. The rainfall distribution bar graphs for 1977, 1986, 2000 and 2010 were individually discussed followed by the discussion of one that combined all the four datasets in one line graph from which, trends of change in distribution and amount of rainfall were detected over time. The changes of the same were discussed alongside changes in population densities and land cover.

CHAPTER FIVE

5.0. RESULTS AND DISCUSSIONS

5.1 Introduction

This chapter starts with the presentation and discussion of the results of the analysis of Land Cover Changes in the Mau forest complex in 1973, 1986, 2000 and 2010. The results are discussed under post classification visual comparison, post classification area comparison, trend, magnitude and rates of change, overlay and NDVI results.

The study went on to discuss human activities and deforestation based on some of the activities observed and captured in the field which this study believed had contributed to the deforestation in the Mau complex. The last part discusses results of integrated analysis in the Mount Londiani forest which include population density and forest cover change, land cover and slopes and land use and soils.

5.2 Land Cover and Land Use Change in the Mau Forest Complex

Land Cover and Land Use Change analysis revealed massive Land Cover and Land Use Changes that had occurred in the forest between 1973 and 2010.

5.2.1 Post Classification Visual Comparison

Figures 5.1a, 5.1b, 5.1c and 5.1d are thematic cover classes for 1973, 1986, 2000 and 2010 Mau Landsat imageries. From the 1973 thematic map (figure 5.1a), the forest was intact with most of the forest being under closed canopy and a small portion under other vegetation with even a smaller part under non-vegetated cover. Non-vegetated areas included built up areas, bare land and even newly prepared farms.

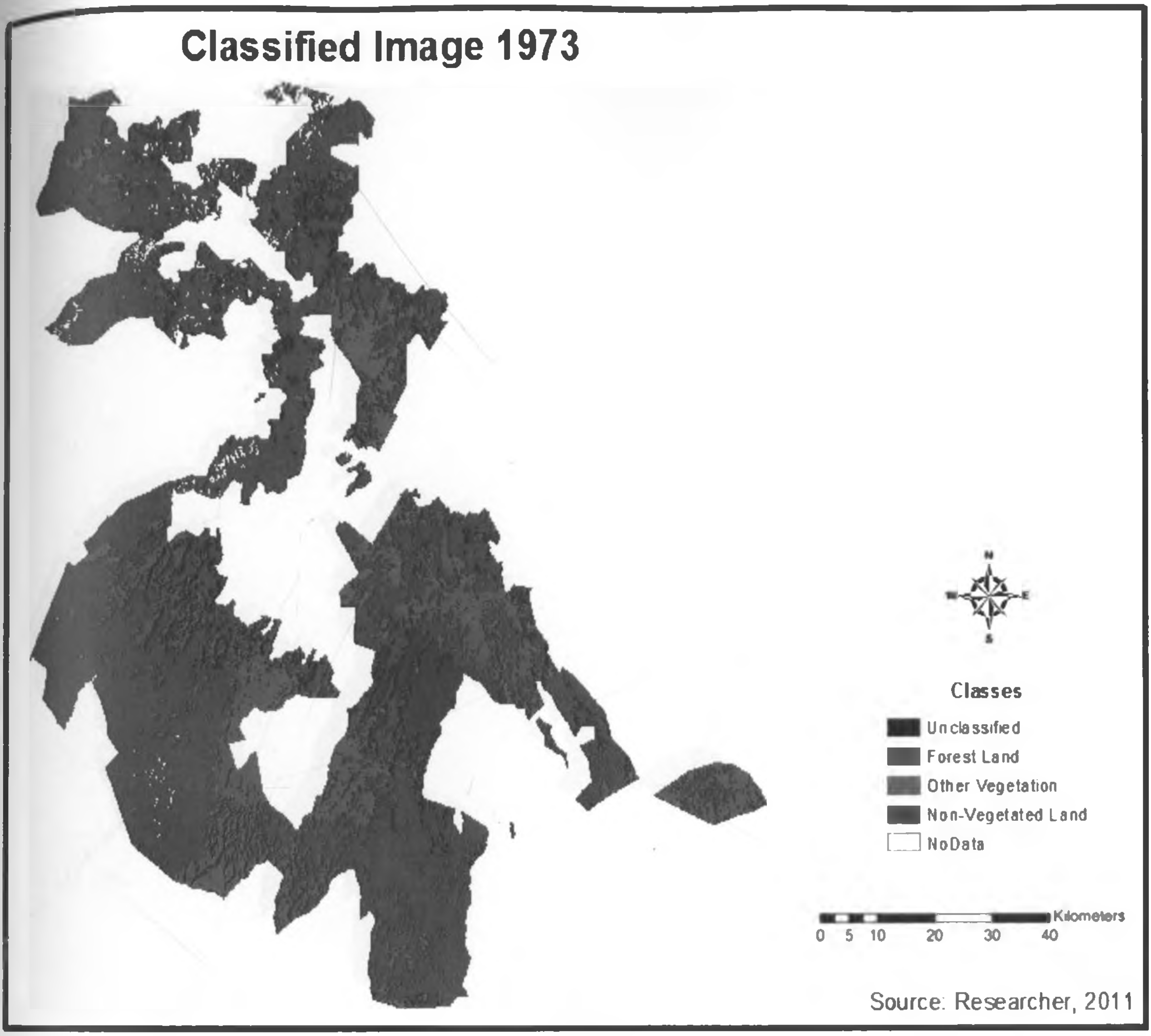


Figure 5.1a: Land cover and land use map of the Mau in 1973

The 1986 thematic class map showed a lot of decrease in coverage of the areas under forest and other vegetation while area under non-vegetation increased (figure 5.1b). The areas under non-vegetation increased so much in the Eastern Mau, Mount Londiani, Maji Mazuri, Molo, Tinderet and South West Mau forests, among others. These areas were probably being opened up for agriculture and logging for the timber industries that had just been set up after Kenya's attainment of independence. Urban centres were also being set up to host the timber industries, agricultural processing industries and an ever increasing population that was coming from outside this region to work in the factories being set up. Such urban centres were Kericho, Londiani, Molo, Maji Mazuri, Timboroa, Elburgon and others.

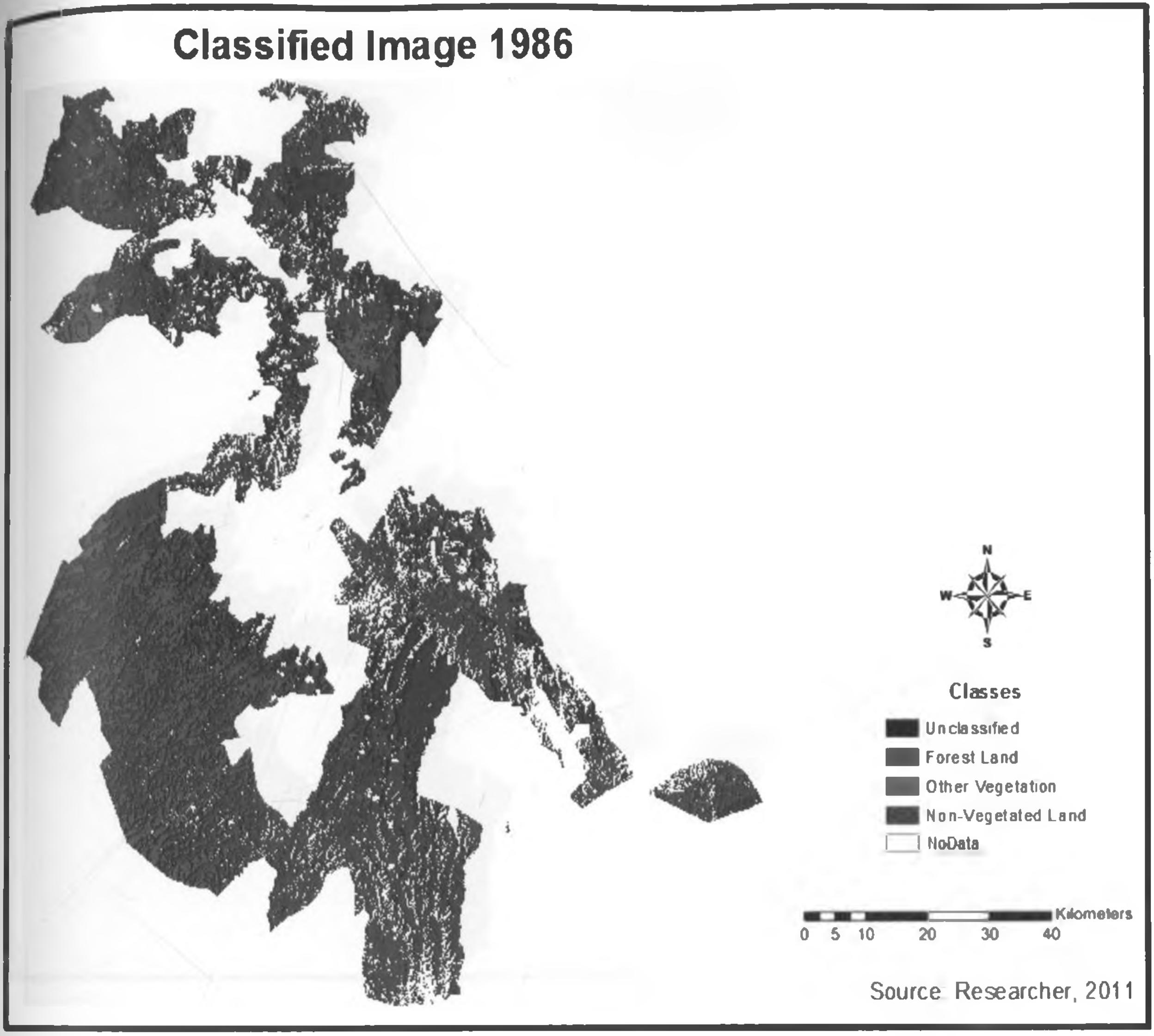


Figure 5.1b: Land cover and land use map of the Mau in 1986

The period between 1986 and 2000 showed the worst degradation of the forest when compared with the other periods during the study (figure 5.1c). Much of the degradation of the forests was still witnessed in the northern and central blocks as well as in Eastern Mau and Eburru forests. Various reports reviewed in this study singled out land grabbing and illegal land allocation as the main course of forest degradation in the Mau forest complex during this period. It was during this period that Molo forest was completely cleared of its forest and turned into farmland and settlement.

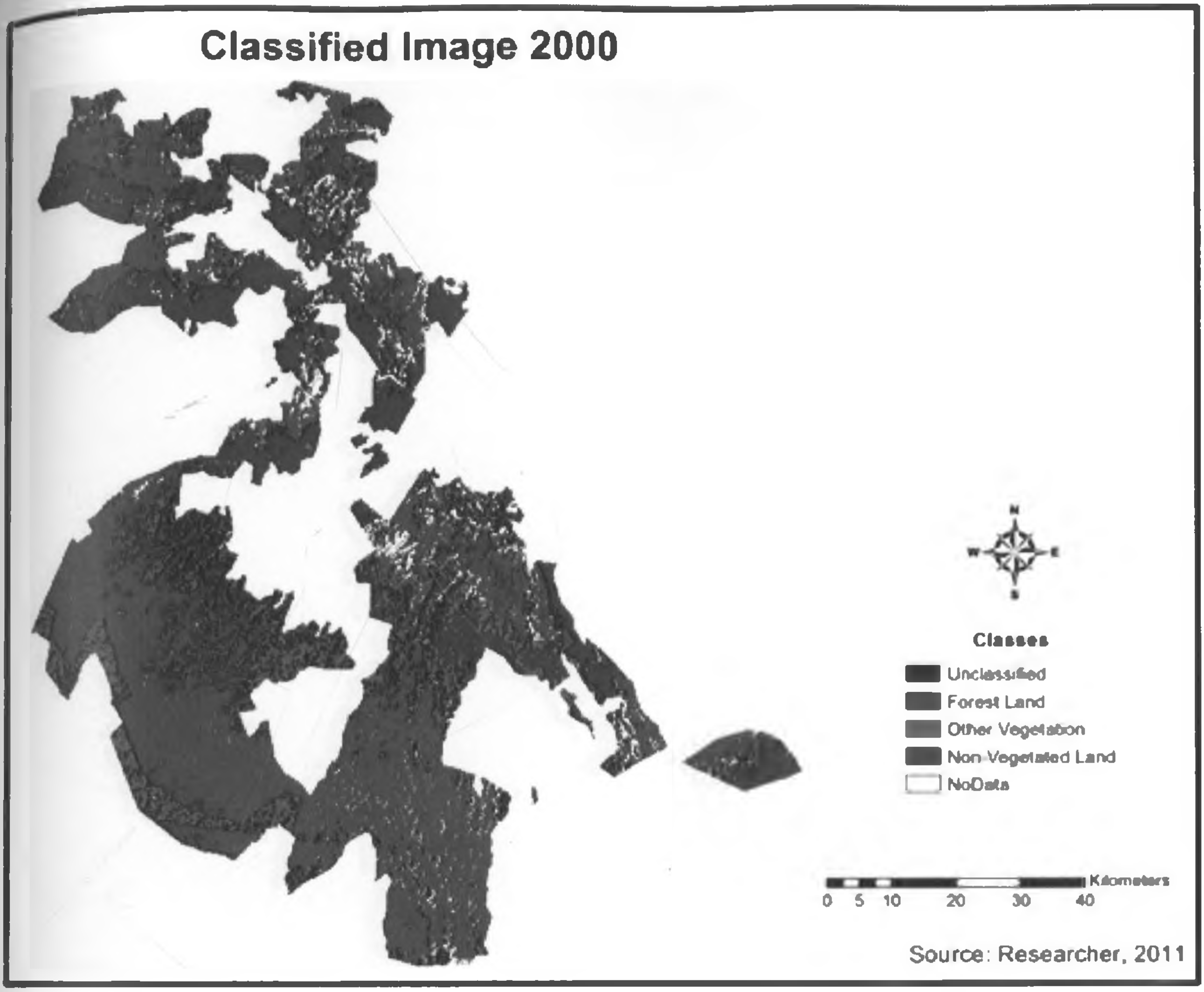


Figure 5.1c: Land cover and land use map of the Mau in 2000

The period between 2000 and 2010 (figure 5.1d), indicated a lot of improvement in the area under other vegetation and a decrease in the area under non-vegetation. While legal excision of the Maasai Mau to settle the landless plus other illegal allocations took place during this period, the area under vegetation cover increased while that under non-vegetation decreased due to the initiatives of the Mau Rehabilitation Secretariat that led to the eviction of squatters, repossessing land illegally got and planting of trees in the areas that were under non-vegetation.

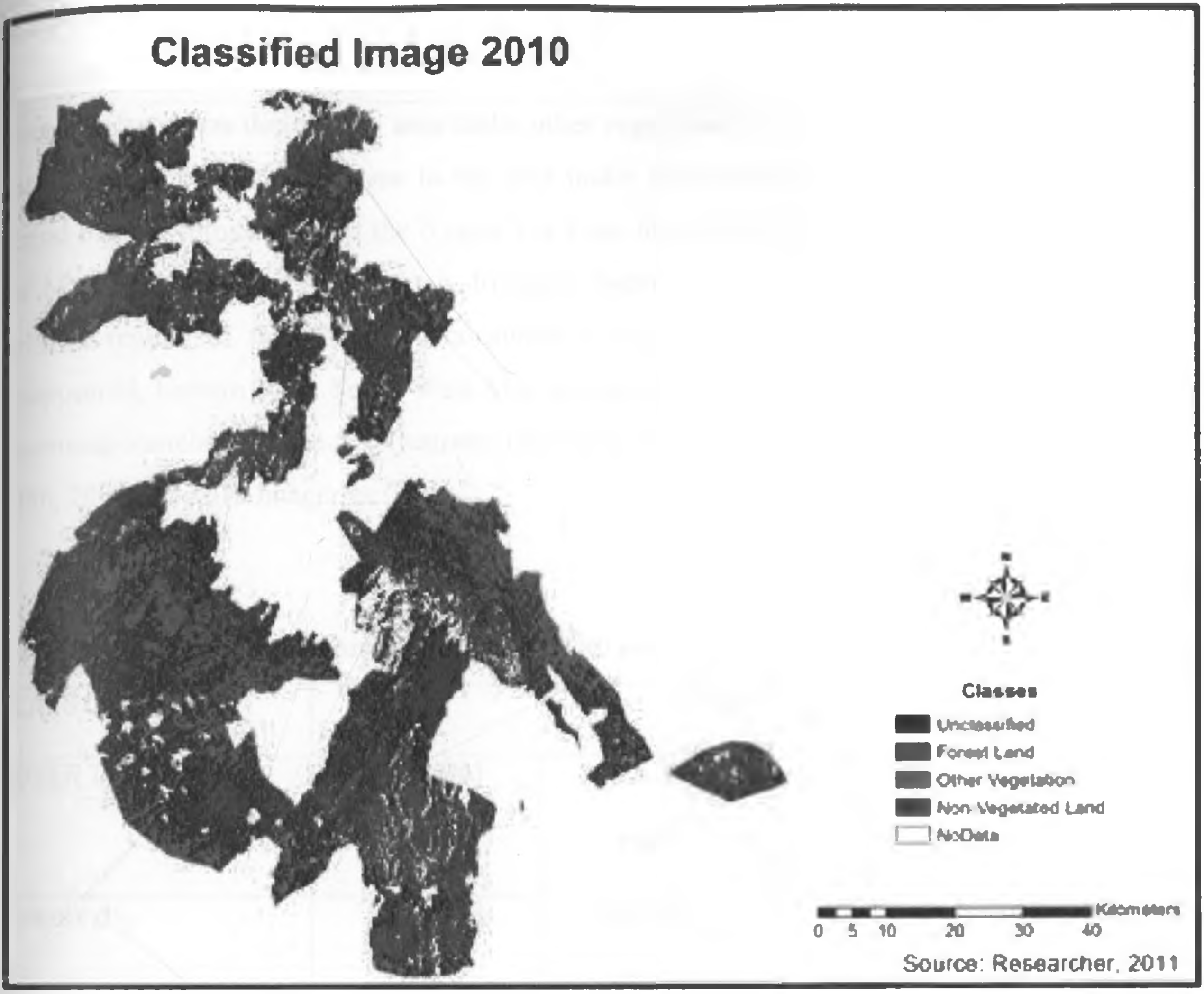


Figure 5.1d: Land cover and land use map of the Mau in 2010

5.2.2 Post Classification Area Comparison

In 1973, closed canopy forest occupied the highest class with 68% of the total classes. The other vegetation occupied about 22% of the classes while non-vegetated land was 10%. Clearance of forest land for forest products and other human needs for the forest land were established when land cover and land use for 1973 and 1986 were compared. Forest land was 63.8% in 1986 while area under other vegetation was 20.1%, a reduction of 4.2% and 1.86% respectively from the coverage in 1973. During the same period, non-vegetated land changed from 10% to 17.1%, an increase of about 7% representing land cleared for timber, farming and settlement, especially the urban centres which accommodated the upcoming industries and the required labour force plus other commercial activities.

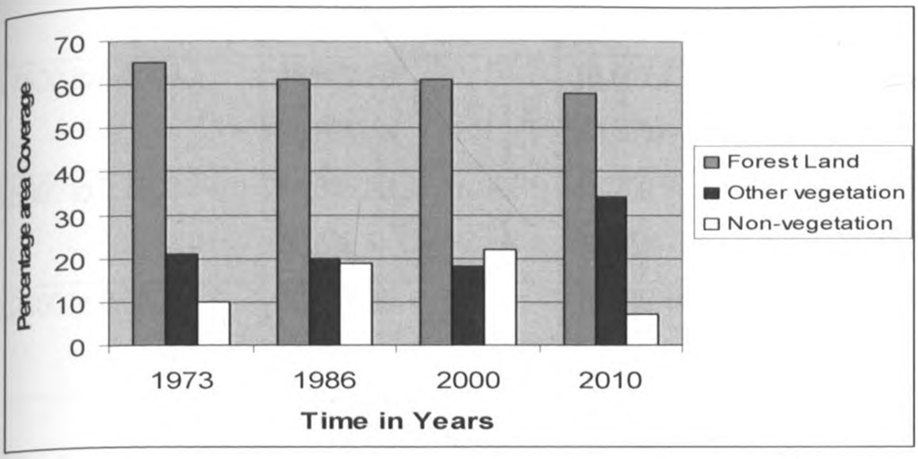
The period between 1986 and 2000 had a lot of anthropogenic activities that in the end resulted in negative impacts on the forest and the environment. While the area under closed canopy reduced by about 1.2% during these 14 years, the area under other vegetation reduced by about 6% and area under non-vegetated land increased by about 7.2%. This means that, more clearance was done in the area under other vegetation than in the closed canopy forest but both resulted in the increase in the area under non-vegetated land. It was during this period that the introduction of the Nyayo Tea Zone had some parts of the forest, not only in the Mau excised for growing of tea. Irregular forest land allocation to individuals by the political regime of that time also consumed a big part of the forest. The Molo forest disappeared, Eastern Mau, South-West Mau among others highly degraded with some parts becoming wasteland. Table 5.1 illustrates time series land cover class quantification for 1973, 1986, 2000 and 2010 imageries.

Table 5.1: Thematic Cover Class Areas for 1973, 1986, 2000 and 2010 classified imageries

CLASS CATEGORY	AREA			
COVER TYPE (Class)	AREA (HA) 1973	AREA (HA) 1986	AREA (Ha) 2000	AREA (Ha) 2010
Forestland	286426.08 68%	239994.05 62.8%	243913.15 61.6%	207868.59 53.9%
Other vegetation	92483.64 22%	76844.94 20.1%	55998.46 14.1%	132961.68 34.5%
Non- vegetated land	42167.88 10%	65505.20 17.1%	96250.57 24.3%	44560.71 11.5%

Due to legal excision of the Maasai Mau (2001) and the illegal allocations just before the 2002 general elections, the forest land under closed canopy reduced from 61.6% in 2000 to 53.9% in 2010. Fortunately, the general outcry from various stakeholders for conservation of the Mau complex and the ultimate involvement of the Mau Rehabilitation Secretariat, championed by the Office of the Prime Minister led to the increase in the area under other vegetation from 14.1% in 2000 to 34.5% (about 20.4% increase) in 2010. This increase in the area under other vegetation resulted in the decrease in the area under non-vegetation which reduced by about 12.3%.

Graph 5.1 illustrates percentages of cover class areas in each of the years considered in the spatial change analysis.



Graph 5.1 Percentage cover class areas against time

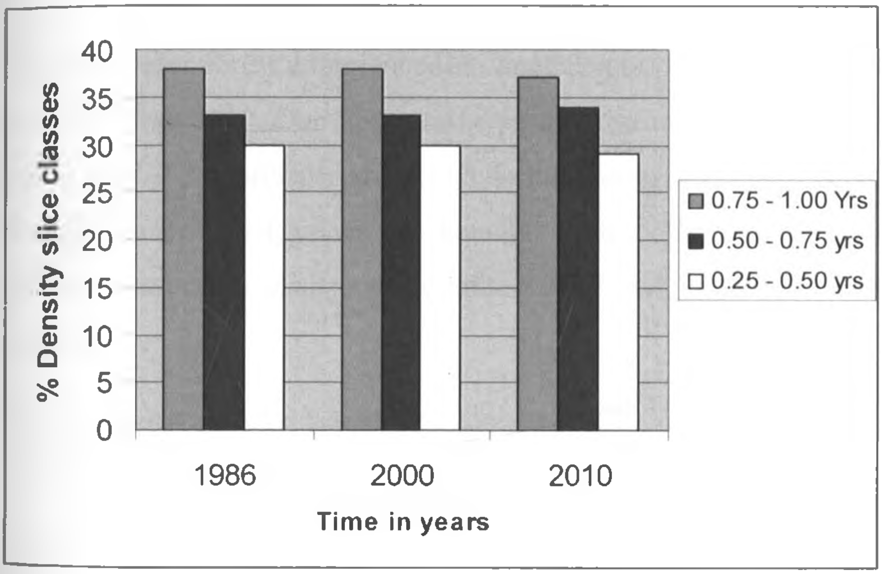
The results of the Normalized Difference Vegetation Index used to complement the cover classification exercise revealed a general degradation in plant health in the Mau forests over time. The three density slice classes used were 0.25 – 0.50 μm for sparsely (least healthy) vegetated areas; 0.50 – 0.75 μm for areas with moderately dense (healthy) vegetation and 0.75 – 1.00 μm for dense (healthiest) forest all of which revealed the same trend of change with those of the cover classes (Table 5.2, graph 5.2 and Appendix 2).

The density slice class 0.75 – 1.00 μm reduced all through (1986 – 2010) and this is the areas under forest cover which also decreased due to reasons already stated (Table 5.2). The area under 0.50 – 0.75 μm increased during the study period and this could not be accounted for in terms of regeneration and planting of trees alone but also in terms of acreages of crops in the farms. The area under 0.25 – 0.50 μm class increased from 1986 figure in 2000 but decreased in 2010, also as a result of regeneration, planting of trees and presence and absence of crops in the farms. The percentage accounting for vegetation excluding crops must have experienced decrease as forest cover and area under other vegetation decreased.

Table 5.2: Density Slice Class Areas for the 1986, 200 and 2010 Landsat imageries

Class Category (µm)	1986 Area (Km²)	2000 Area (Km²)	2010 Area (Km²)
0.7500 to 1.0000	16,882.79 38.09%	16,882.79 37.80%	15,239.74 37.1%
0.5000 to 0.7500	14,386.23 32.5%	14,269.90 32.95%	13,765.82 33.5%
0.2500 to 0.5000	13,057.30 29.5%	13,512.44 30.3%	12,120.03 29.5%

Graph 5.2 shows percentage temporal distribution of density slice classes.



Graph 5.2 Percentage density slice classes against time.

5.2.3 Trend, Magnitude and Rate of Land Cover Change

Between 1973 and 1986, forest cover had decreased by 46432.03 hectares (-4.2%), other vegetation decreased by 15638.70 hectares (-1.86%) while non-vegetated land increased by 23337.32 hectares (7.0%). The forest land and land under other vegetation was being lost to non-vegetated activities. Farming, logging and settlement especially in the upcoming urban centres contributed to this change.

Between 1986 and 2000, the forest cover increased by 3919.10 hectares (1.2%), area under other vegetation further decreased by 20846.48 hectares (-6.0%) while area under non-vegetated cover increased by 30745.37 hectares (7.2%). During the period 2000 to 2010, the area under forest decreased by 36044.10 hectares (-8.7%) while area under other vegetation increased by 77963.56 hectares (20.4%) and area under non-vegetated land decreased by 51689.86 hectares (-12.3%).

Between 1973 and 1986, there was an annual rate of change in forest land of -3571.69 hectares; area under other vegetation had an annual rate of change of -1202.92 hectares while the area under non-vegetation changed at an annual rate of 1795.15 hectares. The period between 1986 and 2000 had a positive annual rate of change in the area under forest of 279.93 hectares, an annual rate of change in the area under other vegetation of -1489 hectares while the area under non-vegetation increased at annual rate of 2196.07 hectares. Negative sign means a reduction in land cover under study.

The area under forest experienced an annual rate of change of -3604.4 hectares during the period 2000 to 2010. During the same period, the area under other vegetation changed at the rate of 7796.3 hectares per annum while the area under non-vegetation experienced a rate of change of -5168.99 hectares per annum. Table 5.3a below illustrates the magnitudes and trends of land cover change while table 5.3b shows the annual rates of change for the years under study.

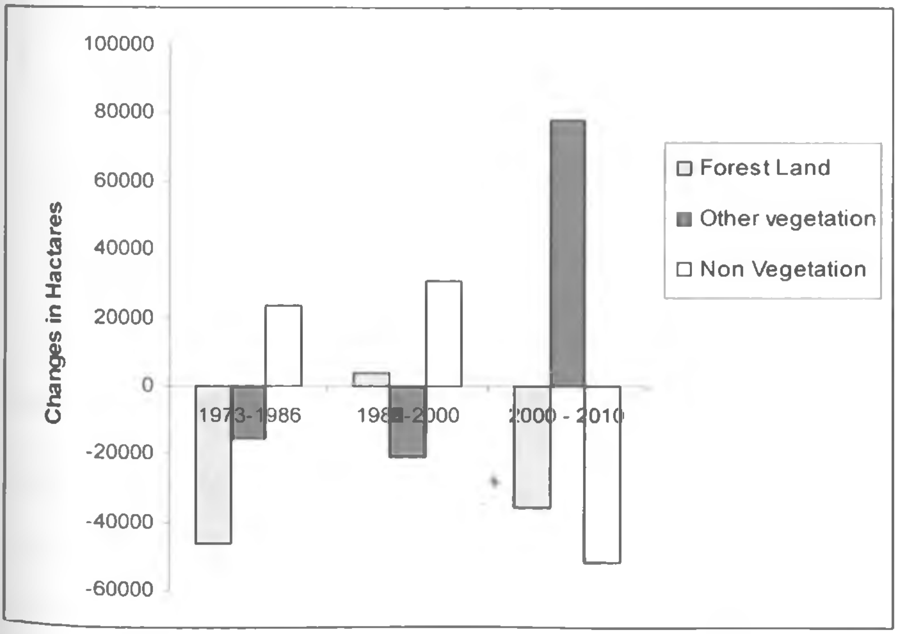
Table 5.3a Trends and Magnitude of Land Cover Change

	1973 – 1986		1986 – 2000		2000-2010	
Land cover category	**Areas (Ha)**	**% change**	**Areas (Ha)**	**% change**	**Areas (Ha)**	**% change**
Forest land	-46432.03	-4.2	3919.10	1.2	-36044.6	-8.7
Other vegetation	-15638.70	-1.86	-20846.48	-6.0	77963.22	20.4
Non-vegetated land	23337.32	7.0	30745.37	7.2	-51689.0	-12.3

Table 5.3b Annual Rates of Change in Land Cover Category

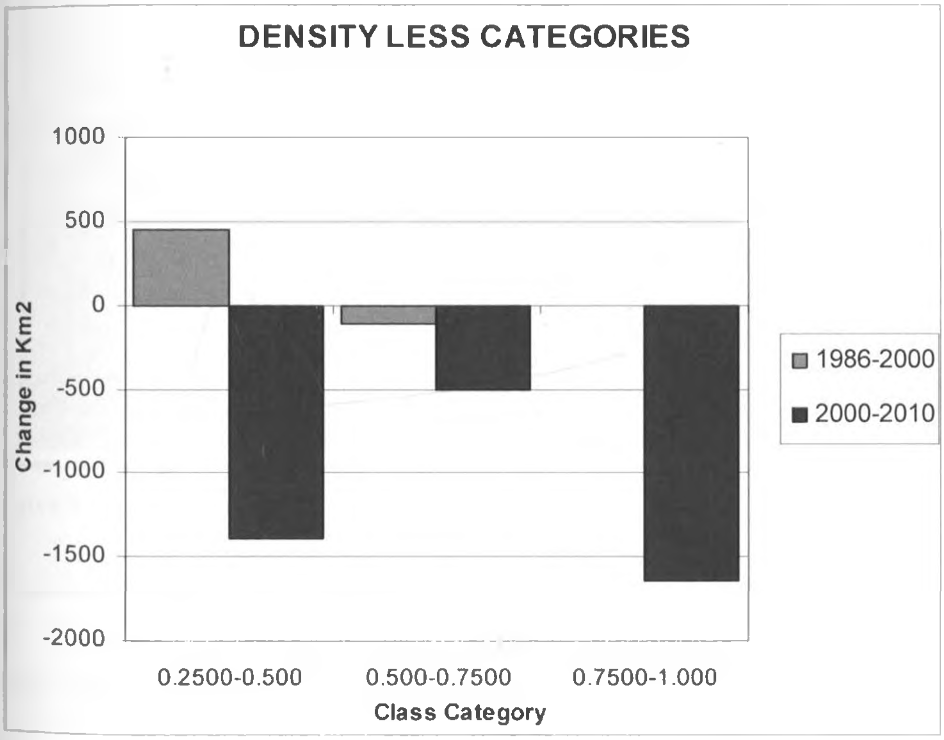
	Annual Rate Change		
Land cover category	1973 – 1986 (Ha)	1986 – 2000 (Ha)	2000 – 2010 (Ha)
Forest land	-3571.69	279.93	-3604.40
Other vegetation	-1202.92	-1489.00	7796.30
Non-vegetated land	1795.15	2196.07	-5168.99

These changes could be justified by the fact that as human activities increased, more land was converted from other vegetation to agriculture, settlement and even clearance to get timber for construction, among others. These processes continued adding to the increase in areas under non-vegetated cover. The slight increase in the area under forest, this study believes was a matter of chance and not policy restriction. Graph 5.3 below indicates changes in cover classes in hectares against time. The values above the X- axis represented cover types that had increased while the values below the X- axis represented the cover types that decreased over the same period. Outcry for conservation of the Mau and change in leadership are believed to have brought this positive result.



Graph 5.3: Coverage class changes with time

The Normalized Difference Vegetation Index (NDVI) results using density slices revealed same trend of change, save for the range 0.75 to 1.00 µm that did not change during the period 1986 to 2000. It had the same value for both 1986 and 2000 hence the value zero, which is not shown in the graph below (graph. 5.4). During the same period (between 1986 and 2000), the vegetation whose density slice fell between 0.50 and 0.75 µm decreased by 116.33 km^2 and area under 0.25 and 0.50 µm increased by 455.14 km^2. Between 2000 and 2010, all the three classes of density slices decreased in coverage with most decrease being realized in the 0.75 to 1.00 class (1643.05 km^2). The decrease in the 0.50 to 0.75 µm class was 504.08 km^2 and that in the 0.25 to 0.75 µm class was 1392.42 km^2. Graph 5.4 shows the quantitative change in coverage for each density slice class for 1986, 2000 and 2010 Landsat imageries used. These results show that, as time went by, the greenness of the forest and general vegetative cover decreased as the trees became less healthy (less chlorophyll content) and less dense.



Graph 5.4 Coverage density slice changes with time.

5.2.4 Thematic Class Overlays

The results of overlay operations revealed both the desirable and undesirable changes as well as classes that were relatively stable over time and these changes could help in making informed management decisions (Figures 5.2a, 5.2b, 5.2c and 5.2d).

In terms of location of change, the emphasis was on forest land and land under other vegetation. The changes between 1973 and 1986, 1986 and 2000, and lastly, 2000 and 2010 are presented in the tables 5.4a, 5.4b and 5.4c.

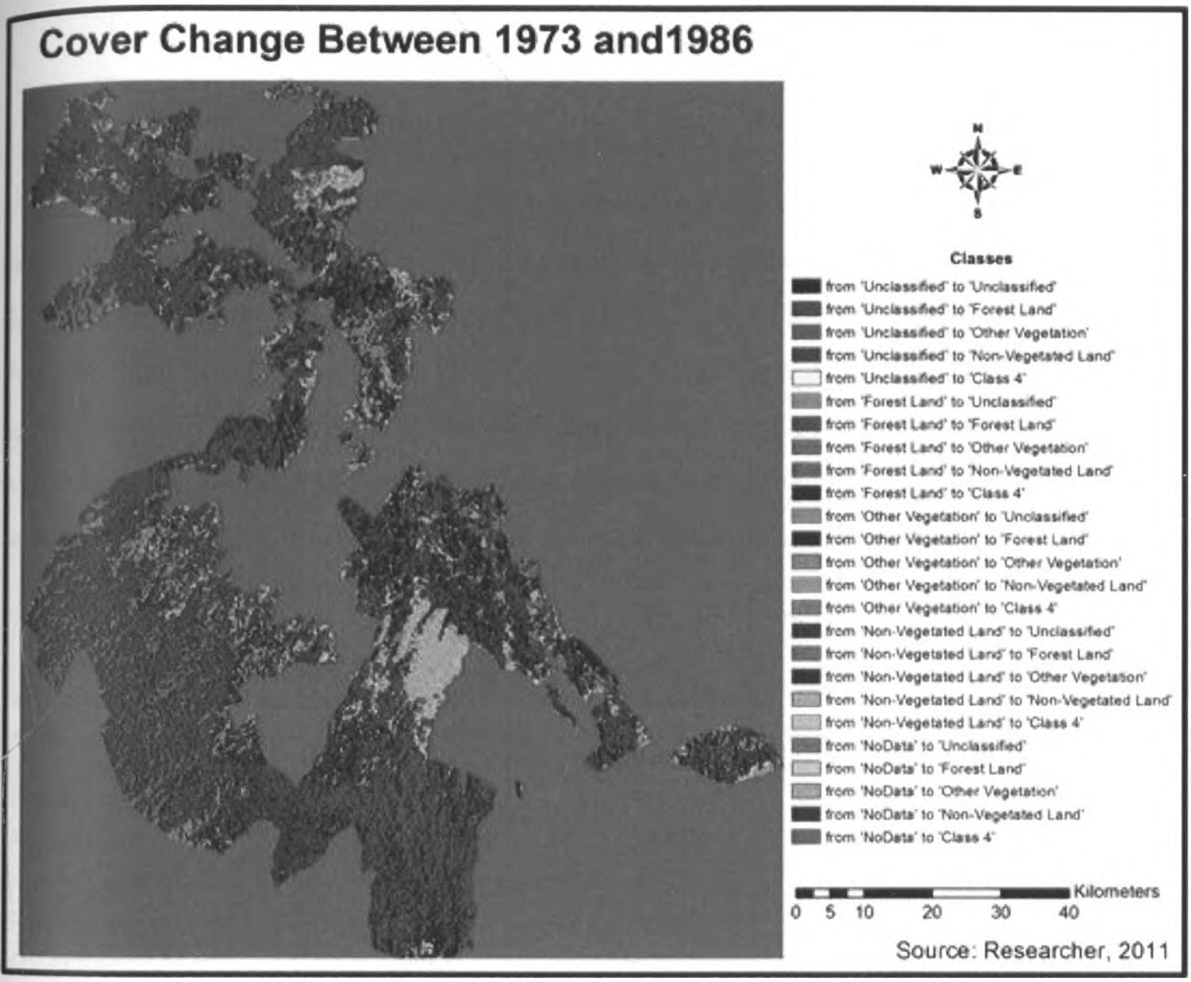


Figure 5.2a: An overlay of 1973 and 1986 images

Table 5.4a: Changes in Land Cover and Land Use between 1973 and1986

1973	1986	Area (Ha)	%
Forest Land	Forest Land	179057.02	42.34
Forest Land	Other Vegetation	47282.78	11.18
Forest Land	Non-Vegetated Land	29885.20	7.07
Forest Land	No-Data	31045.09	7.34
Other Vegetation	Forest Land	51855.42	12.26
Other Vegetation	Other Vegetation	25773.42	6.09
Other Vegetation	Non-Vegetated Land	8410.20	1.99
Other Vegetation	No-Data	6079.85	1.44

Non-Vegetated Land	Forest Land	11065.04	2.62
Non-Vegetated Land	Other Vegetation	2533.41	0.60
Non-Vegetated Land	Non-Vegetated Land	26412.99	6.25
Non-Vegetated Land	No-Data	1836.90	0.43
No-Data	Forest Land	973.56	0.23
No-Data	Other Vegetation	73.10	0.02
No-Data	Non-Vegetated Land	583.44	0.14

Figure 5.2a shows how the land cover types namely Forest Land, Other Vegetation, Non-Vegetated Land and No-data changed to and from each other between 1973 and 1986. From the attribute table (Table 5.4a) above the results revealed that, forest land was converting at the highest rate to the other land cover types. Thus, 25.6% of the forest land was converted to the other land cover types while 15.7% of Other Vegetation, 3.6% of Non-Vegetated Land and 0.36% of No-data changed to the other land cover types. No-data represents the part that was covered by cloud at the time the image was taken and therefore the real cover could not be ascertained. Logging and farming were the main cause of deforestation.

Table 5.4b: Changes in land use and land cover between 1986 and 2000

1986	2000	Area (Ha)	%
Forest Land	Forest Land	150606.01	10.98
Forest Land	Other Vegetation	28538.65	2.08
Forest Land	Non-Vegetated Land	48921.66	3.57
Forest Land	No-Data	15037.92	1.10
Other Vegetation	Forest Land	48500.18	3.54
Other Vegetation	Other Vegetation	13977.28	1.02
Other Vegetation	Non-Vegetated Land	10749.40	0.78
Other Vegetation	No-Data	2251.64	0.16
Non-Vegetated Land	Forest Land	26075.58	1.90
Non-Vegetated Land	Other Vegetation	9137.33	0.67
Non-Vegetated Land	Non-Vegetated Land	25079.36	1.83
Non-Vegetated Land	No-Data	4919.96	0.36
No-Data	Forest Land	20324.36	1.48
No-Data	Other Vegetation	3677.62	0.27
No-Data	Non-Vegetated Land	11404.88	0.83

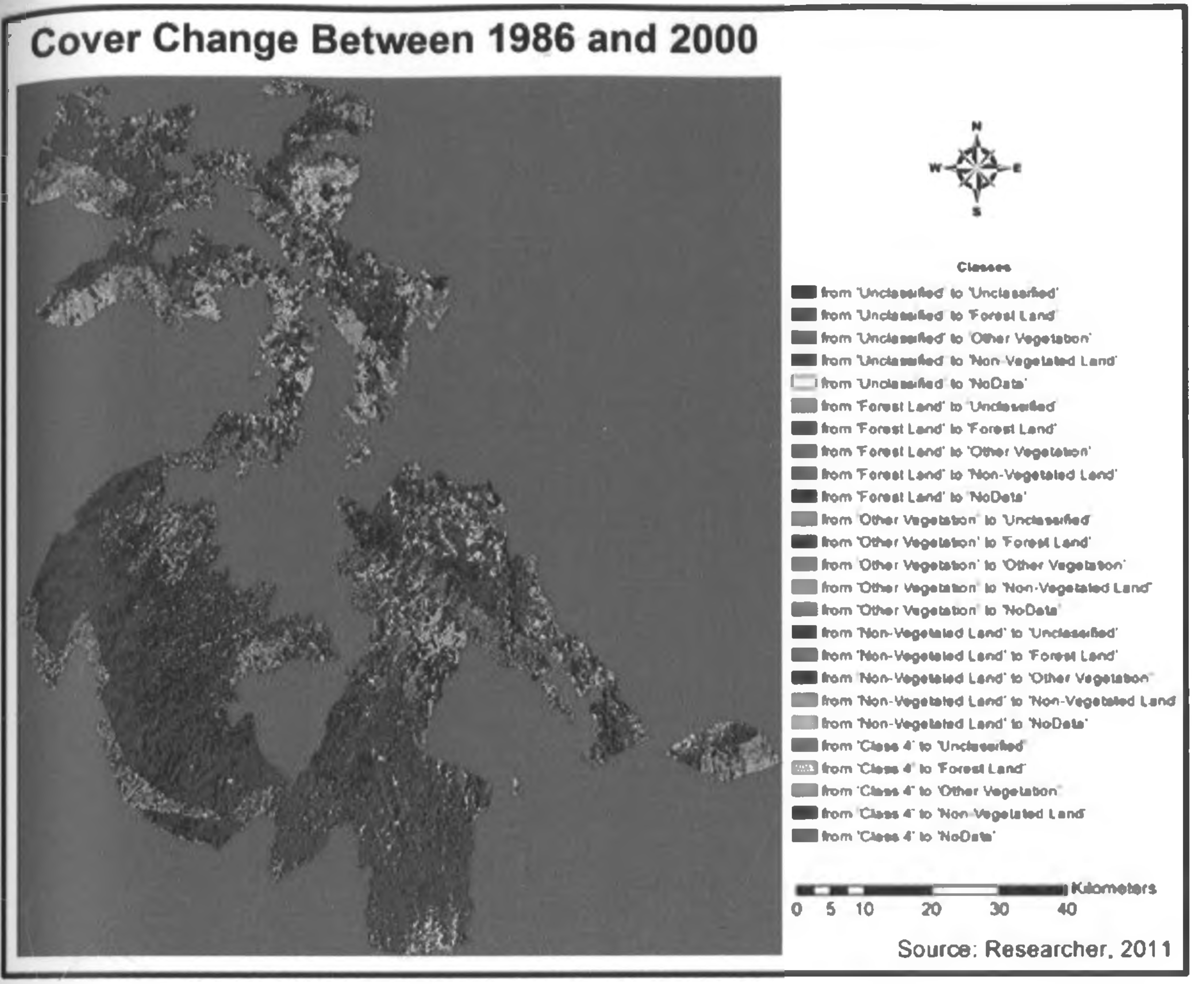


Figure 5.2b: An overlay of 1986 and 2000 images

The above results (Table 5.4b) show that forest land still gave most of its portion to other cover types. 6.75% of Forest Land changed to the other land cover types while 4.48% of Other Vegetation, 2.93% of Non-Vegetated Land and 2.58% of No-data changed to the other land cover types. Forest land mainly changed to farm land but was captured either under other vegetation to show crops in the farms or under non-vegetated land to mean farms that were prepared and were waiting to be planted. Other Vegetation was changed to forest where land had been left fallow and regenerated into thick vegetation cover while it changed to non-vegetated cover where crops had been harvested and no longer stood in the farms and or the farms prepared for another planting, although some changed to bare or waste land.

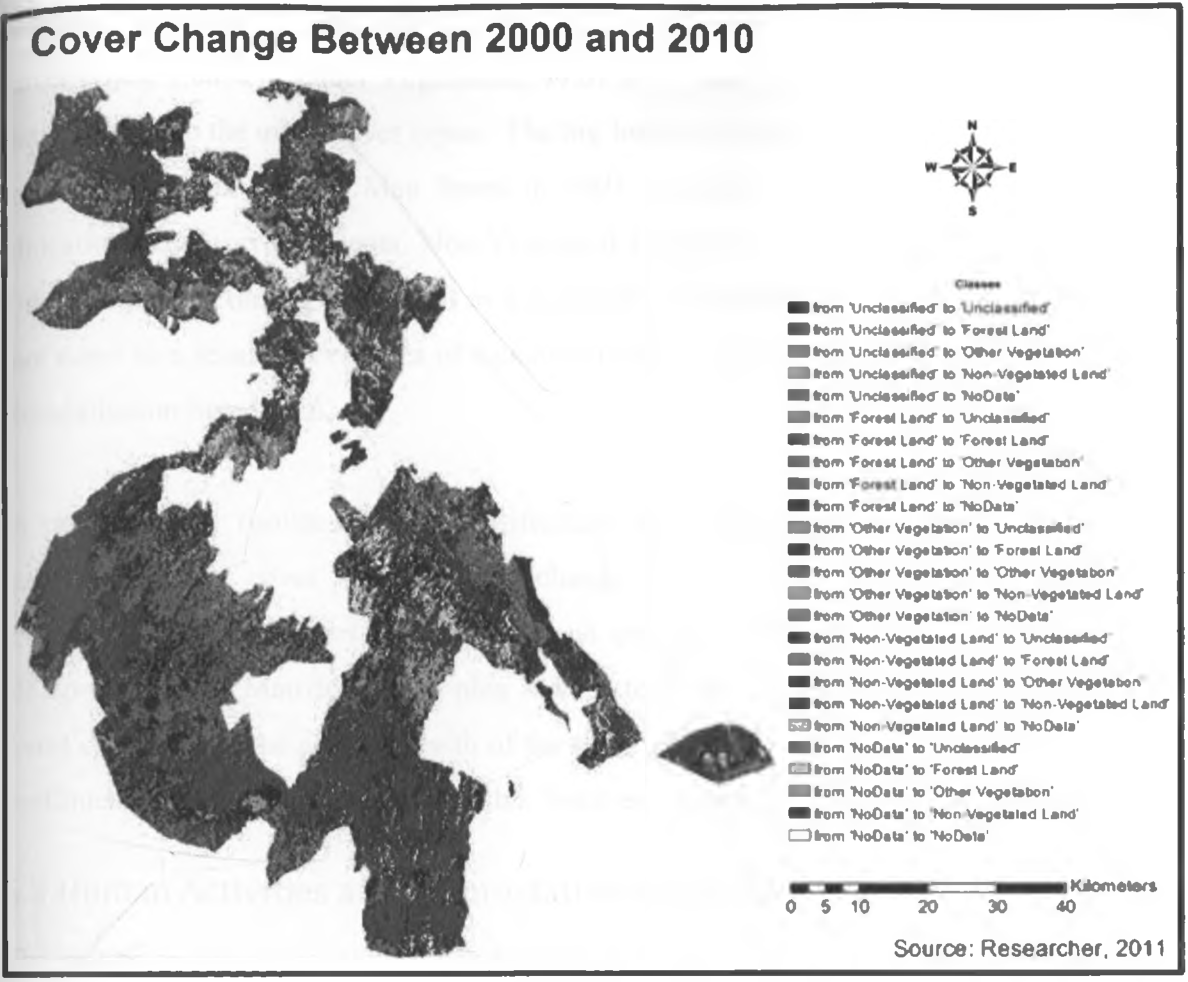


Figure 5.2c: An overlay of 2000 and 2010 images

Table 5.4c: Changes in land use and land cover between 2000 and 2010

2000	2010	Area (Ha)	%
Forest Land	Forest Land	126995.61	30.19
Forest Land	Other Vegetation	78056.90	18.56
Forest Land	Non-Vegetated Land	20569.91	4.89
Forest Land	No-Data	20380.25	4.85
Other Vegetation	Forest Land	20424.19	4.86
Other Vegetation	Other Vegetation	22947.77	5.46
Other Vegetation	Non-Vegetated Land	7460.68	1.77
Other Vegetation	No-Data	4408.73	1.05
Non-Vegetated Land	Forest Land	47213.49	11.23
Non-Vegetated Land	Other Vegetation	25619.91	6.09
Non-Vegetated Land	Non-Vegetated Land	13576.03	3.23
Non-Vegetated Land	No-Data	9651.15	2.29
No-Data	Forest Land	14814.55	3.52
No-Data	Other Vegetation	6303.63	1.50
No-Data	Non-Vegetated Land	2182.68	0.52

Attribute table (Table 5.4c) shows that, 28.30% of forest land was converted to the other cover types, 7.68% of Other Vegetation, 19.61% of Non-Vegetated Land and 5.54% of No-data changed to the other cover types. The big loss in forest land might have come about due to the excision of Maasai Mau forest in 2001 to settle the landless coupled with illegal allocations and encroachments. Non-Vegetated Land converted much to forest land and to Other Vegetation during this period as a result of tree planting and regeneration of vegetation that came as a result of evictions of squatters from the forest championed by the Mau Forest Rehabilitation Secretariat.

In summary, the results of post classification visual comparison, post classification area comparison, land cover and land use change trends, rates and magnitudes as well as comparisons of the changes in percentage and quantity of the density slice classes with time all agree that, the Mau forest complex have extensively changed (degradation) in terms of forest cover and in the general health of the trees. Thus, forest conservation efforts should be continued if the enormous benefits of this forest ecosystem were to be achieved.

5.3 Human Activities and Deforestation in the Mau Complex

The ground truthing process confirmed that there were a number of human activities that may have contributed to deforestation and subsequently to environmental degradation in the Mau forest complex. The following sub-sections outline specific human activities that were observed and captured in the field.

5.3.1 Logging of the Trees from Mau Complex

Logging has a long history in the Mau forest complex and was mainly done to supply timber to the Industries in Molo, Njoro, Maji Mazuri, Timboroa, Londiani, Elburgon and Nakuru. Timber industry was very popular in the 1970s and early 1980s and created jobs and encouraged the growth of these centres. The labour force in these factories created market for the farm produce and rental houses among other services.

Forestry was a very key sector in Kenyan economy just after independence when the government started to establish industries that could make her generate revenue in order to provide the citizens with basic needs such as health facilities, schools and infrastructure. Most of these factories collapsed in late 1980s and early 1990s due to mismanagement and bad governance. Logging still goes on in the Mau forest complex as can be seen from plate 1 below.

Plate 1: Logged timber in the forest Source: Researcher, 2011

5.3.2 Urban Centres

As already mentioned, urban centres developed in the Mau forest complex region, some with the sole aim of processing timber and wood products while some doubled as farm produce processing centres. Maji Mazuri belonged to the first category while Nakuru belonged to the second. Thus, forest land was cleared to construct houses for industries, offices and residential purposes.

5.3.3 Extraction of timber for fencing and building

Timber has been and is still being used to construct houses although its use as the main material for walls of buildings has greatly reduced due to reduction in the availability of timber. It is also used for fencing homesteads and property boundaries. Plate 2 below shows trees that have been cut in the periphery of the forest with the forest in the background to the left for building purposes.

Plate 2: Cut trees for fencing and building Researcher, 2011

5.3.4 Agricultural Activities

There are both large scale and small scale farming in and around the Mau complex. There are the Tea plantations around Kericho but such crops like Maize and Vegetables are very common. Plate 3 shows farms of Cabbages, English Potatoes and maize (at the far back) in an area that was formerly forest land but has since been taken, settled and farmed on by people. The river is in front, flowing from the right of the photo between the cabbage farm and the vegetation westwards through the trees and exiting at the left corner of the photograph.

The farms have gone up to the river banks, causing a major interference with both the river buffers and general riparian vegetation beside siltation of the river beds and pollution of the river waters from the chemicals used in the farms. This reduction in the depth of the rivers coupled with the reduction in rainfall amounts has led to some permanent rivers drying up while some become seasonal. Plate 4 is an aerial view of a newly prepared farm inside the forest. The trees are first logged to pave way for the agricultural activities.

Plate 3: Farming on formally forest land. Source: Researcher, 2011

Plate 4: Newly prepared farm inside the forest Source: UNEP, 2005

5.3.5 Wood fuel Collection and Charcoal Burning

Fire wood and charcoal are the main sources of domestic energy not only in the Mau region but in the rural set up in general. A part from felling trees for domestic energy, many local people in the community collect fire wood and or burn charcoal for sale to earn a living that can make them provide for their families.

Plate 5: Live tree cut and left to dry for fire wood Source: Researcher, 2011

Plate 5 above shows a tree that was cut and left to dry being broken into pieces for fire wood and part of it could be used for fencing. The plate below (plate 6) shows a donkey transporting charcoal from Mount Londiani forest to Londiani Township for sale. The donkey is alone because its owner remained behind having been engaged in a casual talk by the researcher. The study found out that both dry and live trees were cut for fire wood while charcoal is produced from newly cut trees.

Plate 6: Charcoal being transported by a donkey to the market Source: Researcher, 2011

5.3.6 Grazing of Livestock in the Forest

Mau forest complex in general is being used to graze livestock given that, it is neighboured by people who are both in crop and livestock farming as well as pastoralists. Not a single block in the Mau complex is without grazing as can be seen from the photo below taken from Mount Londiani forest. Major grazing is done at the edges of the forests but during dry spell, the animals go right inside.

Plate 7: Cattle grazing in the Forest Source: Researcher, 2011

5.3.7 Fire breakouts in the Forest

Destruction of forests by fire especially during dry seasons is a common scene in the Kenyan forests. Mau forest complex has been affected by fire more than any other water tower in Kenya. Plate 8 shows a section of the forest seriously burnt and after such severe fires, it takes time before vegetation can regenerate. In most cases, it takes too long to rain even after fire outbreaks since they occur during droughts, leading to mass drying of burnt trees, leave alone the fauna that get burnt and killed during the actual burning of the forest. This has been a single cause of major loss of most plant and animal species from the forest ecology.

Plate 8: Burnt Section of the Forest Source: UNEP, 2005

5.3.8 Environmental Impact of Land Cover Land Use Change

Going by the observations made in the field plus the results of the image analysis, this study is convinced that the above human activities were among the factors that contributed to the general forest cover reduction. Clearing the forest for other uses that exposed the soil such as farming on steep slopes caused a lot of soil loss due to erosion and this eventually resulted in wasteland as can be seen in plate 9 below.

Plate 9: Part of Mau forest that turned into wasteland Source: UNEP, 2005

In summary, the above factors and processes have resulted in the reduction of forest cover, not only in the Mount Londiani forest, but in the entire Mau forest complex. The study believes that the general environmental degradation and reduction in rainfall totals and distribution has partly come as a result of deforestation of the Mau and this has actually led to reduction in soil fertility and siltation as well as drying of some rivers.

5.4 Integrated Analysis: Mount Londiani Forest

Mount Londiani forest covers parts of Koibatek District in the Baringo County, Londiani and Kipkelion Divisions in Kericho County and Molo Division in Nakuru County and covers an area of about 103 hectares. Figure 5.3 shows the forest boundary of Mount Londiani forest and its location in the Mau forest Complex while Figure 5.4 is an administrative map showing the sub-locations falling in the Mount Londiani forest. The population density maps for these Sub-locations for 1979, 1989, 1999 and 2009 are given in Appendix 5.

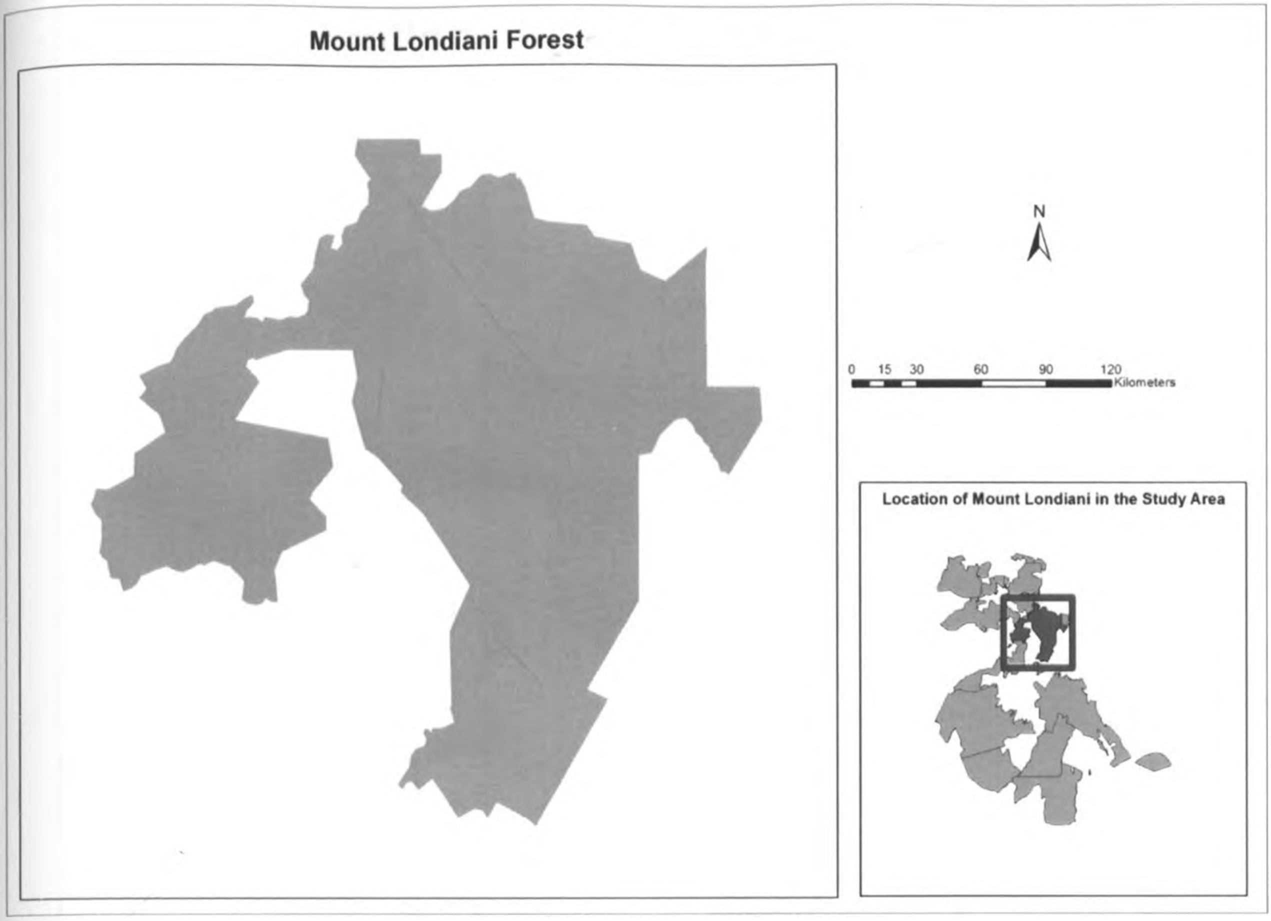


Figure 5.3: Gazetted extent of Mount Londiani Forest, 1973.

The following are results and discussions of the comparative analysis involving the various thematic maps and the rainfall graphs. The study used comparative analysis as opposed to overlay operations for ease of perception and understanding by the would be users of this report. The information used are in the Appendices 2 to 5 which are thematic maps for soils, slopes, land cover and population, the latter two being time series maps. The rainfall variations over time form the last discussion in the chapter ending with the combined line graph to show the comparative variations for the years 1977, 1986, 2000 and 2010 repectively.

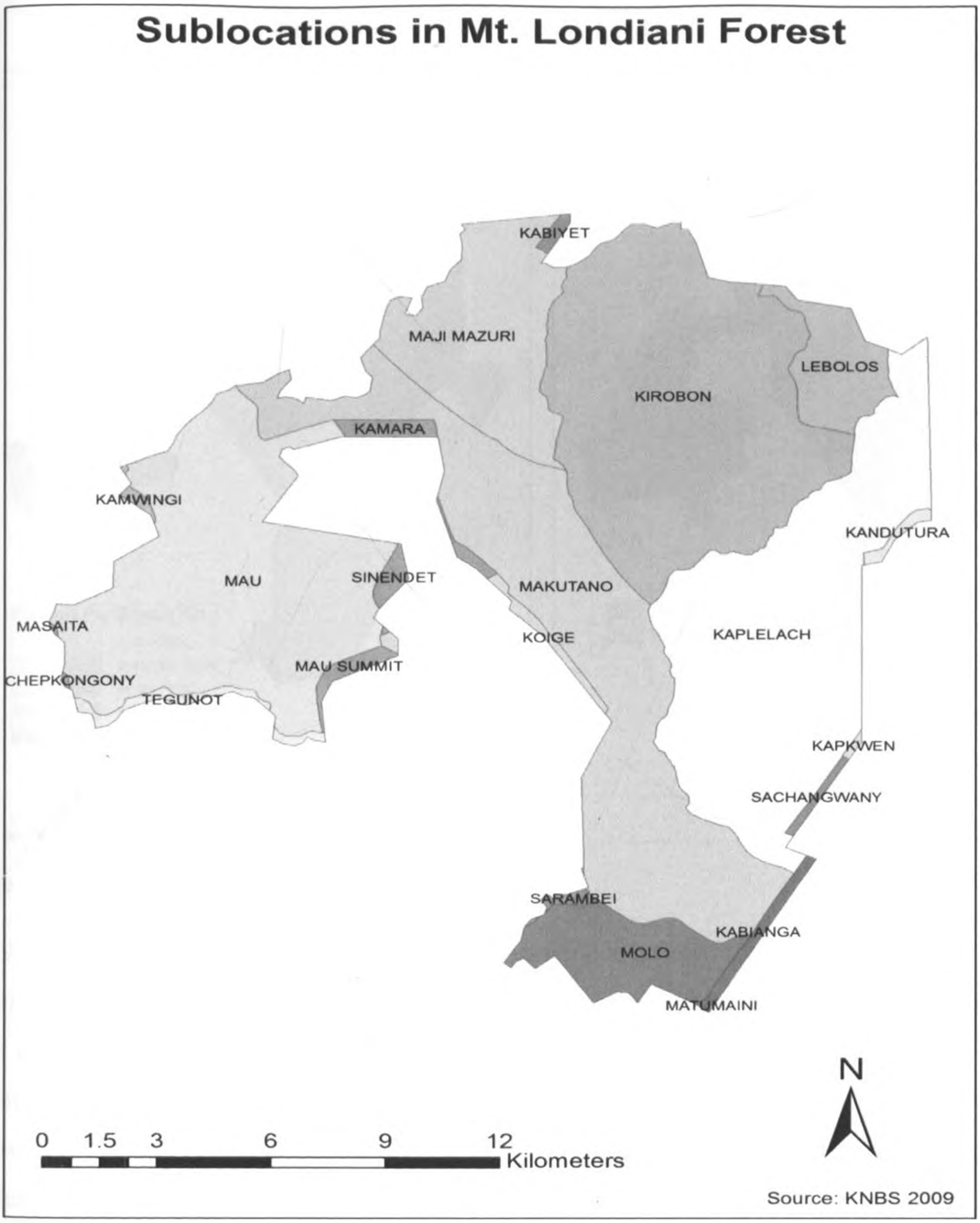


Figure 5.4: Administrative Units of Mt. Londiani Forest

5.4.1 Population Density and Land Cover in Mount Londiani Forest

Since Mount Londiani forest forms parts of the administrative units in the surrounding, this study used the same population densities for those administrative units to factor in the densities in the forest itself. The following figures (5.5a, 5.5b, 5.5c, and 5.5d) give results of the time series comparative analysis of the population densities on one hand and land cover changes of Mount Londiani forest on the other.

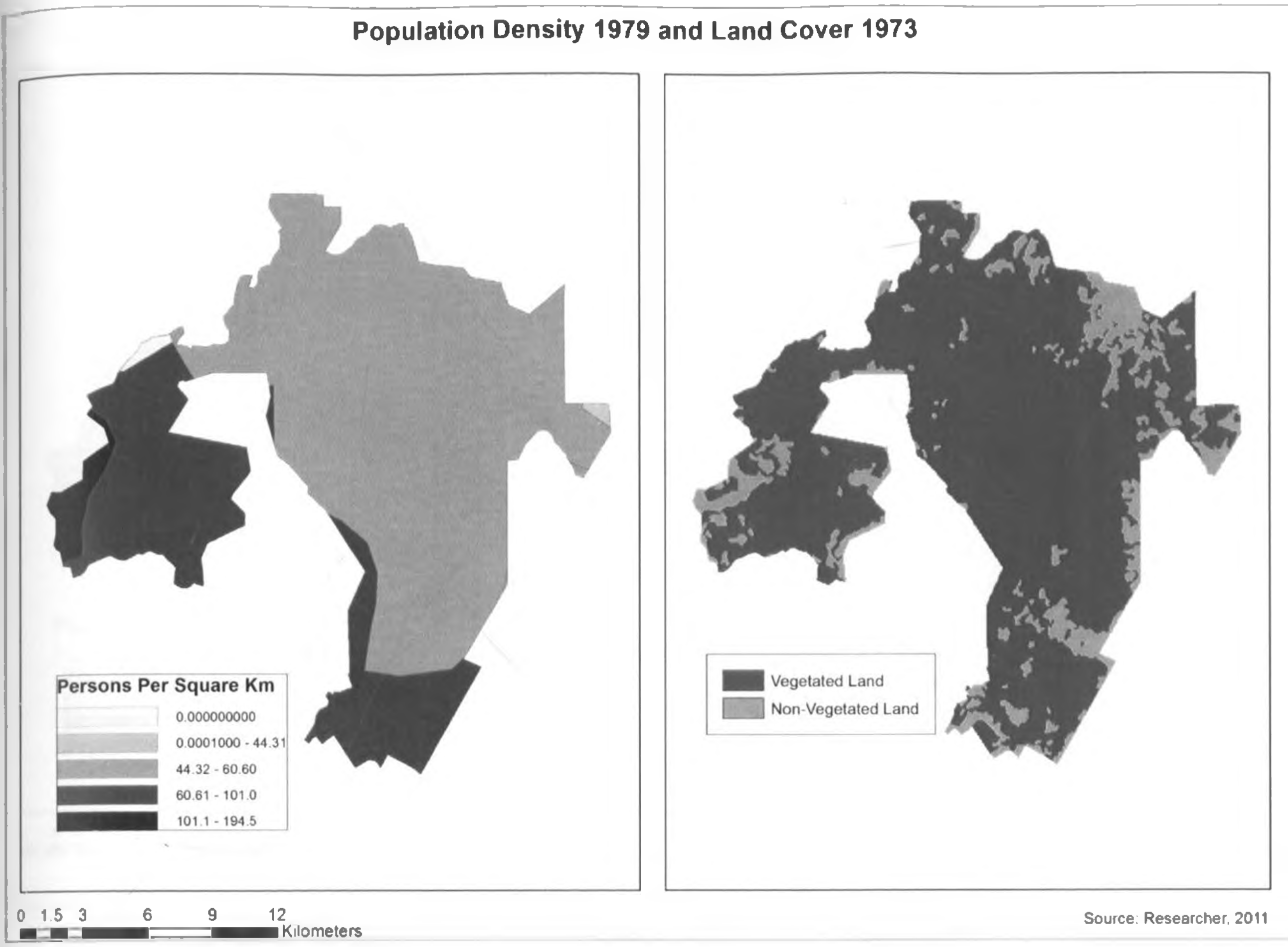


Figure 5.5a: Population Density for 1979 and 1973 land cover

In 1973, the forest was not degraded since the interference by the local communities was still small due to low population densities. By 1979 the population densities had increased due to both natural increase and addition of people from outside areas who came to work in the urban centres such as Elburgon, Molo, Londiani, and Maji Mazuri especially in the timber industry and in agricultural sector. Thus, forest was cleared for urban settlement, timber to be processed in the factories and for agriculture.

Between 1979 and 1989 (Fig. 5.5b) the population densities were more than doubled and people started exerting pressure on the forest cover. More people from the surrounding areas started utilizing the forest for timber for house constructing, clearing the forest for agriculture and at the same time logging for industrial purposes, especially in the late 1970s and early 1980s. More forest was cleared to give room for urban settlement to accommodate the timber industries and the labour force for those factories. These activities resulted in deforestation which was witnessed in all the blocks of Mau Complex. Figures 5.5b and 5.5c compare 1989 population density with 1986 land cover; 1999 density with 2000 cover respectively.

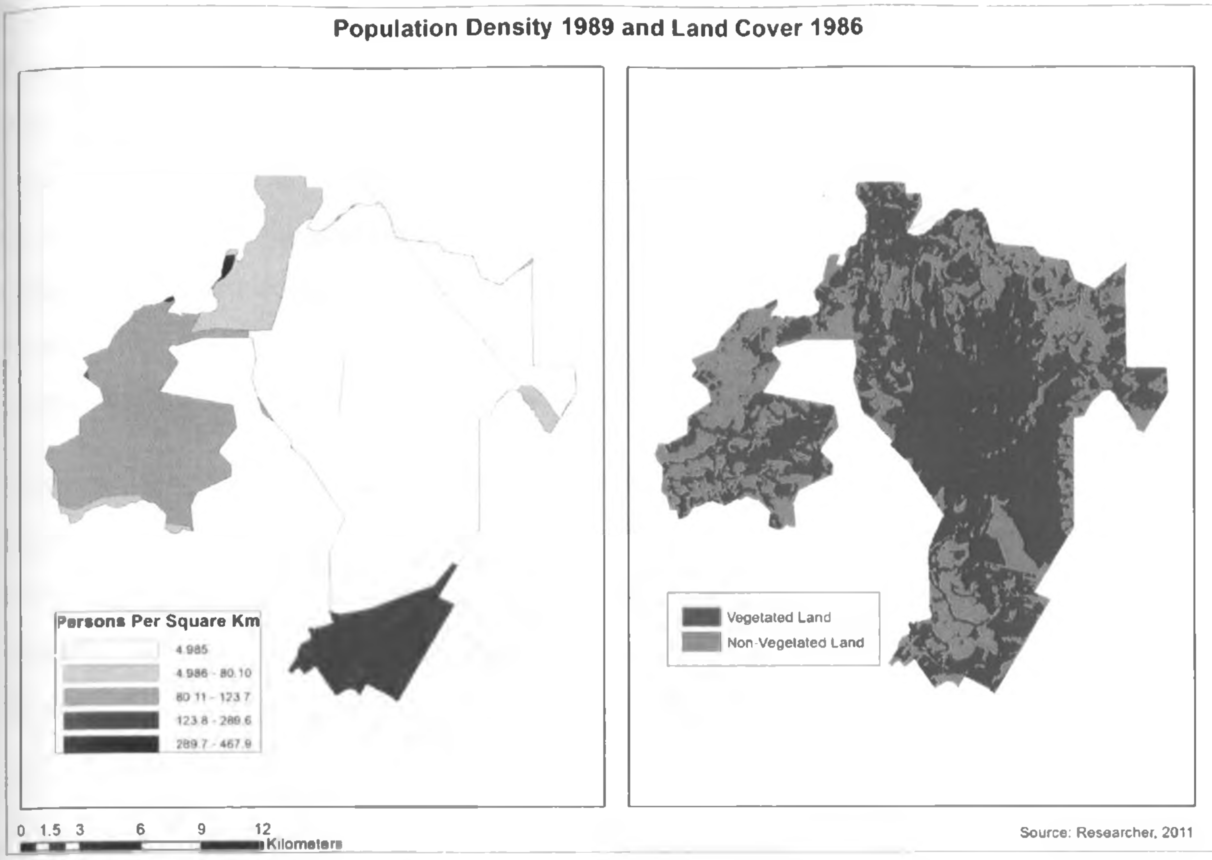


Figure 5.5b: Population Density for 1989 and 1986 Land Cover

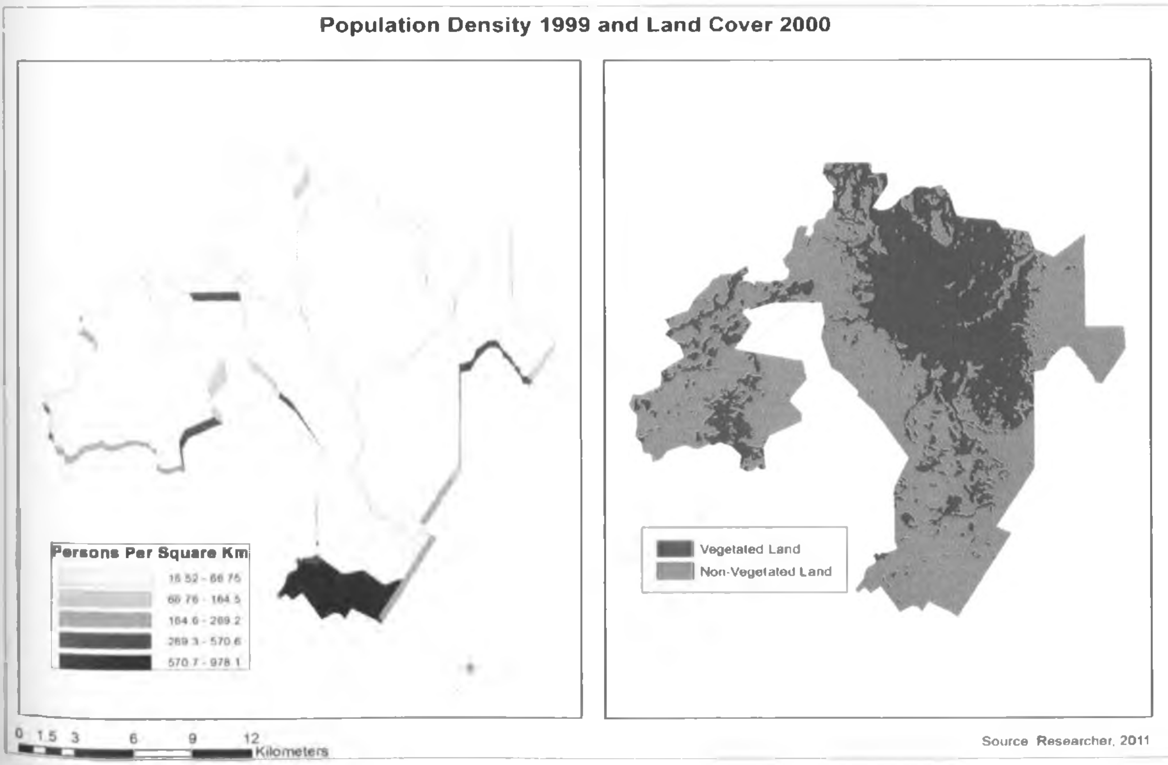


Figure 5.5c: Population Density for 1999 and 2000 Land Cover

Between 1989 and 1999, the population densities increased further, almost doubling the 1989 figures. The change of forest land to non-vegetated land between 1986 and 2000 almost doubled as well. Most timber industries collapsed in the 1980s and even some of the urban centres that came up as a result of the industries ceased to be active e.g. Maji Mazuri. Though there was decline in the amount of timber used in the factories in the surrounding due to such collapse, the forest continued to be degraded as was witnessed in the 2000 image analysis results. This scenario was brought about by increase in population in the neighbourhood and interference by outsiders who used their political good will to illegally acquire forest land.

Between 1999 and 2009, the population densities increased even further from the 1999 figures. When the land covers for 2000 and 2010 were compared, the latter was found to have had very good forest cover despite higher population densities. This increase in forest cover was attributed to tree planting and regeneration of vegetation which came about as a result of the evictions of squatters from the forest.

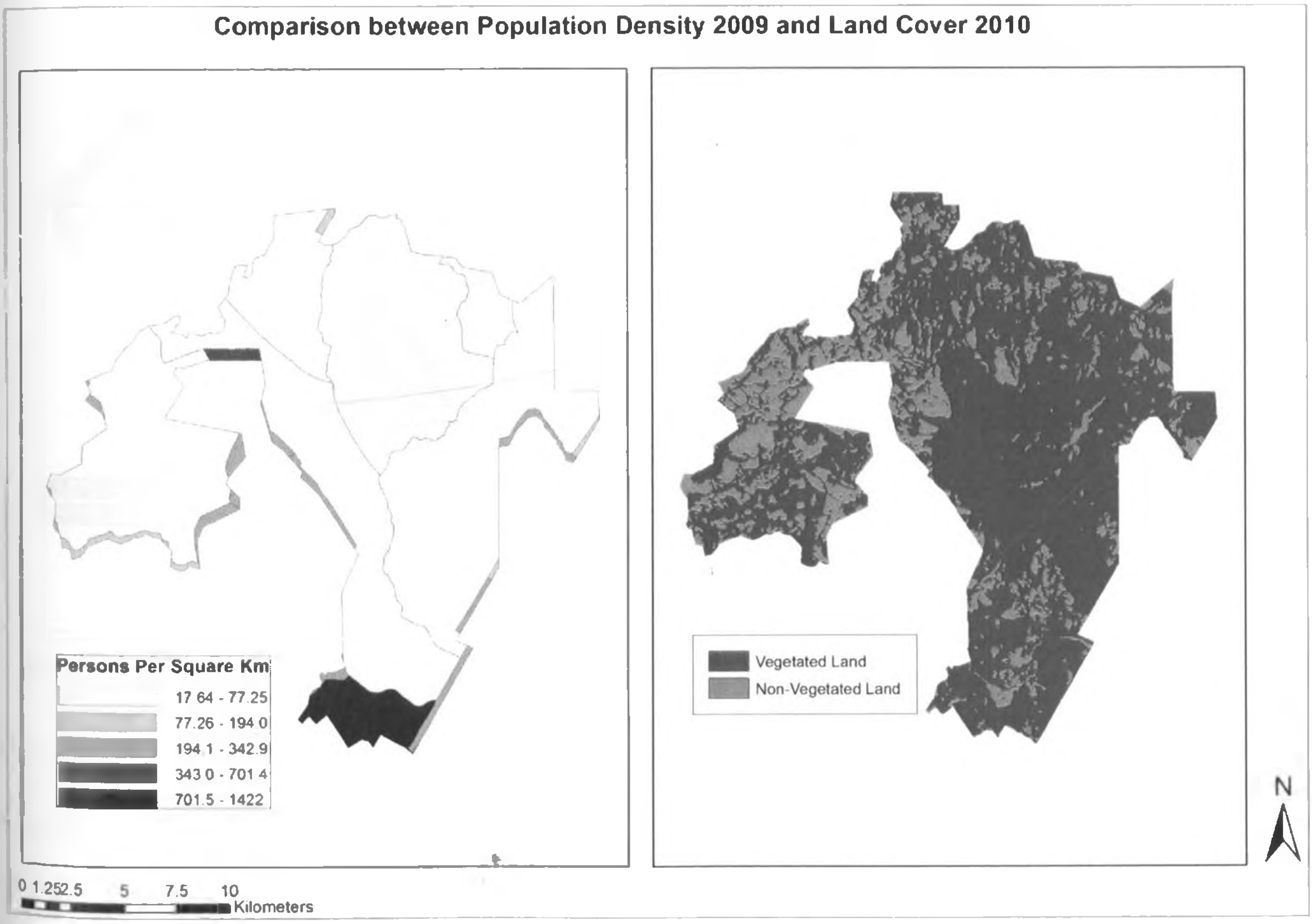


Figure 5.5d: Population Density for 2009 and 2010 Land Cover

5.4.2 Slopes and Land Cover Change in Mount Londiani Forest

Mount Londiani forest is generally steeper on the outer parts but becomes gentle inwards. From the slopes thematic map, it is clear that the forest has steep gradients (i.e. 8.8^{0}-9.9^{0}) on the northern and eastern parts. When the two maps were compared, it was observed that, although the forest cover was intact in 1973, the few open areas were found in this steepest gradient indicating presence of rock- out crops and not as a result of human activities. The next in steepness (7.6^{0}-8.7^{0}) runs through a long strip (outer) from northern part through the eastern part to the southern part.

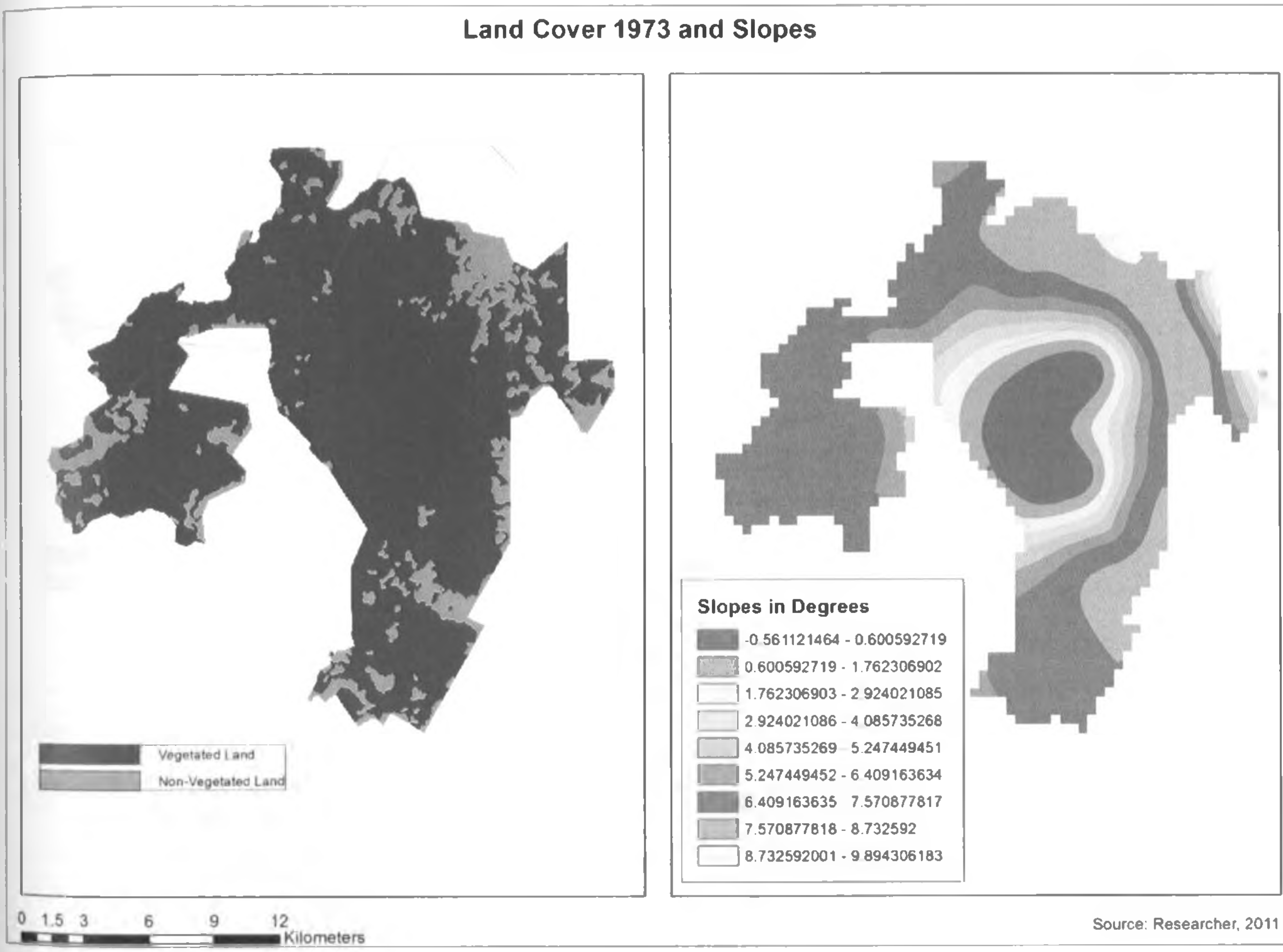


Figure 5.6: Land Cover for 1973 and Slopes of Mount Londiani forest

The 1986 land cover shows much of the forest land converted to non-vegetated cover without caring about the steepness of the land. Being a mountainous ecosystem, the use of Mau complex needed to be thoroughly checked and controlled. But from the manner in which the forest cover of 1986 was portrayed, steep slopes were cleared and left bare, exposing such areas to agents of mass wasting. Since the soil no longer has trees or grass whose roots hold the soil together, when it absorbs water, it becomes saturated, heavy and gives way and may result in a mudflow, landslide etc depending on the steepness of the slope. Overland flow also increases due to decrease in infiltration of water into the soil causing floods in the lower regions. All these are disasters in waiting and must be safe-guarded through mitigating actions.

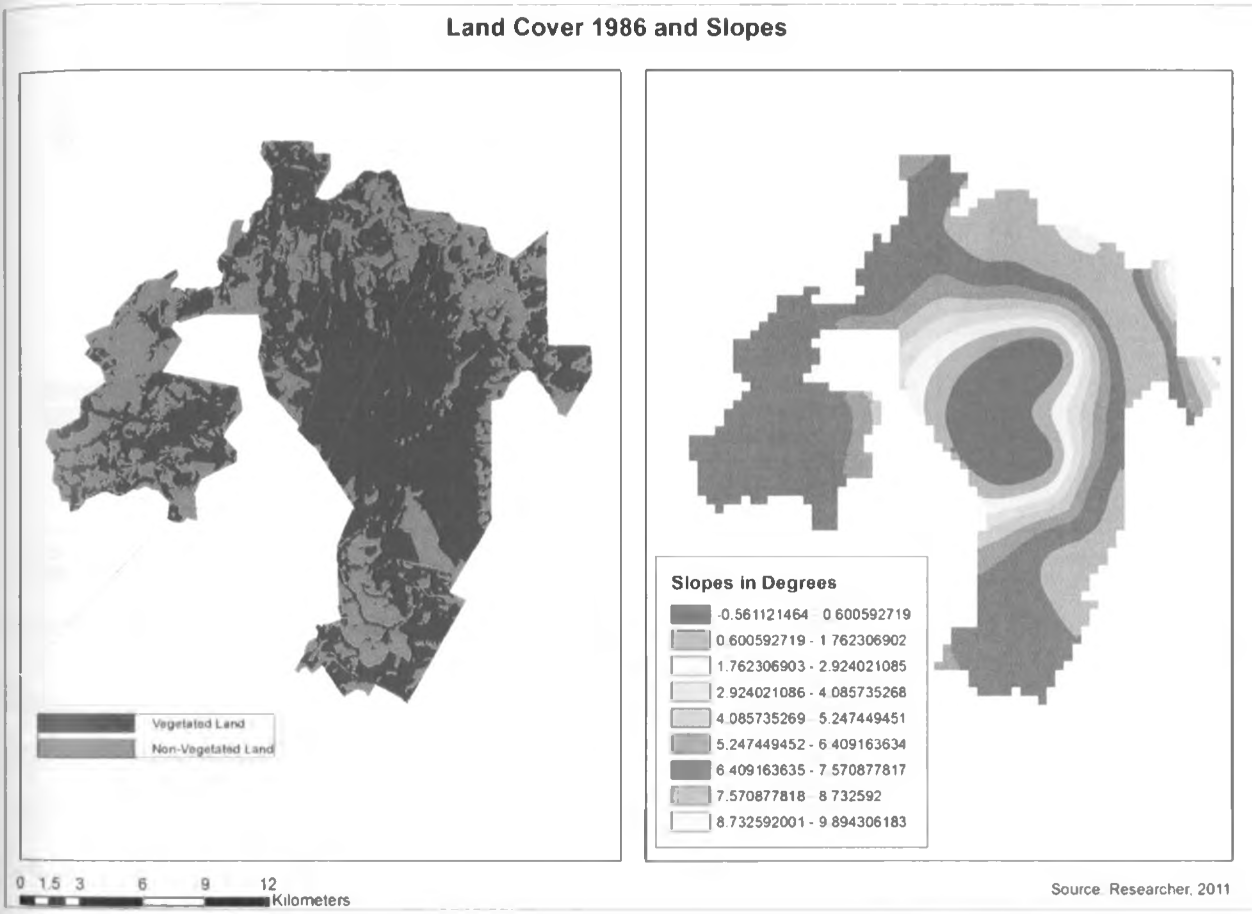


Figure 5.7: Land Cover for 1986 and Slopes of Mt. Londiani

The situation worsened in 2000 when more than 1/2 of the forest was cleared and left without vegetation, mainly for agricultural purposes. Figure 5.8 shows the very steep slopes cleared and put under agriculture and other non-forest uses. This kind of land use clearly shows that, either there are no properly stipulated land use policies in force or, if they are there, there is laxity on the part of government organs and administrative agencies to implement them. There have been cases of landslides in parts of Kenya including the Mau region and unless such unwarranted actions are checked and controlled, many lives and property may be lost.

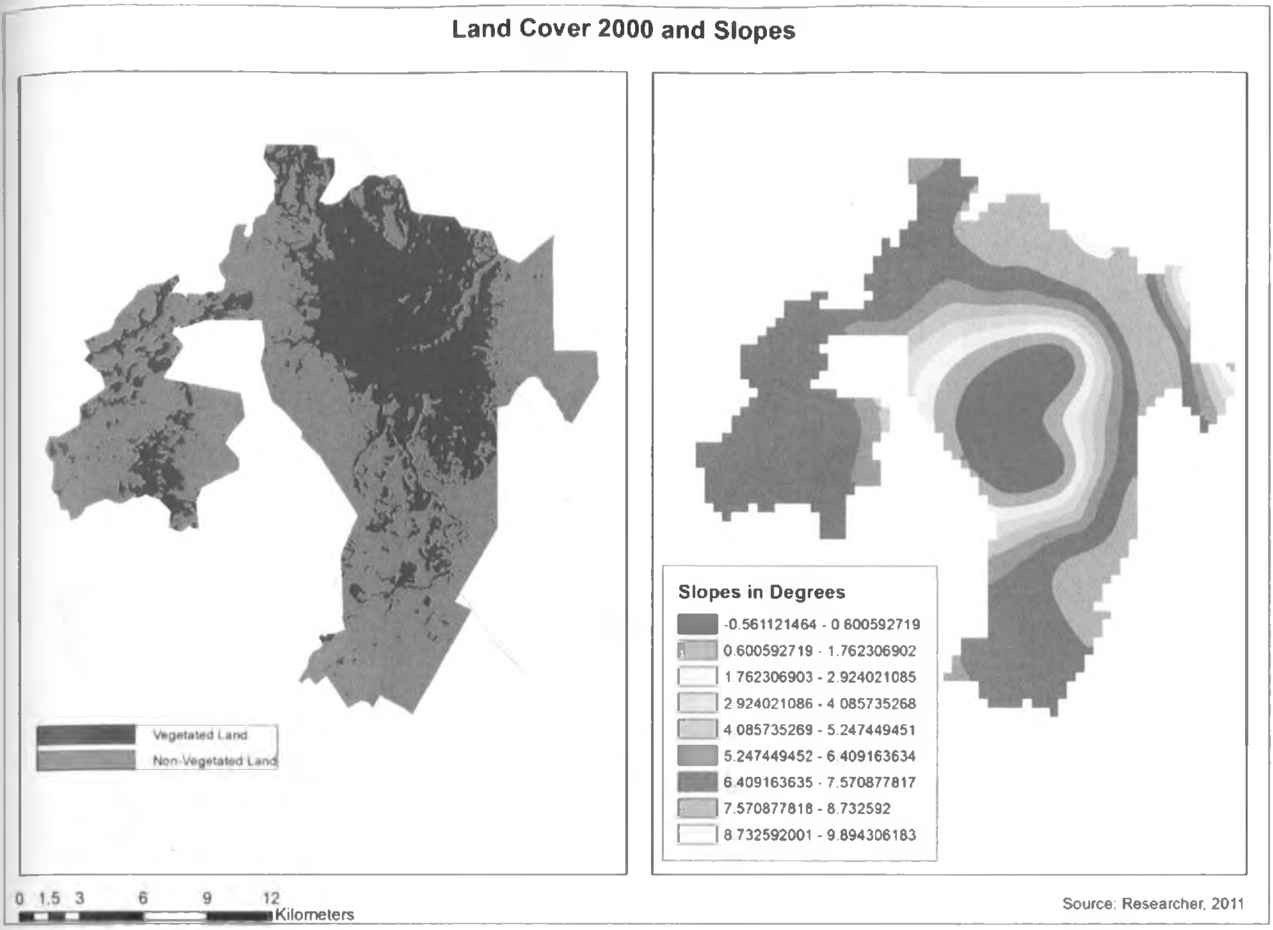


Figure 5.8: Land Cover for 2000 and Slopes of Mt. Londiani

When figures 5.8 and 5.9 were compared, it was noticed that, the forest cover improved such that, the steep slopes were securely covered by vegetation in 2010 unlike the case in 2000. This positive change was necessitated by prevailing conditions that had to be reversed through joint concerted efforts. Thus, the various action and advocacy groups for the conservation of the Mau complex, plus the good will from the new leadership in the country made it possible for the Mau conservation processes to be put in place – evictions and tree planting. Although this positive achievement was made, the study believes that, the importance of Mau forest complex was the driving force towards the forest restoration and not simply the fact that, steep slopes had been deforested and the reverse needed to be put in place to avoid any disastrous events occurring.

This study therefore came up a geo-database which could be used as a tool for land cover and land use change detection that would assist various stakeholders to visually perceive, understand and get the reasons and logic behind forest resource conservation and sustainability in development which calls for the application of purpose driven land use laws, policies and regulations. Creation of such a tool encompassed analysis of these variables, a gap left out by the studies that have been done in the Mau forest complex.

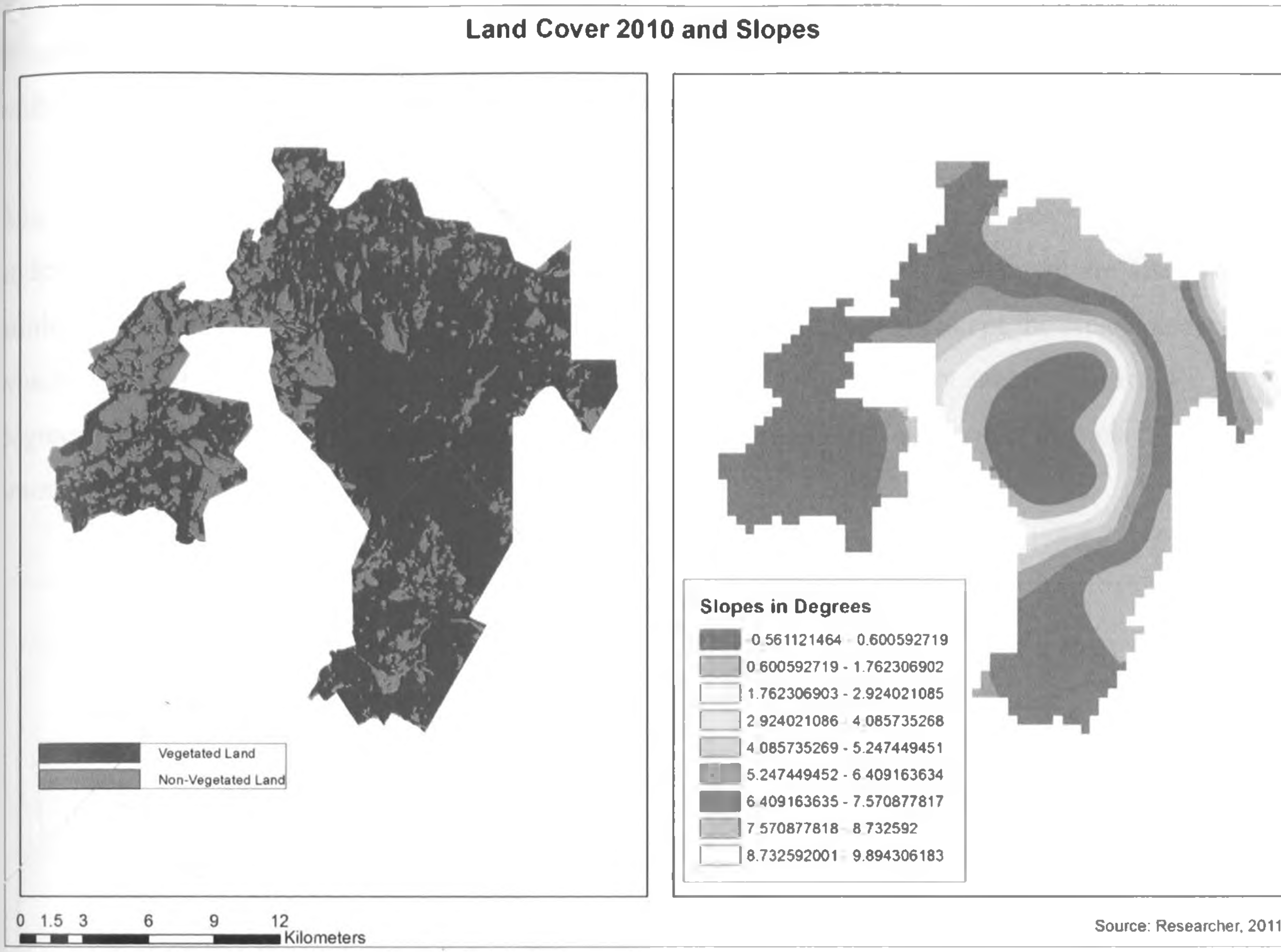


Figure 5.9: Land Cover for 2010 and Slopes of Mt. Londiani

5.4.3 Slopes and Soils in Mount Londiani Forest

Mount Londiani forest is endowed with six main types of soils as can be seen in Figure 5.10. The Cambisols are well drained, shallow to moderately deep, dark brown, friable clay loam to clay. Nitisols are also well drained, extremely deep dark reddish brown, friable slightly smeary clay. Both Cambisols and Nitisols have acidic humic topsoil and developed from volcanic origin. Andosols and Phaeozems have almost same characteristics as the first two since they all developed from volcanic processes. They are well drained, deep and smeary clay. The only different soil is the Regosol, developed from granites. It is extremely drained and has less capacity to hold back water.

Various parts of the forest are covered by different slopes and therefore different soils are found at different gradients (Figure 5.10). The soils on steep slopes are more vulnerable to mass movement when exposed than those on gentle slopes. At the same time such exposure causes the soils to lose their nutrients through erosion and general degradation of the land. Nitisols are generally found in the steep slopes of between 6.4 and 8.7 degrees. The Phaeozems, Planosols and Regosols are found in the gradient of between 6.4 and 7.6 degrees while Cambisols and Andosols cut across all the slopes from about -0.6 to 8.7 degrees.

When the soils are well protected and there is totally no interference, erosive forces would be under control and would not cause many problems. Losses through mass movement are also minimal or totally eliminated. Most of these soils are deep and compact except the Regosols which are loose. The gradient at which the Regosols are found is very steep (from 6.4 degrees) and when exposed, would very easily get eroded and could also result in rock fall among others (Fig. 5.10).

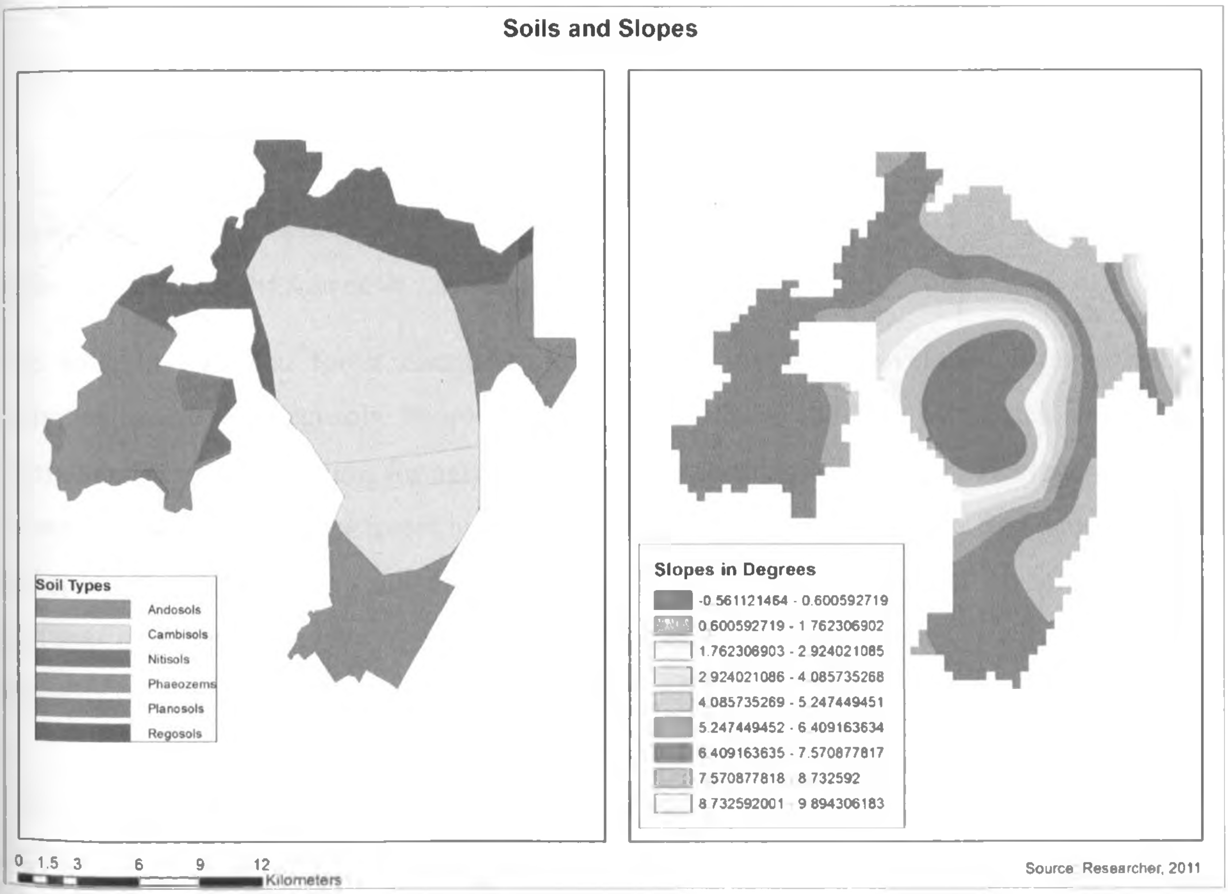


Figure 5.10: Soils and Slopes of Mt. Londiani Forest

In summary, the kind of exposure of the various soils in the varied landscapes pause serious danger to both man and environment. All these are policy problems which should be addressed.

5.4.4 Land Use and Soils in the Mt. Londiani Forest

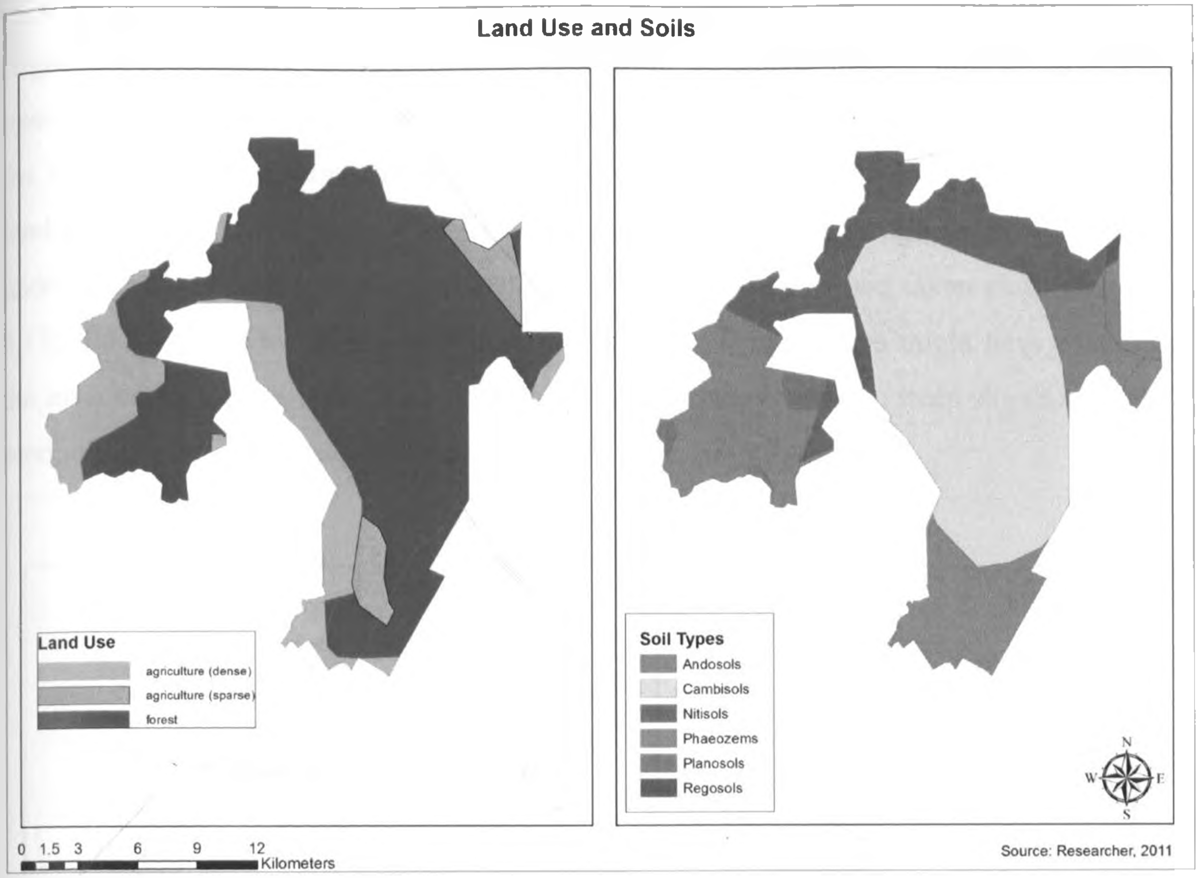


Figure 5.11: Land Use and Soils of Mt. Londiani Forest

The soils in the Mau forest complex are fertile having been developed from volcanic activities except the Regosols. People have been attracted to the Mau by its rich soils, high rainfall and cool temperatures for agriculture and other economic activities. The land use map shows that Mount Londiani forest has three land use types namely; forest, dense agriculture and sparse agriculture. The study established that the land use was not based on soil types but was sparingly done so as not to interfere with the forest ecosystems. This is why agriculture was only near or a long the edges of the forests and not inside the forest (Figure 5.11).

The study also established that the use of the land in Mount Londiani forest in particular and the Mau forest complex in general is not dictated by the soils or the crops but by the purpose for which it has been preserved and used - forestry. Any other activities being carried out are seen to negatively impact on the forest ecosystem

5.4.5 Land Use and Land Cover in the Mt. Londiani Forest 1973

By 1973, the Mau forest complex was mainly under forest and therefore the yellow parches (figure 5.12) generally did not come up as a result of change in land use but were merely open or bare land from the beginning rock out crops although some were settled areas. When the two maps were compared, the observation was that, there was no relationship between land use and land cover type. The areas marked as dense or sparse agriculture were actually under forest except where encroachment and illegal allocations had taken place (see figure 5.12). Lack of land use policy or failure to implement it in the area might have encouraged the invaders of the forest to discriminatively clear even the forests on steep slopes as could be seen in the figures 5.12 and 5.13 below.

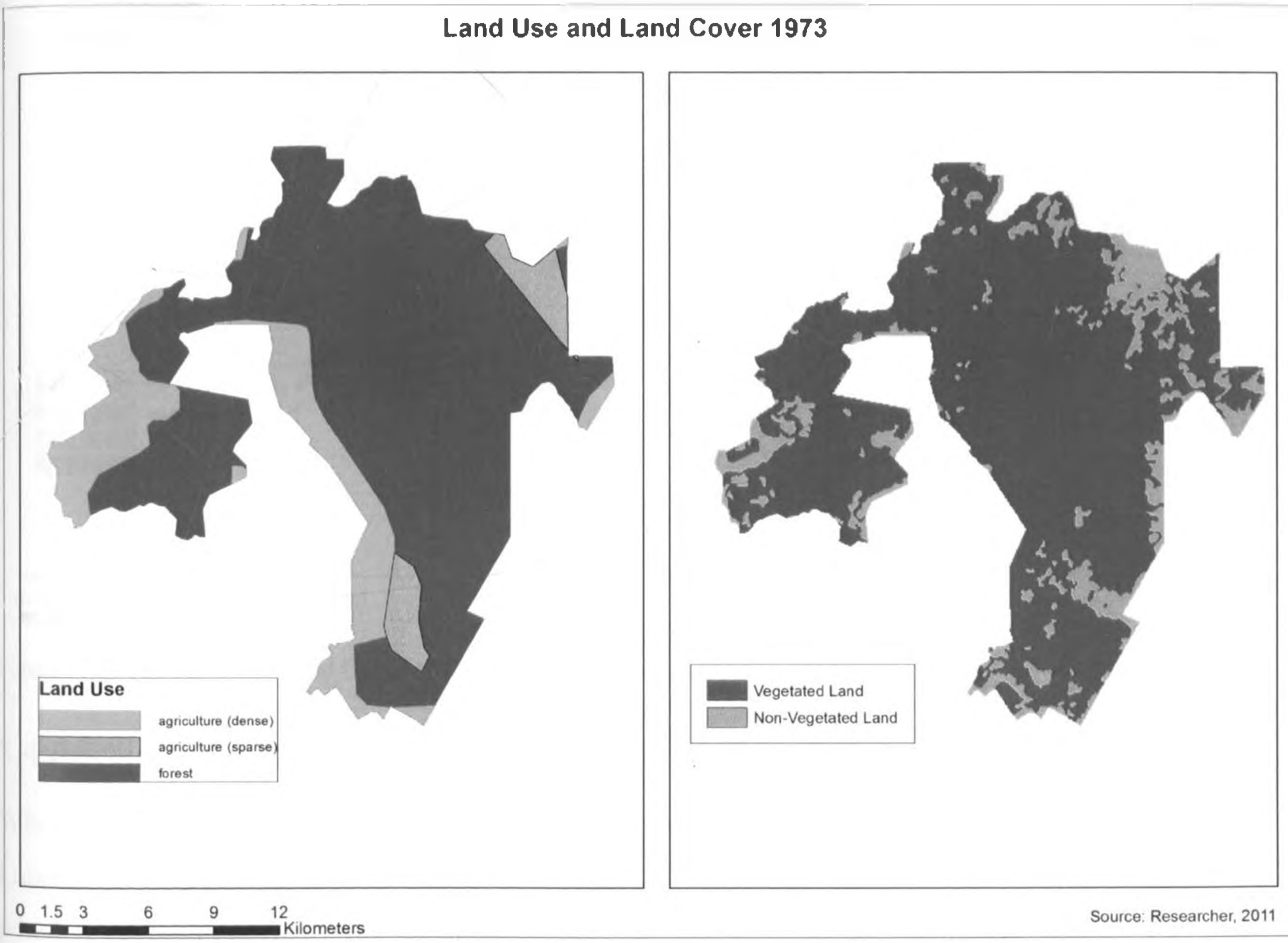


Figure 5.12: Land Use and Land Cover of 1973 of Mt. Londiani Forest

The year 2000 had worst regard for the manner in which land was used in that, more than half of the forest land cleared (figure 5.13) due to the reasons already mentioned.

In summary, Kenya lacked proper land use laws and policies which could give guidance and direction on how to use land. In the absence of such a document, this study came up with these investigations to assess the level of application of land use policies and to provide avenues for its enactment and or implementation where it was not existing and or used. The geo-database developed by this study will enhance the perception and understanding of those involved in forest resource management on how best to make informed decisions.

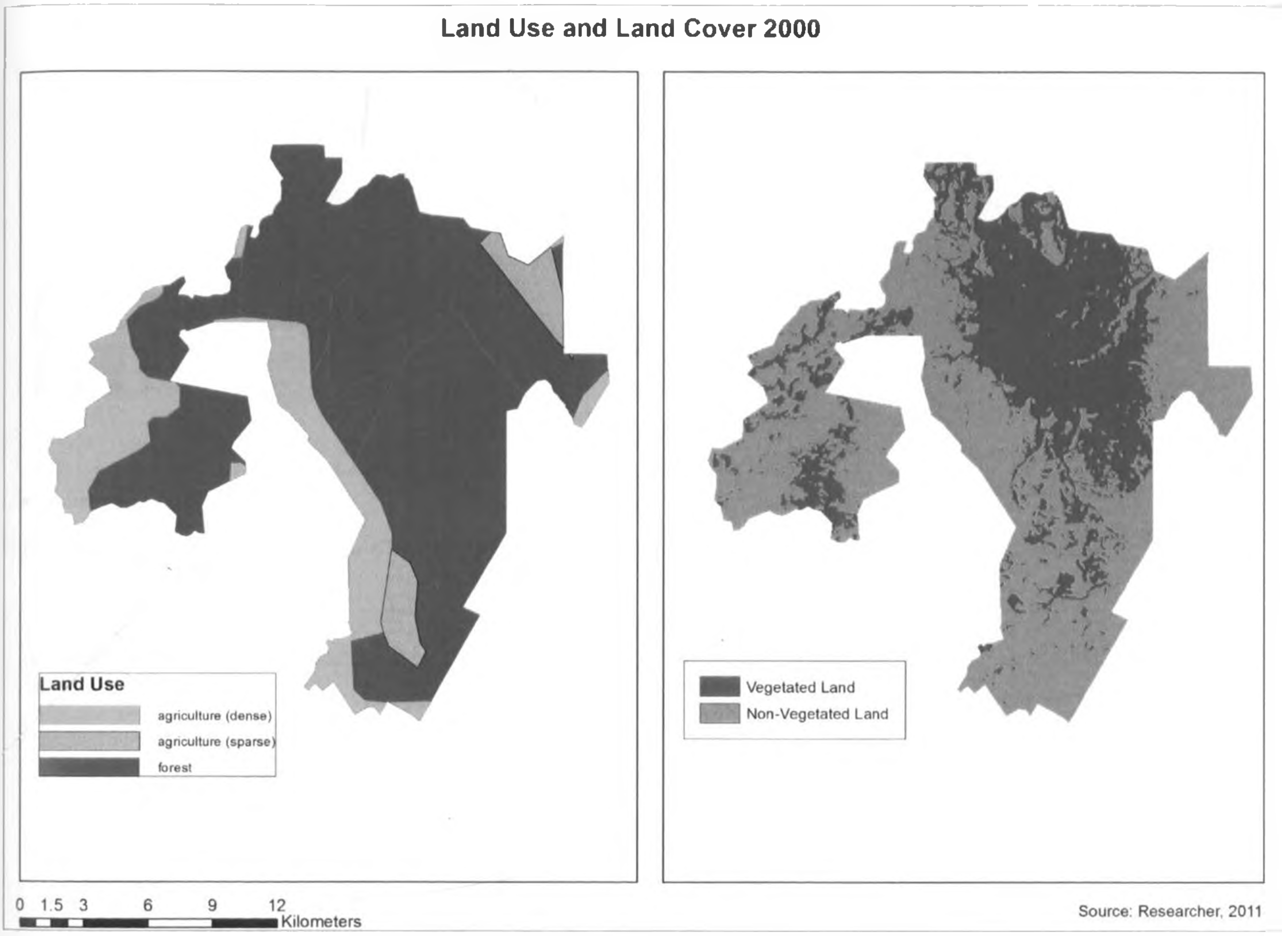


Figure 5.13: Land Use and Land Cover of 2000 of Mt. Londiani Forest

5.4.6 Soils and Land Cover in the Mt. Londiani Forest

When the soils map and land cover maps for 1973 and 2000 were compared, it was clear that Land cover was not based on the soil type but just on space to utilize for non-forest activity, whether agriculture, quarrying or urban settlement. The 1973 cover was intact with all the soil types put under forest. When the 2000 land cover was compared with the soils map, it was apparent that the enormous destruction of forest cover and putting the land under other uses had nothing to do with the soil type. The destruction was almost uniform affecting all types of soils, meaning that, all the soil types had equal chances of being converted into other land uses. Land use policy application, government restrictions and local communities' awareness and participation would make the difference by dictating the manner in which the land would be used.

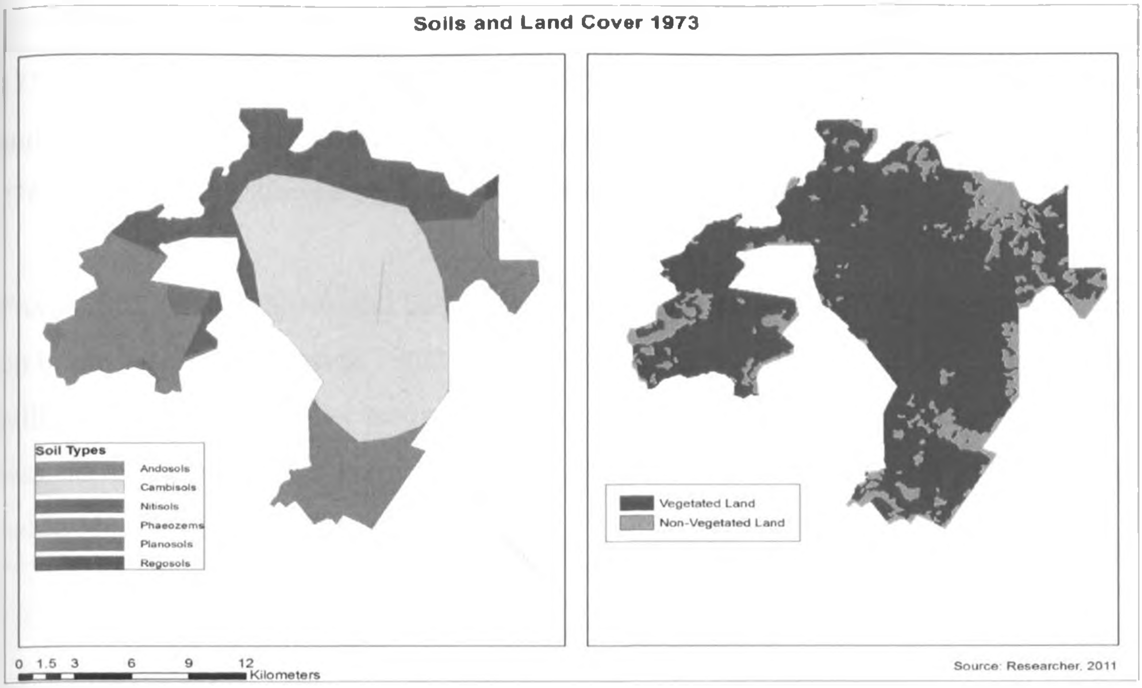


Figure 5.14: Soils and Land Cover of 1973 of Mt. Londiani

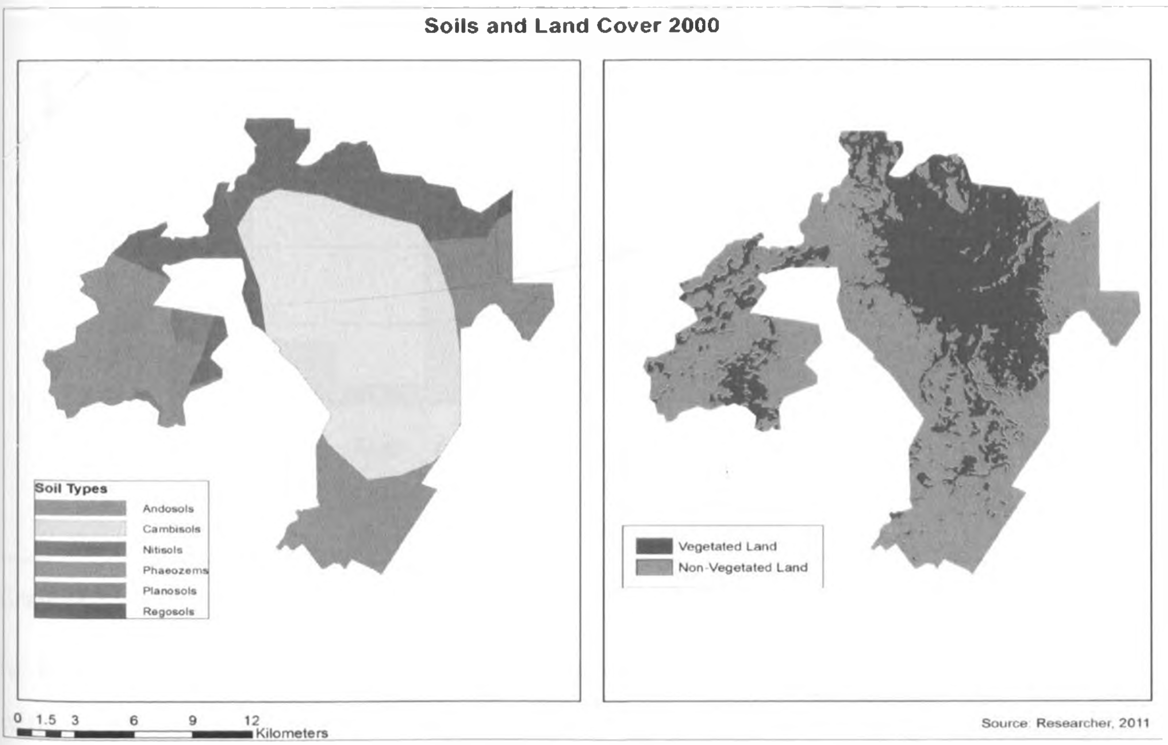
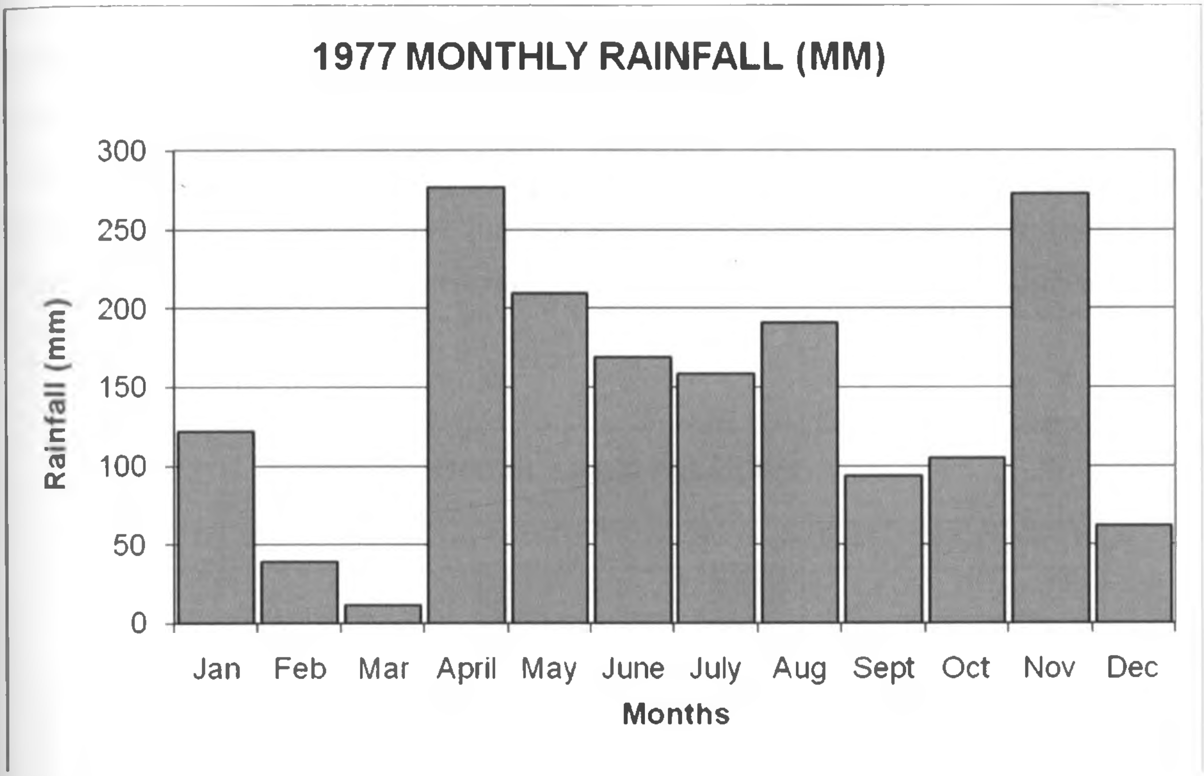


Figure 5.15: Soils and Land Cover of 2000 of Mt. Londiani Forest

5.4.7 Changes in Rainfall Distribution in Mount Londiani Forest area

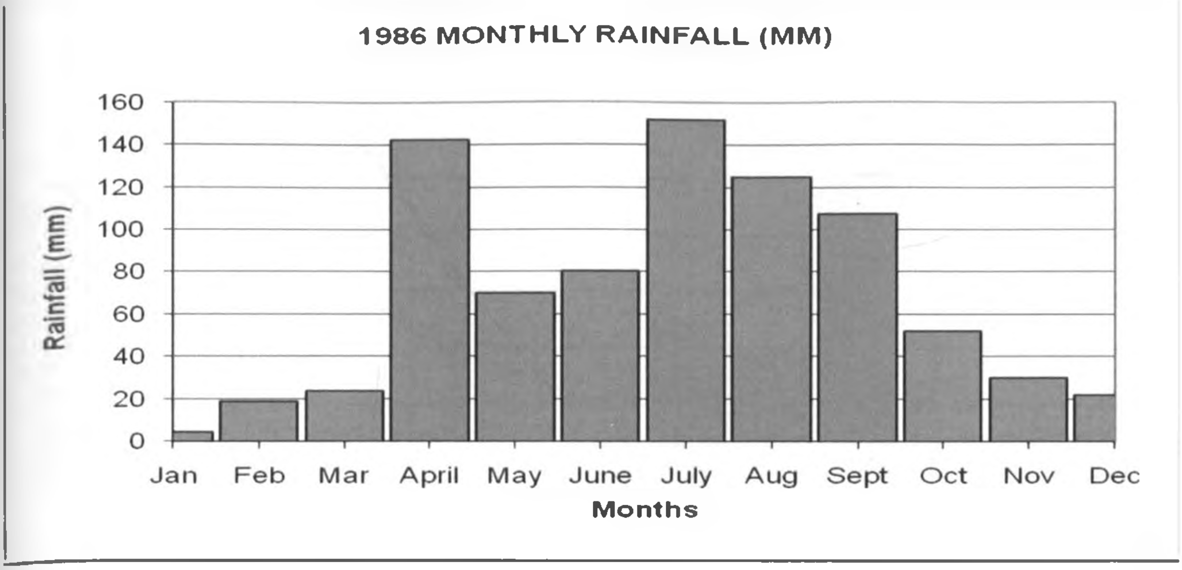
Western and north-western parts of Mau complex where Mount Londiani forest falls receive continental type of rainfall which is influenced by altitude. Generally speaking, the Kipkelion and Londiani Divisions receive low rainfall than other parts of the Mau complex in the western and northern blocks. It was also established that the months from November to March area usually dry months. In 1977 rainfall distribution was such that, January had about 121.7 millimetres of rainfall which drastically reduced to 39 and 11.1 millimetres in February and March respectively. From the miserable amount in March, April recorded the highest of 276.3 millimetres followed by November which had 272.6 millimetres.

From April to July, the rainfall had a downward trend reaching 157.9 millimetres but picking up immediately in August to 190.2 millimetres. September had 93.2 while October had 104.6 millimetres with November having the second highest rainfall recorded that year. December was the third driest after February and March with 61.7 millimetres of rainfall. Graph 5.5 below shows the Monthly rainfall for 1977.



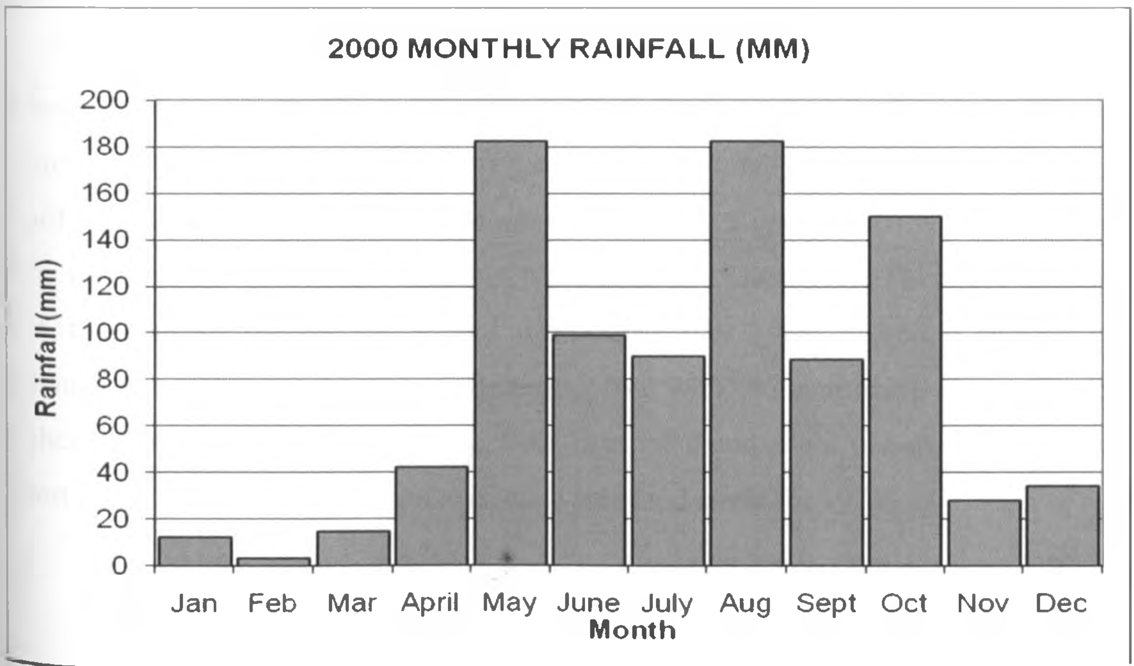
Graph 5.5: Monthly Rainfall for1977 in Mount Londiani Forest (mm)

In 1986, January had the least amount of rainfall of 4.3 millimetres followed by February with 19.1 millimetres while March and December had 24 and 22 millimetres respectively. April, July and August were the months with highest rainfall of 142.4, 151.7 and 125 millimetres respectively with the peak in July. May and June had moderate rainfall of 70.2 and 80.5 millimetres respective while September had quite reasonable amount of 107.2 millimetres which reduced drastically to 52.2 and 30 millimetres in October and November respectively.

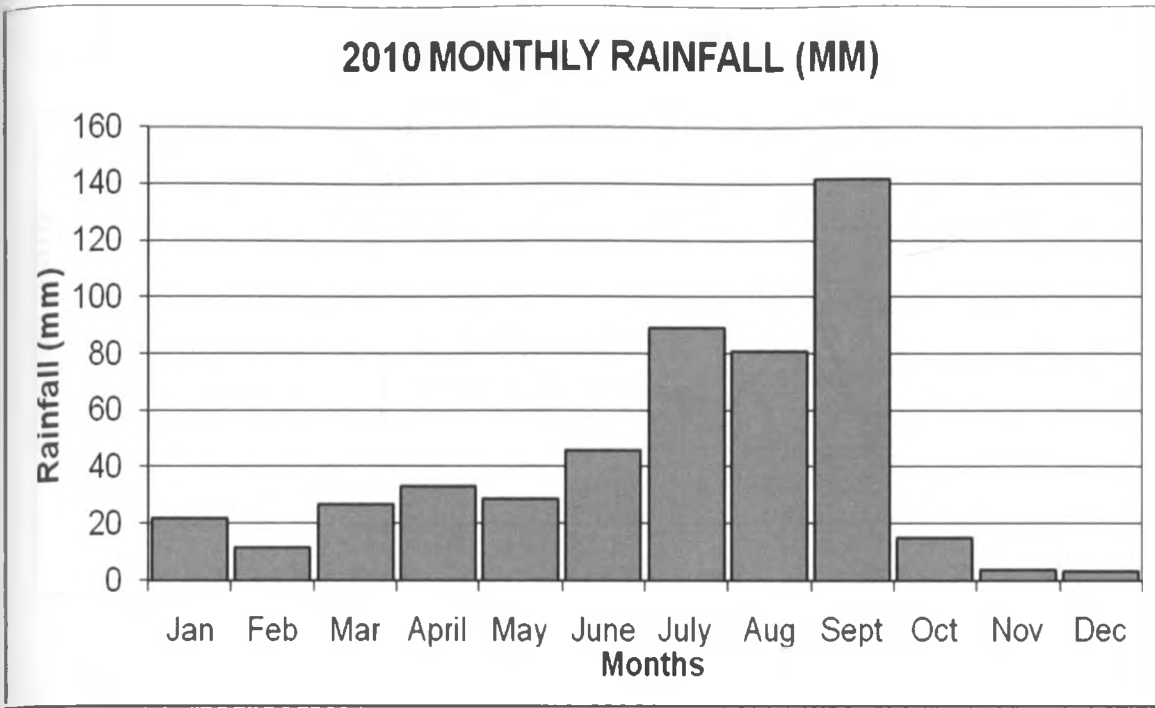


Graph 5.6: Monthly Rainfall for 1986 in Mount Londiani Forest (mm)

The rainfall in 2000 was generally low with only three months having rainfall of 150 millimetres and above. The rest were below 100 millimetres. January to March were quite dry with 12.2, 3.1 and 14.8 millimetres of rainfall respectively. April still had little (42.4) while May was the peak month with 182.6 millimetres followed by August, 182.4 millimetres and November with 150.2 millimetres. June and July had 98.9 and 90.1 millimetres respectively while November and December were fairly dry, 28.11 and 34.2 millimetres respectively.



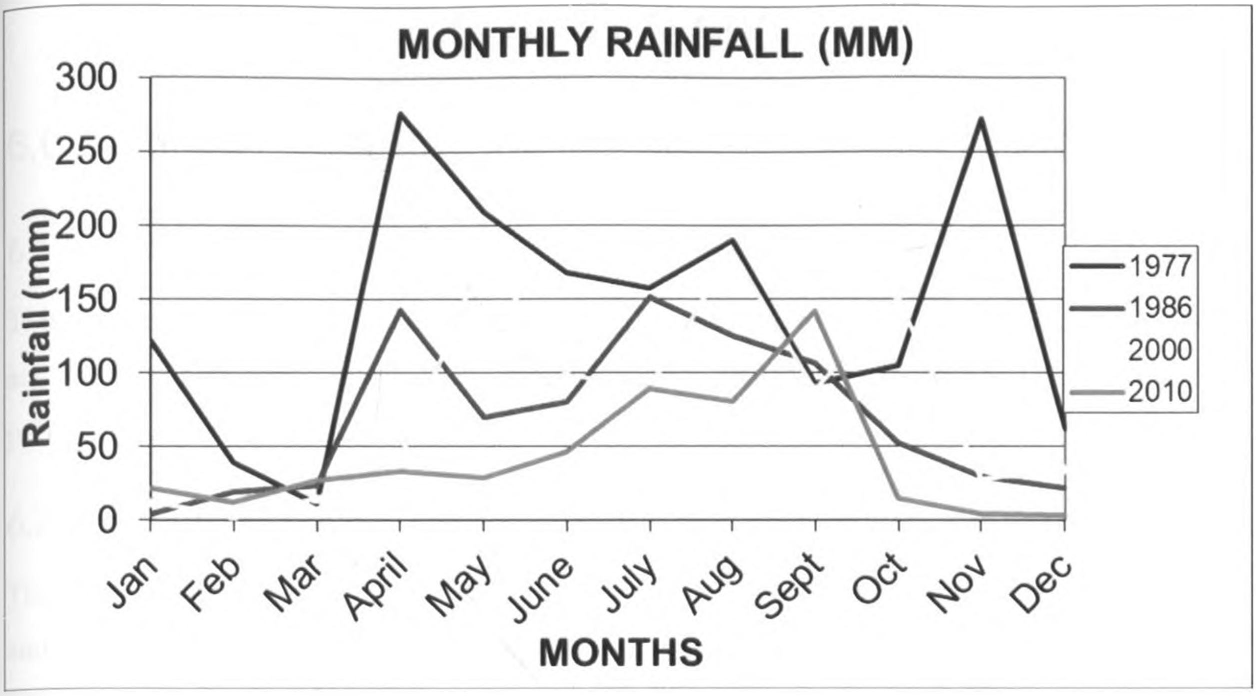
Graph 5.7: Monthly Rainfall for 2000 in Mount Londiani Forest (mm)



Graph 5.8: Monthly Rainfall for 2010 in Mount Londiani Forest (mm)

The year 2010 had the least rainfall which was also poorly distributed throughout the year with all the months receiving below 100 millimetres, except September which received 142 millimetres. November and December were the driest Months with 4 and 3.2 millimetres while February and October had 12 and 15 millimetres respectively. Apart from July, August and September which had 89.2, 80.8 and 142 millimetres, the year was generally dry.

When all the four years were compared (Graph 5.9), the study established that, November to March was usually dry except in 1977 when January and November had a lot of rainfall. April to October were generally cool months except last year (2010) when it was dry up to June followed by even a drier spell in November and December. The study also observed that, the peak of rainfall had shifted from April after 1986 to around May and August although the peak for 2010 was in September (but with 142 mm only). Generally, 1977 had highest amount of rainfall which was well distributed and could in part, be attributed to the forest cover that was still in its original state (see land cover for 1973).



Graph 5.9: Comparison of monthly rainfall for the Years 1977, 1986, 2000 and 2010 (mm).

Between January and March, the rainfall in 2010 were higher than in 2000 while between April and August 2000 rainfall was higher than the same period in 2010. In the Month of September, 2010 had more rainfall than 2000 but come October to December, 2000 had more rainfall than 2010. The fact that 2000 had more rainfall than 2010 despite less forest cover means that other factors other than forest cover do influence rainfall in the Mau in general and Mt. Londiani in particular. This variance could be explained mainly by the influence of the Congo air masses and Lake Victoria basin.

In summary, the rainfall totals and distribution reduced and fluctuated over the study period and the reduction was not necessarily the result of forest degradation, although the study believes that, forest reduction played a role in rainfall variations since its ability to carbon sink, modify microclimate and to provide aesthetic services is reduced resulting in generally warmer atmosphere and degraded environment not favouring moist conditions..

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter started with a summary of the research findings based on the research objectives and working hypothesis followed by conclusions and ended with recommendations to both policy makers and to the scholars for future research.

6.2 Summary of Findings

The following are the summary of research findings obtained from the analyses of land cover and land use change in the Mau forest complex and the integrated analyses in the mount Londiani forest:

1. Land Cover and Land Use Changes have occurred in the Mau forest complex over time both within and at the edge of the forests and were attributed mainly to increase in human population. The changes in land use and land cover resulted in the general degradation of the forest complex.

2. The three cover classes used were forest land, other vegetation and non-vegetated land. The following facts were detected from the classes:

i) Between 1973 and 1986, forest cover decreased by 4.2%, area under other vegetation reduced by 1.86% while area under non-vegetation had an increase of 7.00%. The losses in forest cover and other vegetation was a gain to the area under non- vegetation.

ii) Between 1986 and 2000, area under forest cover increased by 1.2% while area under other vegetation reduced by 6.00% and area under non-vegetation increased by 7.2%. That is, forest land was not interfered with this period and regenerated while other vegetation converted to non-vegetation.

iii) Between 2000 and 2010, forest cover decreased by 8.7% although areas under other vegetation and non-vegetated land changed positively during this period. That is, area under other vegetation increased by 20.4% while area under non-vegetation for the first time decreased by 12.3%. The forest cover degenerated due to excision of Maasai Mau in 2001 to settle the landless and land grabbing by powerful personalities in the government of the day. The increase in other vegetation and decrease in the area under non-vegetation came about as a result of evictions from the forest and tree planting exercise during this period. Thus, much of non-vegetated land and a bit of forest land converted to other vegetation.

iv) The annual rates of change in the three cover classes were not uniform but kept on changing in all the three periods under study. Secondly, the changes were both negative and positive, although the changes that impacted negatively to the forest cover and the environment were more than those that impacted positively.

v) The highest annual rate of change (reduction hence negative) in forest cover was during the period 2000 -2010 (i.e. 3604.4ha.) despite evictions and tree planting exercise that happened during this period. This could be explained by the fact that, most of the trees planted were captured under other vegetation and not forest land.

vi) The period between 2000 and 2010 brought most positive benefits to the Mau forest complex and its environment than the other periods despite the reduction in forest cover. This is because the area under other vegetation had the highest annual rate (increase hence positive) of change. In fact this is the only period this class had a positive change, meaning that, the journey to recovering the former closed forest canopy of Mau forest complex if walked well, could succeed.

vii) Decrease in forest cover over time was accompanied by degradation in the plant health as was revealed in the NDVI analysis results.

viii) The rate at which forest land was converting to other vegetation and non-vegetated land was higher than the rate at which the two were converting to forest land. That kind of scenario was disastrous and needed to be changed.

3. From the integrated analysis in Mount Londiani forest, it was found out that:

i) Population densities of the sub-locations had increased over the study period (1973-2010) and that, there was some relationship between increase in population densities and reductions in forest cover over time.

ii) The increase in population densities has had negative impacts on the forest cover in the Mau forest complex as the locals tended to depend on forest products for their well-being including farming, extracting building materials, wood fuel, and charcoal burning among others, as could be seen from the accompanied photographs. More forest degradation came as a result of increase in population densities, legal land excision as well as illegal land allocations by the past regimes.

iii) This study established that both gentle and steep slopes were cleared of their vegetation as land use changed both in the Mt. Londiani forest and the entire Mau forest complex.

iv) When the soils in the Mount Londiani forest were compared with the changes in land cover and land use, it was found out that, there was no relationship between land cover and soils or land use and soils since the soils were almost of the same fertility in the entire area.

v) The rainfall totals and distribution had changed (reduced) over time and this reduction was not necessarily the result of deforestation but was influenced by other factors like the Congo Air masses, the Lake Victoria Basin, the Inter-Tropical Convergence Zone and the altitude.

4. The factors identified as responsible for the changes in land cover and land use in the Mau forest complex included the following:

i) Agriculture
ii) Logging to get timber for the timber industries within and around Mau complex.
iii) Settlement especially for small urban centres that were coming up with the establishment of the timber industries.
iv) Extraction of building materials by the local populace.
v) Excision of forest land by the government to settle the landless.
vi) Illegal land allocations to and by the persons within the corridors of power.
vii) Grazing
viii) Fuel wood and Charcoal burning

5. The Land Cover and Land Use Changes in the Mau forest complex resulted in the following environmental impacts:-

1. Interference with the biodiversity (flora and fauna) in the forest. Some species were phased out while some became endangered species.
2. The general ecological importance of the Mau forest complex was eroded or tampered with.

3. The ability to carbon sink and to act as micro-climate modifier was reduced due to reduction in forest cover and in the chlorophyll content. Thus more carbon dioxide remained in the atmosphere.
4. Its ability to serve as water catchments was affected resulting in reduction in rainfall totals and distribution which in the end resulted in reduction in river channel flows for almost all the rivers flowing from the complex. Some rivers became seasonal while some dried up completely.
5. Steep slopes got exposed through clearing of the forest and this posed a lot of environmental risks. Exposed slopes were prone to mass wasting, landslides, rock fall, etc. Thus, biodiversity including man was exposed to environmental disasters should such events occur.
6. The changes in land cover in the Mau forest complex have indirectly affected the wildlife in the conservation areas that depended on the Mau ecosystem.

In summary, the findings of this study were in line with under mentioned working hypothesis earlier formulated to guide the study: ***"Land Cover and Land Use Changes are not due to human activities"***.

6.3 Conclusion

This study established that, Mau forest complex had undergone a lot of changes in its land cover and land use over time due to different anthropogenic factors. These changes resulted in the reduction of the forest cover plus reduction in the health status of the trees in all the 22 blocks and this resulted in various environmental impacts.

The research answered the following stipulated research questions:

1. What is the present status of Mau forest complex?
2. What are the Land Cover and Land Use Changes that have occurred over time?
3. What are the human activities that have contributed to the forest cover changes in the Mau forest complex?
4. What are the environmental impacts of the land cover change in the Mau forest complex?

From the answers to the above questions, the study concluded that:

The forest cover change occurred sporadically in all the 22 blocks with some losing their covers more than the others. This could probably be explained by the fact that the people came from different sources and with different motives to impact on the forests. The local communities approach from their local areas to get their basic needs. Illegal allocations targeted various blocks while legal excisions were specific to particular blocks.

Conversion of forest land to agricultural land involving both small scale and large scale farming plus settlement were the main cause of deforestation in the Mau. These to say the least, were the reasons why various parts of the forests, mainly the Eastern Mau, South West Mau, Southern Mau and the Northern blocks were cleared.

Another conclusion by this study is that the rates at which the three cover classes used in this study were converting to each other were not uniform. The rate at which forest land was converting to non-forest land or to other vegetation cover was higher than the rate at which either of the two was converting to forest cover. This generally means that, forest cover was giving way to other non-forest uses and if this trend was left unchecked, the forest ecosystem (Mau) would be under a big threat of extinction and would disappear with all its environmental, ecological and economic importance.

The study went ahead to conclude that, the first cause of deforestation was logging to supply timber to the timber industries that were set up just after attaining self-governance. This was one way the self-attained government was to raise funds for self-sustenance and to supply the basic requirements to her citizens (forest being one of the main natural resources Kenya was gifted in alongside agriculture and tourism). Forest was also being cleared for urban settlement to house the timber industries and the labour force working in these factories.

The factors that caused change in Land Cover and Land Use such as increase in population caused different environmental impacts as indicated by the analysis of the satellite imageries and field survey data especially photographs taken during field visits. Thus increase in population created pressure on the forest land which ended up being cleared for various human needs. This reduction in forest cover reduced services of trees as carbon sinks meaning that, more carbon dioxide stay in the atmosphere thereby increasing atmospheric warming which contributes to the global warming.

The reduction in forest cover has also impacted on the issues of micro-climate modification. Forest is a micro-climate modifier due to the fact that breezes, rains and temperatures are all modified by forests especially on mountainous environments such as the Mau. The cool temperatures and cool moist winds form rains in such environments which are then transferred to other regions. Also, when it rains in these regions, the water flows in the river systems and over large areas influencing micro-climates in such places. With reduction in forest cover, this service ceases or is reduced, resulting in high temperatures with dry conditions.

The reduction in rainfall over time which was observed could be as a result of reduction in forest cover. The aftermaths of the reduction in rainfall amounts and distribution is already being felt beyond the Mau ecosystem as some rivers from the Mau complex have dried up and only flow during wet seasons especially during the long rains. Downstream projects such as the Sondu-Miriu Hydropower project that require water from the Mau could be in problems and the intended vision may not be achieved in the end should this situation continue.

Clearing the forest land for agriculture made the soils to generally be degraded and poor in nutrients rendering them less productive and if such activities were allowed to continue, then the Mau region wouldn't be able to support any meaningful agriculture.

The use of fertilizers, fungicides, pesticides and herbicides in the farms may have led to pollution both of surface and underground water causing health complications to both flora and fauna in the study area and beyond since it supports regions beyond its coverage in many aspects.

The study concluded that, lack of land use policy and or its implementation in Kenya was the result of converting forest land to non-forest uses and farming on very steep slopes. Forest Act 2005 is still at its infancy and much needed to be done.

In conclusion, this study achieved its objectives which were:

i) To determine the present status of land cover and land use of the Mau forest complex.
ii) To investigate land cover and land use changes in the Mau complex over time.
iii) To analyse the factors that have contributed to the land cover changes in the Mau.

iv) To analyse the environmental impacts of the land cover and land use changes in the Mau forest complex.

6.4 Recommendations

This study found out that the Land Cover and Land Use Change dynamics in the Mau have been very rapid and without any control whatsoever. This has resulted in a number of environmental impacts that, if not checked and controlled, may reach irreversible state.

6.4.1 Recommendation to Policy Makers

1. Conservation efforts in the Mau have yielded positive results and therefore should be continued.

2. The Government should enact laws policies and regulations on Land Use and forest resource management which should incorporate all stakeholders with clear-cut jurisdictions of enforcement and implementation by the various agencies.

3. The Government should also develop a good and vibrant geo-database of the Mau forest complex to enhance decision making on conservation.

6.4.2 Recommendations to Researchers

1. Further research should be done on the impacts of land cover and land use changes in the Mau on the livelihoods of the people within the regions hinterland to the Mau Ecosystem.
2. Further studies should be done on the impacts of deforestation of the Mau forest complex on downstream projects, such as the Sondu-Miriu Hydropower Project.
3. Further research should be done on the impacts of riverine degradation in the Mau forest complex on the river discharge and sedimentation.
4. Studies should be carried out on the impacts of land cover and land use changes on the conservation areas depending on the Mau forest complex.

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APPENDICES

APPENDIX 1: Landsat false colour composite imageries of Mau forest complex

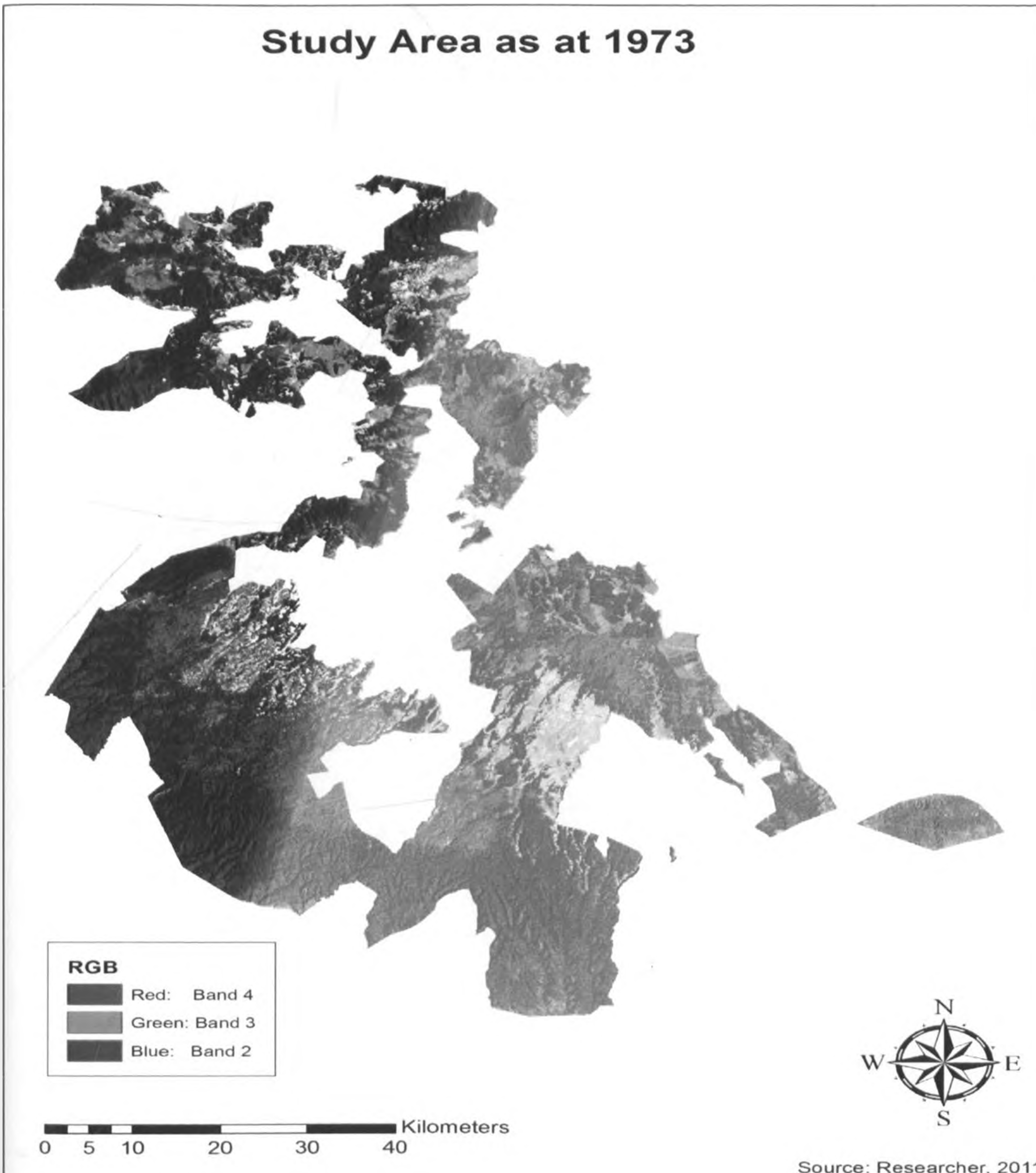

Figure 6.1a: NIR false colour composite of bands 4, 3 and 2 for the study area as at 1973

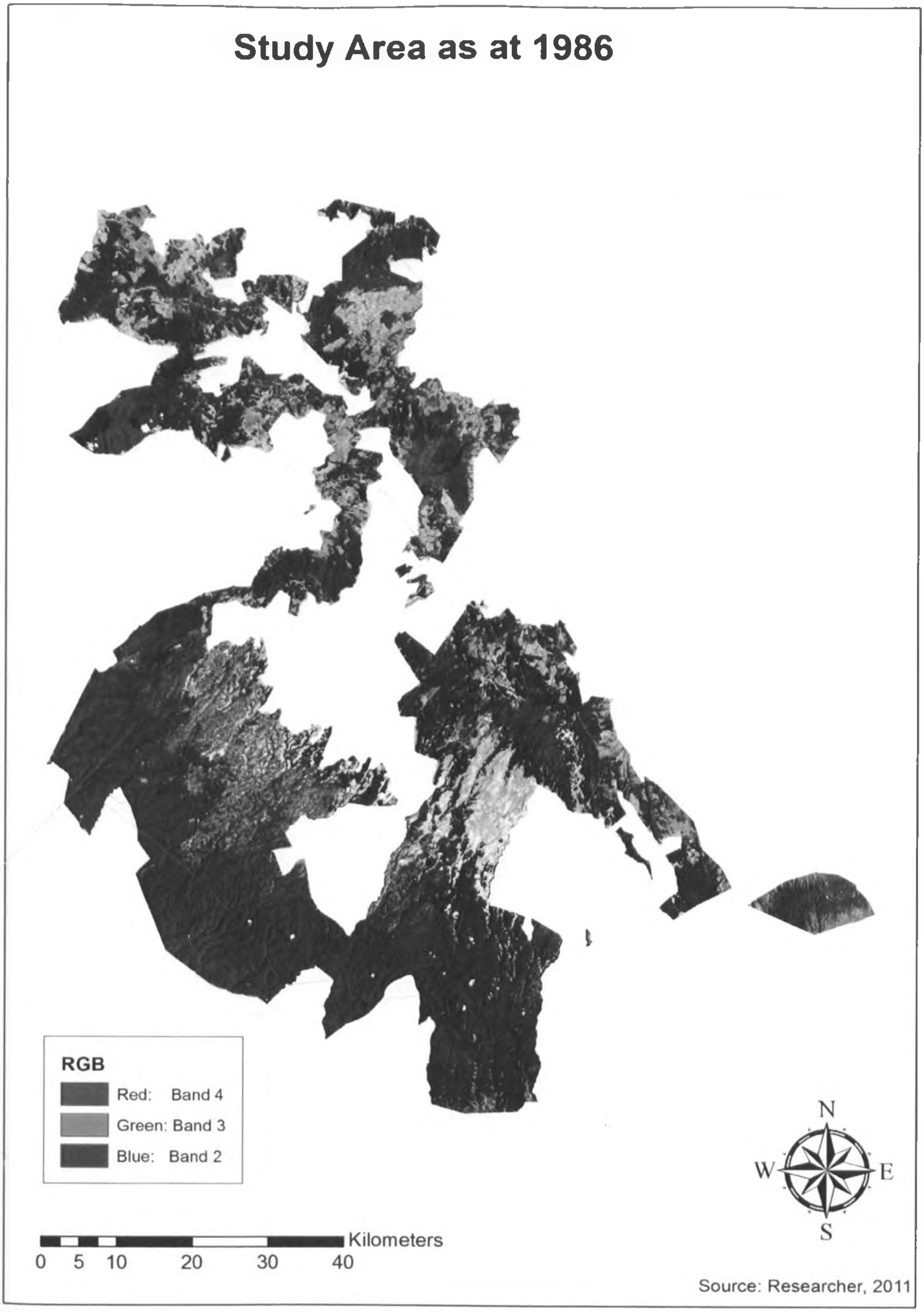

Figure 6.1b: NIR false colour composite of bands 4, 3 and 2 for the study area as at 1986

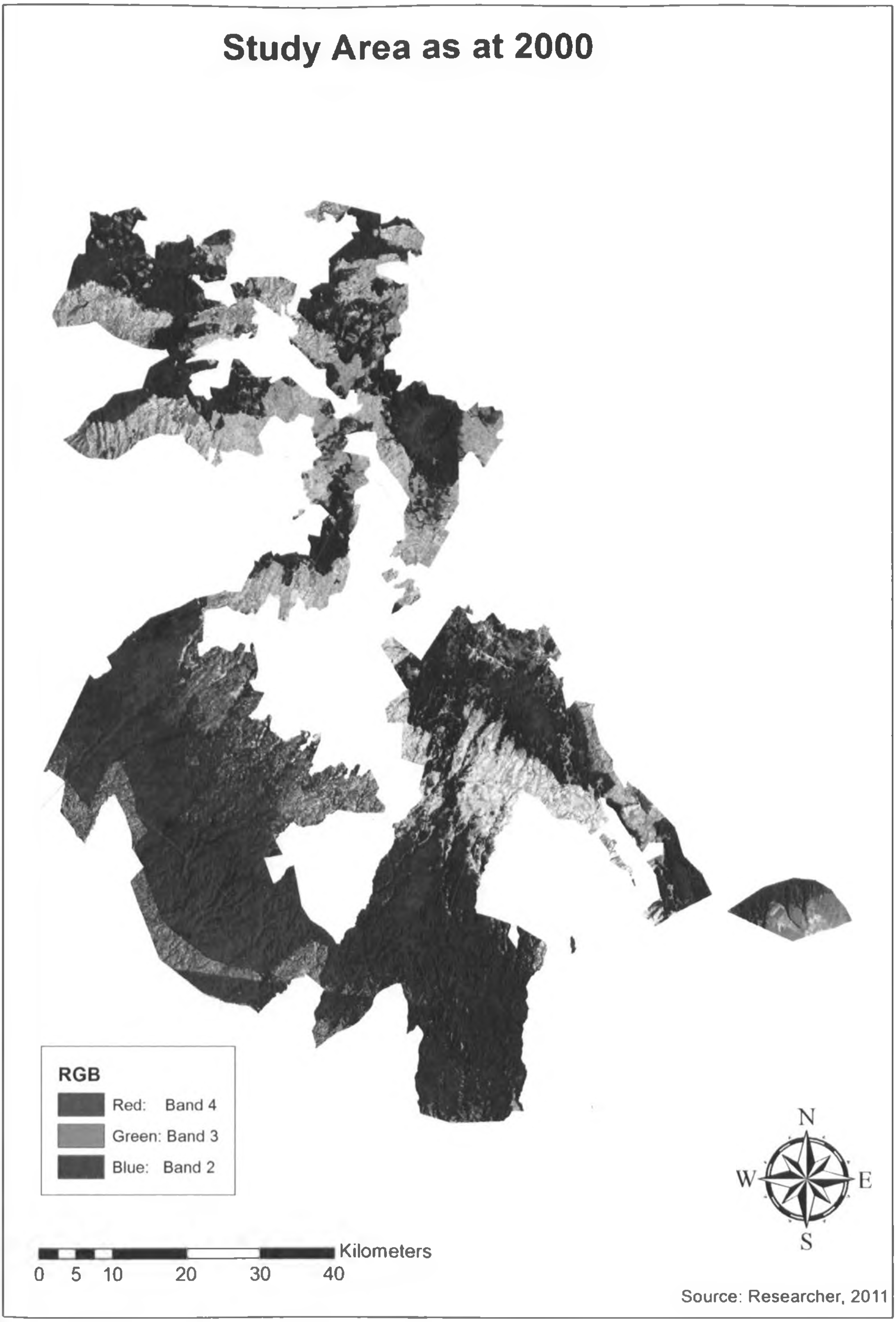

Figure 6.1c: NIR false colour composite of bands 4, 3 and 2 for the study area as at 2000

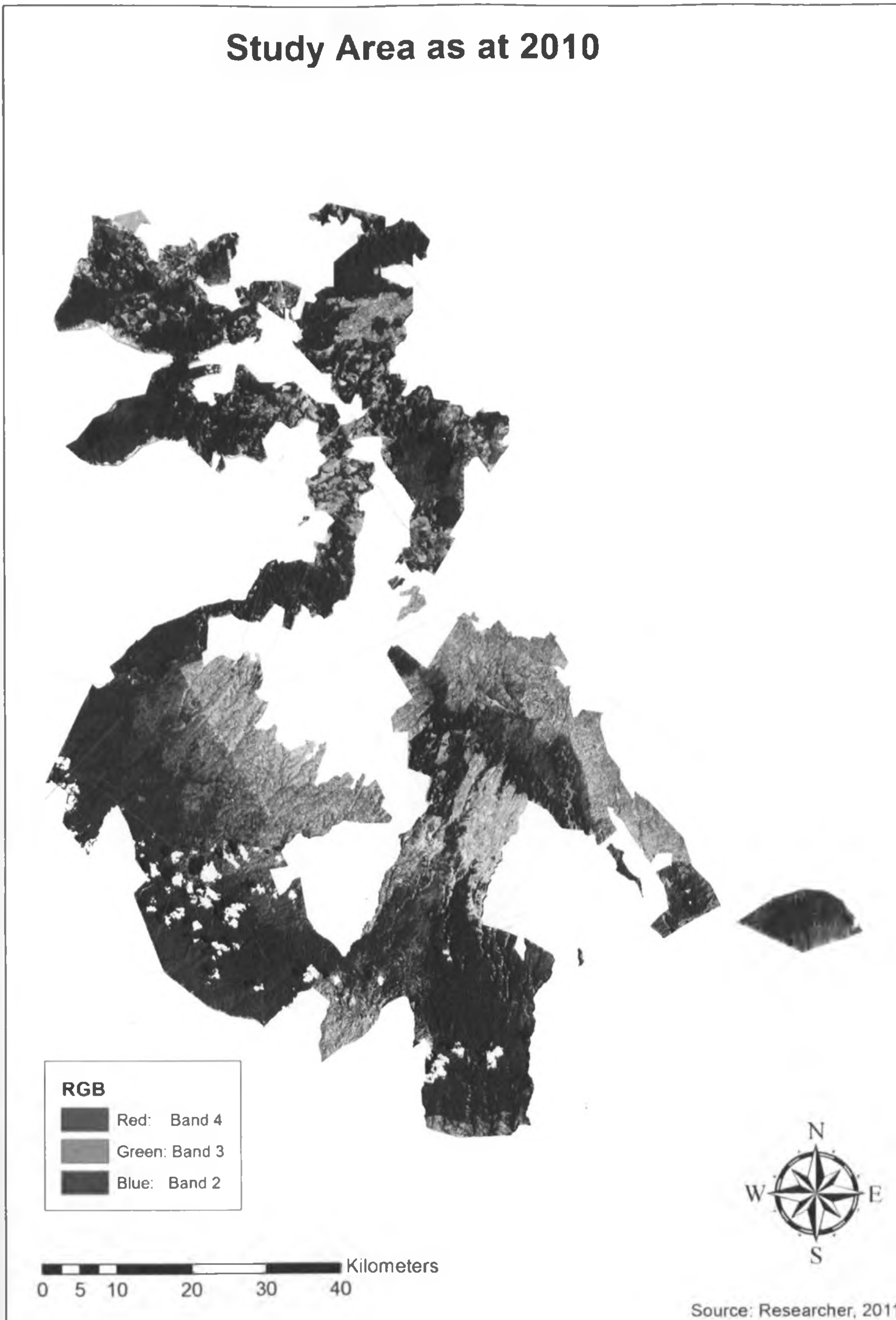

Figure 6.1d: NIR false colour composite of bands 4, 3 and 2 for the study area as at 2010

APPENDIX 2: The Normalized Difference Vegetation Index (NDVI) Analysis

This was another instrument used in the analysis of variations in plant health in terms of the amount of chlorophyll content present in the plants. The more the chlorophyll, the more the green vegetation present in the pixel. The standard algorithm was used for calculations giving valid results that fall between -1 and +1 of density slices. But for the purposes of this study, the values from 0.25 to 1.00 density slices were used since this is the range within which vegetation fall. Values below 0.25 of density slices are for non-vegetated areas and therefore were not included in the results and discussions in Chapter 5).

(a) NDVI for 1986 - the brighter pixels show more vegetation while the darker pixels have less vegetation. Darker pixels have less chlorophyll and therefore less vegetation.

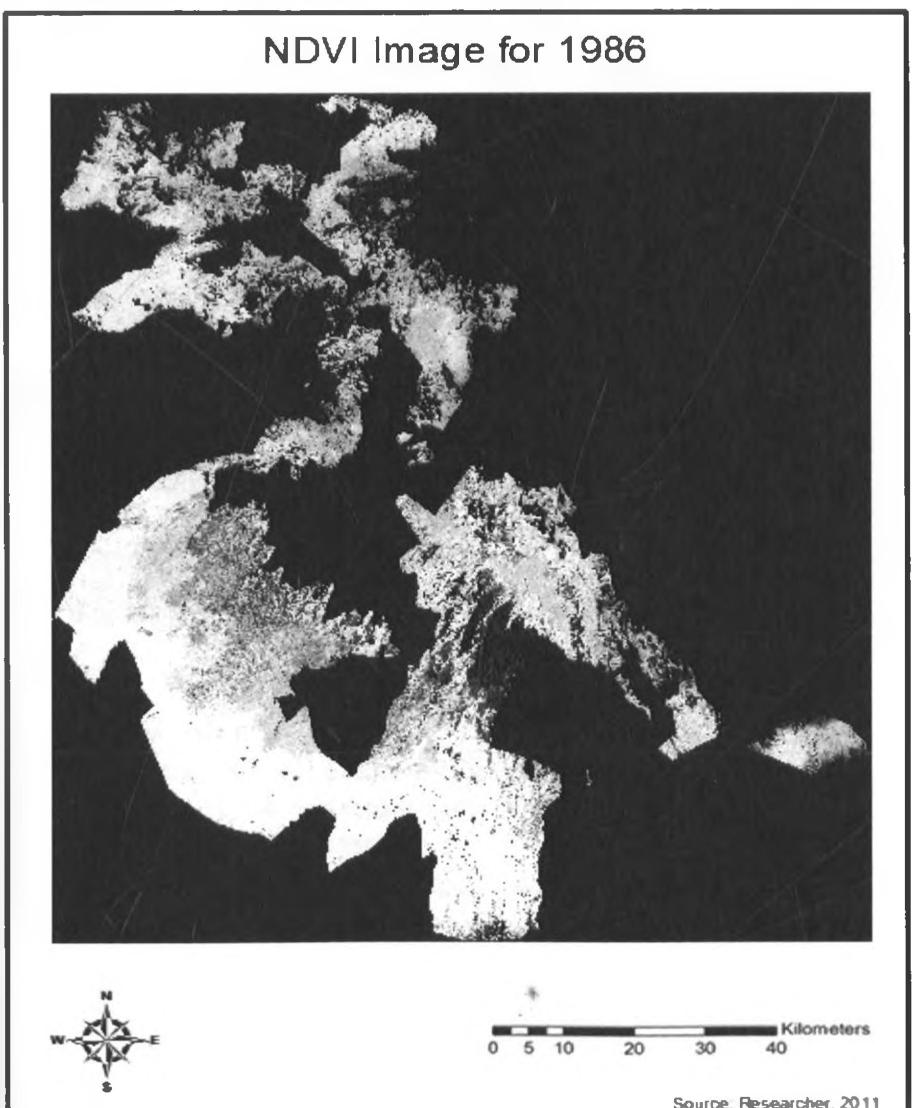

Figure 6.2a: NDVI for 1986, grey scale.

This has been represented by colours using density slices as shown in figure 6.2b below:

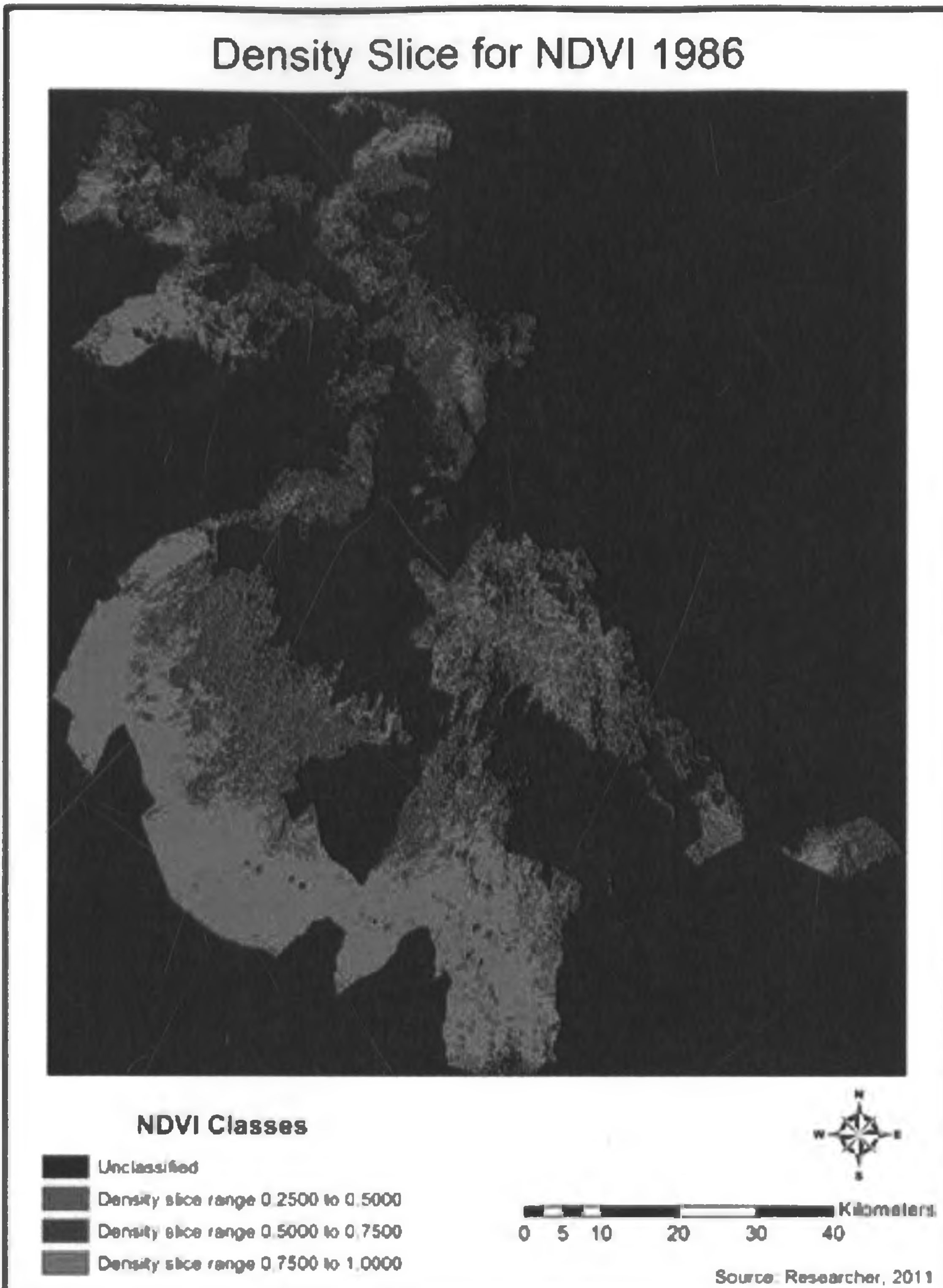

Figure 6.2b: Density Slices for NDVI – 1986 Image

Table 6.1: NDVI Classification, 1986

Density Slice Range	Total	Percentage	Accumulated Percentage
Unclassified	12503.48	74.06	74.05
0.2500 to 0.5000 [Magenta]	13057.30	3.28	77.34
0.5000 to 0.7500 [Maroon]	14386.23	7.87	85.21
0.7500 to 1.000 [Sea Green]	16882.79	14.79	100

The results show that 14.79% which represents 16882.79 km^2 was occupied by closed canopy forest with NDVI range of between 0. 75 and 1.00 followed by 7.8715%, representing 14386.23km^2 of relatively dense vegetation of NDVI range of between 0.50 and 0.75. The last category, 3.28%, represented 13057.30m^2 of open vegetation of NDVI range of between 0.25 and 0.50. The regions with dense slices below 0.25 represented no vegetation and therefore were not included in the NDVI values used.

(b) NDVI for 2000 (grey scale).

Figure 6. 3a: NDVI for 2000, grey scale.

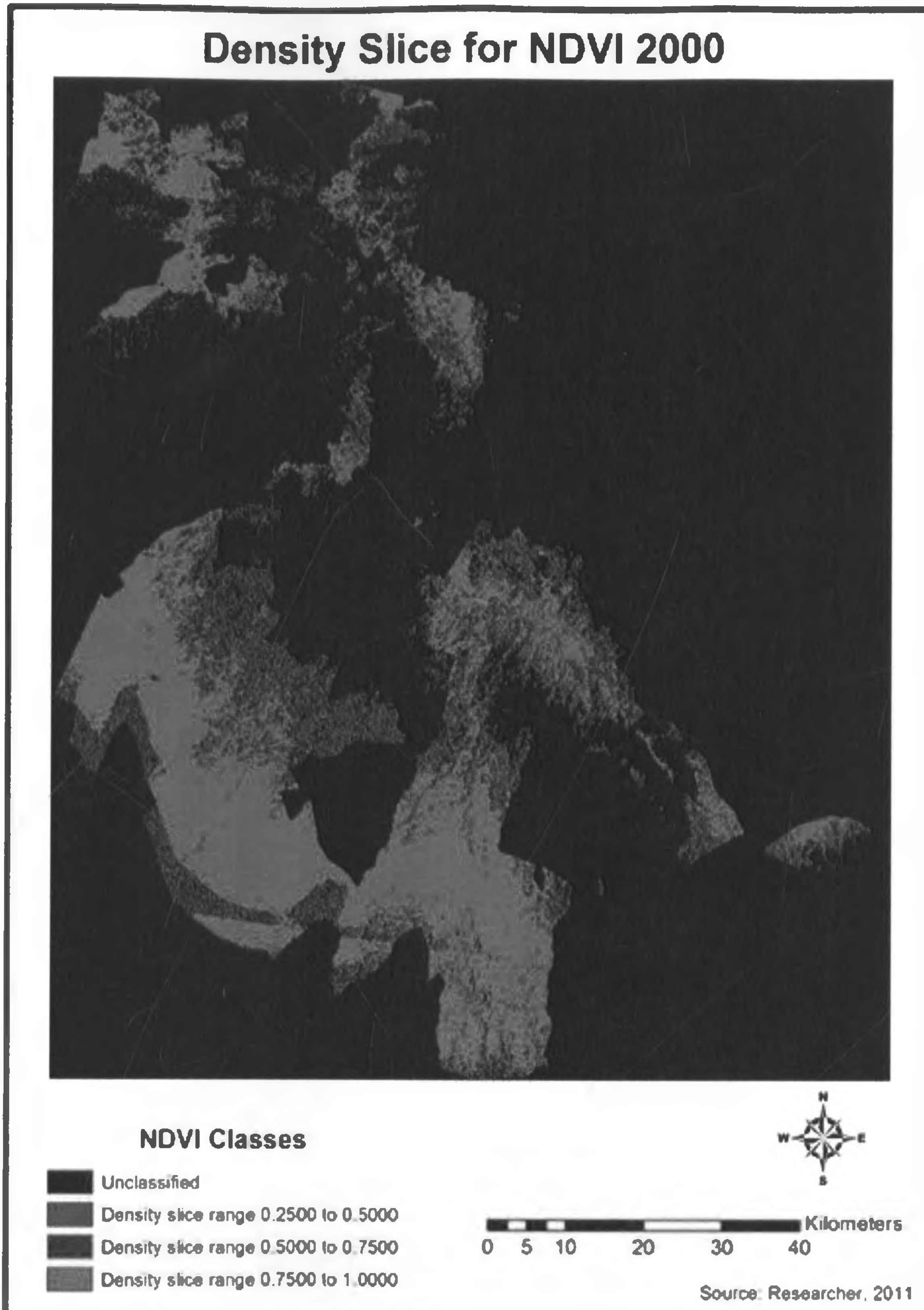

Figure 6.3b: Density Slices for NDVI – 2000 Image

Table 6.2: NDVI Classification, 2000

Density Slice Range	Total	Percentage	Accumulated Percentage
Unclassified	12896.48	76.39	76.39
0.2500 to 0.5000 [Magenta]	13512.45	3.65	80.04
0.5000 to 0.7500 [Maroon]	14269.90	4.49	84.52
0.7500 to 1.000 [Sea Green]	16882.79	15.48	100

The table shows that 15.48%, representing 16882.79 km^2 was occupied by dense vegetation (closed canopy) of NDVI range of 0.75 to 1.00. This was followed by 4.49%, of less dense forest representing 14269.90 km^2 of NDVI range of 0.50 to 0.75, then 3.65% - representing 13512.45km^2 of NDVI range of 0.2500 to 0.50. This is the area of sparse vegetation.

(c) NDVI for 2010 (grey scale).

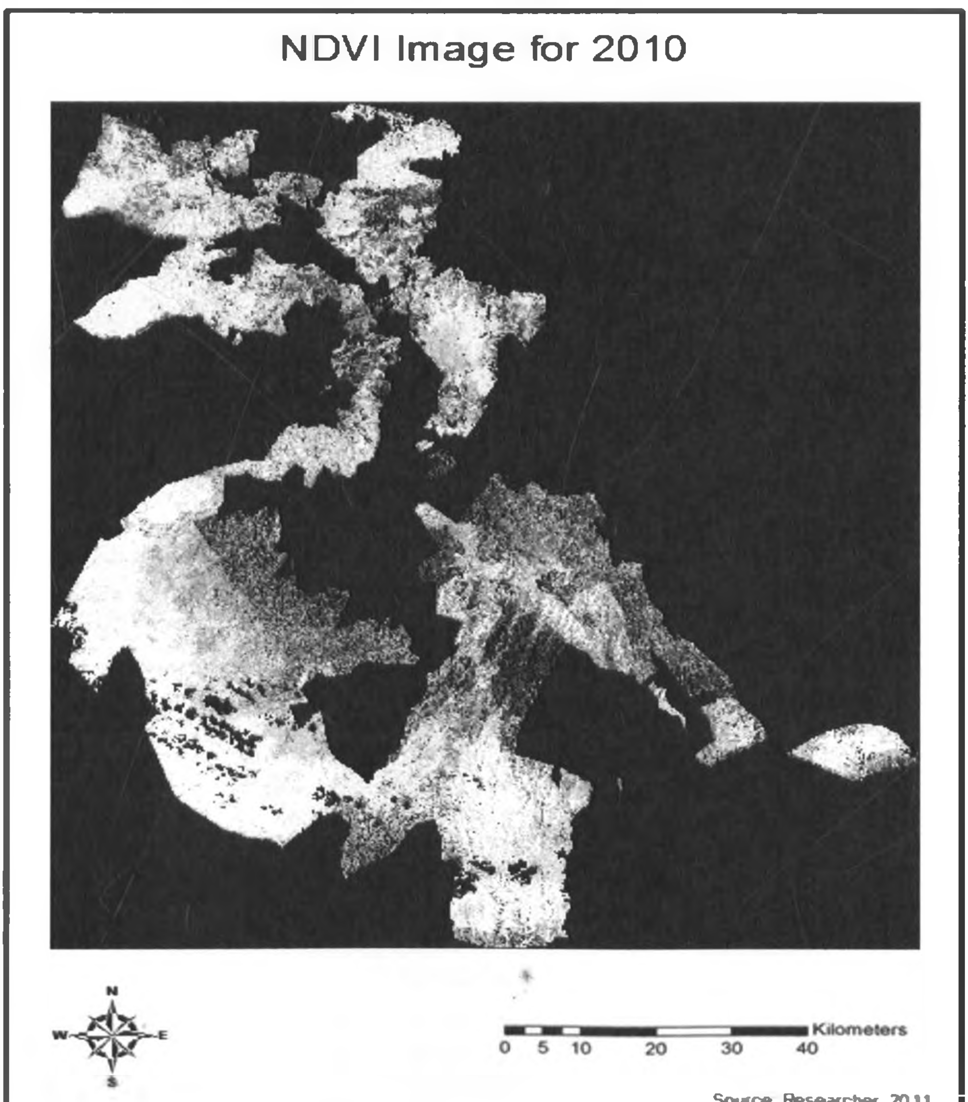

Figure 6.4a: NDVI for 2010, grey scale.

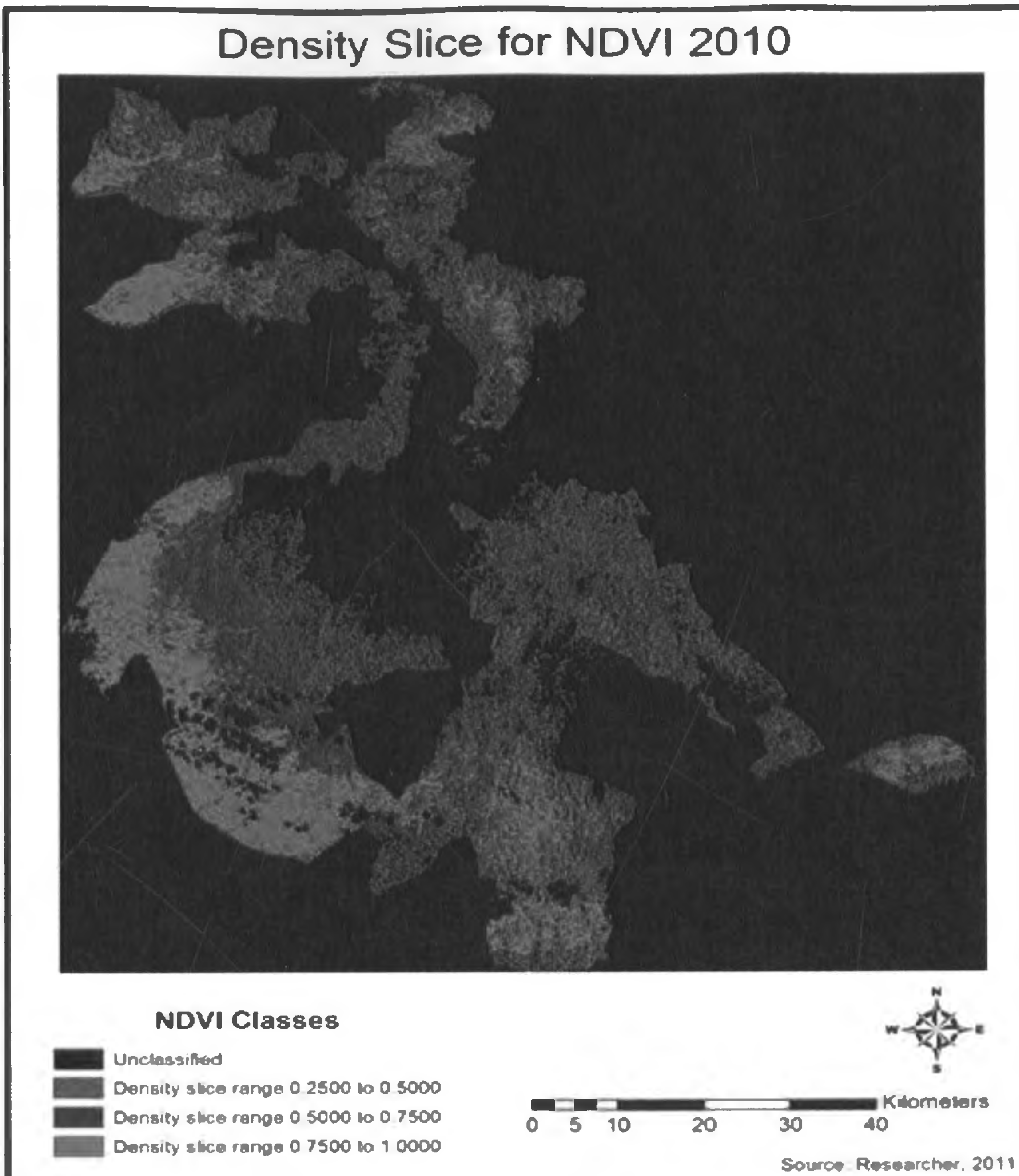

Figure 6.4b: Density Slices for NDVI – 2010 Image

Table 6.3: NDVI classification, 2010

Density Slice Range	Total	Percentage	Accumulated Percentage
Unclassified	11162.26	73.25	73.24
0.2500 to 0.5000 [Magenta]	12120.03	6.28	79.53
0.5000 to 0.7500 [Maroon]	13765.82	10.80	90.33
0.7500 to 1.000 [Sea Green]	15239.74	9.67	100

The results show that 9.67%, representing 15239.74 km^2 was occupied by dense vegetation (closed canopy) of NDVI range of 0.75 to 1.00; this was followed by 10.80%, representing 13765.82 km^2 of reasonably dense forest with NDVI range of 0.50 to 0.75, then 6.28%, representing 12120.03 km^2 of open vegetation of NDVI range of 0.25 to 0.50

APPENDIX 3: Soils of Mount Londiani Forest

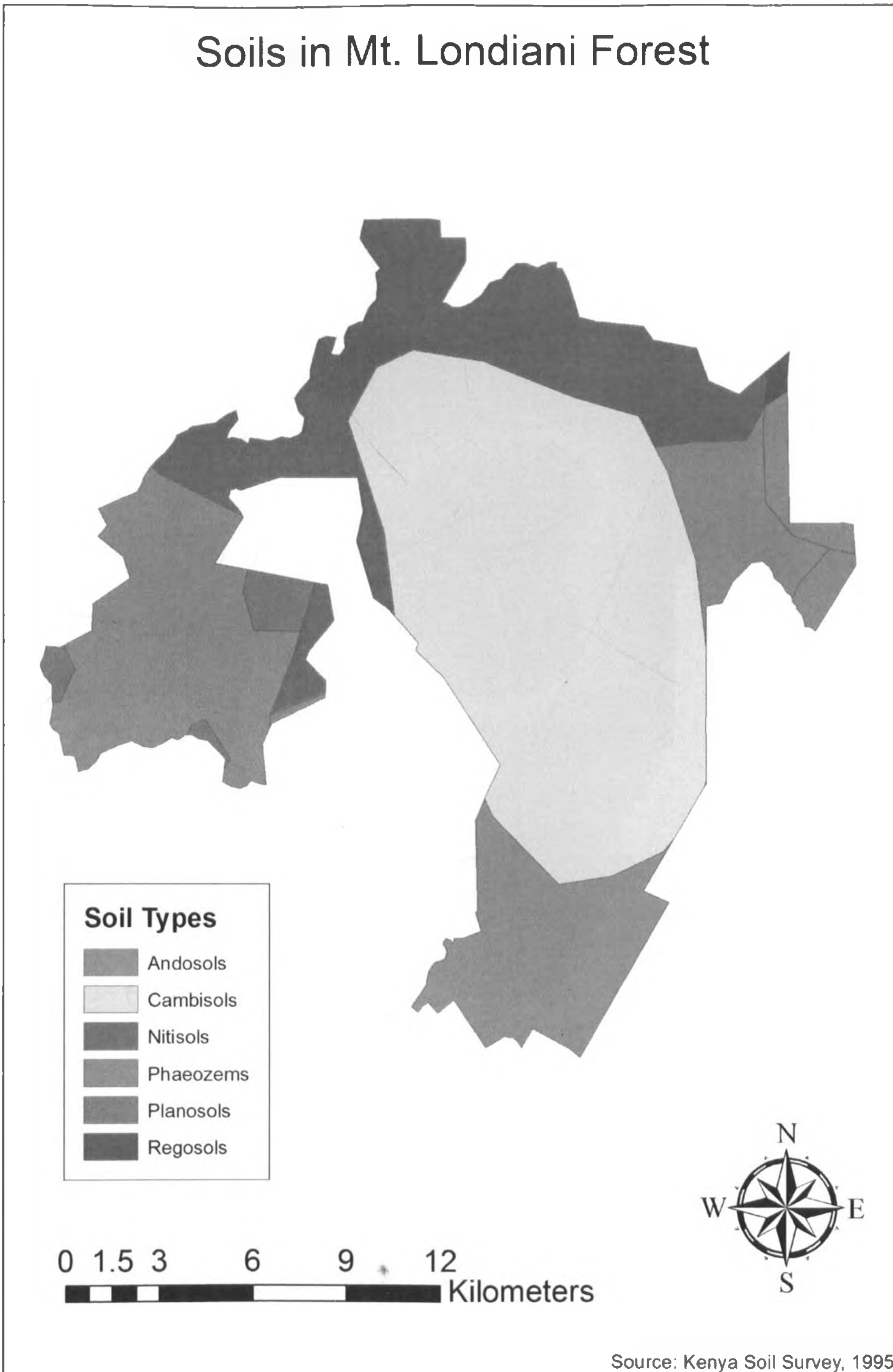

Figure 6.5: Soils found in the Mount Londiani Forest

APPENDIX 4: Slopes of the Mt. Londiani forest

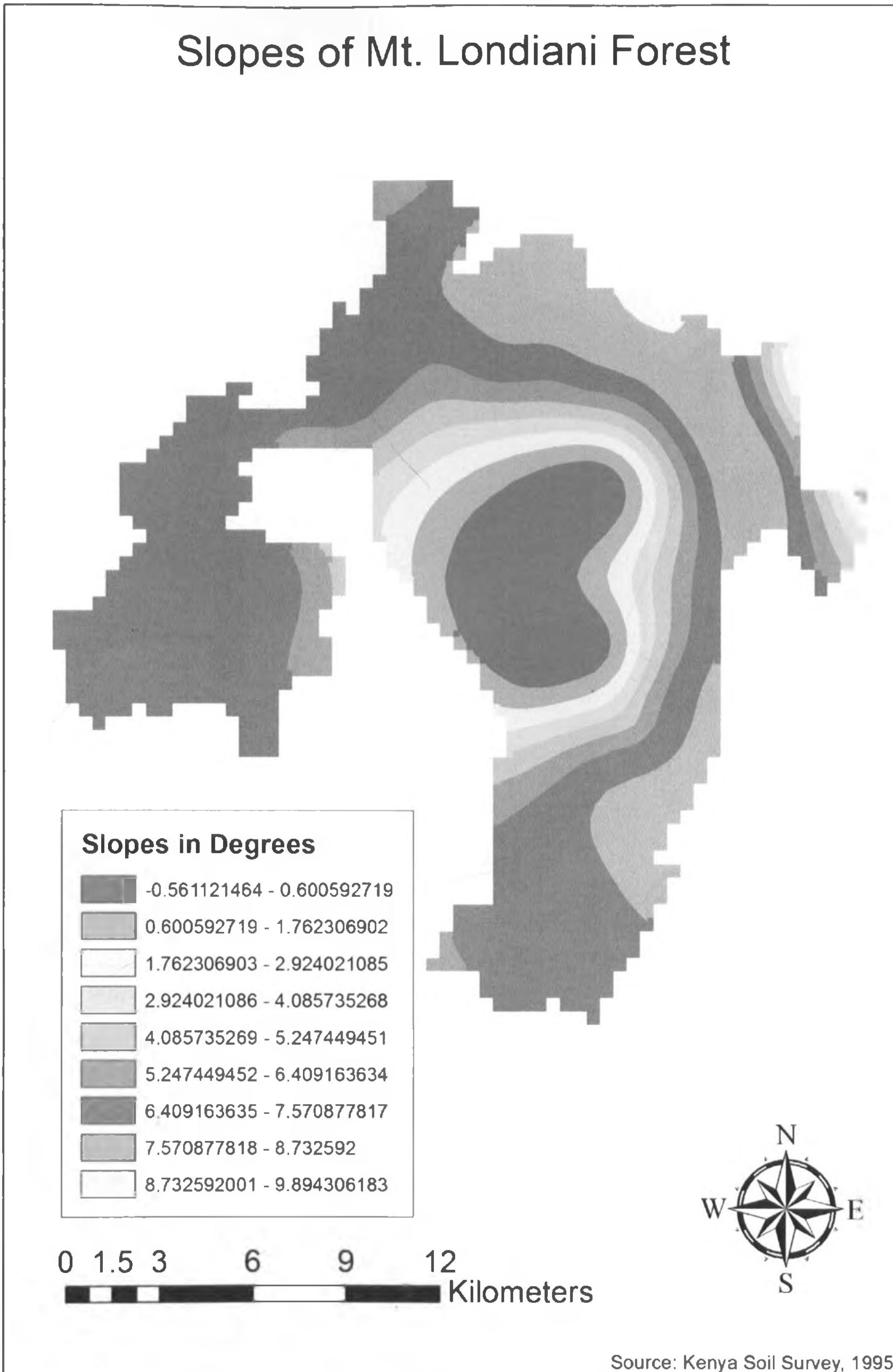

Figure 6.6: Slopes in the Mount Londiani Forest

APPENDIX 5: Land Cover in the Mount Londiani Forest

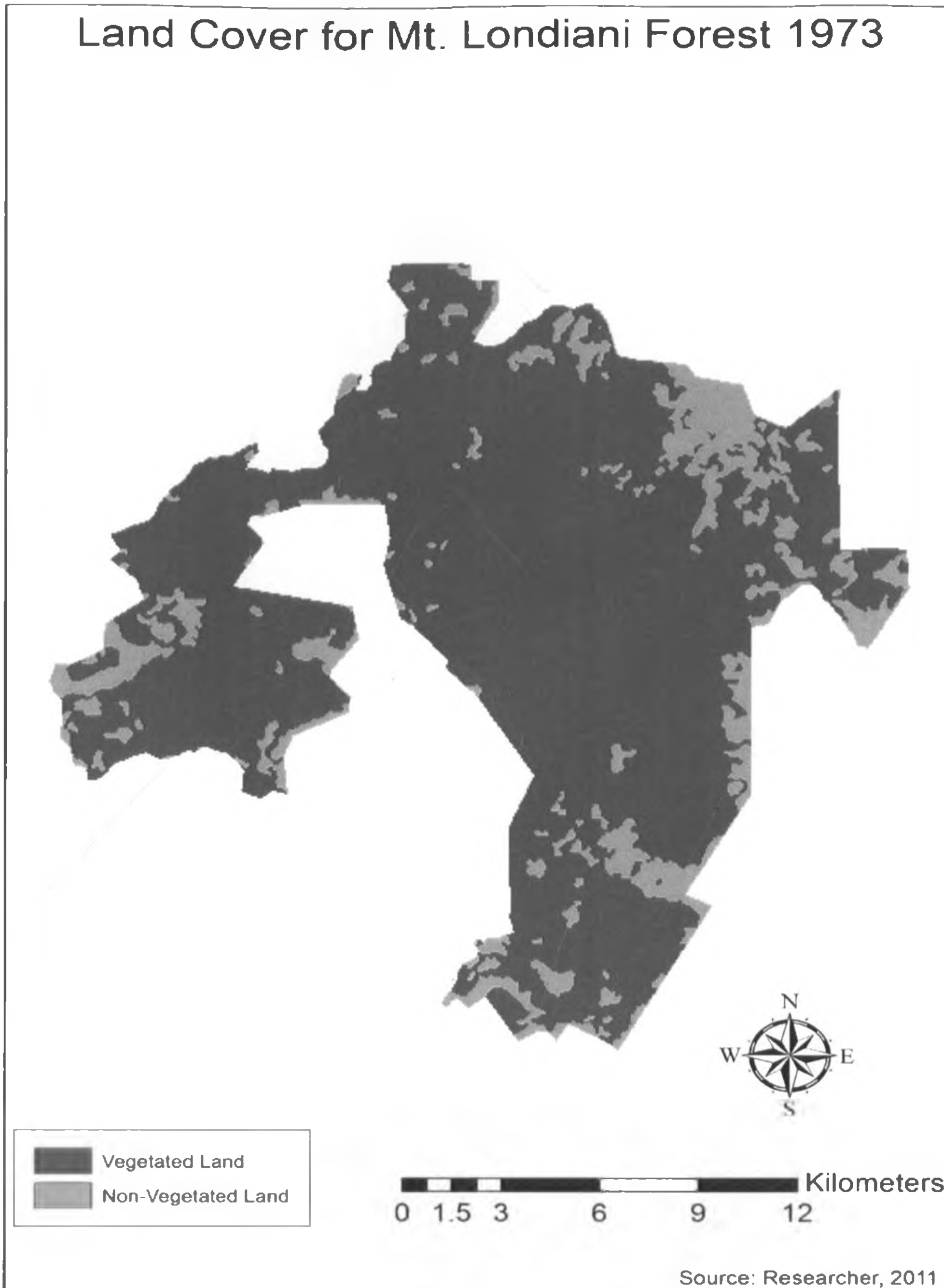

Figure 6.7a: Land Cover in the Mount Londiani Forest in 1973

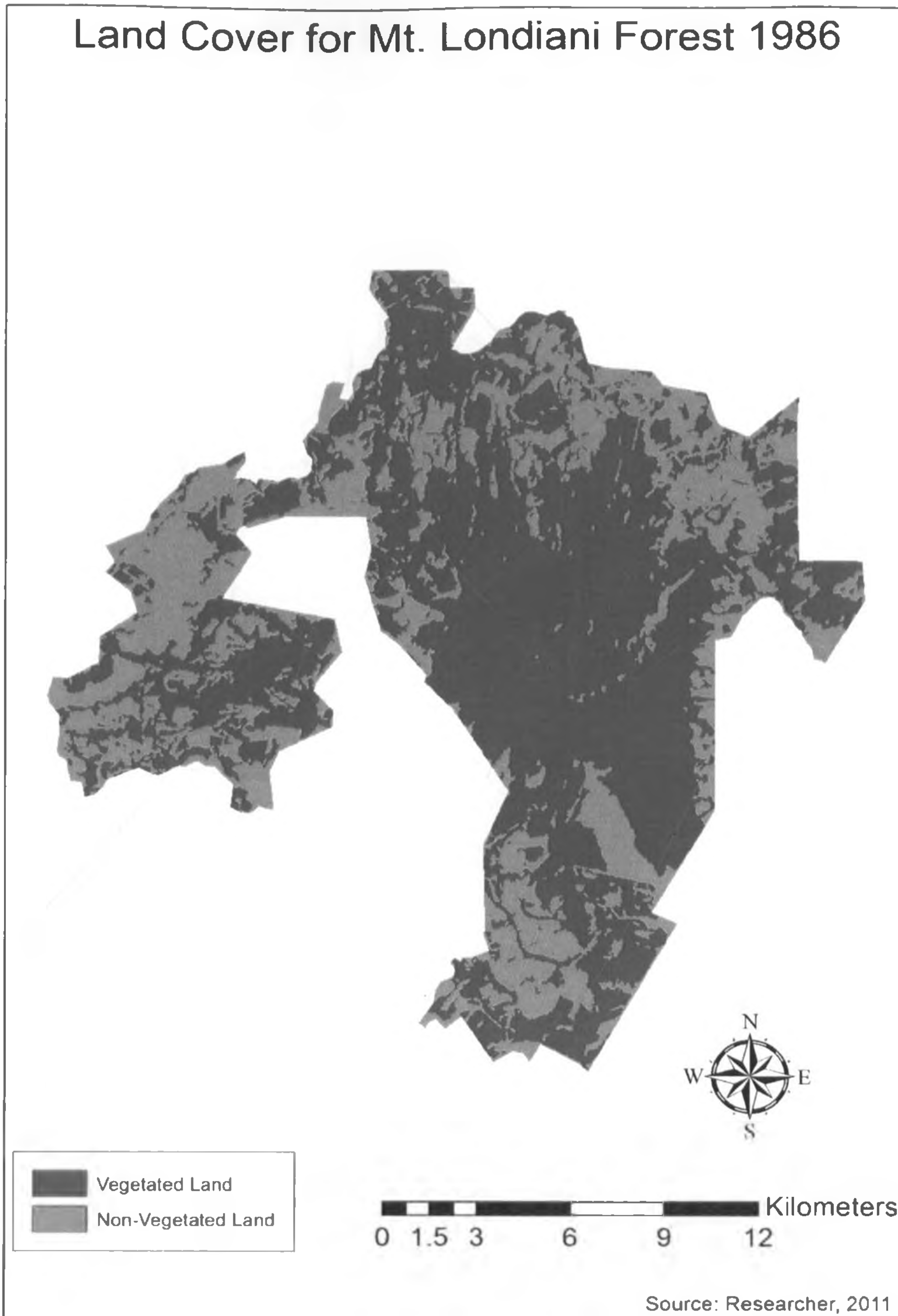

Figure 6.7b: Land Cover in the Mount Londiani Forest in 1986

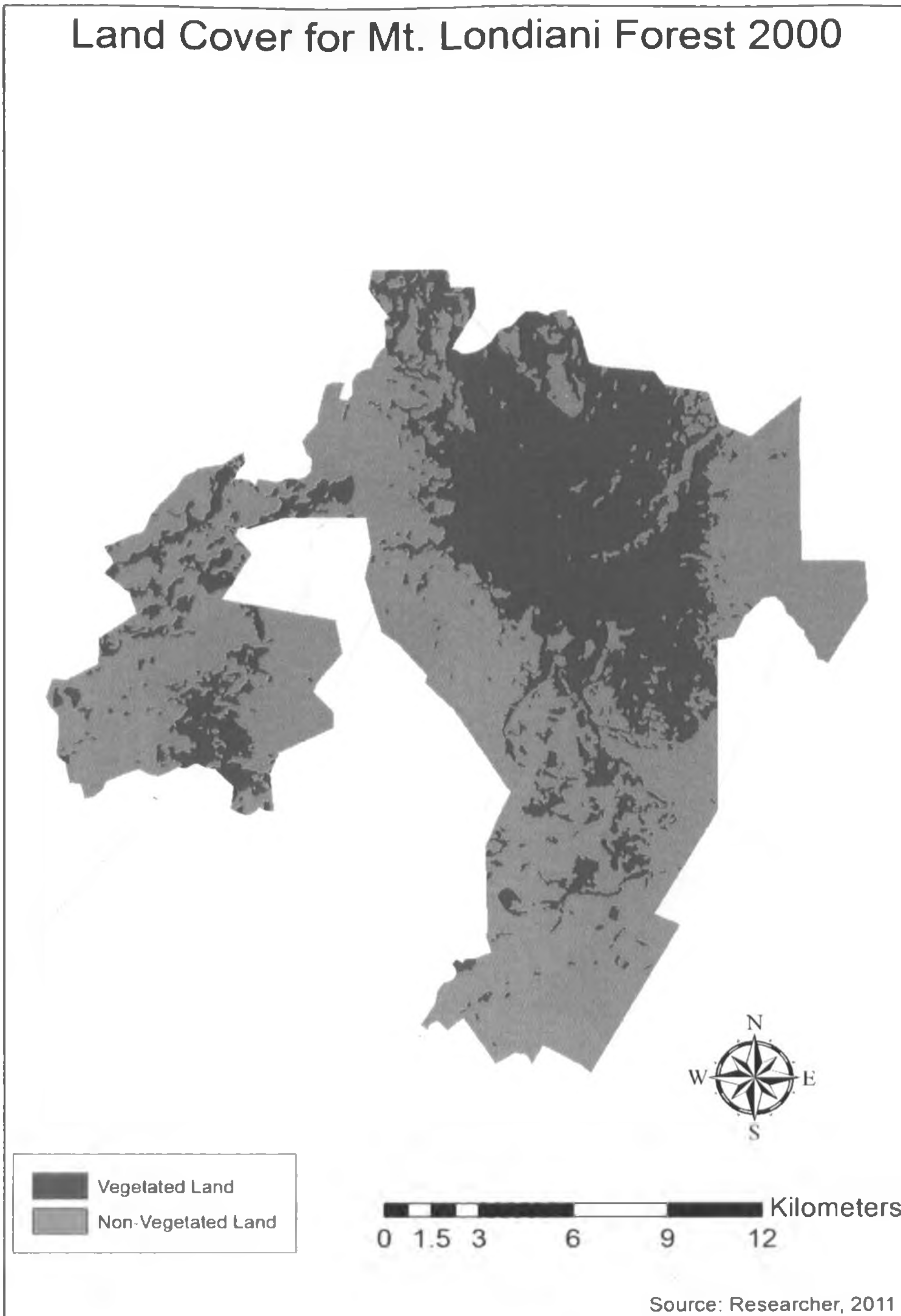

Figure 6.7c: Land Cover in the Mount Londiani Forest in 2000

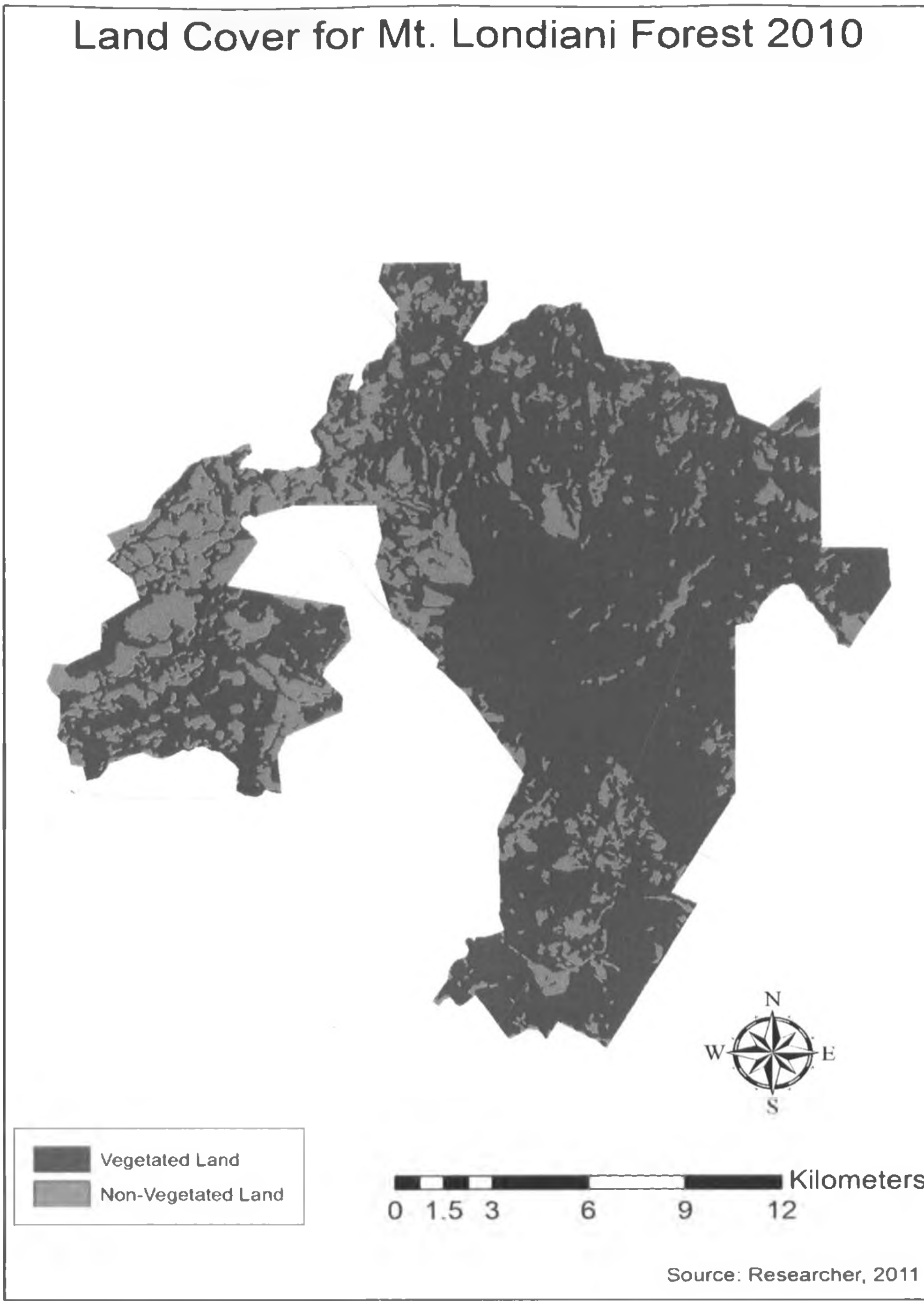

Figure 6.7d. Land Cover in the Mount Londiani Forest in 2010

APPENDIX 6: Population Densities in the Mt. Londiani Forest

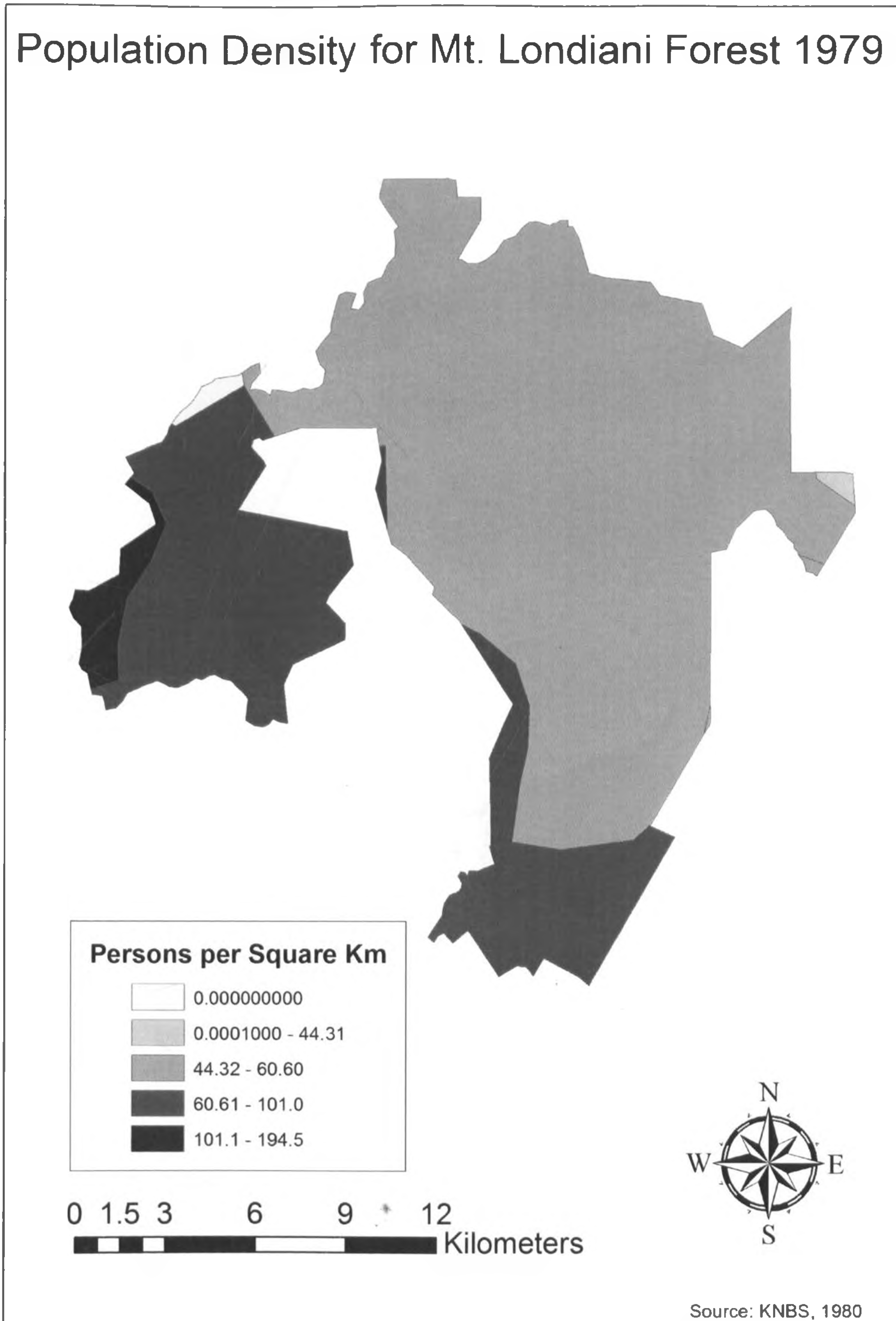

Figure 6.8a: Sub-locations: Population Densities for 1979.

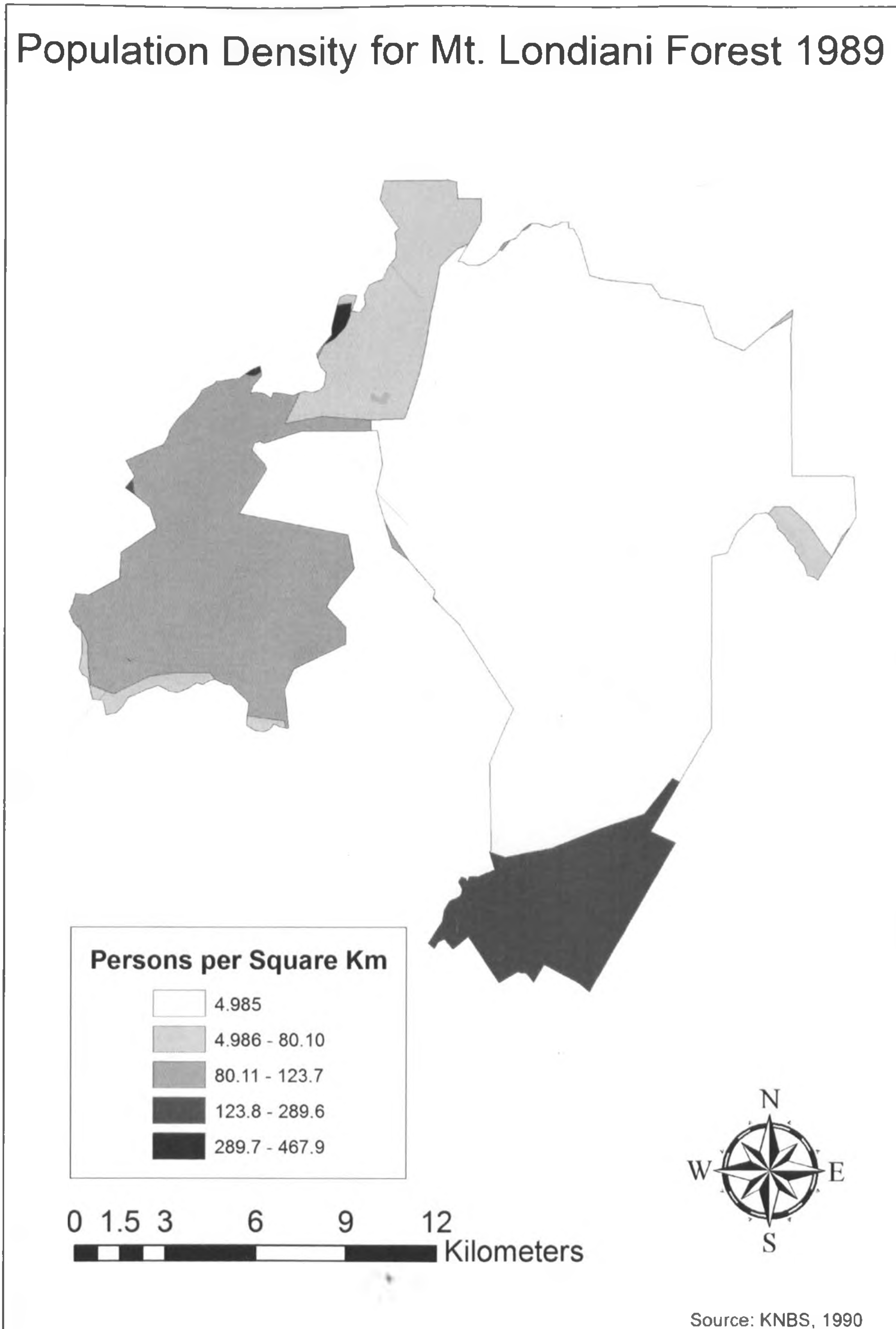

Figure 6.8b: Sub-locations: Population Densities for 1989.

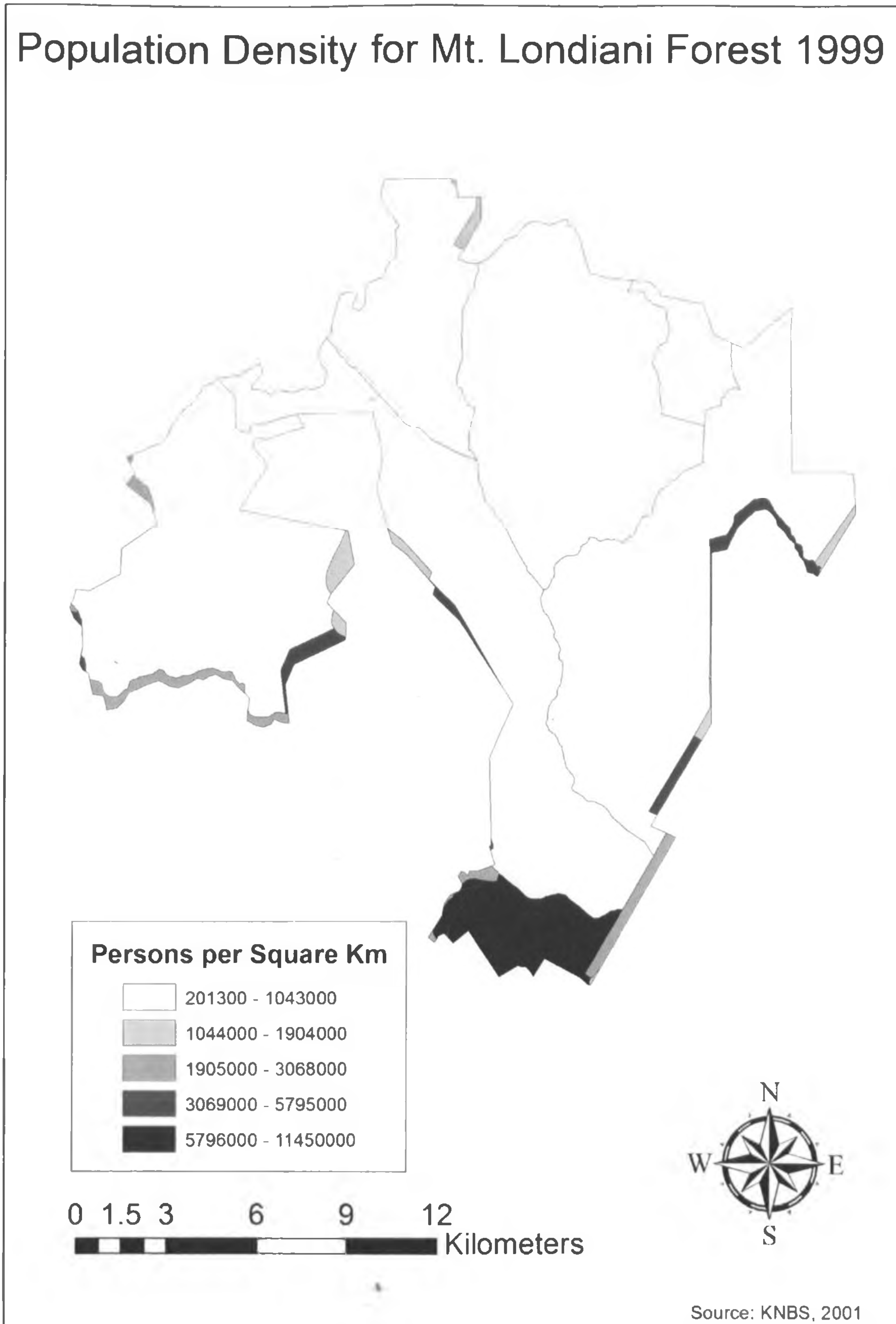

Figure 6.8c: Sub-locations: Population Densities for 1999.

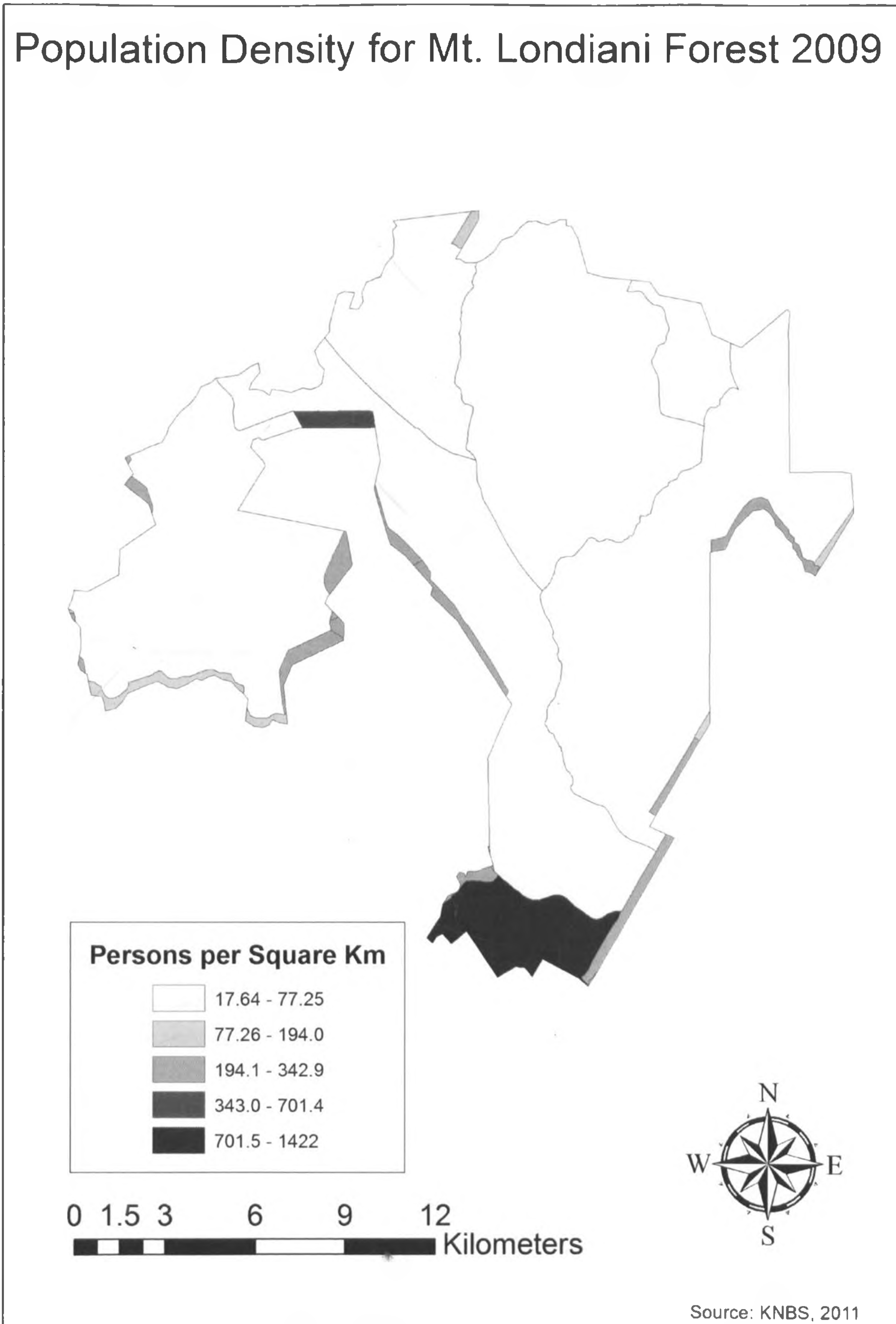

Figure 6.8d: Sub-locations: Population Densities for 2009

APPENDIX 7: GPS Ground control points

Coordinates in UTM - WGS 84.

ID	X_COORD	Y_COORD
1	93272.47253	19474.25395
2	99238.61615	20332.69188
3	99066.92857	16083.42412
4	90439.62736	13465.18843
5	96534.53667	11533.70309
6	102715.28977	12435.06291
7	103788.33719	15997.58033
8	107822.99546	16469.72119
9	109840.32460	12735.51619
10	105333.52546	8743.77981
11	101213.02339	8700.85791
12	98938.16288	6855.21636
13	97521.74029	4065.29309
14	109840.32460	4623.27774
15	111814.73184	7670.73240
16	108981.88667	7413.20102
17	95418.56736	-4519.08622
18	112673.16977	-2287.14760
19	114948.03029	-7523.61898
20	116192.76529	-4647.85191
21	119969.89218	-3016.81984
22	123789.94097	-8210.36932
23	124948.83218	-6364.72777
24	125206.36356	3421.46464
25	130786.21011	3721.91792
26	133018.14873	2563.02671
27	132846.46114	8915.46740
28	124691.30080	-11129.05829
29	123231.95632	-18039.48363
30	125335.12925	-17910.71794
31	129584.39701	-13618.52829
32	140658.24632	-20357.26604
33	138941.37045	-4647.85191
34	141302.07476	-5549.21174
35	142890.18494	-7866.99415
36	145336.73304	-6579.33725
37	133061.07063	-4862.46139
38	136408.97856	-24263.15863
39	136022.68149	-20400.18794
40	119841.12649	-29714.23949

41	112029.34132	-32117.86570
42	114776.34270	-32418.31897
43	107393.77649	-35852.07070
44	145336.73304	-69416.99379
45	147396.98407	-59888.33276
46	143104.79442	-61133.06776
47	145508.42063	-52934.98552
48	150229.82924	-44178.91863
49	145036.27976	-40873.93259
50	142632.65356	-37912.32173
51	143705.70097	-34178.11673
52	151775.01752	-39114.13483
53	155766.75390	-38126.93121
54	154994.15976	-43706.77776
55	161389.52235	-57913.92552
56	156796.87942	-59459.11380
57	176884.32700	-70876.33828
58	176884.32700	-70876.33828
59	170016.82355	-63708.38155