EÖTVÖS LORÁND UNIVERSITY

FACULTY OF INFORMATICS

INSTITUTE OF CARTOGRAPHY AND GEOINFORMATICS

CHANGE DETECTION AND ANALYSIS; A CASE STUDY OF NORTHERN MAU FOREST, KENYA

Jackson Mwangi Muthee

Student of Cartography MSc

Dr. Várga Zsofia

Lecturer ELTE Institute of Cartography and Geoinformatics

Budapest, 2022

DECLARATION

I, undersigned MUTHEE JACKSON MWANGI (NEPTUN CODE: D8YGMY), declare that the present master's thesis is my original intellectual product in full and that I have not submitted any part or the whole of this work to any other institution. Permissions related to the use of copyrighted sources in this work are attached.

<u>I AGREE</u> to the publication of the accepted master's thesis in pdf form on the website of the Institute of Cartography and Geo-informatics.

Budapest, 15th May 2022

____

(Signature of the student)

Dedication

I would like to dedicate this thesis to my parents

Acknowledgments

My gratitude goes to my dedicated supervisor Dr. Várga Zsofia who guided me through all the stages of writing this project. I also thank the Institute of Cartography and Geo-informatics, Eötvös Loránd University for the good learning environment and assistance they offered to me throughout the whole period of study and writing of the dissertation.

TABLE OF CONTENTS

DECLARATION..i
DEDICATION..ii
ACKNOWLEDGEMENT..iii
List of Figures..v
List of Tables..vi
ABSTRACT..vii
INTRODUCTION..1
Background of study..1
Statement of the Problem 1
Research Questions..2
Objectives of the Study 2
Research Hypotheses..2
Scope of the study..2
Limitations of the study..3
LITERATURE REVIEW..4
Introduction..4
Mau Forest and its role..4
Drivers of Land Use and Land Cover Change..5
Consequences of Land Cover and Land Use Change..5
Study Area..6
Location..6

The Climate of the Area…………………………………………………………………..…7

Topography and drainage of the Area…………………………………………………….……8

Geology and Soils…………………………………………………………………...……..…8

Vegetation Cover…………………………………………………………………………….……8

Economic Activities……………………………………………………………………….….....8

METHODOLOGY………………………………………………………………........…......10

Introduction…………………………………………………………………...…......……..10

Data Sources……………………………………………………………………….…......…...10

Satellite Image Data Acquisition………………………………………………………..…...10

Satellite Image Data Processing……………………………...……………….…..……...11

Band stacking ………………………………………………………………………….…......11

Pan-sharpening………………………………………………………………….…………..12

Normalized Difference Vegetation Index (NDVI)………………… ……………..…………….14

Reclassification for NDVI Layers……………………………………………………………15

Generation of Image Classification Scheme……………………………………...…………15

Land Cover and Land Use Classification…………………………………..………....16

Land Cover Change Detection………………………………………………………...…16

Determining the Accuracy of Land Cover Classification…………………………...………..17

RESULTS AND DISCUSSIONS……………………………………….……………….…18

Introduction………………………………………………………….…………………….……18

Post Classification Area and Visual Comparison…………………………...………....…....18

Post Classification Area Coverage Comparison 2000 - 2015…………………….…………..24

Thematic Class Overlays…………………………………………………………...…....25

Accuracy Assessment Results……………………………...……………...…......…...31

Trends in Land Cover Change…………………………………………………….…......36

Normalized Difference Vegetation Index results…………………………………….....37

Population Change……………………………………………….…………………41

Drivers of the land cover change………………………………………………….…42

CONCLUSION AND RECOMMENDATIONS…………………………...……..44

References…………………………………………………………………………45

List of Figures

Figure 1: Location of the Study area in Kenya……………………….…………..……....7

Figure 2: Full-color composite image 2000 and the clipped image………...…………….......12

Figure 3: Full-color composite image 2005 and the clipped image……….………..…....... 13

Figure 4: Full-color composite image 2010 and the clipped Image………..……... ……....13

Figure 5: Full-color composite image 2015 and the clipped image…………………...……....14

Figure 6: Classified Image for the year 2000……………………………..……........19

Figure 7: Percentage coverage of land cover categories in 2000……………………..........19

Figure 8: Classified image for the year 2005……………………………...…...……..20

Figure 9: Percentage coverage of land cover categories 2005……………………………...21

Figure 10: Classified Image for the year 2010……………………………..…….........22

Figure 11: Percentage coverage of land cover categories 2010…………………………......…...22

Figure 12: Classified image for the year 2015……………………………..……......23

Figure 13: Percentage coverage of land cover categories 2015……………………..…….........24

Figure 14: Land use land cover change 2000-2005……………………….……..……....25

Figure 15: Land cover changes from 2005-2010…………………….………....……27

Figure 16: Land cover change between 2010- 2015……………………………………..……........29

Figure 17: NDVI Image 2000…………………………………………………………..……..........38

Figure 18: NDVI Image 2005……………………………………………………….……….….........38

Figure 19: NDVI Image 2010…………………………………………………………..…..........39

Figure 20: NDVI Image 2015…………………………………………………......……....…40

Figure 21: Change in vegetation health 2000 to 2015……………………………...…………41

Figure 21: Change in vegetation health 2000 to 2015…………………………………...………42

List of Tables

Table 1: Landsat Images used in the classification.………………………………………….......11

Table 2. NDVI Re-Classifications……………………...……………………………………..15

Table 3: Land Cover area for the 2000, 2005, 2010 and 2015…………………………...….......24

Table 4: Land Cover changes, 2000-2005…………………………………...……...….......26

Table 5. Land Cover changes between 2005 and 2010……………………………..……........28

Table 6: Land Cover changes between land cover categories 2010-2015……….……..…..........30

Table 7: Error Matrix for 2000 land Cover Classification…………………………….………32

Table 8: Error Matrix for 2000 land Cover Classification……………………………...…..33

Table 9: Error Matrix for 2000 land Cover Classification……………………………………….34

Table 10: Error Matrix for 2000 land Cover Classification…………………………………..…..35

Table 11: Trends and rates of Land Cover change………………………………...………......37

Abbreviations

USGS United States Geological Survey

NEMA National Environment Management Authority

UNEP United Nations Environmental Programme

UNFCCC	United Nations Framework Convention on Climate Change
FAO	Food Agricultural Organization
KWFG	Kenya Forests Working Group
NDVI	Natural Vegetation Differenced Index
KIFCON	Kenya Indigenous Forest Conservation Programme

Abstract

Mau forest is the largest water tower as well as the largest closed-canopy forest in the East African region. It has economic as well as ecological benefits for the whole region and has over 15 rivers originating from it. Despite this, the forest has been undergoing extreme land cover changes over the past four decades, resulting in environmental and hydrological changes. There is currently no exhaustive review of the drivers and the rate of the changes within the forest. The objectives of the study were to determine the extent and rate of changes by use of remote sensing methods and to investigate the causes of the changes around the Northern Mau block.

The data used for the study were satellite imageries, topographical maps, and population data from the area. Four Landsat images sought between 2000 and 2015 were used in the study. The satellite images were for 2000, 2005, 2010, and 2015 and covered the Northern Mau Forest. The images were classified using the supervised classification method and compared with one another by use of the QGIS software. Four land cover categories were used in the classification scheme namely deep forest, light forest, other vegetation, bare land, and other categories. The post-classification area, as well as visual comparison, were undertaken to obtain the rates and the intensity of the land use and land cover changes within the Northern Mau Forest from 2000 to 2015. Class overlay operation was also done by use of the QGIS software to identify the changes that had occurred between the five land cover categories. NDVI operations were also conducted over the Northern Mau Forest to ascertain the health of the vegetation cover over the period.

The study found out that Land cover and land use changes occurred in the whole area of study and that the area under forest cover reduced significantly and that farming activities increased immensely throughout the period of study. The study found that there was an increase in population within the forest throughout the period of study which resulted in increased economic activities. The main economic activities which influenced forest cover were farming, logging for timber, charcoal burning, and government excision. NDVI analysis showed a general decrease in vegetation health throughout the period of study. The study recommends that agricultural activities within the forest should be banned, conservation measures such as tree planting should be practiced within the forest, and that there should be more advocation for the use of alternative sources of clean and renewable energy apart from wood to reduce tree logging.

CHAPTER 1

1.1Background of the study

Land cover changes within forested areas result in increased global warming because of increased carbon dioxide in the atmosphere since trees act as carbon dioxide traps (Hansen et al., 2009). The forests also support essential economic activities such as agriculture due to the conducive climate more so the cool temperatures and high rainfall amounts. As a result, land-use changes, as well as their drivers within forested zones, are worth researching. Continuous research on these changes is essential in the prediction and prevention of extreme effects this would have on the environment as well as people. Remote sensing methods, as well as Geographical Information Systems, are essential in determining the rate at which changes have taken place and hence were dimmed suitable for use within this study (Kiage et al, 2006). The Northern Mau Forest ecosystem has undergone a lot of land cover changes because of multiple causes, some of which can be attributed to climatological changes as well as human activities. The main human activities include extensive farming activities, charcoal burning as well as tree logging for timber. The increased population near the Northern Mau Forest from the year 2000 has contributed immensely to the increased human activities. The destruction of the forest cover has resulted in the decreased river discharge of rivers with some of them becoming seasonal. The decreased river discharge has led to effects on development investments such as the Lake Nakuru National Park, the Sound Miriu Hydro Power Station, and the Olkaria Geothermal plant in Naivasha. There is inadequate extensive research on the rates and causes of changes in the Northern Mau Forest as most previous studies have concentrated on the Maasai Mau and the South West Mau Forest blocks and little research has been carried out on the Northern blocks hence the need for more focus on this area.

1.2 Statement of the problem

The decrease in areas under forest cover in Kenya is an issue of great concern especially due to the crucial role forests play within the environment. The bulging population within the forested areas as well as the increased demand for the forest products has led to deforestation. Forest depletion have severe consequences on the environment and hence the need for continuous monitoring by use of remote sensing and GIS methods. Analysis of land cover changes within the forested areas is important in the development of the necessary measures that are necessary to reduce the depletion.

1.21 Research questions

1. What land use and land cover changes can be identified in the study area?

2. What are the underlying causes of land cover and land-use changes in the study area?

1.3 Objectives of the study

1. To determine the extent of land cover and land-use change in the study area.

2. To investigate the major probable causes of land cover and land-use changes in the study area.

1.4 Hypothesis

1. There has been significant land cover and land-use changes from the year 2000 – 2015.

2. There is a relationship between land cover changes and forest cover changes between 2000 and 2015 in the study area.

1.6 Scope of the study

The study was carried out on the Northern Mau Forest which is a block of the extensive Mau Forest block. It was conducted over 15 years from the year 2000 to the year 2010 and consisted of five-year intervals in 2000, 2005, 2010 and 2015. Satellite imagery was used in the generation of the land cover and land use categories whereas past remote sensing data were used in determining the causes of the changes. The study determined land-use changes for the periods 1990- 2000, 2000- 2005, and 2005- 2010. Eventually, a change detection analysis between 1995 and 2010 was carried out. An NDVI analysis was also determined to evaluate the change in the health of vegetation over the period after which population change within the area of study was computed. The different drivers of land cover change and how they have influenced land cover changes between 2000 and 2015 were also investigated. The study also gave recommendations on policies that need to be put in place for the continued sustainability of the Northern Mau Forest.

1.7. Limitations of the study

They were some limitations that were experienced during the study. In this nature of research, it is usually essential that all images that are being used for the land use and land cover change detection fall within the same period of the year and fall within the same season to enhance effective comparison. In this study, however, this was not possible due to the presence of cloud cover on some satellite images making them unsuitable for use. The images used were for December 2000, September 2005, August 2010, and July 2015. The study carried out also had the limitations of not being able to obtain all the information on land use and land cover causes in the Mau Forest because of reliance on online sources. There are also instances in which the analysis of images by use of QGIS software were influenced by the Landsat image quality regarding the period in which it was taken as well as the prevailing weather conditions.

CHAPTER 2

2. LITERATURE REVIEW

2.1 The Mau Forest and its role

Mau Forest is the largest water catchment area within the East African region and it is a source of 12 rivers draining into Lakes Victoria on the Nile River basin, Baringo, Nakuru, Turkana, and Lake Natron in Tanzania. The main rivers are Sondu, Nyando, Mara, Njoro, and Molo (Olang et al, 2011). During periods of dry weather, the rivers are known to offer reliable water to the people living within the adjacent areas throughout the year. Within the Mara River basin, for example, approximately 8 million people depend on the water from the river Mara. Mau forest is comprised of 22 blocks that have been gazetted as forest reserves (NEMA, 2013). The study focuses on the Northern Mau Forest blocks which comprise Tinderet, Londiani, Maji Mazuri, Nakboi, Chemorogok, and Timboroa forest blocks. Mau forest forms the largest block of closed-canopy montane forests in East Africa (Wass, 1995).The forest plays a role in supporting the livelihoods of forest adjacent communities as well as contributing to the economy of the country through its variety of products. It is a major habitat for wildlife with the main ones being elephants and antelopes and as a result contributes to the country's biological diversity (G.O.K., 2009). According to the United Nations Framework Convention on Climate Change (UNFCCC), forests also play a vital role in climate mitigation by reducing the Greenhouse gases emissions (UNFCCC, 1992) and this has been the case in Mau Forest where temperatures are moderate ranging between 8 degrees Celsius to 28 degrees Celsius. The area around Mau Forest also has numerous large and small wheat farms and other forest products such as honey, medicinal plants, and wild fruits for local consumption (UNEP 2005). The forest comprises indigenous Juniperus procera or African pencil cedar forests consisting of natural vegetation making it a habitat for a wide variety of 450 bird species. The forest is also home to the Agiek community who have habited within the Mau Forest for a long period before the colonial period in Kenya (Jackline Klopp, 2011). The government and the United Nations Environment Programme(UNEP) based in Nairobi, claim that the forest is critical to Kenya's tea industry. Mau forest also has significant cultural, social, and economic implications on the surrounding communities as they depend on the forest for water, firewood, grazing area, food, and medicines (D. K. Langat, 2016).

2.3 Drivers of land use and land change

There have been high rates of deforestation within areas in the tropics (James K. A, 2006). The Food and Agriculture Organization (FAO) estimated that during the 1980s and 1990s, forests within the tropics reduced at the rate of 15.4 million hectares annually (FAO, 2018). Within the forests in Kenya, the Mau Forest has had the most reduction rates in terms of forest loss since the 1970s. Land use and land cover change contribute immensely to environmental change. Most of the land use/land cover changes have resulted from increased agricultural activities with most agricultural land originating from forests as well as grasslands (Hosea et al, 2018). Most of the converted forests to agricultural lands are within the tropics and the Northern Mau Forest is no exception in this as most people in the neighboring communities depend on agriculture as their means of livelihood (Gibbs et al, 2010). The region near Mau Forest has a favorable climate for agricultural activities with rainfall amounts ranging from 1400 mm to 2500 mm and hence the increased rates of conversion (Hosea et al, 2017). Besides agriculture, other human activities that have led to land use/land cover changes within the forest include illegal settlement, immense charcoal burning, Illegal logging as well as forest fires (KFS, 2019). According to the Kenya Forest Service report, reckless actions including deforestation, illegal human settlements, and conversion of land to farmland in the Mau Forest are leading to changes in the climate system of the area (KFS 2019). There has also been a great association between rapid population increase and migrations to regions near tropical forests with deforestation and ecosystem defragmentation (Tiffen, 1994)

2.4 Consequences of Land use and land change

The land cover change within the Mau Forest ecosystem has resulted in the reduction in levels of carbon sequestration which has the effect of increasing the levels of carbon emitted into the atmosphere and hence climate change (K. D. Kinoti and Mwangi, 2020). Some of the climate change indicators within the Mau Forest include unpredictable rains, prolonged periods of droughts as well as hot seasons within the Mau Forest ecosystem. Reports from the Kenya Meteorological department 2016 show that there has been a significant decline in the rainfall amounts within the Mau Forest because of forest reduction. The increased encroachment into the Northern Mau Forest has also resulted in an intense water crisis in the areas with the perennial rivers becoming seasonal through the reduction in river discharges and as a result leading to widespread conflicts over the commodity (KWFG, 2001). According to research carried out by Meyer, the reduction in water amounts from the Northern Mau region has also resulted in severe impacts on different infrastructural establishments within the surrounding areas. Notable examples include effects on the Sondu Miriu Hydropower plant, the Olkaria Geothermal plant which is located near Naivasha town within Kenya's rift valley, Maasai Mara National reserve, and most tea growing regions within the Kericho highlands that rely on water from the Mau Forest (Meyer, 1994). There are also high risks of flooding in the lower areas as the trees are being cut down as previous studies on indigenous trees have shown that they play a part in holding water during floods and a result giving it more time to infiltrate into the ground (Chaudhry, 2021). Deforestation has resulted in more surface runoff as well as increased water flows into streams increasing flooding risks in the neighboring towns such as Narok. Reduction in forest cover in Kenya especially within the Northern Mau Forest has resulted in reduced livelihoods of many people around the forest brought about by a reduction in land produce, cases of famine as well as drought.

2.5 Study Area

2.51 Location

The Mau Forest is located in the South-western part of Kenya within the Rift valley region, approximately 170 kilometers (about 105.63 mi) North-West of Nairobi, Kenya's capital city. The forest lies between latitudes 00 19'N and 00 93'S and longitudes 34°9' - 36° 6' E. It borders Narok county to the South, Bomet county to the Southwest, Nakuru county to the North, and Kericho County to the west. The study focuses on the blocks located in the northern part of the forest which includes mount Londiani, Tinderet, Northern Tinderet, Timboroa, Nabkoi, Kilombe Hill, Metkei, Maji Mazuri, Chemorogok, and Lembus forest blocks. The neighboring towns are Eldama Ravine, Molo, Karbanet, Londiani, and Kericho. The study investigated land cover and land use changes change from the year 2000 to the year 2015 on the Northern Mau Forest block only as the whole Mau Forest occupies an exceptionally large area, approximately 40,000 km^2 (Swart, 2016).

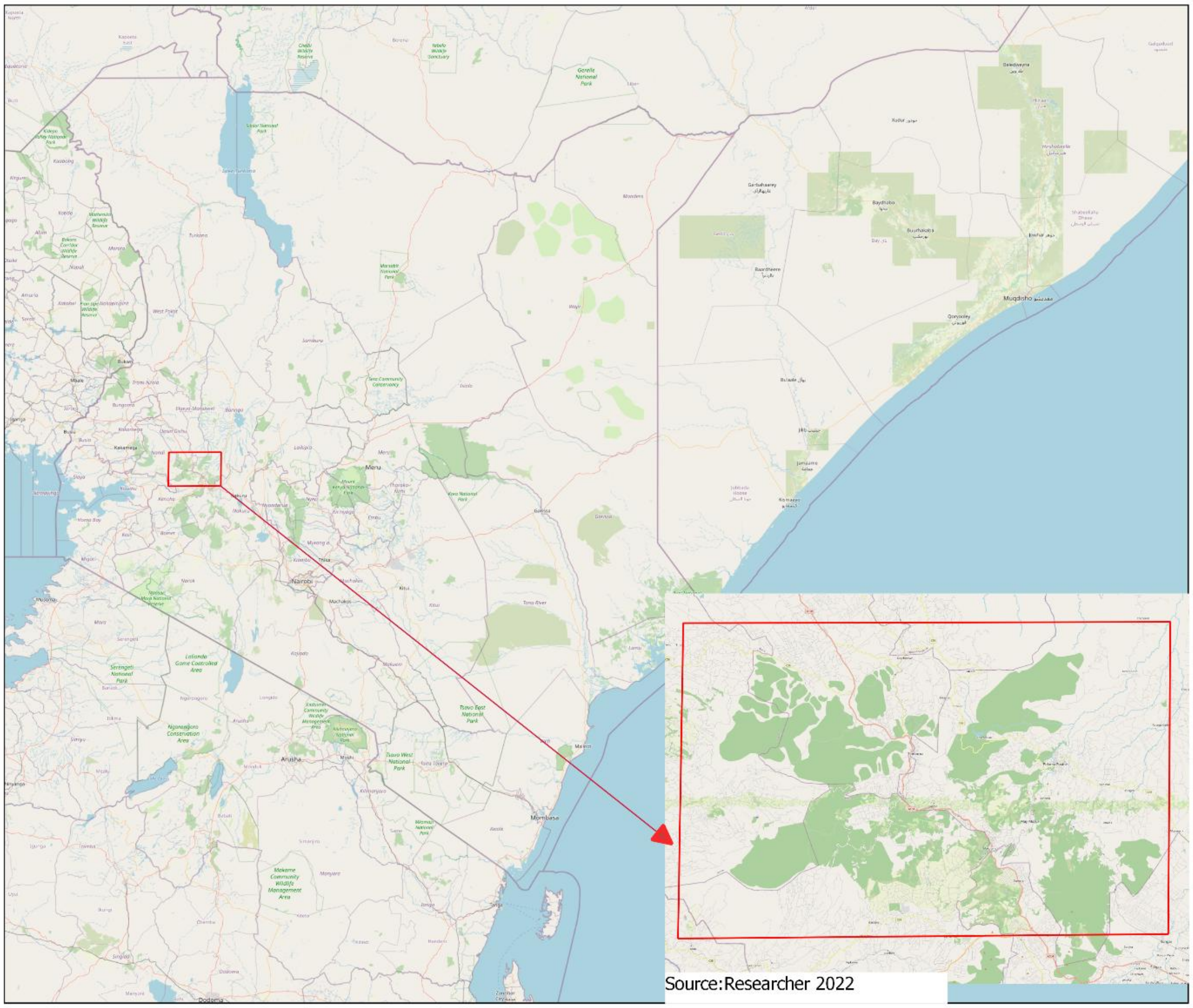


Figure 1: The Location of the Study area in Kenya.

2.52 Climate of the area

The area has an annual precipitation of 1735 mm whereas the annual average temperature per month is 18.1°C (Acker et al, 2007). The maximum temperature in the northern Mau Forest is approximately 30° C with the hottest months being experienced between December to March. The coldest month is July with an average temperature of 23.9° C (Nakuru D.D.P., 1997-2001). The temperatures in the Mau Forest complex are strongly influenced by altitude and physical features such as forest cover, escarpment, and mountains.

2.53 Topography and Drainage of the Area

The major topographical features within the Northern Mau Forest are escarpments, rolling plains, hills as well as plains. The altitude ranges between 1000 to 3200 meters above sea level. There exists surface as well as underground water resources in the Northern Mau complex area. The major rivers that originated from the Northern Mau Forest include River Nyando, river Molo, river Yala, and river Nzoia. Previous studies done within the area of study have shown that the rivers discharge has been reducing in their discharge and this has been caused by the extreme land cover and land-use change patterns in the area such as the conversion of forest land to farmland.

2.54 Geology and soils

The rocks within the Mau Forest are of volcanic origin. Previous geographical studies on the area of the study indicate that the area consists of quaternary volcanic deposits especially pyroclasts and sediments (Ayuyo, 2012). The topsoil comprises clay loam to loam with a sub-angular blocky structure and is mostly acidic with pH values of 5.6 to 6.4. The uplands areas comprise Ferrosols, Nitisols, Cambisols, and Acrisols (FAO, UN, 1995). The lowland areas comprise Vertisols, Planosols, Cambisols, and Solonetz soils.

2.55 Vegetation cover

The vegetation within the study area comprises shrubs and forests within the hilly areas, grasslands with scattered trees within the plains, and bamboo forests within the mountainous regions. Escarpments consist of woodlands as well as bushes whereas those regions at extremely high altitudes have acacia forests as well as woodlands (Luke et al, 2011).

2.56 Economic Activities

The major economic activities that are undertaken within the Northern Mau Forest area are crop growing, livestock keeping, lumbering, quarrying, beekeeping, and commercial activities. Various indigenous communities within the Mau Forest engage in diverse economic activities. The dominant ones are the Kalenjin, Ogiek and the Maasai. The Kalenjin community is involved in farming activities especially crop growing and livestock keeping. The Ogiek communities are hunters and gathers depending on the forest for food and shelter (MFRS, 2009). The Maasai community is dependent on nomadic pastoralism and depends on the Mau Forest for pasture as well as water. There has been a migration of other communities in the recent past due to the forest's agricultural potential especially for agricultural purposes due to the presence of fertile soils as well high rainfall amounts with the Main communities being the Kikuyu and the Kisii who are farmers. The immigration of the farmers to the Mau Forest ecosystem has in a big way led to interference in the Mau Forest with many people starting up farming activities within the forest illegally. The major crops cultivated are tea, maize, beans, Irish potatoes, tomatoes, onions, cabbages, beans, millet, sorghum, pyrethrum, sugarcane, coffee, and wheat. Most of the farming takes place on a small-scale basis. Tea farming is the main export earner in Kenya and areas within the Mau Forest account for a big percentage of the commodity. The farming activities have resulted in the mushrooming of food processing industries in the neighboring towns. The common types of livestock reared are sheep, cattle, donkeys, and goats. Sawmills are located within the Elburgon region and are dependent on the Mau Forest for the raw materials. The wood products are transported and sold in neighboring towns such as Molo, Njoro, Mau Narok and Keringet.

3.0 Methodology

3.1 Introduction

The study seeks to employ remote sensing techniques as well as statistical analysis methods to investigate the land cover and land use extent on the Northern Mau Forest block, the trends as well as identify the possible drivers of the changes since these methods are effective in the analysis of land-use dynamics (Kiage et al, 2006).

3.2 Data Sources

The study will make use of both primary and secondary data types. The main primary data type will be Landsat 7 and Landsat 8 satellite images from the United States Geological Survey (USGS) topographical maps and population data. Satellite images for the years 2000, 2005, 2010, and 2010 were used to produce land use maps, intervals which we thought would be enough to determine changes over the area. The Land sat images were preferred for the study due to their effectiveness for vegetation cover analysis more so vegetation discrimination and measurement of chlorophyll.

3.2.1 Satellite Image Data Acquisition

The images were first assessed to determine their suitability by looking at the quantity of cloud cover as well as the season between the years 2000 and 2015. Only images that had a cloud cover of less than 5% and mostly between July and September were selected and downloaded to ensure quality results. It was not easy to obtain satellite images for the same months for the four years because some had extensive amounts of cloud cover and hence unsuitable for use. The images obtained were for December 2000, September 2005, August 2010, and July 2015. Table 1 below shows the data of the images that were used in the study indicating their temporal resolution and the period in which they were taken.

Landsat Sensor	Date	Spatial Resolution
Landsat 7 TM+	12/2/2000	30 m
Landsat 7 TM+	21/9/2005	30 m
Landsat 7 TM+	18/8/2010	30 m
Landsat 8 OLI	7/7/2015	30 m

Table 1: Landsat Images used in the study.

The QGIS software was used for the processing of the images and used too for clipping out the Northern Mau Forest which was the area of interest as well as the creation of land use classification maps. The whole study area was put through the land cover and land use analysis.

3.3 Satellite Image Data Processing

In order to enhance the quality of satellite imagery, image processing was done. This would ensure that there was an effective land cover classification analysis. Two operations were done under the pre-processing, mainly atmospheric correction and pan-sharpening can we make in one step and band stacking will be the second. For the year 2005 we had some extra work, because the Landsat had an SLC failure in 2003 and these images were created also ‘zigzag’, with no data lines. The QGIS built-in ‘No data fill’ function was used to repair the missing value.

3.3.1 Band stacking

Band stacking refers to the process of combining various light channel bands to produce color composite images. The process is usually undertaken because Landsat images occur as single raw bands showing various channels of light within the electromagnetic spectrum, features on the ground show the grey color reflectance making them hard to distinguish among them. As a result, different image bands were combined for the years 2000, 2005, 2010, and 2015 in order to produce color composite images which are easier to distinguish. In this case, red, green, and near-infrared bands were combined in producing the color infra-red images. The color composite images were created by use of the QGIS 3.16 software build virtual raster tool under Raster Processing tool. The created color composite images for all the years were then clipped over the area of interest; the Northern Mau Forest boundary as of 2000, by use of the extraction clipping tool in the QGIS software to create four clipped images which would be easier to work with for the rest of the classification processes. Figures 2, 3, 4 and 5 show the resulting color composite images for the years 2000, 2005, 2010, and 2015 and the clipped images for the same period. The images were subjected to atmospheric correction and stacked bands into a multiband image.

3.3.2 Pan sharpening

Pan sharpening is a method that involves the combining of panchromatic as well as multi spectral images to increase the color resolution. This was performed on all the satellite images to increase its resolution. It was performed using the QGIS software.

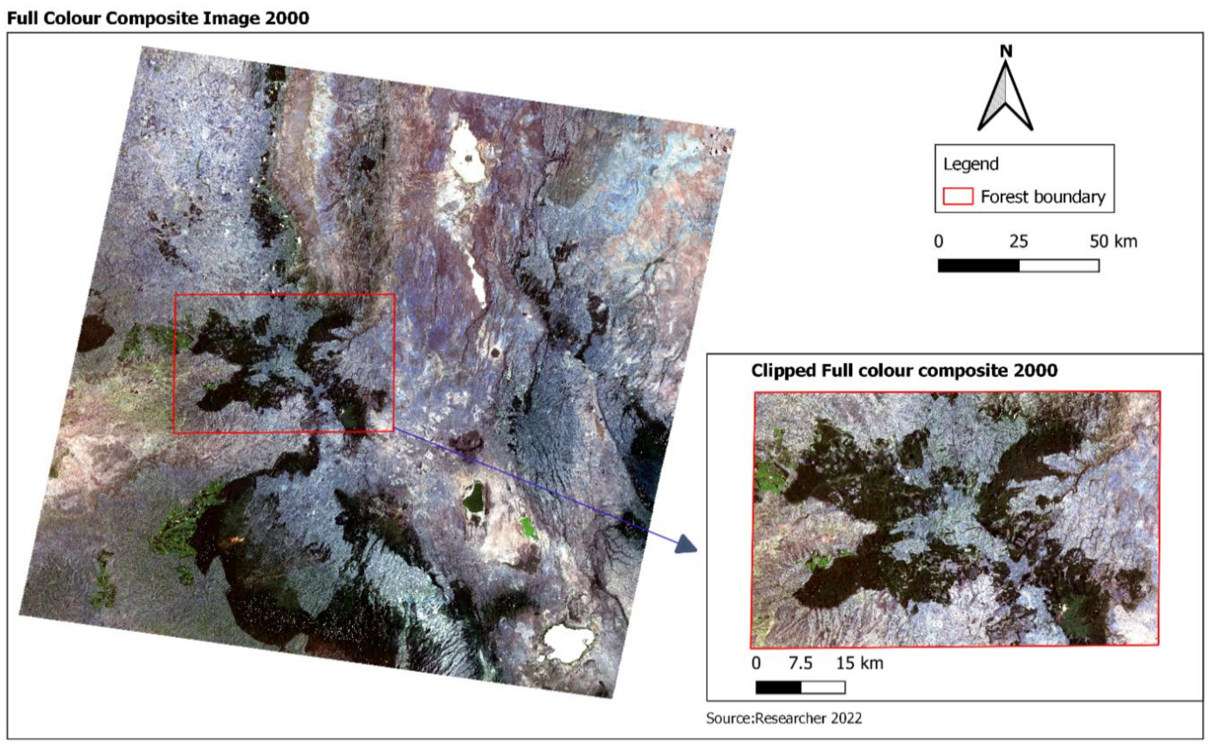


Figure 2: Full - color composite image for the year 2000 and the clipped color composite image.

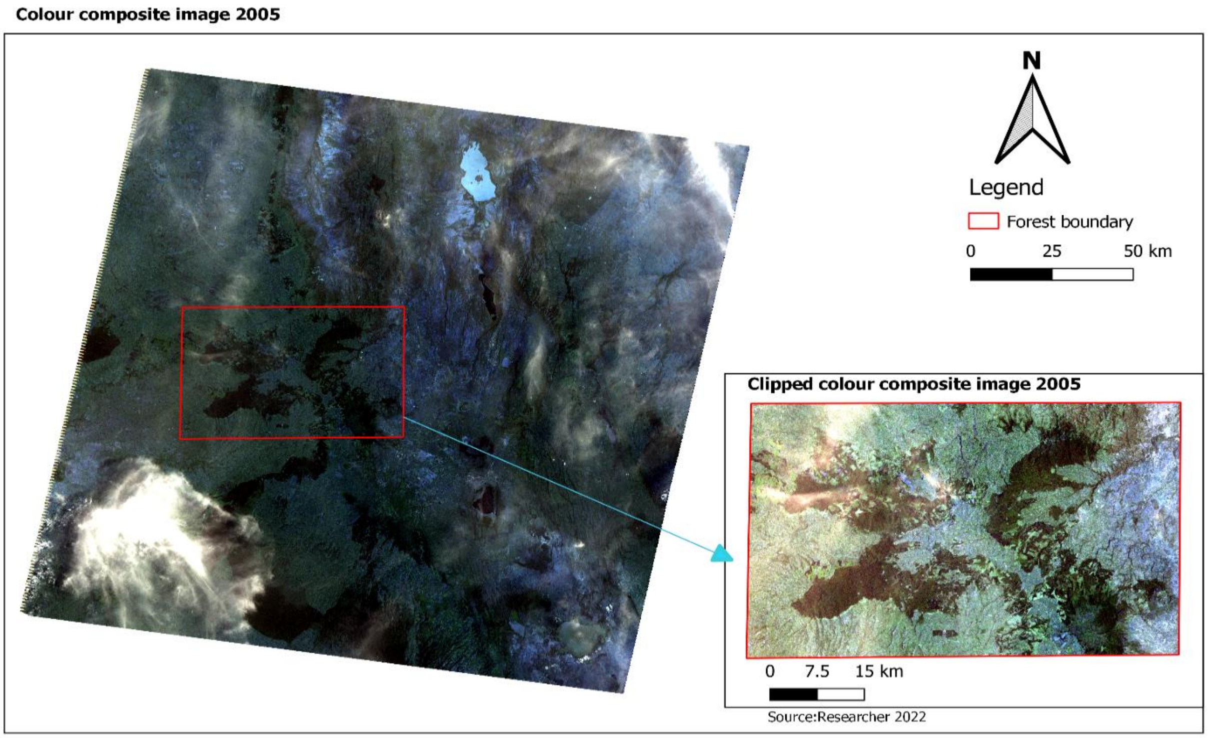


Figure 3: Full-color composite image 2005 and the clipped image.

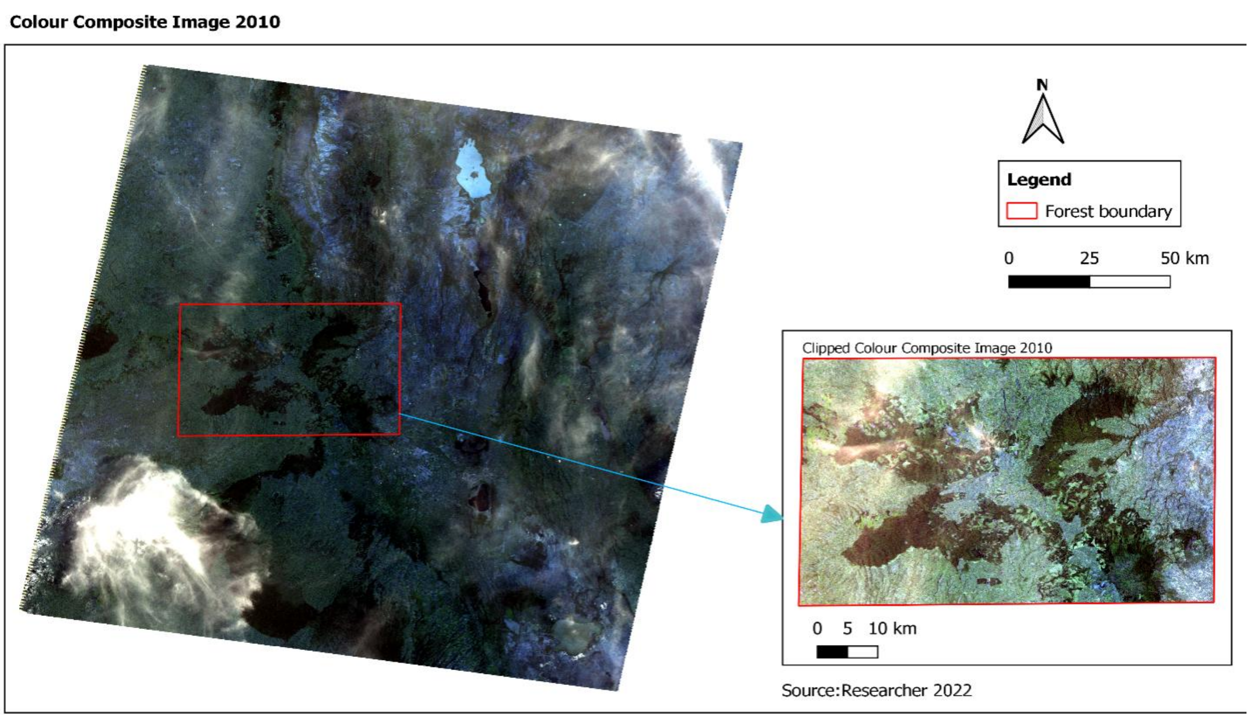


Figure 4: Full-color composite image 2010 and the clipped Image

Colour Composite Image 2015

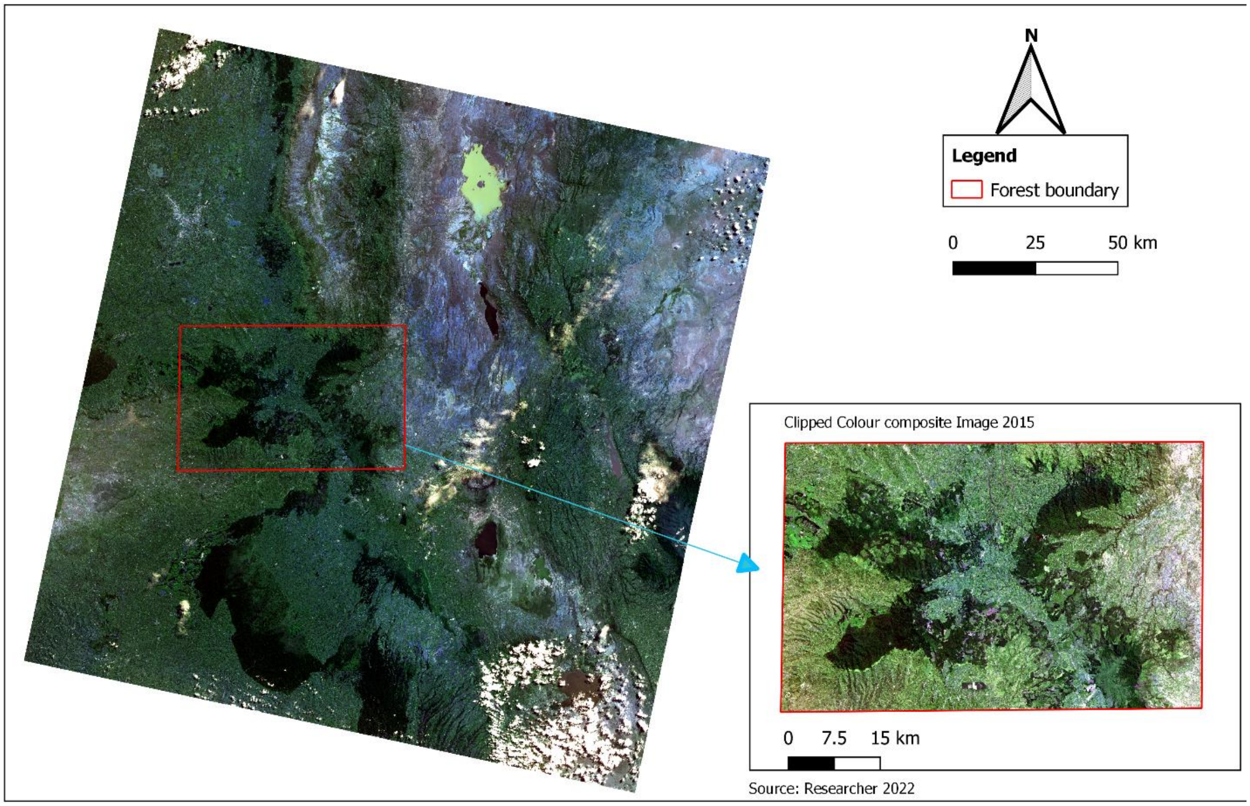


Figure 5: Full-color composite image 2015 and the clipped image

3.4 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index was applied to the Northern Mau Forest too to detect the change detection for vegetation from the year 2000 to 2015. This was obtained from the four Landsat images used in the study and this would give information on the health of the vegetation cover over the period as it shows the content of green vegetation in the leaf's pixels.

NDVI applies the visible 'red range' and near-infra-red (NIR) sunlight reflected by plants in assessing the vegetation density in a particular given area. The chlorophyll pigments that are found in leaves usually absorb the visible light mainly within the red (*and blue*) spectrum and use them for the process of photosynthesis, the process in which the plant leaves convert light energy to chemical energy. These absorbed red range and reflected NIR range are used to constract NDVI index. In Landsat 7, the red spectrum is found in band 3 whereas it's found in band 4 in Landsat 8. The near-infra-red lights are then strongly reflected from the structure of the cell (band 4 in Landsat 7, and band 5 in Landsat 8).

The NDVI values mainly fall between -1 and 1. The -1 value shows the water surfaces, the values nearby 0 describe the artificial or rock surfaces, and the range (between 0 and 1) belong to the 'living', plants area. Regions that have a lot of vegetation cover mainly give high NDVI values as a result of having high reflectance in the Near Infra-Red and low rates of reflectance in the visible red spectrum. Those regions which have very little vegetation cover mainly have very low NDVI values as they have higher reflectance within the visible red spectrum compared to the Near Infra-Red. Thus, grasslands, agricultural areas, and forests can also be separated using NDVI.

Within the study, all the images were subjected to the NDVI analysis by use of the QGIS software. Density slices from 0 to 0.25 represented those areas that had very little vegetation, 0.25- 0.50 was used to depict areas with scattered vegetation. 0.50 – 0.75 was used to show regions with moderate vegetation cover whereas 0.75- 1.00 showed those areas with dense vegetation cover.

The NDVI was calculated from the following formula in which NIR represents Near-Infrared Bands,

$NDVI = (NIR - Red)/(NIR + Red)$

The results of the NDVI are given in chapter 5.

3.4.1 Reclassification for NDVI Layers

After preparing the NDVI layers for all years, some post-processing steps could be essential for the analysis analysis. Because I want to analyze changes in forest area, I reclassified the data into 4 classes in the first step (Table 2). I used the QGIS Semi Automatic Classification Plugin Reclassification Tools, as new class value must be an integer.

Origin NDVI value	New value
0-0.25	1
0.25-0.5	2
0.5-0.75	3
0.75-1.0	4

Table 2. NDVI Re-Classifications

From the re-classification, it was possible to obtain the NDVI areal coverage for each of the the individual classes from the years 2000 to 2015 from the individual classification reports generated for each year.The rates of the NDVI changes for each individual year were then calculated in hectares.

3.5 Generation of Image Classification Scheme

The study relied on the supervised classification; a method chosen to enhance the effective choice of the classes to be incorporated into the study. The classification scheme to be used for the study was generated with the use of the year 2000 clipped Landsat image as well as a comparison with four 2007 topographical maps at a scale of 1:50,000 which covered the Northern Mau Forest area. The Map sheets covered North Tinderet, Timboroa, Emining/Esageri, Lumbwa, Londiani, and Rongai areas. The generation involved identifying the information which was identical to both the topographical map as well as within the Landsat image. The information obtained was critical in creating spectral signatures used in creating training inputs for the different classes to be used for classification in the QGIS software. Five classes were applied for this study which included Deep Forest, Light Forest, Other Vegetation, Bare land, and other categories. The deep forest represented areas that had very dense forest cover whereas the light forest represented areas with scarce forest cover. Other vegetation represented shrubs, grassland as well as crops. The other categories represented areas with residential buildings as well as farms that were in the process of being prepared for agricultural activities. Bare land represented areas with no vegetation cover. The researcher put up the signatures for each of the above classes which were essential in aiding the QGIS software in the classification of all the other pixels.

3.6 Land Cover and Land Use Classification

The clipped composite images were used in the classification starting with the year 2000. The developed signatures for each land cover category were used in the classification of all remaining pixels to give new polygons for each land cover category which were deep forest, light forest, other vegetation, bare land, and other categories. The classification applied minimum distance. This led to the generation of the 2000 classified map layer as well as statistical areal coverage for each of the five land categories. The process was repeated for the years 2005, 2010, and 2015 to give four classified maps which will be discussed in chapter five.

3.7 Land Cover Change Detection

A post-classification change detection analysis for the four Landsat images was performed to determine the land cover changes that had taken place from the year 2000 to 2015. QGIS 3.16 software was used for this operation. The classified images for the years 2000, 2005, 2010, and 2015 were overlaid to obtain overlay maps. The year 2000 classified image was overlaid on 2005, 2005 overlaid on 2010, and the 2015 image overlaid on the 2010 image resulting in three overlay maps, one for 2000-2005, 2000-2010, and 2010-2015. The quantities in terms of area change for each of the intervals were also obtained from the post classification.

3.8 Determining the Accuracy of Land Cover Classification

Accuracy determination in land cover classification when using satellite images is crucial since it provides an analysis of how the classification is true in comparison with what is on the ground. The accuracy was done by making a comparison with data that had been verified from the field by use of an error matrix. This was performed by use of the QGIS software. Four categories of statistics were generated, that is, producers' accuracy, user's accuracy, overall accuracy, and the kappa index. The producer's accuracy evaluated the error arising from the omission of pixels of the image for a given land cover category during the classification of the satellite image. It shows how precise the classification was carried out from the dimension of the one doing the image interpretation and was calculated by dividing the correctly classified pixels for any given land cover category by the total number of pixels for the same land cover category. The overall accuracy described the average accuracy from the classification and is calculated by diving the number of pixels that were classified correctly in the image by the total number of pixels within the image.

The user's accuracy determined the error of commission that happened during the image classification and depicted the number of image pixels that were classified erroneously within a given land cover category. The user's accuracy evaluated the accuracy from the user's perspective and showed the number of pixels on the map that was what the classification said they were for all the land cover categories. It was calculated by dividing the number of correctly classified pixels for any specific land cover class by the total number of pixels assigned to that class.

The Kappa index showed the agreement that existed between the preliminary interpretation of the satellite image data and the field-validated data. The Kappa index was obtained by subtracting the expected agreement from the actual agreement after which the result was divided by one minus the expected agreement. In the instance there is a total agreement, $K = 1$, and in scenarios in which there is no agreement, $K = 0$.This process was undertaken by use of the accuracy assessment tool in QGIS.

4.0 Results and Discussion

In this chapter, the results of the Land cover change analysis will be analyzed under post-classification visual comparison, the area change comparison, the trends as well as the magnitude of the changes, the class overlays as well as the NDVI results.

4.1 Post Classification Visual and Area Comparison

Figures 8, 9, 10, and 11 below show the classified images for the years 2000, 2005, 2010, and 2015, respectively. In the year 2000(figure 8) the forest cover was not much disturbed and represented 30% of the total area followed by other categories which comprised of newly prepared farms. The 2000 classified image showed that deep forests as well as the other categories had the highest area among the other land categories. The forest cover was evenly distributed across the area of study. The light forest had the lowest coverage in the year 2000 classified image. The area under the bare land category had more areal coverage compared to the other vegetation category as shown below. The land cover categories for the year 2000 were also displayed in a pie chart to demonstrate the percentage that each of the categories occupied. Deep forest had a percentage of 31% whereas light forest had 2%. The other category had the highest coverage at 46 %, other vegetation had 13% of the total area while bare land occupied the lowest coverage with 8% as shown in figure 9 below.

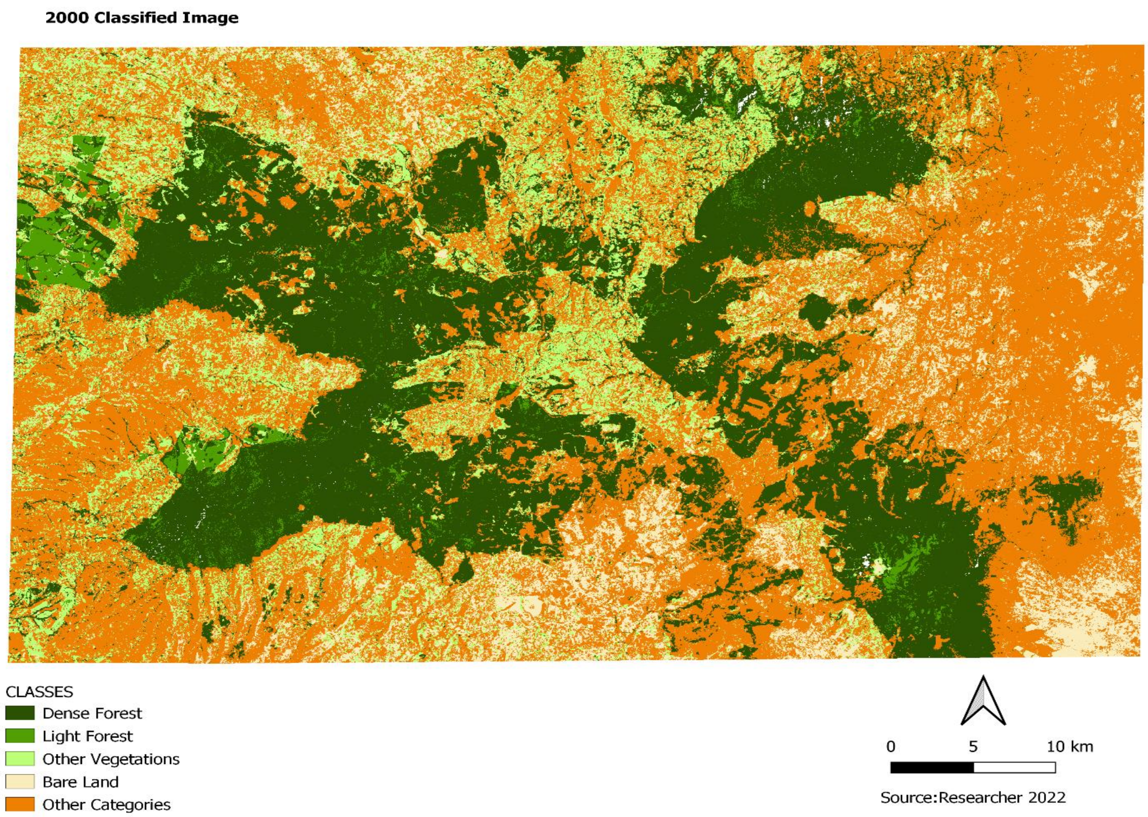


Figure 6: Classified Image for the year 2000

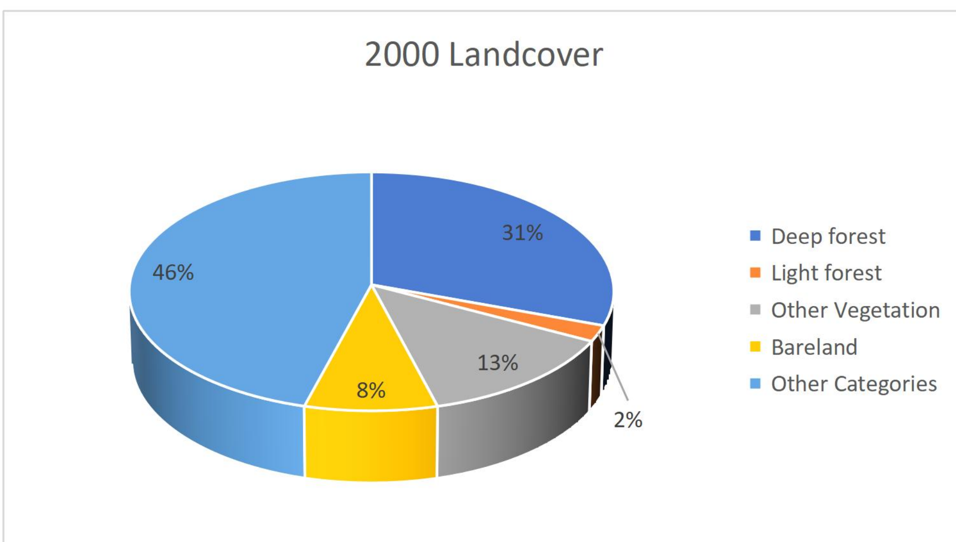


Figure 7: Percentage coverage of land cover categories in 2000.

The year 2005 classified image showed a relative increase in the area under deep forest by cover 14,307.4 hectares whereas the area under light forest decreased by 5,078.3 hectares. Other vegetation decreased by 7173 hectares, bare land decreased by 222,043 hectares while other categories increased by 20,269.7 hectares. During this period, the government of the day had ordered the cutting down of some portions of the forest to create several settlement schemes within the Mau Forest aimed at resettling the Ogiek community as well as other people who had been rendered homeless due to the clashes that emanated from Kenya's general elections in the years 1992 as well as 1997. The slight increase in the deep forest may have been brought up by the efforts of the Mau rehabilitation secretariat task force that fought for a general increase in tree cover on previous bare land.

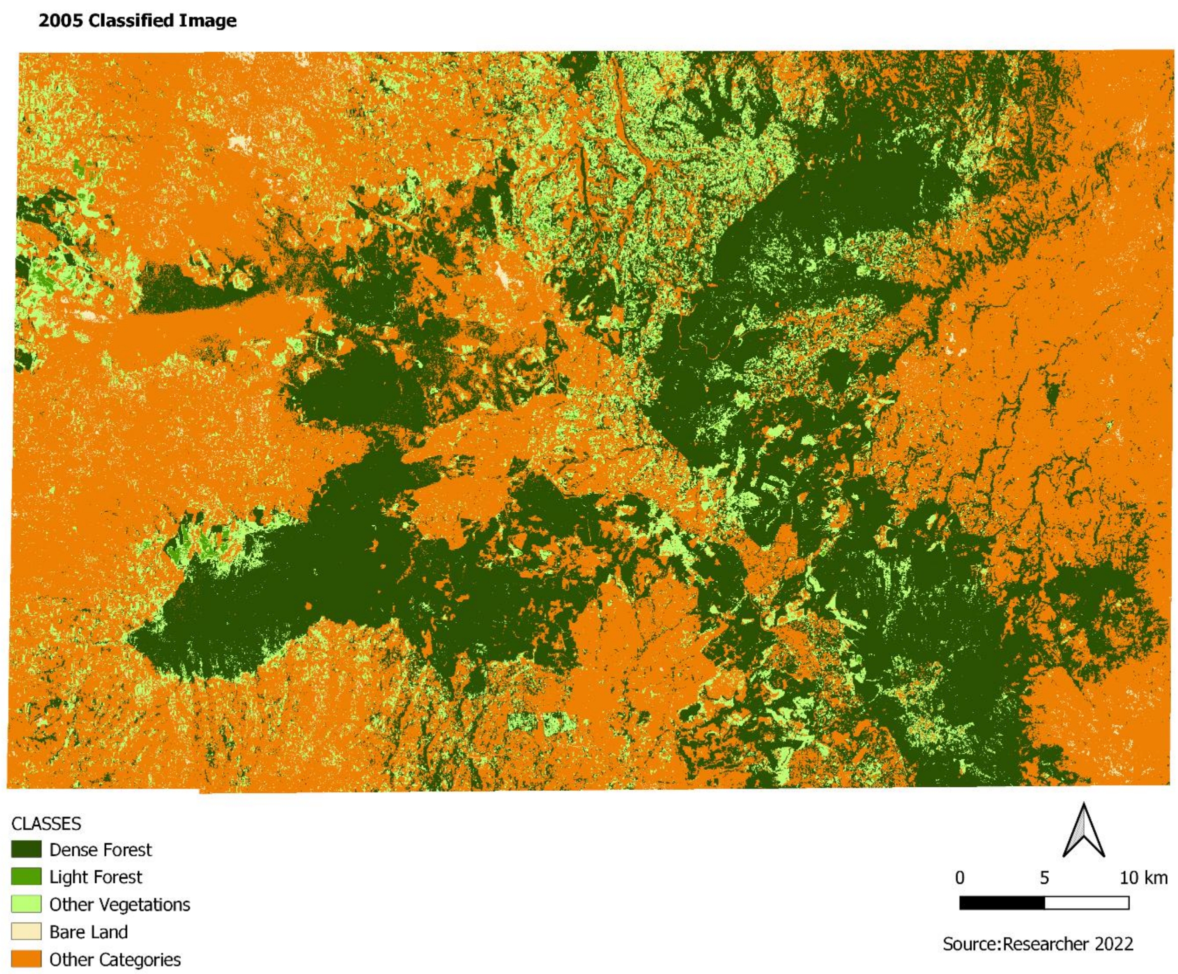


Figure 8: Classified image for the year 2005

The results for the 2005 classified image were displayed in a pie chart to show the percentage coverage of each of the land categories. The dense forest had a coverage of 35% of the total area of study whereas the light forest had coverage of less than 1%. The other category had the highest percentage at 53% whereas other vegetation had 11% of the total area. The region under bare land had the lowest area cover at 1% as shown in figure 10 below.

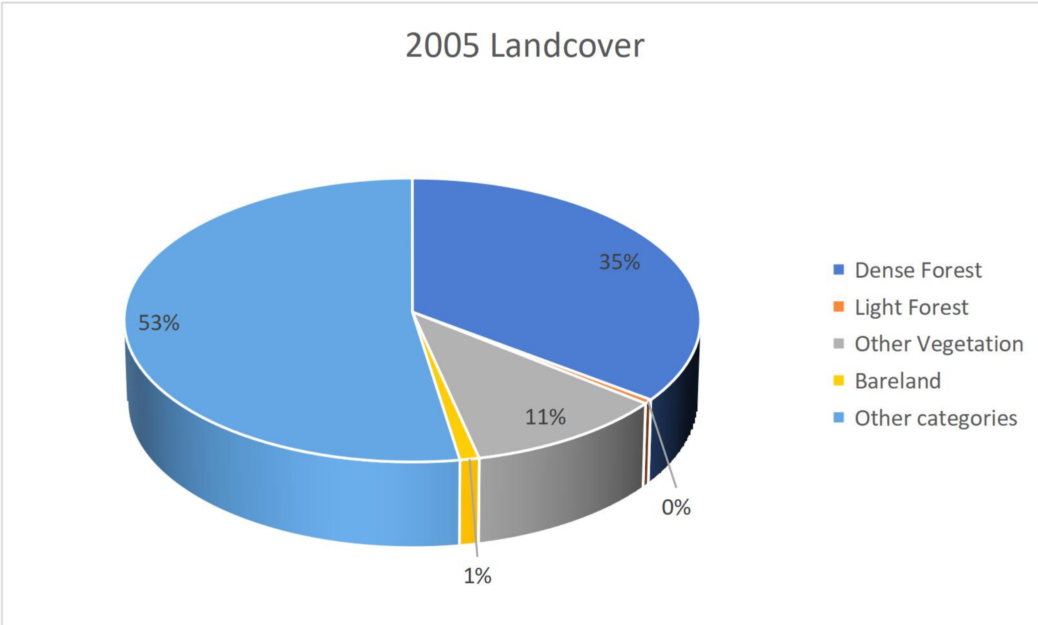


Figure 9: Percentage coverage of land cover categories 2005

The classified image 2010 (figure 10 below) showed a decrease in the area under deep forest and a massive increase in the other categories category compared to 2005. The deep forest decreased by 23,942 hectares with the other categories category increasing by 26,213 hectares. There was a slight increase in the area under light forest by 1512 hectares whereas the area under other vegetation reduced by 1115 hectares compared to 2005. The bare land category reduced by 2667 hectares over this period compared to 2005. Increased anthropogenic activities as well as illegal land allocations contributed to the decrease in deep forests during this period

The coverage of each of the land cover categories for the year 2010 was also displayed in a pie chart as shown in diagram 11 below. Deep forest occupied 27% of the total area whereas 1% represented the light forest cover. The other category occupied 61% of the total area of study while other vegetation occupied 11 % of the area of study. The region under bare land had less than 1% of the total area.

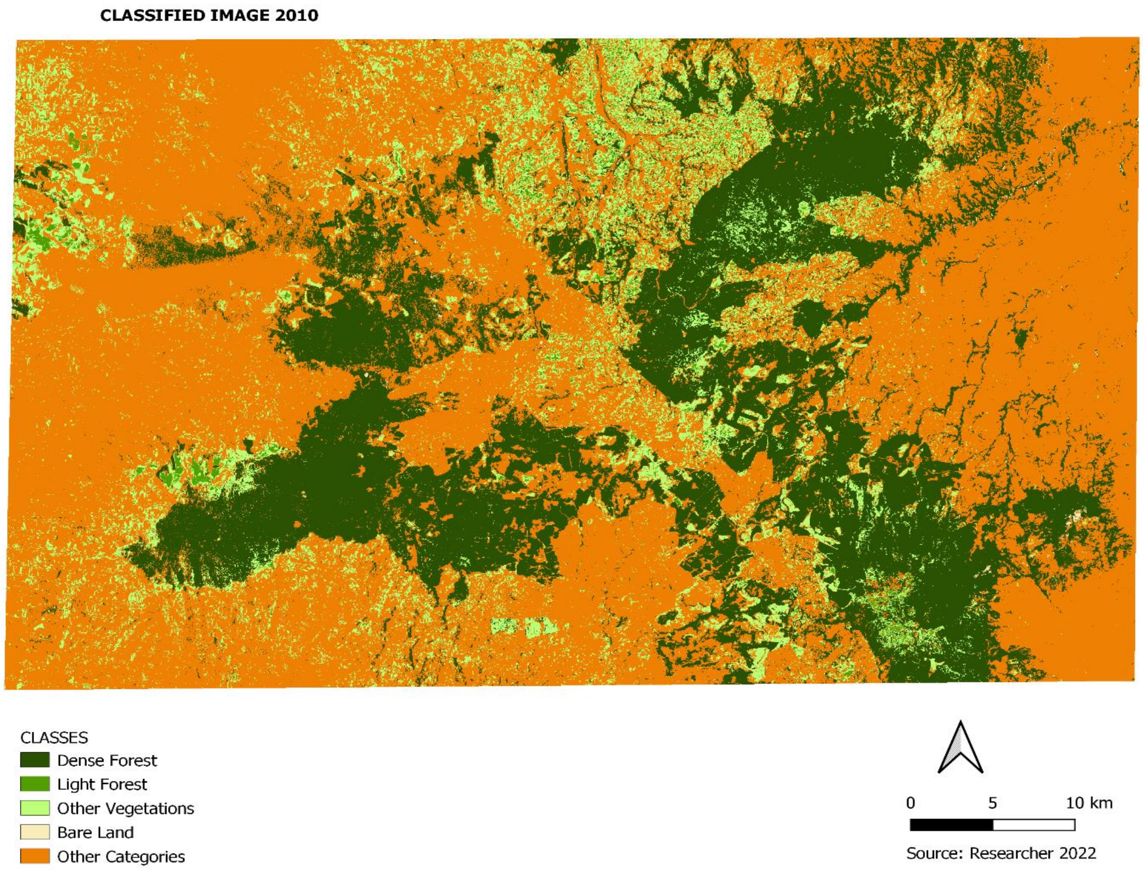


Figure 10: Classified Image for the year 2010

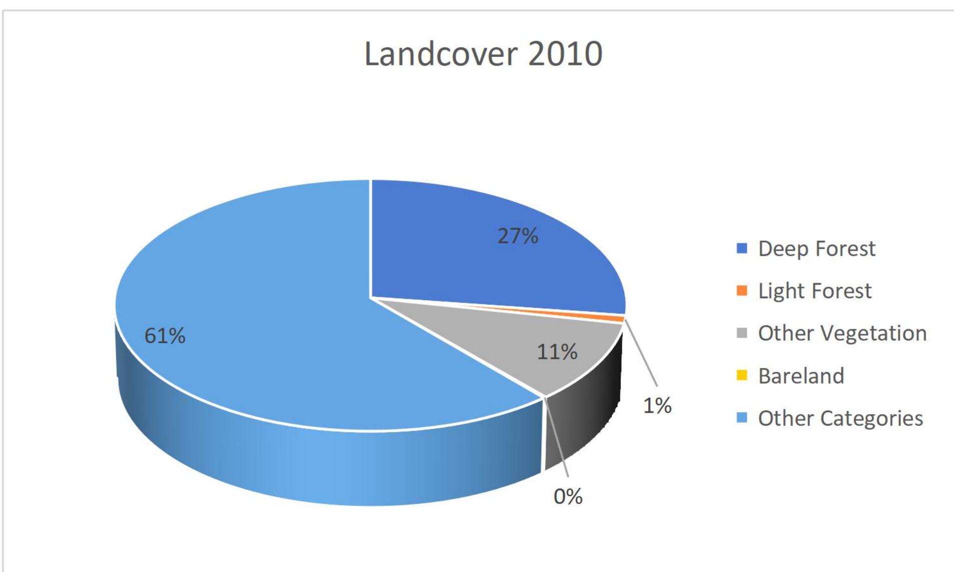


Figure 11: Percentage coverage of land cover categories 2010.

The 2015 classified image (figure 11 showed a reduction in the area under deep forest cover and a drastic increase in area under other vegetation compared to the year 2015. The area under deep forest decreased by 7124 hectares while the area under other vegetation increased by 43306 hectares, more than twice from the year 2010. The area under light forest too increased by 26413 hectares compared to 2005. The area under bare land increased by 4,785 hectares.

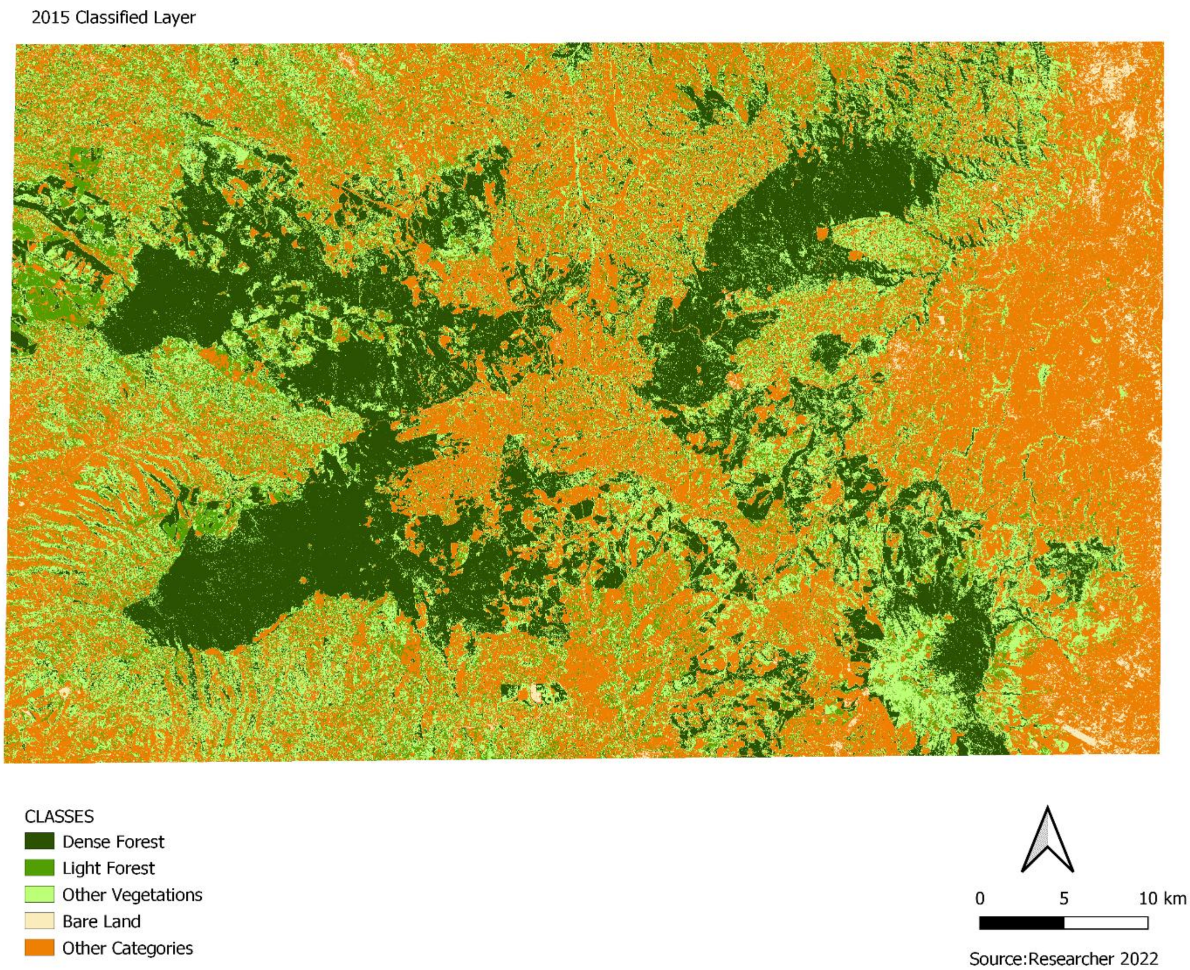


Figure 12: Classified image for the year 2015

The percentage distribution of each of the land cover categories for the year 2015 was also determined and is displayed in figure 12 below. The deep forest category occupied 25% of the total study area whereas light forest occupied 10% of the area. Other vegetation had 25% of the total area of study whereas other categories had 31% of the coverage. The area under bare land was only 1% of the total area.

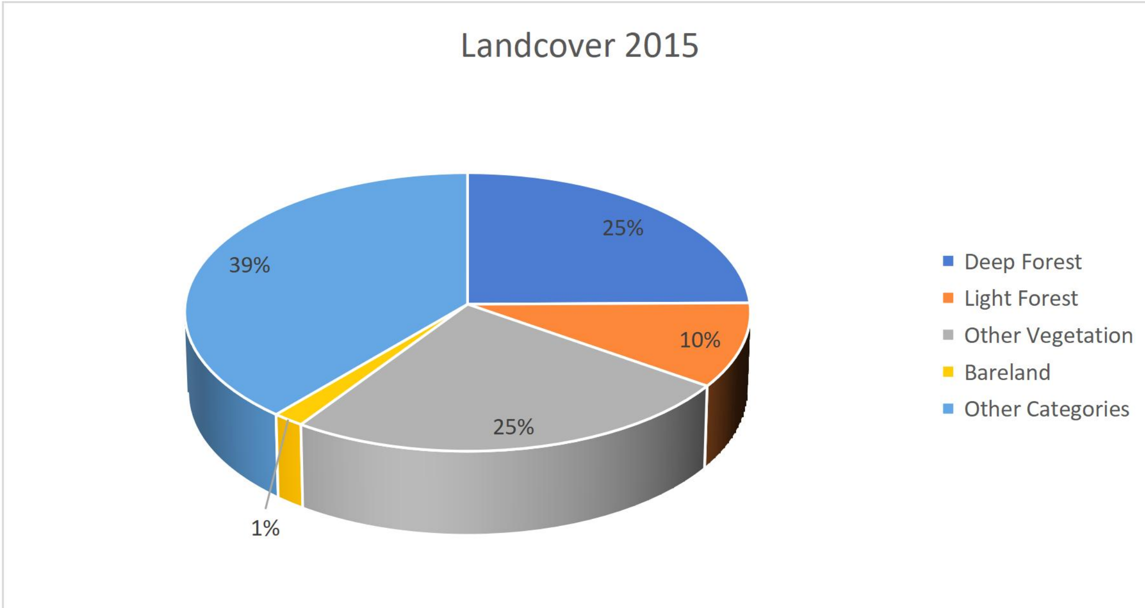


Figure 13: Percentage coverage of land cover categories for the year 2015.

4.3 Post Classification Area Coverage 2000 - 2015

For the land cover classified images(shown above), I made a summarized table below,in order to see better the area changes of any category in hectares. The full examined area was 299636.25 hectares.

CATEGORY	AREA IN HECTARES			
LANDCOVER CLASS	2000	2005	2010	2015
Deep forest	91221.84	105529.2525	81587.3175	74463.2775
Light forest	6546.2625	1467.9675	2979.45	29392.6725
Other Vegetation	39454.605	32281.5825	31166.3025	74472.0075
Bare land	25112.2725	3068.8425	401.6925	5186.9925
Other Categories	137018.8575	157288.6125	183501.495	116121.308

Table 3: Land Cover area for 2000, 2005, 2010 and 2015.

From the table 2 above, it was observed that the two forested areas (deep and light) sum was 97768 ha in 2000, while in 2015 this sum became 103856 ha. This meant that the meant the composition and the density of the forested area changed.

4.4 Thematic Class Overlays

The class overlays results showed that all the categories were undergoing a considerable amount of changes over the period. The deep forests and light forests and other vegetation were the major categories of interest for the study. The results are displayed in figures 12,13,14,15 and 16 below.

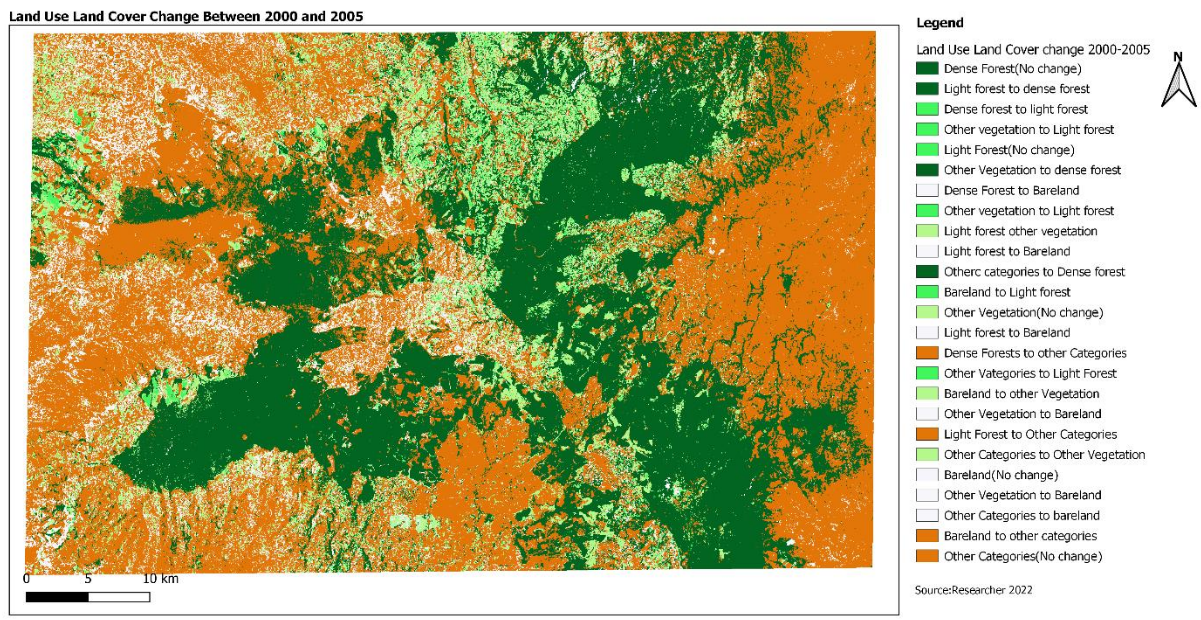


Figure 14: Land use land cover change 2000-2005

Figure 14 above shows how the land cover categories, that is deep forest, light forest, other vegetation, bare land, and other categories changed from and into each other from 2000 to 2005. According to table 3 below, the dense forest contributed to other land categories at the highest rate with 22,834.7 hectares being converted to other categories. This represented 24.57% of the total area of forest cover in 2000. In this amount, 96.8 hectares were converted to light forest, 4,886.8 hectares were converted to other vegetation, 180 hectares were converted to bare land, and 17,220.8 hectares were converted to other categories. The light forest category contributed 3,981.6 hectares to the rest of the category representing 60% of total cover in 2000 while other vegetation changed by 17,213.92 hectares to the rest of the categories. A total of 40,865.6 hectares of land under other categories class changed to the rest of the classes. Over the same period, there was a massive change in land cover from bare land to other categories comprising 24,323.7 hectares.

2000	2005	Area in Hectares
Dense Forest	Dense Forest	68838.57
Light Forest	Dense Forest	20859
Other Vegetation	Dense Forest	4378.825
Bare land	Dense Forest	1442.525
Other Categories	Dense Forest	28511.525
Dense Forest	Light forest	96.825
Light Forest	Light forest	52.235
Other Vegetation	Light forest	627.85
Bare land	Light Forest	60.85
Other Categories	Light forest	161.8
Dense Forest	Other vegetation	4886.8
Light forest	Other vegetation	2184.5
Other Vegetation	Other vegetation	11504.3
Bare land	Other vegetation	2831.425
Other Categories	Other vegetation	10871.3
Dense Forest	Bare land	180.25
Light Forest	Bare land	76.05
Other Vegetation	Bare land	702.95
Bare land	Bare land	788.1
Other Categories	Bare land	1321.875
Dense Forest	Other categories	17220.825
Light Forest	Other categories	1678.825
Other Vegetation	other categories	22240.125
Bare land	Other categories	19989.825
Other Categories	Other categories	96152.475

Table 4: Land Cover changes, 2000-2005

Figure 13 below the changes that took place between 2005 and 2010 among the five land cover categories. The areal changes between the two years have been shown in table 3 below. Over the period, the forest had changes of 24,607.5 hectares to the rest of the land cover categories representing 23.3% of total forest cover in 2005. From this, 1,443.3 hectares were changed to other vegetation, 195.8 hectares were converted to bare land, whereas 22,968 hectares were converted to other categories. Light forest had minimal changes to other land cover classes over the period with only 37 hectares being converted to the rest of the classes representing 0.01% of the light forest cover in 2005. Other vegetation had a change of 2,835.3 hectares to other land cover classes representing 8.7% of the total cover in 2005. Of this, 1416.4 hectares changed to light forest whereas 1,418.9 changed to other categories. Bare land had significant changes too with 3,058.3 hectares changing to other land cover categories and this was approximately 98% of the total coverage in 2005. The other categories category had considerable change over the period having a change of 997 hectares which represented 0.06% of the changes. This was the lowest rate of change over the period.

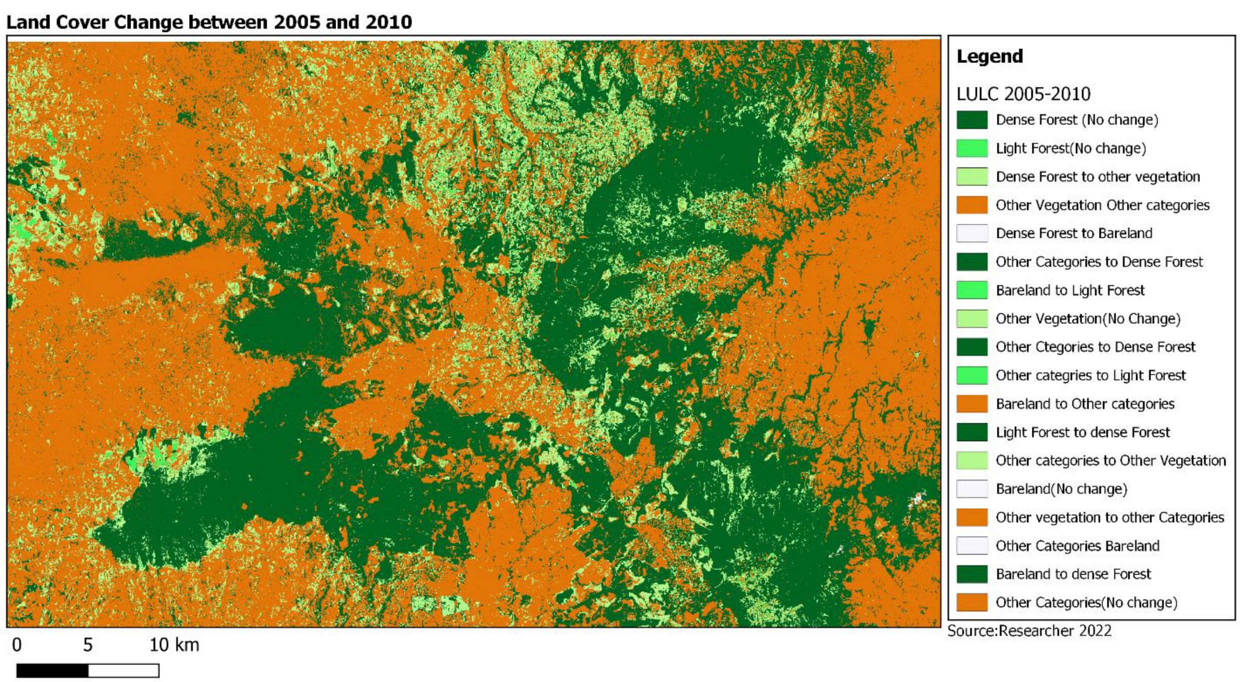


Figure 15: Land cover changes from 2005 to 2010

2005	2010	Area in Hectares
Dense Forest	Dense Forest	80921.8
Other Categories	Dense Forest	665.5
Light forest	Light Forest	1430.9
Other Vegetation	Light Forest	1416.4
Bare land	Light Forest	4.1
Other Categories	Light Forest	127.9
Dense forest	Other vegetation	1443.3
Other Vegetation	Other Vegetation	29446.3
Bare land	Other Vegetation	73
Other categories	Other vegetation	203.6
Dense forest	Bare land	195.4
Bare land	Bare land	10.5
Other Categories	Bare land	195.8
Dense Forest	Other Categories	22968.8
Light Forest	Other Categories	37
Other Vegetation	Other Categories	1418.9
Bare land	Other Categories	2981.2
Other Categories	Other Categories	156095.7

Table 5. Land cover changes between 2005 and 2010

Figure 14 below represents the changes that occured among the classes between the years 2010 and 2015. Table 15 below shows the areal change in hectares during the period. Deep forest had a change of 19,933 hectares to other land cover classes which represented 24.4% of the total coverage in 2010. From this, 125.2 hectares changed to light forests, 87.2 hectares changed to bare land and 19,720.6 hectares changed to other vegetation. Light forest had considerable changes over the period too, with a total of 11,377 hectares being converted to other land use classes. This represented less than 1 percent of the category's total in 2010. From this, 3,375.9 hectares changed to other vegetation, 2,544.6 hectares changed to deep forest, 5,432.8 hectares changed to other vegetation and 20,597.4 hectares changed to other categories. Other vegetation had a change of 65,106.3 hectares to other land cover categories, bare land changed by 5,166 hectares to other land cover classes while other categories changed by 22,077.3 hectares.

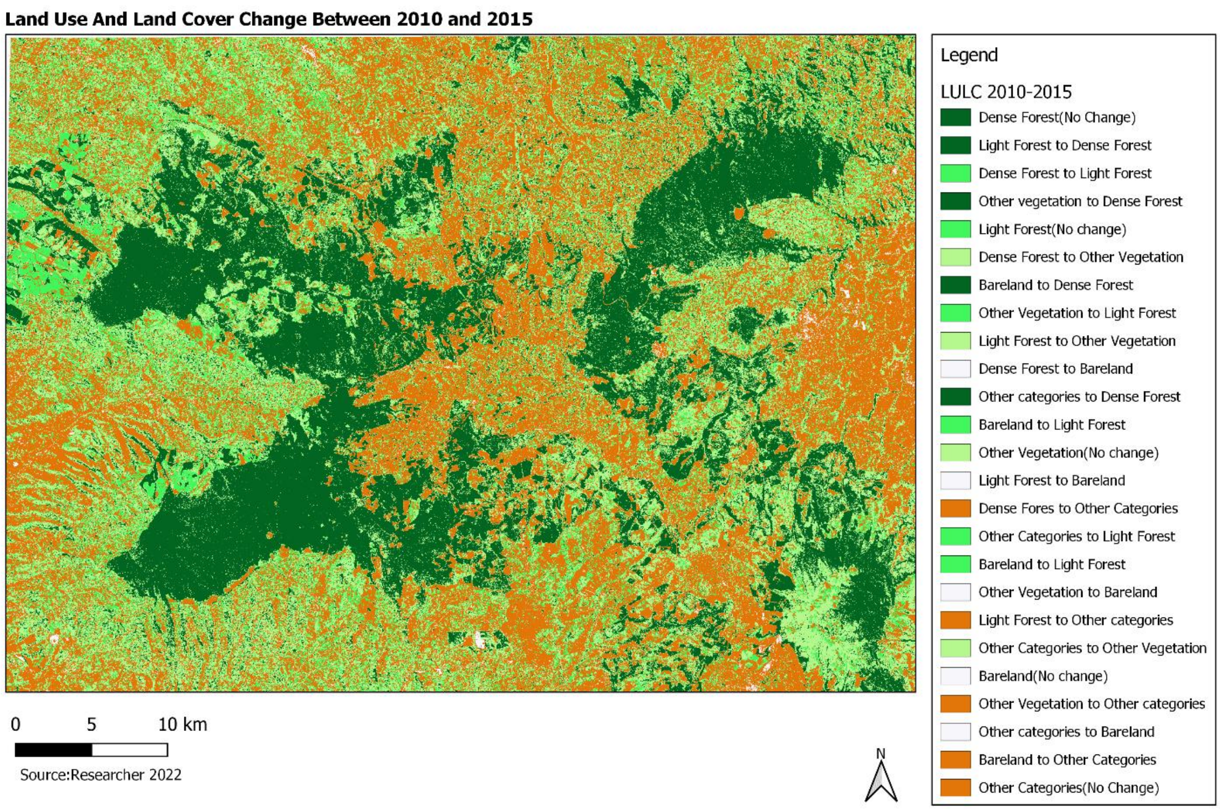


Figure 16: Land cover change 2010 - 2015

2015	2010	Area In Hectares
Deep Forest	Deep forest	51154.3575
Deep Forest	Light Forest	125.1675
Light Forest	Other Vegetation	3375.9
Deep Forest	Bare land	87.2325
Deep Forest	Other Vegetation	19720.62
Light Forest	Deep forest	2544.6825
Light Forest	Light Forest	793.62
Light Forest	Other Vegetation	5432.8275
Light Forest	Bare land	24.0975
Light Forest	Other Categories	20597.445
Other Vegetation	Deep forest	20069.325
Other Vegetation	Light Forest	722.0925
Other Vegetation	Other Vegetation	9365.805
Other Vegetation	Bare land	142.47
Other Vegetation	Other Categories	44172.315
Bare land	Deep forest	47.5875
Bare land	Light Forest	17.46
Bare land	Other Vegetation	136.8225
Bare land	Bare land	18.0675
Bare land	Other Categories	4967.055
Other Categories	Deep forest	7771.365
Other Categories	Light Forest	1321.11
Other Categories	Other Vegetation	12854.9475
Other Categories	Bare land	129.825
Other Categories	Other Categories	94044.06

Table 6: Land Cover changes between various Land Cover categories from 2010 to 2015

4.1 Accuracy Assessment Results

Accuracy in satellite image classification was computed based on the error matrix in which four statistics categories were applied. That is, producers' accuracy, user's accuracy, kappa index and overall classification accuracy. The four accuracy categories were applied to all the years under study. In the year 2000, the producer's accuracy was 92% for deep forest, 100% for light forest, 99.9% for other vegetation, 99.7 for bare land, and 84.4% for other categories. Within the same year, the user's accuracy was 99.9% for deep forest, 69.7% for light forest, 55% for bare land, 69% for other categories, and 99.8% for other categories. The Kappa index for dense forest was 0.99%, light forest had 0.69%, other vegetation had 0.52%, bare land had 0.67% whereas other categories had 0.99%. The overall accuracy was 89.35 whereas the Kappa index was 0.83 as shown in table 7 below.

> ERROR MATRIX (pixel count)						
> Reference						
V_ Classified	Deep Forest	Light Forest	Other Vegetation	Bare land	Other Categories	Total
Deep Forest	121156	0	0	0	92	121248
Light Forest	2962	6820	0	0	0	9782
Other Vegetation	0	0	1326	1	1049	2376
Bare land	0	0	4	4682	2089	6775
Other Categories	57	0	0	8	50467	50532
Total	124431	6820	1330	4691	53697	190969
> AREA-BASED ERROR MATRIX						
> Reference						
V_ Classified	Deep Forest	Light Forest	Other Vegetation	Bare land	Other Categories	Area
Deep Forest	0.2993	0	0	0	0.0002	912218400
Light Forest	0.0065	0.015	0	0	0	65462625
Other Vegetation	0	0	0.0723	0.0001	0.0572	394546050
Bare land	0	0	0	0.057	0.0254	251122725
Other Categories	0.0005	0	0	0.0001	0.4494	1370188575
Total	0.3233	0.015	0.0724	0.0571	0.5322	3045171375
Area	984526954	45640473	220336843	173926386	1620740720	3045171375
SE	0.0001	0.0001	0.0013	0.0005	0.0014	
SE area	373578	304130	4021237	1421606	4266143	
95% CI area	732213	596094	7881624	2786347	8361640	
PA [%]	92.5852	100	99.9327	99.7798	84.4321	
UA [%]	99.9241	69.7199	55.8081	69.107	99.8714	
Kappa hat	0.9989	0.6926	0.5236	0.6724	0.9973	
Overall accuracy [%] = 89.2996						
Kappa hat classification = 0.8352						
Area unit = metre^2						
SE = standard error						
CI = confidence interval						
PA = producer's accuracy						
UA = user's accuracy						

Table 7: Error Matrix for 2000 land Cover Classification.

In the year 2005, the producer's accuracy was 97.4% for dense forest, 100% for light forest, 100% for other vegetation, 99.9% for bare land, and 96.7% for other categories. The user's accuracy was 99% for dense forest, 99.8% for light forest, 80.8% for other vegetation, 84% for bare land, and 99% for other categories. Dense forest had a kappa index of 0.98, light forest had 0.99, and other vegetation had 0.79. Bare land had 0.83, whereas other categories had 0.99%. The overall accuracy for the classification was 95% whereas the Kappa index was 0.92 as shown in table 8 below.

> ERROR MATRIX (pixel count)						
	> Reference					
V_ Classified	Deep Forest	Light Forest	Other Vegetation	Bare land	Other Categories	Total
Dense Forests	112693	0	0	0	1063	113756
Light Forest	0	1332	0	0	2	1334
Other Vegetation	343	0	3662	0	523	4528
Bare land	0	0	0	1238	235	1473
Other Categories	136	0	0	1	80724	80861
Total	113172	1332	3662	1239	82547	201952
> AREA-BASED ERROR MATRIX						
	> Reference					
V_ Classified	Dense Forest	Light Forest	Other Vegetation	Bare land	Other Categories	Area
Dense Forest	0.3433	0	0	0	0.0032	1055292525
Light Forest	0	0.0048	0	0	0	14679675
Other Vegetation	0.008	0	0.0857	0	0.0122	322815825
Bare land	0	0	0	0.0085	0.0016	30688425
Other Categories	0.0009	0	0	0	0.5156	1572886125
Total	0.3522	0.0048	0.0857	0.0085	0.5327	3045171375
Area	1072530297	14657666	261075873	25811896	1622286843	3045171375
SE	0.0004	0	0.0006	0.0001	0.0005	
SE area	1324261	15557	1886954	293540	1606285	
95% CI area	2595552	30491	3698429	575339	3148319	
PA [%]	97.4734	100	100	99.9246	96.7906	
UA [%]	99.0655	99.8501	80.8746	84.0462	99.8306	
Kappa hat	0.9856	0.9985	0.7908	0.8391	0.9964	
Overall accuracy [%] = 95.7969						
Kappa hat classification = 0.9292						
Area unit = metre^2						
SE = standard error						
CI = confidence interval						
PA = producer's accuracy						
UA = user's accuracy						

Table 8: Error matrix for 2005 land cover classification

In the year 2010, the producer's accuracy was 67% for dense forest, 94.7% for light forest, 100% for other vegetation, 100% for bare land, and 99.9% for other categories. The user's accuracy was 99.9% for sense forest, 74.5% for light forest, 11% for other vegetation, 61% for bare land and 93% for other categories. In terms of Kappa index, dense forest had 1, light forest had 0.74, other vegetation had 0.1 bare land had 0.6 and other categories had 0.85. The overall accuracy was 85% with the user's accuracy over the year being 0.73% as shown in table 9 below.

> ERROR MATRIX (pixel count)						
	> Reference					
V_Classified	Dense Forest	Light Forest	Other Vegetation	Bare land	Other Categories	Total
Dense Forest	164580	0	0	0	4	164584
Light Forest	1378	4039	0	0	0	5417
Other Vegetation	9618	42	1245	0	56	10961
Light Forest	77	0	0	125	0	202
Other Categories	7152	3	0	0	105073	112228
Total	182805	4084	1245	125	105133	293392
> AREA-BASED ERROR MATRIX						
	> Reference					
V_Classified	Dense Forest	Light Forest	Other Categories	Bare land	Other Categories	Area
Dense Forest	0.2679	0	0	0	0	815873175
Light Forest	0.0025	0.0073	0	0	0	29794500
Other Vegetation	0.0898	0.0004	0.0116	0	0.0005	311663025
Bare land	0.0005	0	0	0.0008	0	4016925
Other Categories	0.0384	0	0	0	0.5642	1835014950
Total	0.3991	0.0077	0.0116	0.0008	0.5647	3045171375
Area	1215380973	23458518	35400097	2485721	1719637266	3045171375
SE	0.0005	0.0001	0.0003	0	0.0004	
SE area	1671287	256358	944622	137608	1355021	
95% CI area	3275723	502463	1851460	269712	2655842	
PA [%]	67.1274	94.7001	100	100	99.9063	
UA [%]	99.9976	74.5616	11.3585	61.8812	93.6246	
Kappa hat	1	0.7436	0.1032	0.6185	0.8535	
Overall accuracy [%] = 85.1834						
Kappa hat classification = 0.7313						
Area unit = metre^2						
SE = standard error						
CI = confidence interval						
PA = producer's accuracy						
UA = user's accuracy						

Table 9: Error Matrix for 2010 land cover classification.

In 2015, the producer's accuracy was 95.4% for dense forest, 98.7% for light forest, 99.9% for light forest, 21% for bare land, and 84% for other categories. The user's accuracy was 99.6% for dense forest, 08.6% for light forest, 66.5% for other vegetation, 25.5% for bare land, and 99.2% for other categories. The kappa index was 0.99 for dense forest, 0.98 for light forest, 0.6 for other vegetation 0.24 for bare land, and 0.98 for other categories. The overall accuracy was 88.5% whereas the kappa index was 0.83 as shown in table 10 below.

> ERROR MATRIX (pixel count)						
	> Reference					
V_Classified						
Dense Forest	Dense Forest	Light Forest	Other Vegetation	Bare land	Other Categories	Total
Light Forest	22371	0	0	73	0	22444
Other Categories	0	1759	1	1	22	1783
Bare land	43	3	598	48	207	899
Other Categories	0	0	0	1386	4029	5415
Total	0	13	1	70	11675	11759
	22414	1775	600	1578	15933	42300
> AREA-BASED ERROR MATRIX						
	> Reference					
V_Classified	Deep Forest	Light Forest	Other Vegetation	Bare land	Other Categories	Area
Dense Forest	0.2437	0	0	0.0008	0	744632775
Light Forest	0	0.0952	0.0001	0.0001	0.0012	293926725
Other Vegetation	0.0117	0.0008	0.1627	0.0131	0.0563	744720075
Bare land	0	0	0	0.0044	0.0127	51869925
Other Categories	0	0.0004	0	0.0023	0.3786	1161213075
Total	0.2554	0.0965	0.1628	0.0205	0.4488	3045171375
Area	777831476	293739261	495639134	62538354	1366614350	3045171375
SE	0.0017	0.0006	0.0039	0.0019	0.0035	
SE area	5311091	1680632	11729711	5665278	10533836	
95% CI area	10409739	3294040	22990234	11103945	20646318	
PA [%]	95.4205	98.7169	99.9468	21.2292	84.3631	
UA [%]	99.6747	98.654	66.5184	25.5956	99.2857	
Kappa hat	0.9956	0.9851	0.6001	0.2404	0.987	
Overall accuracy [%] = 88.4598						
Kappa hat classification = 0.8390						
Area unit = metre^2						
SE = standard error						
CI = confidence interval						
PA = producer's accuracy						
UA = user's accuracy						

Table 10: Error Matrix for 2015 Land Cover Classification

4.4 Trends in Land Cover Change

There was a varying trend in changes in each land cover category from 2000 to 2015 in which some categories had a decrease whereas some had an increase in acreage. Table 5 below shows the trends and the rate of the changes that took place between various categories from 2000 to 2015. Between 2000 and 2005, deep forest increased by 14,307.4 hectares (15.5%), light forest decreased by 5,078.3 hectares (77.5%) while other vegetation decreased by 7173 hectares (18.1%). Bare land had the highest decrease with 22,043 hectares which represented a change of 87.7% whereas other categories increased by 20,269.7 hectares (14.8%). The light forest cover was being lost to other categories especially farming activities.

In the period between 2005 and 2010, the deep forest decreased by 23,942 hectares (22.7%), light forest decreased by 1,511 hectares (102%) and other vegetation decreased by 1115.28 hectares (3.5%). Bare land decreased by 2667 hectares (87%) whereas other categories increased by 26,212.9 hectares (16.7%). The deep and the light forest were being lost to other categories especially farming during this period.

The period between 2010 and 2015 had the most massive rates of change in bare land and light forest categories. Over this period, deep forest decreased by 7,124 hectares (8.7), light forest increased by 26,413.2 hectares (886%) while other vegetation had an increase of 43,305.7 hectares (138%). The area under the bare land category increased by 47,785.2 hectares (1193%) whereas the area under other categories decreased by 67,380 hectares (36.7%). The intense agricultural activities during this period resulted in an increase in the other vegetation category. Increased land cover under light forest was contributed by the various task force advocating for tree planting in the Mau. These changes can be justified by the fact that increased human activities within the forest led to more conversion of forested land to farmlands, settlement areas as well as tree logging to obtain timber and hence the slight increase in the area under other categories over the period.The table 10 below shows the trends in land cover changes.

	Change In Ha	% Change	Change in Ha	% Change	Change in Ha	% Change
Land Cover Category	2000-2005		2005-2010		2010-2015	
Deep forest	14307.4	15.50%	-23,942	22.70%	-7124	8.70%
Light forest	-5,078.30	77.50%	1,511.50	102%	26,413.20	886.00
Other Vegetation	-7173	18.10%	-1,115.28	3.50%	43,305.70	138%
Bare land	-22,043	87.70%	-2667	87%	4,785.20	1193%
Other Categories	20,269.70	14.80%	26,212.90	16.70%	-67,380	36.7

Table 11: Trends and rates of Land Cover change

The results obtained from the visual comparison, area comparison, class overlays as well as the trends in land use within the Mau Forest point out that the forest has been undergoing extreme land cover changes and that the forest cover has been degraded.

4.5 Normalized Difference Vegetation Index results

The NDVI results were used alongside classification to show plant health over the period of study. The major slices of concern regarding plants were 0.25-1.00 microns and the rest of the values below this were not used within the analysis. Figures 15, 16, 17 and 18 show a visual comparison between the NDVI slice from 2000 to 2015. There was a relative change in NDVI across all the years. Slices ranging from 0.75 - 1.00 decreased by 29, 776 from 2000 to 2005. Slices ranging from 0.5 – 0.75 increased by 180, 678.1 hectares whereas slices between 0.25 – 0.5 decreased by 111,902 hectares. The general deterioration in the vegetation health may have been contributed by the reduction in the intensity of the light forest and other vegetation categories over the period. Figures 17 and 18 below show the NDVI images for 2000 and 20005.

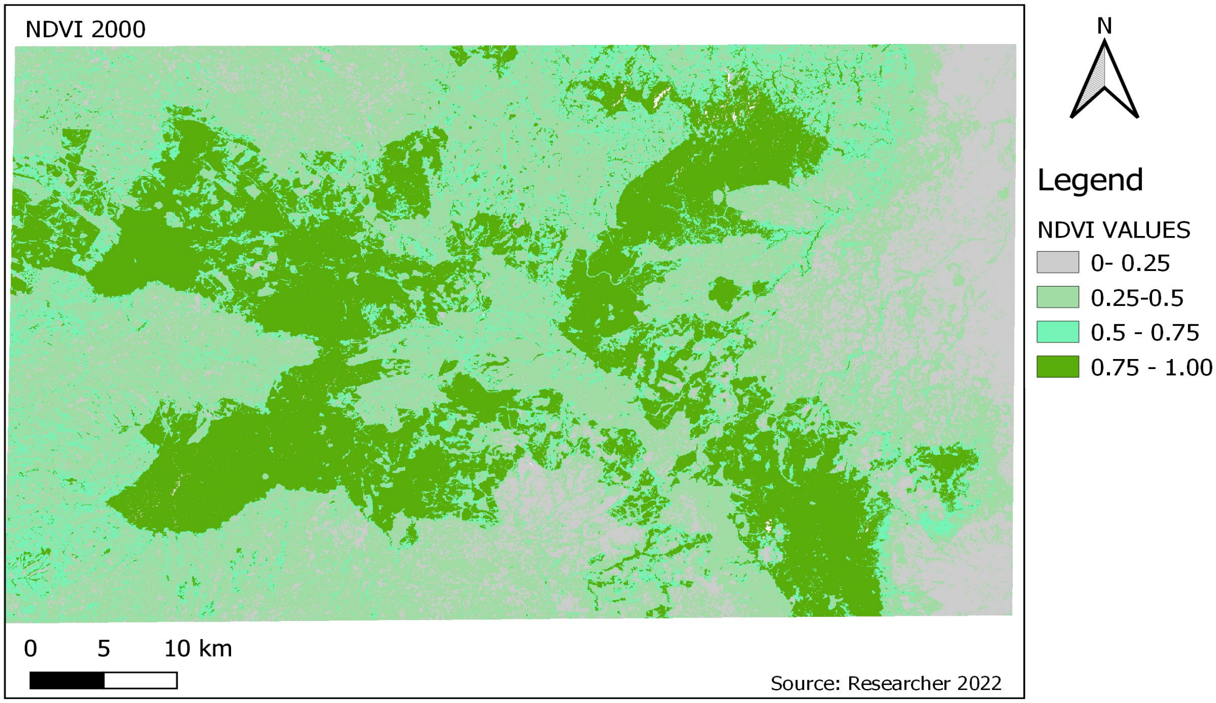


Figure 17: NDVI Image 2000

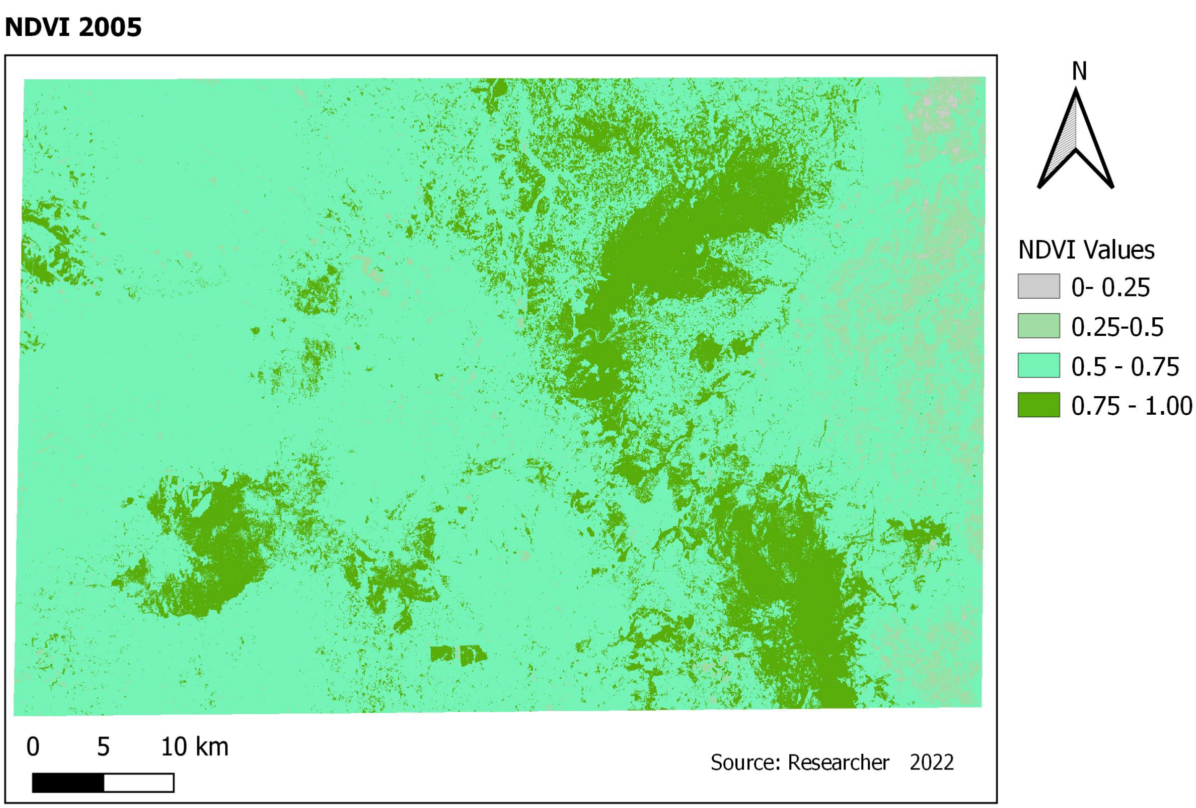


Figure 18: NDVI image 2005

The period between 2005 and 2010 had a decrease of 8,298.1 hectares in slices 0.25 – 0.5, slices between 0.5 – 0.75 reduced by 144,069 hectares while slices between 0.75 – 1.00 increased by 15, 493 hectares. In the period between 2010 and 2015, NDVI slices between 0.25 – 0.5 had a decrease of 287 hectares, 0.5 – 0.75 hectares decreased by 11,199.7 hectares whereas the slices between 0.75 – 1.00 increased by 12,921.8. Although there was a reduction in area under deep forest, the increase in plant health over this time increased due to the increase in the area under other vegetation as well as light forest. Figures 19 and 20 below show the NDVI images for the years 2010 and 2015.

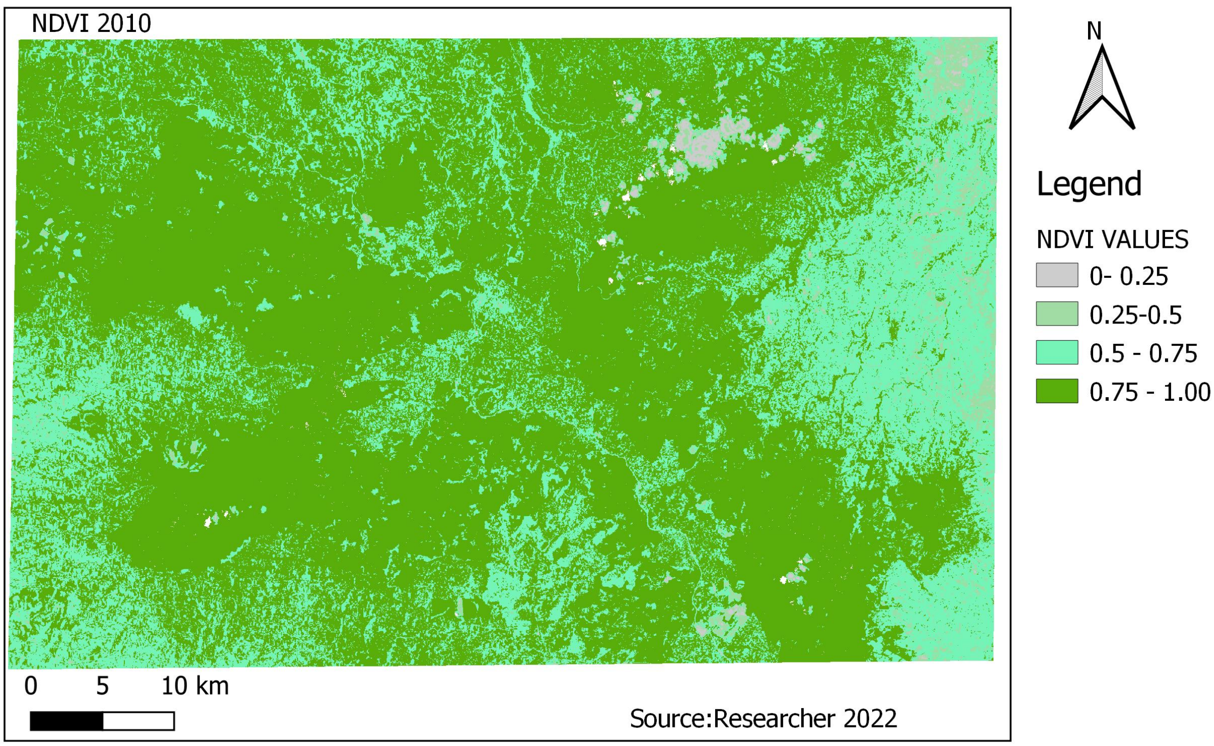


Figure 19: NDVI image year 2010

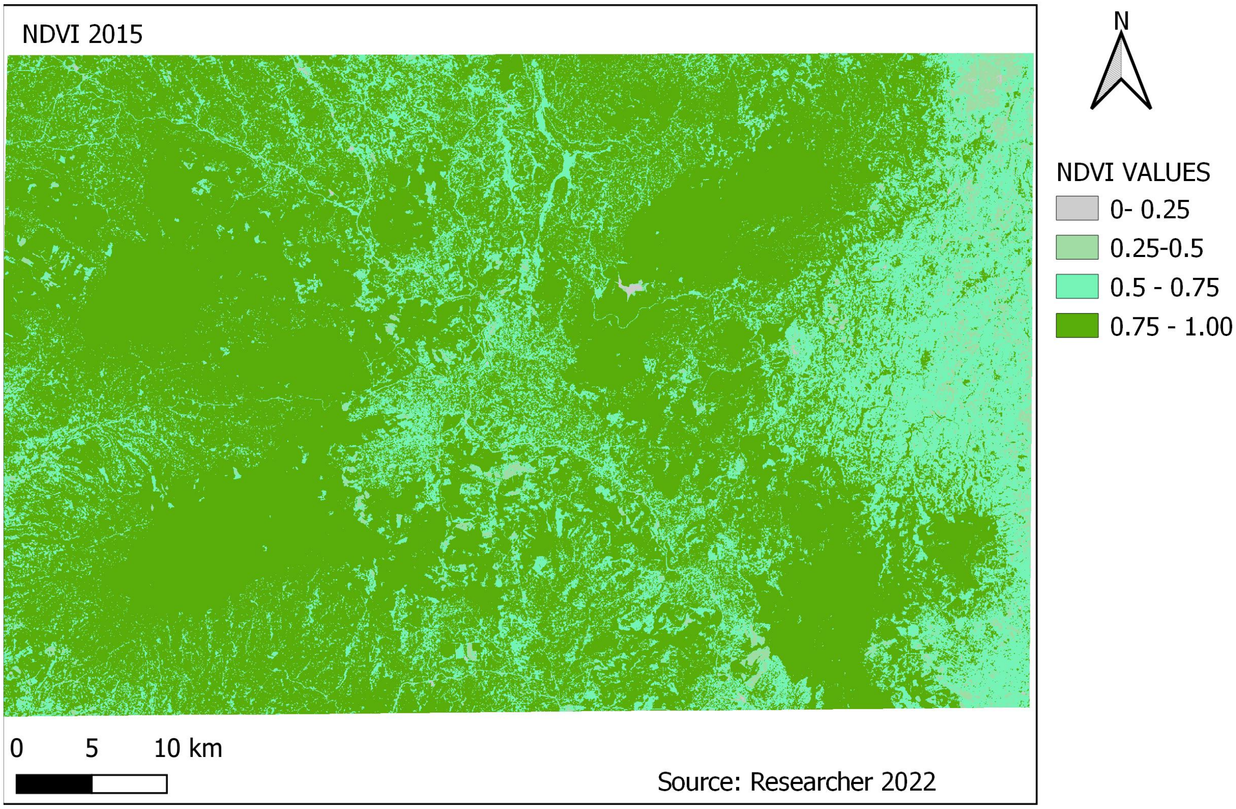
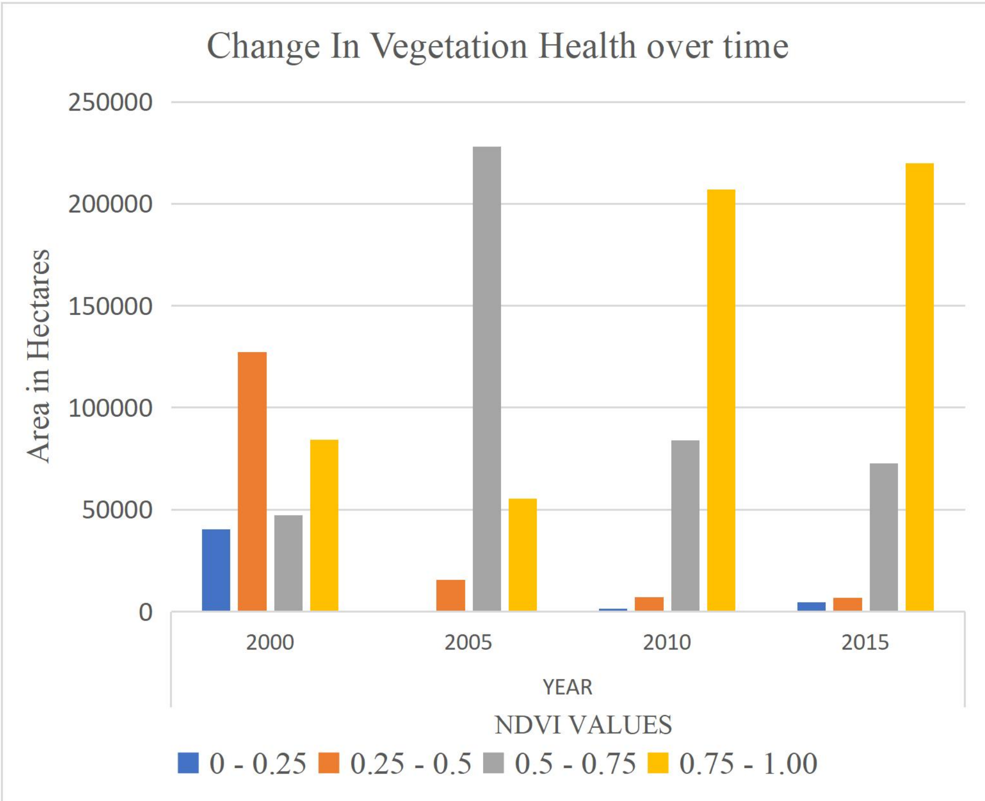


Figure 20: NDVI image 2015

The change in NDVI over the period of study was also displayed in a bar graph to show the trend over the years as shown in figure 21 below. The graph shows a relative decrease in the plant health between 2000 and 2005 and then increased plant health from 2005 to 2015, changes which resulted from increased crop cover especially tea.

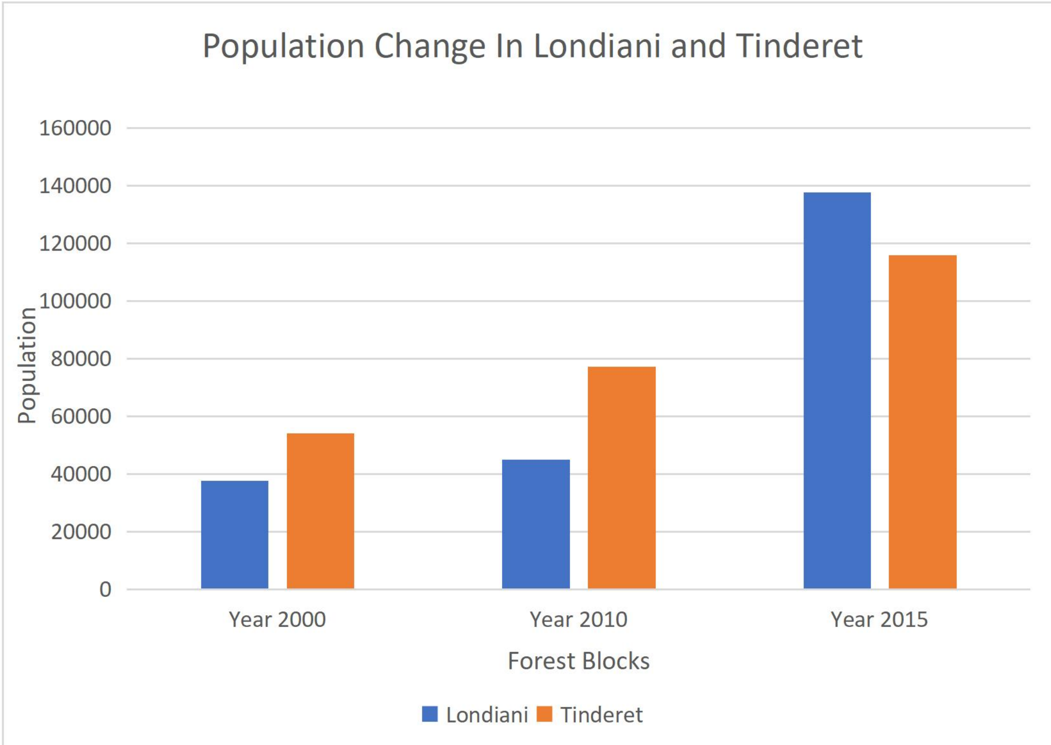


Data source: https://www.knbs.or.ke/

Figure 21: Change in vegetation health 2000 to 2015

4.6 Population Change

The study noted that land cover was taking place because of increased human activities within the Northern Mau Forest region. Population figures over two forest blocks, Tinderet and Londiani were taken and compared with each other to monitor the population trend with an assumption that there was a similar population increase within the other Forest blocks. Only three years were included since the National census takes place every 10 years in Kenya. The data that was used was for the census which took place in 1999, 2009 and 2019. The results showed that the population over the years from 1999 has been increasing rapidly and this has resulted in increased economic activities within the forest blocks, especially agriculture and logging and this happens as the people look for means of livelihood. Table 19 below shows the population change that took place.



Data source: https://www.knbs.or.ke/

Figure 22: Population Change in Tinderet and Londiani

4.7 Drivers of the land cover change

Different causes of the land cover changes within the Northern Mau Forest were identified and they included increased crop cultivation within the forest, tree logging, building of settlement areas, charcoal burning, grazing of livestock and livestock grazing within the forested area. It was noted that a lot of the changes resulted from human activities. Agriculture was the leading cause of the changes, and this happened due to the increased demand for land for cultivation because of increased population. The increase in population also led to the setting up of settlements and the growth of shopping centers.

Within the Mau Forest, the most common source of fuel is firewood and charcoal and the increase in population led to more demand leading to forest degradation. There were also instances in which the charcoal burning resulted in forest fires. Traditional farming practices such as the burning of vegetation as a method of clearing farmlands for cultivation also resulted to the fires. There is also a lack of governance in regarding forest protection and this had led to illegal cutting down of trees. The slight increase in the light forest during the period of study was brought up by the ministry of forest efforts to increase the area under forest cover within the forest.

5.0 Conclusions and Recommendations

Conclusion

The study conducted revealed that the Northern Mau Forest block had undergone changes over the period of study due to numerous factors and this had resulted in the reduction on the area under forest cover. The research conducted answered the research questions that had been set up for the study.

Between 2000 and 2005, deep forest increased by 14,307.4 hectares (15.5%), light forest decreased by 5,078.3 hectares (77.5%) while other vegetation decreased by 7173 hectares (18.1%). Bare land decreased by 22,043 hectares which represented a change of 87.7% whereas other categories increased by 20,269.7 hectares (14.8%).

Between 2005 and 2010, the deep forest decreased by 23,942 hectares (22.7%), light forest decreased by 1,511 hectares (102%) and other vegetation decreased by 1115.28 hectares (3.5%). Bare land decreased by 2667 hectares (87%) whereas other categories increased by 26,212.9 hectares (16.7%).

Between 2010 and 2015, deep forest decreased by 7,124 hectares (8.7), light forest increased by 26,413.2 hectares (886%) while other vegetation had an increase of 43,305.7 hectares (138%). The area under the bare land category increased by 47,785.2 hectares (1193%) whereas the area under other categories decreased by 67,380 hectares (36.7%).

Increased agricultural activities were the main causes of the changes being experienced in the Northern Mau Forest. Other causes of the changes within the forest included tree logging and charcoal burning. Increased population within the study area was a key factor to the changes that occured.

Recommendations

After conducting the research, the researcher made up the following recommendations that would be useful to the government and the local communities:

1. Settlement of people in forested areas should be stopped as this has been a major cause of forest reductions in the area of study.

2. It is also necessary to keep on carrying out studies on the changes that are occurring within the Mau Forest as a way of having up to update information on the current trends within the forest so that the ministry of forestry and other concerned parties can take appropriate measures.

On the causes of the land cover change which were identified within the Northern Mau Forest Block, the study recommends that:

1. The Kenyan government under the Ministry of Forestry should promote the usage of alternative forms of energy apart from firewood to reduce over-reliance on firewood for fuel.
2. The cutting down of trees to create agricultural land should be prohibited and strict laws put to reduce it.

REFERENCES

Acker, J. G., & Leptoukh, G. (2007). Online analysis enhances use of NASA earth science data. *Eos, Transactions American Geophysical Union*, *88*(2), 14-17, https://doi.org/10.1029/2007EO020003

Ayuyo, I. O. (2012). *Geospatial analysis of land cover and land use change in the Mau forest complex of Kenya* (Doctoral dissertation,University of Nairobi, Kenya).Doi: http://erepository.uonbi.ac.ke:8080/xmlui/handle/123456789/6736

Chaudhry, S. (2021). Political Economy of Forest Degradation and Climate Changes in Kenya: Case Study of the Maasai Mau Forest

D.K.Langat, E.K Maranga, A.A.Aboud, J.K. ACheboiwo.(2016) "Role of Forest Resources to Local Livelihoods:The Case of East Mau Forest Ecosystem, Kenya", International Journal of Forestry Research, vol.2016, Article:id 4537354, 10 pages;https://doi.org/10.1155/2016/4537354

FAO, The state of the world's forests (2018) – forest pathways to sustainable development. Rome. Accessed online on 5th Feb 2022 Available from http://www.fao.org/3/i9535en/i9535en. Pdf

Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., & Foley, J. A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, *107*(38), 16732-16737.

Government of Kenya (GoK). 2009. Interim Coordinating Committee: Office of the Prime Minister: "Frequently Asked Questions About the Mau Forest Complex" (Version 1, November 2, 2009).

Hansen, M. C., Stehman, S. V., & Potapov, P. V. (2010). Quantification of global gross forest cover loss. Proceedings of the National Academy of Sciences, 107(19), 8650-8655.https://doi.org/10.1073/pnas.0912668107

KFWG, Kenya Forests Working Group.(2001) Excision and settlement in the Mau Forest. Kenya Forest Working Group report, Nairobi, Kenya.

Jacqueline M. Klopp (2001) "'Ethnic Clashes' and Winning Elections: The Case of Kenya's Electoral Despotism." Canadian Journal of African Studies 35,vol. 2 : 473-517.DOI:10.1080/00083968.2001.10751230

James K. A. Benhin (2006) "Agriculture and Deforestation in the Tropics: A Critical Theoretical and Empirical Review," AMBIO: A Journal of the Human Environment, 35(1), 9-16,https://doi.org/10.1579/0044-7447-35.1.9

Kenya Forest Service (2019) Narok County profile on forestry and wildlife conservation, 25th Feb 2022

Kiage, L. M. (2006). Vegetational Change and Land Degradation in the Lake Baringo Area, Kenya, During the Late Holocene: Evidence from the Paleorecord and Remote Sensing.

Kinoti, K. D., & Mwangi, M. J. (2020). Assessment of Forest Rehabilitation and Restocking Along Mt. Kenya East Forest Reserve Using Remote Sensing Data. *African Journal of Science*, *1*, 1–16.

Minority Rights Group International (2012). World Directory of Minorities and Indigenous Peoples-Kenya:Hunter-gatherers:http://www.refworld.org/docid/49749cf84a.html [accessed 30 Feb 2022]

M. Tiffen, M. Mortimore, F. Gichuki (1994), More people, less erosion: environmental recovery in Kenya, ODI, London, UK.

National Environment Management Authority—NEMA.(2013) Mau Complex at a Glance-Report; National Environment Management Authority: Nairobi, Kenya.

Olang, Luke Omondi, and Peter Musula Kundu.(2011) Land degradation of the Mau Forest complex in Eastern Africa: a review for management and restoration planning. Vol. 528. In-Tech.

Swart, R. (2016). Monitoring 40 years of land use change in the Mau Forest Complex, Kenya. *A land use change driver analysis*, https://edepot.wur.nl/404611

Turner, B., Meyer, W. B., & Skole, D. L. (1994). Global land-use/land-cover change: towards an integrated study. In *Ambio* (pp. 91-95).

UNFCCC (1992). Available from https://unfccc.int/resource/docs/convkp/conveng.pdf, accessed on 22nd Feb 2022

UNEP (2005) Maasai Mau Forest Status Report, Nairobi, Kenya. Available from http://www.iapad. org/wp-content/uploads/2016/01/maasai_mau_report-1.pdf.accessed on 25th Feb 2022

Wass, P. (1995). *Kenya's indigenous forests*. IUCN, Gland, Switzerland, and Cambridge, UK in collaboration with ODA. https://agris.fao.org/agris-search/search.do?recordID=KE2005100339