ANALYSIS OF SPATIAL AND TEMPORAL LAND COVER CHANGE AND ASSOCIATED DRIVERS IN EASTERN MAU FOREST

BY

ANTONY ODUYA NDUBI

RESEARCH PROJECT SUBMITTED IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR MASTER OF ARTS DEGREE IN ENVIRONMENTAL PLANNING AND MANAGEMENT IN THE DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES, THE UNIVERSITY OF NAIROBI

NOVEMBER 2016

DECLARATION

This research project is my original work and has never been submitted for examination or degree award in any other University.

……………………………. ………………………………

Signature Date

Antony Oduya Ndubi

(C50/60306/2013)

This research project has been submitted for a degree award with our approval as University supervisors.

……..……………. Date……………..

Dr. Isaiah A. Nyandega,
Department of Geography and
Environmental Studies,
University of Nairobi.

………………………. Date………………..

Dr. Daniel E. Kapule,
Department of Geography and
Environmental Studies,
University of Nairobi.

DEDICATION

To my wife Resla Nabwire, my children Michelle Nelima, Stanely Ndubi, Bruno Okeka and Sandra Auma, and to my parents the late Simon Ndubi and Mama Celecenzia Nelima.

ACKNOWLEDGEMENT

I would like to express my gratitude to the University of Nairobi for granting me the opportunity to study. I would also like to thank the Wangari Maathai Institue for Peace and Environmental Studies for having funded the fieldwork in this study.

My appreciation also goes to my supervisors, Dr. Isaiah A. Nyandega and Dr. Daniel E. Kapule for their tireless guidance throughout my research period. I also thank Dr. Thuita Thenya for his time and guidance during the project proposal preparation stage.

Lastly, I thank my research assistants, Victor Cheres and Grace Chelgat for their support and assistance during field data collection.

TABLE OF CONTENTS

List of Figures

List of Plates

List of Tables

LIST OF ACRONYMS

ASALs	Arid and Semi-Arid Lands.
CBD	Convention on Biological Diversity.
CBOs	Community Based Organizations.
CFAs	Community Forest Associations.
DPC	District Peace Committee.
EfD	Environment for Development.
EMCA	Environmental Management and Coordination Act.
ESRI	Environmental Systems Research Institute.
ET	Evapo-Transpiration.
ETM	Enhanced Thematic Mapper.
FAO	Food and Agriculture Organization of the United Nations.
GCPs	Ground Control Points.
GIS	Geographical Information Systems.
GHG	Green House Gases.
GoK	Government of Kenya.
GPS	Global Positioning System.
ISRIC	International Soil Reference and Information Centre.
ITCZ	Inter-Tropical Convergence Zone.
KFS	Kenya Forest Service.
KFWG	Kenya Forests Working Group.
KNBS	Kenya National Bureau of Statistics.
KWS	Kenya Wildlife Service.
NASA	National Aeronautics and Space Administration.
NEAP	National Environment Action Plan.
NEMA	National Environment Management Authority.
NEPAD	New Partnership for African Development.
NTZDC	Nyayo Tea Zone Development Corporation.
OLI	Operational Land Imager.
REMA	Rwanda Environment Management Authority.
RGB	Red, Green and Blue.
SoK	Surveys of Kenya.
TM	Thematic Mapper.
UN	United Nations.
UNECD	United Nations Conference on Environment and Development.
UNEP	United Nations Environment Programme.
UNFCCC	United Nations Framework Convention on Climate Change.
UNFF	United Nations Forum on Forests.
USDA	United States Department of Agriculture.
USGS	United States Geological Survey.
WCED	World Commission on Environment and Development.
WRI	World Resources Institute.

ABSTRACT

Land cover changes in any ecosystem vary in space and time in terms of effects on ecosystem services. The spatial-temporal analysis of land cover changes in Eastern Mau Forest of Kenya was carried out to address the problems of types of land cover changes; nature of drivers of land cover changes and; resource use sustainability. The objectives of addressing the above problems were to determine the types and amount of spatial-temporal land cover changes; the drivers of land cover changes and; sustainable ways of using forest resources. The hypotheses used to guide in achieving the study objectives were that no significant land cover changes had occurred; there were no unique drivers behind land cover changes and; that forest resources use was sustainable in Eastern Mau Forest.

The data used in this study included Landsat imageries, topographic maps, forest boundaries, ground control points, sub-location and county boundaries, rivers shapefile, settlement shapefile, population data and forest resource use data. The data files were required in spatial-temporal analysis of forest cover change using geo-spatial and geo-statistical analysis techniques. The geo-spatial analysis techniques used were digital image classification, classification overlay and land cover change detection while the geo-statistical analysis techniques were area geometry computation, error matrix computation, temporal and spatial autocorrelation.

The results of data analysis showed that there were seven land cover classes in Eastern Mau Forest including indigenous forest, cropland, grassland, plantation forest, shrubland, built-up area and bare ground. In the 1986-2014 period plantation forest changed by 19,007.91 hectares, grassland by 7,227.54 hectares, indigenous forest by 6,052.32 hectares, shrubland by 3,008.79 hectares, cultivated fields by 57.96 hectares, built up area by 11.97 hectares and bare ground by 5.94 hectares. The study concluded that there was more land cover change on the eastern side of the area of study than on the western side; that indigenous and plantation forests were the most likely land cover types to disappear; that cropland and built up area expansions were the main drivers of land cover change; and that sustainable use of forest resources would only be possible if expansion in cropland was checked or reduced. The study therefore recommended that resettlement activities be reduced or eliminated in the Eastern Mau Forest area. Excision of forest land for crop cultivation should not be encouraged. Lastly, scientific research should be carried out on sustainable plantation forest activities and favourable exotic tree species as a measure against unchecked cropland expansion.

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background

Land cover change in forest ecosystems leads to forest degradation that has an effect of lowering levels of carbon sequestration thereby increasing carbon emissions into the atmosphere which consequently contributes to climate change. The land cover change in Eastern Mau Forest that mostly results from the different conflicting interests leads to massive forest loss. Little information is available on the amount of forest loss and this requires appropriate tools and approaches like Geographical Information Systems and Remote Sensing to determine the extent of forest destruction.

The main goal of this study was to determine the land cover changes that have taken place in Eastern Mau Forest between 1986 and 2014 as a result of forest resources use conflicts in form of different forest resources use interests. The study generated multi-temporal information on land cover in the forest for 1986, 1995, 2003 and 2014, and looked at the influence of forest resources use conflicts on land cover change in the Eastern Mau Forest. The multi-temporal land cover information was generated from medium resolution Landsat satellite images and this was later validated by field data collection through direct field observation. Resource use conflict information in terms of the different drivers of land cover change was also collected by visiting the area of study for direct field observation and interviewing different stakeholders.

The problem of resource use conflict and its impact on natural environment is one that has been felt in many parts of the world. Mostly, the impact has been degradation of the natural environment. Destruction of forests is leading to a serious water crisis as perennial rivers are becoming seasonal and downstream flooding of rivers is increasing. There is increasing loss of biodiversity as well as increase in carbon dioxide emissions as a result of forest cover loss. Poor soil and water resources conservation in deforested land leads to soil erosion and decreasing crop yields in areas of high agricultural potential. According to one of the Kenya Forests Working Group reports (KFWG, 2001), the Mau forests complex decreased in area by approximately 340km^2, translating to 9% forest loss, from 1964 to 2000. Rapid population growth and migrations to areas deemed to be favourable for agriculture are a concern in tropical regions worldwide due to the resultant rapid deforestation and ecosystem defragmentation (Tiffen et al, 1994).

Little information is available on spatial and temporal extent of land cover change that occurs as a result of natural resource use conflict. It is important that appropriate tools and approaches like Geographical Information Systems (GIS) and Remote Sensing are used to make information available for decision making and planning (Quaddus and Siddique, 2001). There is an enormous benefit gained by monitoring land cover changes as it provides information regarding areas that have little or no access as well as enable more efficient and cost effective land cover mapping (Maingi and Marsh, 2001).

Satellite images were interpreted and analysed using Geographical Information Systems (GIS) to map and quantify the different land cover types in the different years covered in this study and to also determine the land cover changes that have taken place in Eastern Mau Forest between 1986 and 2014. This study created linkages between changes in land cover that occur in the forest and the different ways in which different forest resources are utilized. The ways of forest resources utilization that were linked to land cover changes include: cultivation of crops, grazing of livestock, charcoal burning, firewood collection, bee keeping, medicine and wild fruits extraction, cutting trees for construction of houses and timber production by saw millers.

1.2. Statement of the Problem

Eastern Mau Forest Reserve continues to face the problem of deforestation due to the occurrence of land cover change within that particular forest ecosystem. This deforestation increases with time despite the fact that policies to safeguard forests against encroachment have been put in place. This study determined the type and amount of land cover change that occurred in Eastern Mau Forest between 1986 and 2014. The 1986 was used as the study datum because it is when policy gazettement of forest excision started to create the Nyayo Tea Zones from the natural forest conservation areas (KFMP, 1994). It was also in 1986 that the government policy banned the shamba system to resettle communities outside of gazetted forests (Adoyo et al, 2012), and it is this resettlement outside the forest conservancy areas that originated the forests resource use conflicts. The two actions by the government were in conflict with each other as a result of Nyayo Tea Zone Development Corporation constructing settlements for their employees on gazetted forest land. The study, therefore, determined the land cover change in general and deforestation in particular that had occurred after the government had put in place the two policies that were aimed at protecting the forest.

The study also determined the resource use conflicts that cause land cover change and deforestation in Eastern Mau Forest. Most of the time, when an issue of deforestation is being addressed, it is not looked at from the context of drivers of such destruction. It is important that the dimension of drivers of deforestation should always be part of the strategies that should be used in tackling such an issue. This is important because drivers of forest cover change emanate from different conflicting interests which should not be neglected because if they are not adequately addressed they will not fail to pose another challenge. All relevant stakeholders should always be brought on board so as to tackle the different forest cover change drivers. There should be initiatives to address both livelihood and conservation priorities as a means of diffusing conflicts between the communities that use forest resources and the state agencies responsible for forest resources conservation. Further, the study determined means of using forest resources sustainably as a way of providing solutions to the land cover change issues that result from different interests competing for forest resources.

1.2.1. Research Questions

This research attempted to solve the following questions:

1. What are the land cover changes that have taken place in Eastern Mau Forest between 1986 and 2014?
2. What are the resource use conflicts that cause land cover change in Eastern Mau Forest?
3. What should be done to ensure that use of resources in Eastern Mau Forest is sustainable and does not cause land cover change that degrades the environment?

1.3. Objective of the Study

1.3.1. General Objective

The general objective of the study was to determine the impact of resource use conflicts on land cover change in the Eastern Mau Forest.

1.3.2. Specific Objectives

Specific objectives of the study were:

1. To determine the type and amount of spatial and temporal land cover change in Eastern Mau Forest between 1986 and 2014.
2. To determine the drivers of land cover change in Eastern Mau Forest between 1986 and 2014.

3. To determine sustainable ways of using forest resources to minimize land cover change in Eastern Mau Forest.

1.4. Research Hypotheses

The hypotheses that were tested in this research were three null hypotheses. These hypotheses are:

1. There was no significant land cover change in Eastern Mau Forest between 1986 and 2014.
2. The drivers of land cover change in Eastern Mau Forest did not have a significant impact on forest cover change that occurred between 1986 and 2014.
3. There are no significant sustainable ways of using forest resources in Eastern Mau Forest.

1.5. Justification of the Study

It is important to generate information on the extent and impact of human activities on the natural environment. The generated information forms the basis for promoting sustainable development. This creates the need for a holistic approach that integrates information from different sources and enrich what is already existing. It is because of this need that the study used Remote Sensing and Geographical Information System tools to provide a platform for integrating such information and provide results on the types, amounts, trends and drivers of environmental change. Once these tools have been used to identify the available environmental problems and the underlying causes then it becomes easy to bring different stakeholders on board for the sake of tackling the common challenge as stipulated by Agenda 21 which prepared frameworks for bringing governments, Non-Governmental Organizations, businesses and universities into a joint effort to resolve the issues that could prevent the realization of sustainable development.

Information from previous studies in Eastern Mau forest indicate that plantation forests have been used in restoring forest degraded areas and provide economic value from their extraction. These studies did not bring out the fact that some exotic tree species like cypress and eucalyptus in the established plantation forests completely changed the original biodiversity state of the area because most of the herbaceous vegetation that previously existed in that area could no longer grow there after introduction of these exotic tree species. It is important to bring out the fact that it is necessary to do further research on the best ways of restoring degraded parts of the forest without changing the original indigenous state of the forest environment. This can be achieved by identifying exotic tree species that are favourable to the particular environment of concern. It is also important to show that the favourable plantation forests can be used to create a buffer around the Eastern Mau Forest area as a way of checking forest encroachment.

There is need to highlight the fact that there exists a gap on the guidelines on how the benefits from gazetted forests should be shared between the government and the local people who stay next to forests. This tends to discourage the local people from conserving forests as they hold the view that it is only the government that benefits from forest resources. It is, therefore, necessary to have clear guidelines on sharing of benefits that come from forest resources. This can be achieved by advocating for having relevant policies in place and ensuring their implementation. This is one way of ensuring that there is no further loss of forest cover.

1.6. Scope and Limitations

1.6.1. Scope

This study covered Eastern Mau Forest reserve with a spatial area of 659 km^2 within the Mau Forests Complex. The duration covered is 28 years from 1986 to 2014 with four time series covering 1986, 1995, 2003 and 2014. The study determined the land cover types in Eastern Mau Forest based on satellite imagery interpretation and field validation. Land cover statuses for the four different years covered were generated and land cover changes determined. The determined land cover changes were for the periods 1986-1995, 1995-2003, 2003-2014, and the overall change of between 1986 and 2014.

The study determined the different drivers of land cover change that come up in form of different conflicting interests in terms of resource use in Eastern Mau Forest and how they have impacted on the land cover changes that have been experienced between 1986 and 2014. It also determined the different unsustainable ways of using forest resources in Eastern Mau Forest contributing to land cover change.

The study generated information that will inform the relevant authorities like policy makers, planners and administrators on the land cover status in the Eastern Mau Forest, impact that comes from different resource use interests and unsustainable ways of using forest resources in Kenya and particularly in Eastern Mau Forest. It also gave recommendations on the policies that should be reviewed for sustainability of Eastern Mau Forest resources. Other recommendations were on the further research that should be done to help check the continued land cover change in Eastern Mau Forest.

1.6.2. Limitations

This study like many other studies had some limitations. First, the study had been planned to cover 30 years, from 1984 to 2014 with a 10 year interval between different years covered. This was not possible due to lack of cloudy free same season images for land cover interpretation. It is important that the images chosen for different years must be of the same season to enable realistic comparison between them. The season that was chosen for this study was that between January and February. Some of the available satellite images of 1984, 1994, 2004 and 2014 falling in that season were too cloudy to be used. It is because of this limitation that the years of study were changed to 1986, 1995, 2003 and 2014. This resulted in having a four time series land cover classification without a uniform interval between the years covered in the study.

There was a limitation in field data validation for 1986, 1995 and 2003 land cover classification generated from satellite images. This was because fieldwork was carried out in 2014 and the data collected from the field was used to validate all data sets from 1986 to 2014. It was not possible to go back in time and get field data of 1986, 1995 and 2003.

The study had a limitation of not being in a position to get all information on the drivers of land cover change in Eastern Mau Forest. This is because most of the key informants who provided information on the drivers of land cover change were themselves staying within the forest boundary. It is, therefore, possible that they could conceal some information from the researcher regarding the activities they are involved in, especially if those activities are considered to be illegal and lead to land cover change.

1.6. Operational Definitions

Biodiversity – Variety of different indigenous herbaceous plants native to Eastern Mau Forest.

Error Matrix - Tabular summary of comparisons between preliminary satellite interpretation data and field validated satellite interpretation data that shows the level of accuracy in satellite image classification.

Geo-Information – Technology that integrates Remote Sensing, Geographical Information System and Global Positioning System to capture, analyse and present data about earth’s physical environment.

Geographical Information System – A system that captures, analyses, manipulates, stores and manages spatial data for provision of information about the earth's physical environment.

Green House Gases – Atmospheric gases that trap radiation from the sun leading to increased heat in the atmosphere in the same way a greenhouse traps sun's radiation without allowing it to escape.

Image Geo-rectification – A process of adjusting images of the same place captured at different times to the same spatial position in cases where there is a shift between them.

Image Layer-stacking – Creating a multi-coloured image by combining different grey-coloured image bands for different light channel radiations.

Image Sub-setting – A process of removing parts of a satellite image that are outside the area of study boundary.

Indigenous Forest – A forest comprised of naturally established trees.

Land Cover Change – Change from one type of physical cover of the earth's surface to another.

Plantation Forest – A forest comprised of exotic tree species.

Producer's Accuracy – A measure of how accurate a satellite image has been classified given the omission of some parts of the image from classes they should belong.

Remote Sensing – Technology of acquiring information about the earth's surface features without being in contact with those features physically, process, analyse and present that information.

User's Accuracy – A measure of how accurate a satellite image has been classified given inclusion of some parts of the image in classes where they should not belong.

CHAPTER TWO

2.0. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1. Introduction

The purpose of this review was to have a better understanding of land cover change and how it contributes to deforestation. It informed the researcher on the previous land cover change studies that have been carried out in different parts of the world as well as in the Mau Forests Complex itself. It was aimed at ensuring that there is no duplication of what has already been done. Strengths, gaps and weaknesses of similar studies done in the past were identified. Moreover, it was the basis for establishment of the theoretical framework for the topic of study. Literature review was done in a thematic structure where themes and topics related to forests, land cover change and geo-information technologies were covered. Themes and topics were looked at starting from the broad perspective to specific context. This was covered from the global context before coming to the African continent, East African region, Kenya and then the Mau Forests Complex.

2.2. The Review

2.2.1. Land Cover

Land cover refers to the elements of land surface that are of different compositions and bear different characteristics (Cihlar, 2000). It is composed of different types including forests, shrubs, grasslands, cropland, bare ground and built up area among others. Forest land cover type provide a range of ecosystem services, and healthy ecosystems support most of the planet's biodiversity. Global environmental goods and services are safeguarded by forests, especially the tropical forests that are mostly found in the developing countries. Forests support more than 1.6 billion people worldwide. This support comes in form of food, fuel and medicine supply as well as provision of livestock grazing areas (UNEP, et al, 2009). The demand for forest ecosystem services increases with the increase in human population (USDA, 2008). Shrubs as a land cover type vary depending on environmental circumstances like climate and soil type. In some environments shrubs grow to become trees while in others they do not. For instance, in arid and semi-arid climates most shrubs do not grow to a height of being considered as trees in a later stage (McArthur, et al, 2007). Grassland cover type refers to open spaces dominated by grass vegetation type (Sam, 2000).

The United Nations Conference on Environment and Development (UNECD), widely referred to as the Earth Summit, that was held in Rio de Janeiro in 1992, put a lot of emphasis on "Sustainable Development" which is development that provides for the needs of the present generation without compromising the capability of the environment to provide for the needs of the future generation (WCED, 1987). Since then "Sustainable Development" has become a fashionable phrase in our daily conversations especially as regards the environment and development. This is an indication of our awareness of human induced influences and environmental crises such as ozone layer depletion, global warming and climate change. This then poses a question of how the environment should be used to provide sustainable development. A sustainable society should persist over generations and be considerable enough to safeguard both its physical and social systems of support.

2.2.2. Forest Resource

Internationally, there are several agreements which touch on the conservation and management of forests due to the high importance attached to forest as a resource. These agreements include the 1971 Ramsar Convention, the 1992 Convention on Biological Diversity (CBD), the 1992 United Nations Framework Convention on Climate Change (UNFCCC), and the 1997 Kyoto Protocol, among others. According to the United Nations World Commission on Environment and Development (WCED) Report, famously known as Brundtland Report of 1987, there is need to raise the level of understanding and commitment to action on the part of individuals, voluntary organizations, businesses, institutes and governments in the areas of population, food security, the loss of species and genetic resources, energy, industry, and human settlements in relation to how they affect the environment (WCED, 1987).

African forests can be generally classified into six tropical and sub-tropical categories. These categories include rainy forests, moisty forests, dry forests, mountain forests, humid forests and plantation forests. African forests play an important role of supporting economic development from community to national level especially in Eastern, Central and Western regions that are endowed with considerable forest cover. In spite of this, only 32.5 hectares, or 5 percent of the total forest land, are formally protected (UNEP, 2006). Forests have a core role in ensuring that long-term socio-economic development goals of New Partnership for African Development (NEPAD) are met. In the East African region, policy issues in management of montane forests are deliberated upon under the umbrella of the East Africa Community which oversees the East African Treaty of 1999 (Better Globe, 2009). African forests have the highest contribution of 6 percent to Gross Domestic Product as compared to forests in other parts of the world. Forests in Uganda contribute to the nation's development economically by providing in excess of US$ 546.6 million through forestry, agriculture, energy and tourism (NEMA, 2008).

The state of Rwanda's forests and woodlands and their importance to the national economy is also well documented. Forests are designated as protected areas which host game parks and forest reserves and make economic contributions to the nation through supply of wood fuel and charcoal renewable energy sources. They also make an indirect contribution to sustainable agriculture and are sources of medicines, fodder, honey, essential oils, as well as handicraft and construction materials. However, they are also threatened with mining, fires and poaching (REMA & UNEP, 2009). The largest forests in Kenya are five montane forest water towers including the Mau Forests Complex, Mount Kenya, the Aberdares Range, Mount Elgon and the Cherenganyi Hills. Most of the Kenyan main rivers have their upper catchments in these forests. They are sources of water for irrigation, agriculture, industrial processes and for the installed hydro-power plants. They provide timber and non-timber products to forest adjacent communities. However, their rampant destruction through extensive irregular allocation of parts of forest land to private holders is a matter of national concern (Akotsi et al, 2006).

The rivers that have their upper catchments in the Mau Forests Complex in Kenya feed into five lakes. Three of these lakes are international water bodies and they include Lake Victoria (shared by Uganda, Kenya and Tanzania), Lake Natron (shared by Tanzania and Kenya) and Lake Turkana (shared by Ethiopia and Kenya). The rivers that feed into Lake Victoria form part of the Nile Basin. Increased sedimentation from these rivers and from Kagera River annually costs farmers in excess of US$ 40 million worth of lost soil. The highest sediment load is experienced during flash floods and can be controlled by maintaining a good forest cover in the upper catchment areas (Better Globe, 2009). In this regard, regional programmes such as the Nile Basin Initiative and others which focus on safeguarding common resources such as Lake Victoria should be facilitated to fulfil their mandates (UNEP, 2007).

2.2.3. Land Cover Change

Land cover change refers to changing of a land cover type to a different other cover type. This includes change from forest land cover to other land cover types. Deforestation that occurs in most parts of the world forests comprises part of the global land cover change. The net annual global deforestation rate is approximately 11.3 hectares, taking into account increases and decreases of forest area. The rate of deforestation of natural forests in developing countries between 1990 and 1995 was estimated to be 13.7 hectares per annum

(FAO, 2012). Forests are increasingly under threat from deforestation in spite of the growing public recognition of the benefits of forest ecosystems. Food and Agriculture Organization of the United Nations (FAO, 2012) estimated annual world's forests conversion to other land cover types to be close to 13 million hectares. From history, deforestation used to be very high in the temperate regions but this trend changed in the last 50-100 years and deforestation rates are now highest in the tropical countries (UNEP et al, 2009).

Degradation and loss of forest ecosystems are as a result of rapid change in population and economically driven incentives that make forest conservation to appear of less benefits than forest conversion (Pearce, 2002). Kenya's forests and woodlands are increasingly under pressure from the growing human population and many are shrinking as a result of human-induced deforestation. The enactment of the 2005 Forests Act has admittedly helped to revitalize the sector by giving the local communities a stake in the management of state and local authority forests. Despite the new law, however, a number of challenges still remain. For instance, the low penalties for offences compared to the value of the forest resources in question, inconsistencies with other sectoral policies and laws, and lack of security of tenure for people living on government and trust lands has resulted in opportunistic exploitations of forest resources, both by the local communities and the government. In 2001, for example, the government excised 61, 000 of state forests predominantly in the Mau Forests Complex, Kenya's largest closed canopy forest and the largest of the country's five water towers (GoK, 2008). Kenya experiences deforestation as a result of conversion of forest land to agricultural land as well as other land uses. The Mau Forests Complex was originally gazetted covering 452,007 hectares. This was reduced by forest excisions to about 416,542 hectares. This forest is the largest closed-canopy montane forest ecosystem in the whole of East Africa. Due to increasing land pressure the intact Mau Forests Complex was viewed as untapped area with high agricultural value potential to be exploited (GoK, 2009).

One of the best options for conserving forests is use of protected areas. In spite of this, ecological processes within a protected area are often affected by land use in surrounding areas. For instance, in India, there are 683 reserves covering not more than 5 per cent of the total area of land. Land use change, infrastructural growth and other anthropogenic activities outside these reserves directly affect ecological processes within the reserves (Karanth, 2010). According to a study done on forests in Eastern Africa between 2001 and 2009, forest cover decreased in most countries and this decrease was strongest outside protected areas (Pfeifer et al, 2012).

In Kenya, protected areas were established in Kakamega Forest, which is the only remaining fragment of tropical rainforest in Western Kenya. This was aimed at preserving the forest's unique biodiversity from conversion by the farmers in the region to agricultural land (Guthiga, 2009). Furthermore, forests are currently undervalued in terms of the goods and services and the socio-economic benefits they provide. The government needs to institute mechanisms to ensure strict enforcement of the logging ban and ensure that the contribution of forests to the national economy is properly accounted for. This should be in addition to having forests in protected areas.

2.2.4. Land Cover Change Drivers

Land cover change drivers are the forces that lead to changes in land cover types. Drivers of land cover change are divided into two broad categories. These categories are proximate causes of land cover change and underlying causes of land cover change. Proximate causes, also known as direct causes, directly modify local land cover especially by human activities. On the other hand, underlying causes, also known as indirect causes are the fundamental forces that influence the local causes. Underlying causes emanate from political, social, demographic, economic, cultural, biophysical and technological interaction aspects (Lambin and Geist, 2007).

The distribution of Kenya's population closely follows rainfall distribution patterns. Only 20 per cent of Kenya's total area has high rainfed agricultural potential and most farmers are dependent on small-scale commercial agriculture (WRI, 2007). This, coupled with the rapid population growth rate of nearly 1 million people per year over the past decade, has placed increased pressure on existing settlements. As a result, there is great demand for arable land and the per capita holding is continually shrinking (UNEP, 2009). Protected forests that are located in high potential areas are valued for their agricultural and human settlement potential. State forests are also subjected to illegal logging and cultivation by people seeking alternative means of livelihood. This demonstrates the need to upscale farm forestry across all the country's ecological zones (GoK, 2009).

Eighty per cent of Kenya's land coverage is in the arid or semi-arid lands (ASALs). These ASALs support pastoralist and agro-pastoralist lifestyles but their woodlands are also a major source of charcoal which is a commodity with a ready market for domestic energy in rural and urban settlements all over Kenya (Better Globe, 2009). The charcoal industry, though robust and capable of earning the government much needed revenue in taxes only came under formal regulation with the gazettement of the charcoal regulations in December 2009. A deeper analysis however reveals that not enough has been done so far to put in place the necessary structures to support the enforcement of these regulations for ensuring that the country's forests and woodlands are sustainably used. It is therefore important that charcoal producers and the relevant enforcement agencies of the government that include the Kenya Wildlife Service (KWS), Kenya Forest Service (KFS), the Kenya Police, local government (national and county) administrators and judicial officers are sensitized on these rules. The country's civil society is already helping to educate the public on this important development. However, more needs to be done by key institutions which are mandated to register and monitor the charcoal producer associations.

Legislations and good practises on forest management in Kenya have never been followed for a long time. This has led to failure in protecting of indigenous forests and sustainable use of plantation forests and other woodland areas (World Bank, 2007). Prior to the enactment of the 2005 Forests Act, most forest-adjacent communities were alienated by exclusion from forest management. The 2005 Forests Act was a timely piece of legislation that instituted the necessary legal mechanisms to comprehensively address the challenges of sustainable forest management. This law has innovative provisions that can correct shortcomings previously experienced and create an enabling environment for developing the institutional capacity of the relevant agencies. It also promotes community participation in forest management and benefit sharing, nurtures transparency and accountability and encourages the formation of public-private partnerships. In addition, it takes cognizance of the role of farm forestry and dry land forests (KFWG, 2013).

The Forests Act also has provisions for enabling forest-dependent community members to register Community Forest Associations (CFAs) and work with Kenya Forest Service (KFS). About 351 CFAs have been registered. More active involvement of local communities is hampered by lack of information on potential benefits as well as lack of awareness on the mechanisms for benefit sharing. Delays in the process of drawing up forest management agreements must be avoided for sustaining the interests of local communities and potential donors (KFWG, 2010). Implementing the Forests Act of 2005 was already causing conflicts with other national legislations under the old constitutional dispensation. This necessitated its review in order to align it with the new constitution. The review could also provide the perfect opportunity to address the thorny issues. For example, the Water Act of 2002 provides for the formation of gazetted catchment areas management committees (World Bank, 2007). The Forests Act also provides for the formation of conservancy level forests management committees. Clear linkages have not been provided in the operations of the two committee categories, each of which is constituted by different individuals. There is also conflict between the 2005 Forests Act and the Wildlife Conservation and Management Act (Cap 376), especially where forests are double-gazetted. The wildlife law does not allow consumptive utilization of natural resources within national wildlife parks while the 2005 Forests Act does (World Bank, 2007).

The Environmental Management and Coordination Act (EMCA) mandates National Environment Management Authority (NEMA) to conserve the biological diversity which has a direct bearing on forest resources. Management of forests and woodlands also has to take into account the National Environment Action Plan (NEAP) of 2009 which recommends a range of actions to address environmental issues in Kenya. The Trust Lands Act, Local Authorities Act and Chief's Authority Act all pose potential risks of conflict of interest. There is therefore need to urgently harmonize all these policies and laws (World Bank, 2007).

With Vision 2030 aiming to eventually raise the country's forest cover to 10 percent, policies need to be put in place to encourage afforestation and reforestation and to also discourage deforestation by making trees more valuable when standing than felled. Furthermore, there is need for enhanced protection of the existing forest resources. In the social pillar of Vision 2030, special attention is paid to the conservation and restoration of Kenya's forests, especially the five water towers. These forests are key in the attainment of the goals of economic, social and political pillars of Vision 2030 (GoK, 2007).

2.2.5. Land Cover Change Study Techniques

Geo-information plays a critical role in providing information on land cover change which in turn provides an important decision making input in the management of the environment and decision making for future planning. It is a very powerful tool in providing precise and timely information on a particular place's land cover changes and their spatial distribution (Reis, 2008). Digital change detection techniques applied in geo-information based on the analysis of multi-temporal satellite images help in understanding the dynamics of different landscapes (Rawat et al, 2015).

Remote Sensing data is used to delineate and differentiate various land cover categories, which would not be easy and would consume more time when traditional ground surveys are used. It provides data with varying scales and resolutions that satisfy both local, regional and global demands in different applications like land cover change mapping. For instance, satellite imageries are the main source of data for deriving land cover information in the European Union's Corine Land Cover project that has generated a land cover database for the whole of Europe for 1990, 2000 and 2006 (Malgorzata, 2010). In land cover classification, a natural colour composite has features depicted in natural or true colour as they appear to a human eye in reality. False colour composites have features appearing in colours other than the colour seen by a human eye in reality. False colour composites are the best for land cover and vegetation studies because they provide good colour contrast between different land cover types (Lillesand and Keifer, 2000).

Remote Sensing and GIS are information technologies that are well established and are applied in the management of land and other natural resources. They are cheaper and accurate alternative in understanding dynamics of landscapes. Digital change detection analysis of satellite imageries based on multi-temporal and multi-spectral characteristics have been proved to have a great potential in enabling understanding of landscape dynamics (Rimal, 2005). Analysis of remotely sensed data combined with some field sample observations for validation can help accomplish land cover classification and change detection in a faster and cheaper way as compared to carrying out field surveys (Diallo et al, 2009).

Landsat satellite images of 1993, 2001 and 2009 were used in the Qalubiya Governorate in the Nile Delta of Egypt to analyse the impact of urban sprawl on agricultural land. Land cover changes in the study area were mapped based on post-classification change detection techniques through cross-tabulation analysis (Shalaby et al, 2010). Remote Sensing and GIS data was used to determine changes in land use in Taita Hills, Kenya as a result of climate change and rapid population growth that increasingly exert pressure on the East African highlands (Pellikka et al, 2004). Geo-information technologies were used to provide land cover and land use change information in Mau Forests Complex between 1973 and 2010 by analysing Landsat images of 1973, 1986, 2000 and 2010. In this study, Geo-information was used to detect the type and amount of changes, their nature and their spatial patterns (Ayuyo et al, 2012).

2.3. Theoretical and Conceptual Framework

Boserupian theory on population and environment brings out the relationship between human beings, environment and development and it is very relevant to developing regions, especially the sub-Saharan Africa. Boserup explores population as an independent variable and how it influences agricultural technology as a dependent variable. She looks at how the relationship between population growth and agricultural technology development affects the productive capacity of resources. This theory is important in addressing challenges that affect sustainable development, meshing growth of economy and protection of the environment, and has an effect on forest resources depletion in Kenya including those in Eastern Mau Forest *(Figures 2.1a* and *2.1b).*

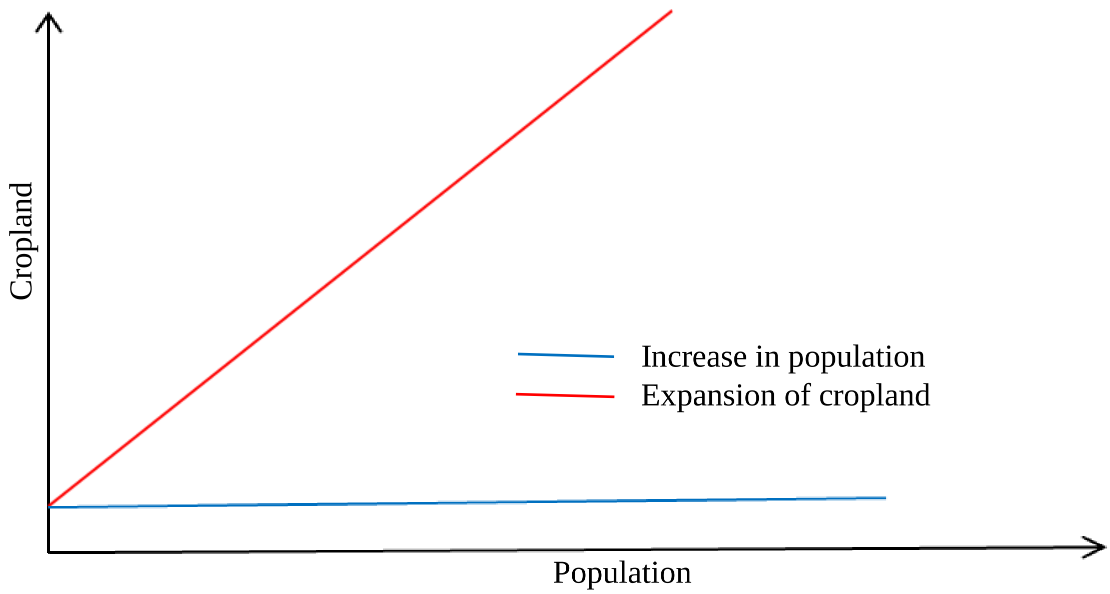

Figure 2.1a: Modified Boserup model (Source: author).

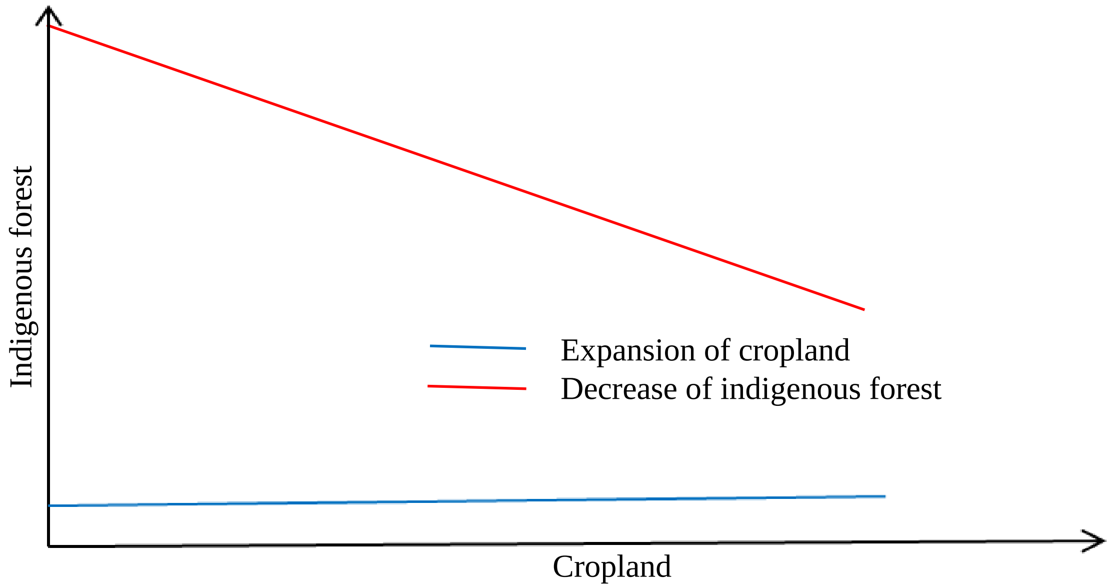

Figure 2.1b: Modified Boserup model (Source: author).

The nexus between humans, environment and development has been depicted by several studies as the interrelationship between these three components. Population pressure theories like the Boserupian theory show that population growth has led to the ever expanding need for increased food supply which has consequently led to increased farming (Svizzero and Tisdell, 2014). Eastern Mau Forest land cover change is driven by both direct and indirect forces *(Figure 2.2)*. Direct drivers of land cover change include clearing natural vegetation to pave way for cultivation and construction of settlements, and overgrazing. Indirect drivers include policies that allow cultivation of forest land and controlled tree cutting for firewood, and cultural practices that allow people to stay in forests. Mitigation measures against the effects of these drivers are necessary for sustainable use of forest resources. If sustainable measures are lacking there will be degradation of forest resources.

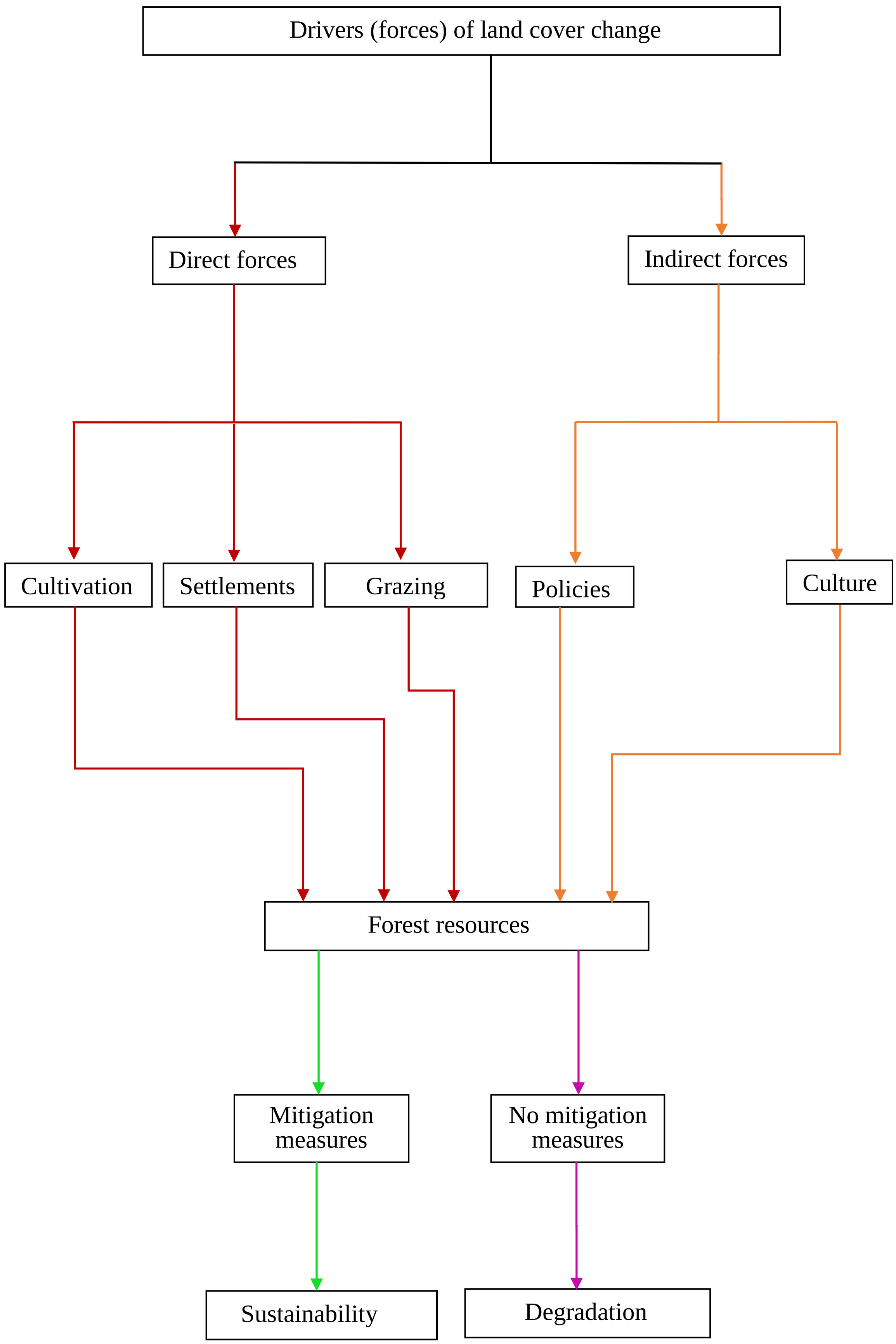

Figure 2.2: Conceptual framework model (Source: author).

The above conceptual framework shows that the drivers of land cover change in Eastern Mau Forest are cultivation of crops, construction of settlements, grazing of livestock, and policies and cultures that allow people to settle on forest land. Where mitigation measures are taken against the drivers of land cover change there is sustainability of usage of forest resources. On the other hand, where there are no mitigation measures there is continued degradation of the forest. Remote Sensing and GIS technologies help to identify forest areas that are degrading, location of direct (proximate) drivers of land cover change and forest areas that are recovering due to mitigation measures. This is achieved by comparing analyses from satellite images of different years and recording locations of the drivers of land cover change using handheld GPS receivers.

The process of how Remote Sensing and GIS technologies are used is as shown in *Figure 2.3*. In the analysis satellite images were clipped based on Eastern Mau Forest boundary. The clipped images were classified by digitizing polygons of different land cover types to get preliminary classification. Field data collection was carried out to validate preliminary classification and get information on the drivers of land cover change. The collected information was used to make changes on the preliminary classification and come up with the final validated classification.

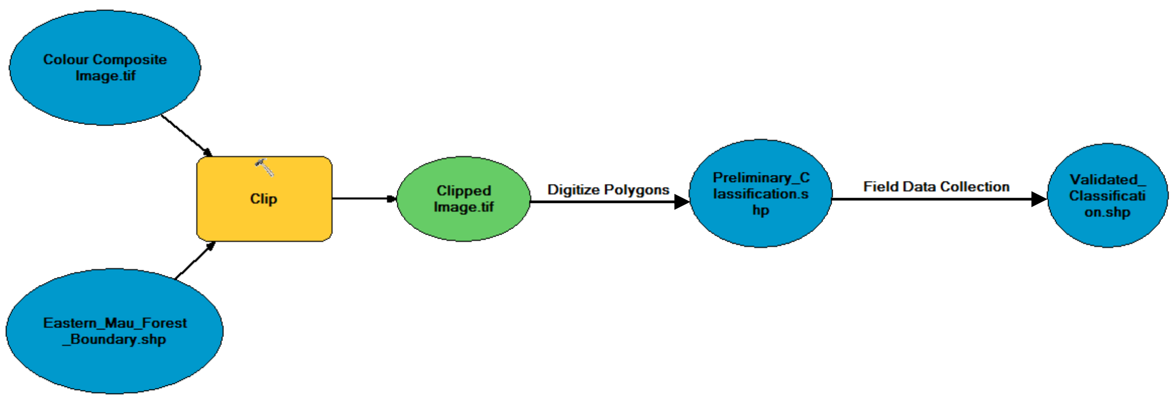

Figure 2.3: GIS model used in image analysis and field data collection (Source: author).

CHAPTER THREE

3.0. THE STUDY AREA

3.1. Location and Size

Eastern Mau Forest is located in Molo Sub-county of Nakuru County in the South Eastern part of Rift Valley Region of Kenya. It lies between 35.69^0 and 36.10^0 East and 0.28^0 and 0.68^0 South *(Figures 3.1* and *3.2).* It is bordered by Naivasha Sub-county to the South, Narok and Bomet Counties to the West, Nyandarua and Laikipia Counties to the East, and Kericho and Baringo Counties to the North. Eastern Mau Forest forms part of the larger Mau Forests Complex *(Figure 3.3)* that is the largest closed-canopy montane forest ecosystem in East Africa. It can be classified as an equatorial forest based on its location but it is taken as montane forest because of the altitude. The Mau complex has an altitude range of between 1,800m and 3,000m above sea level (BirdLife International, 2015). It has 22 forest blocks and covers approximately 416,542 ha with the Eastern Mau covering a spatial area of about 65,900 ha (GoK, 2009). The total Kenya's forest cover is approximately 980,000 ha (UNEP, 2012). Historically, Eastern Mau Forest was occupied by Ogieks from precolonial days who relied on hunting and gathering of wild meat, honey and medicinal plants for their livelihood. The Ogieks practiced communal owned land tenure system where different stretches of land were owned by different clans. This kind of land tenure system has changed with time to individually owned system to change of lifestyle from hunting and gathering to land cultivation for food (Spruyt, 2011).

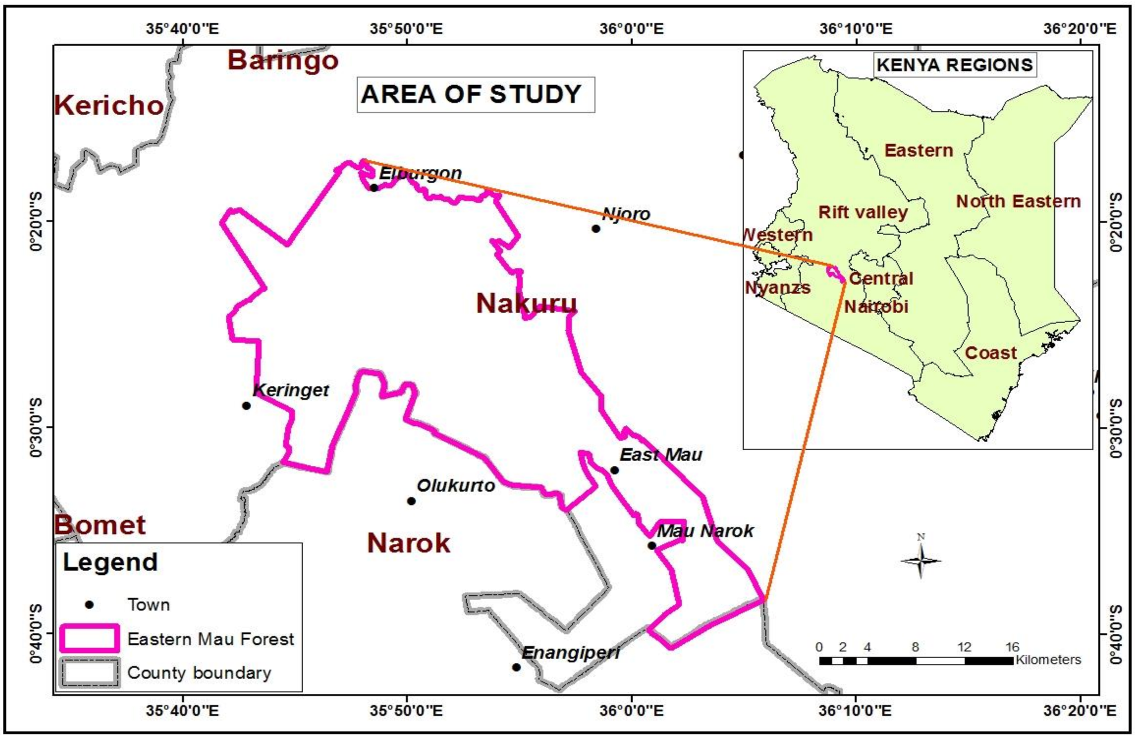

Figure 3.1: Location of Eastern Mau Forest (data source: Sok and KFS).

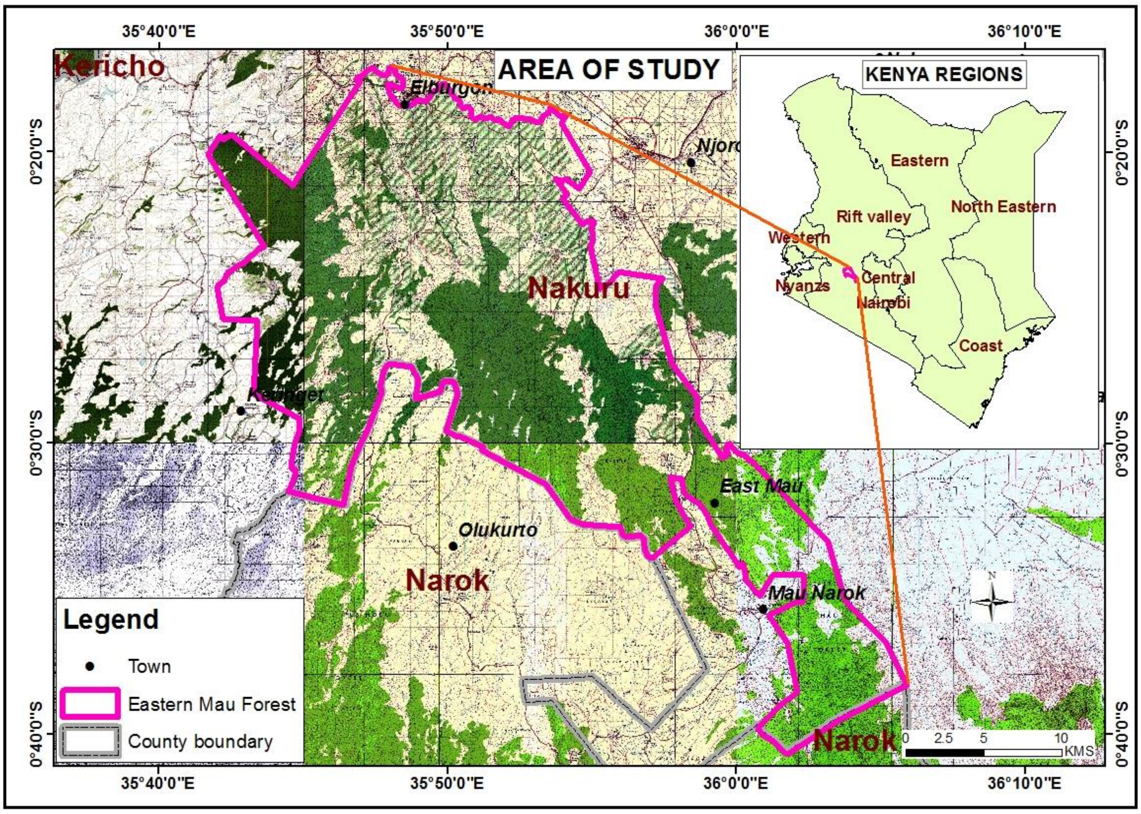

Figure 3.2: Eastern Mau Forest on topographic maps (data source: Sok and KFS).

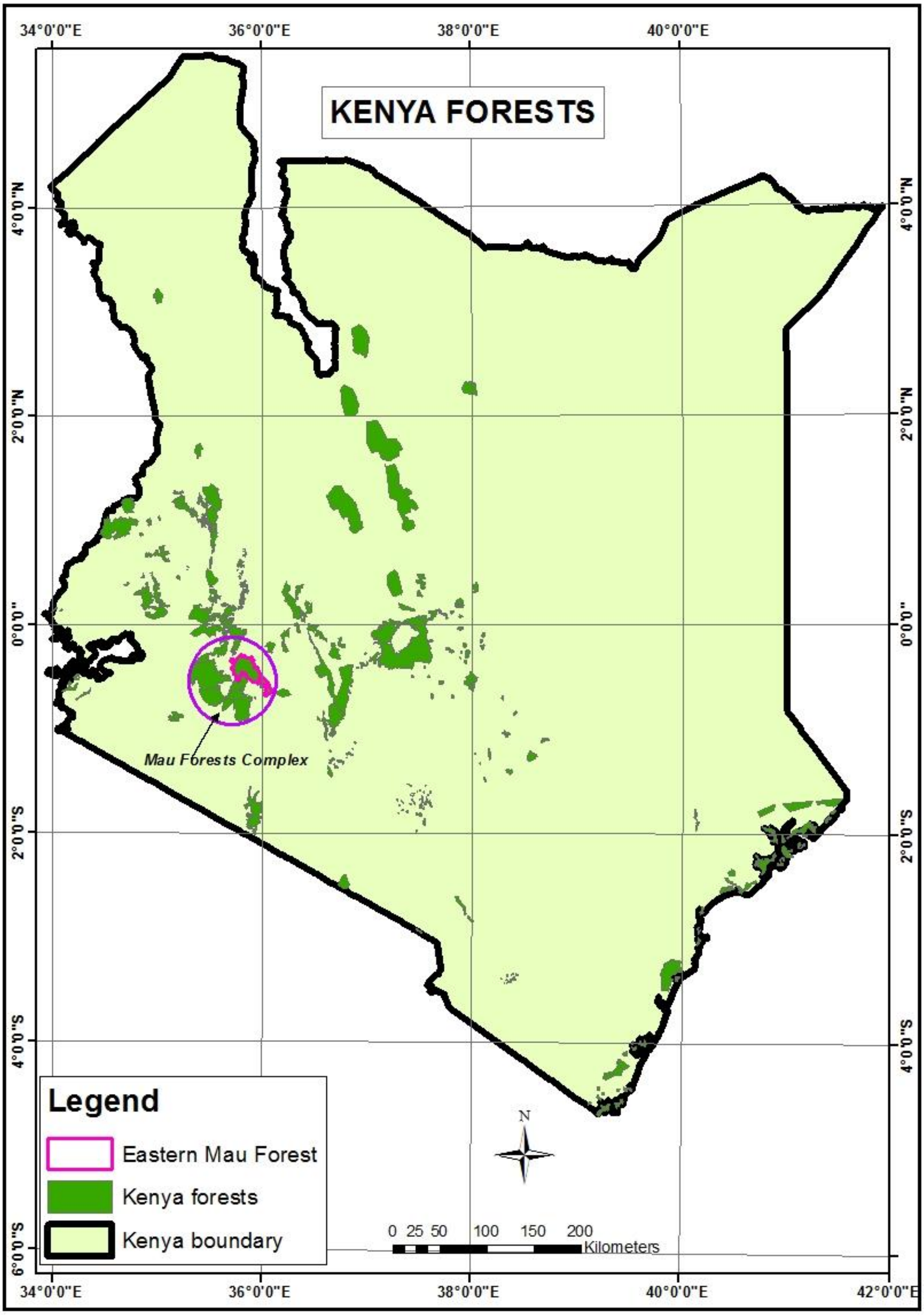

Figure 3.3: Kenya forests (data source: KFS).

3.2. Geology and Soils

Eastern Mau Forest area has both quaternary and tertiary deposits of volcanic nature (Sombroek et al., 1980). The quaternary deposits include pyroclastics and sediments. Tertiary deposits include black ashes and welded tuffs (Olang et al., 2011). The top soils in the plains have a texture of clay loam to loam, with friable consistence and sub-angular weak to moderate blocky structure. The subsoils have silty clay loam to clay loam and clay texture with pH values of 5.6 to 6.4 range, making them slightly to moderately acidic in nature (China, 1993). The soils in the uplands are largely of high silt and clay content, a consequent of Acrisols, Cambisols, Ferrasols and Nitisols (World Soil Information [ISRIC]/FAO-UN, 1995). In the lowlands, Cambisols, Luvisols, Planosols, Vertisols and Solonetz soils from the Holocene sedimentary deposits are prevalent and occur in saline and sodic phases (Olang et al., 2011).

3.3. Climate and Hydrology

Eastern Mau Forest has a modified temperate climate. It is temperate due to relatively high altitudes and modified by the equatorial proximity. The climate experienced in Eastern Mau Forest is largely influenced by the North – South Inter-tropical Convergence Zone (ITCZ) movement and is modified by local orographic effects. In terms of seasonality, the area can be classified as trimodal, with the long rains predominant during the May-June season and short rains prevalent in the September-November season (Kundu, 2007). The rainfall received in Eastern Mau Forest is among the highest in Kenya with annual precipitation ranging from 1,000 mm, with a seasonal regime, to 2,000 mm (BirdLife International, 2015). The mean monthly air temperatures in the area range from a minimum of 17^0C to a maximum of 23^0C (Kundu, 2007). Annual average evapo-transpiration (ET_0) estimates range between 1.3 mm/day and 4.2 mm/day, with an average of about 3.85 mm/day (FAO, 2009).

Eastern Mau Forest is drained by many rivers as illustrated in *(Figure 3.4).* These rivers include: Njoro, Makalia, Enderit, Naishi, Nessuit, Rongai, Elburgon, Mariashoni and Kiptunga. Physical evidence reveals that the rivers in the Eastern Mau Forest have had significant decline in their discharges, coupled by dwindling water quality (Olang et al., 2011). Some studies have associated this decline to land cover and land use changes in the area, for instance, unplanned conversion of forest and woodlands into agriculture and built up area within the headwaters (Kundu et al., 2007; Owido et al., 2003).

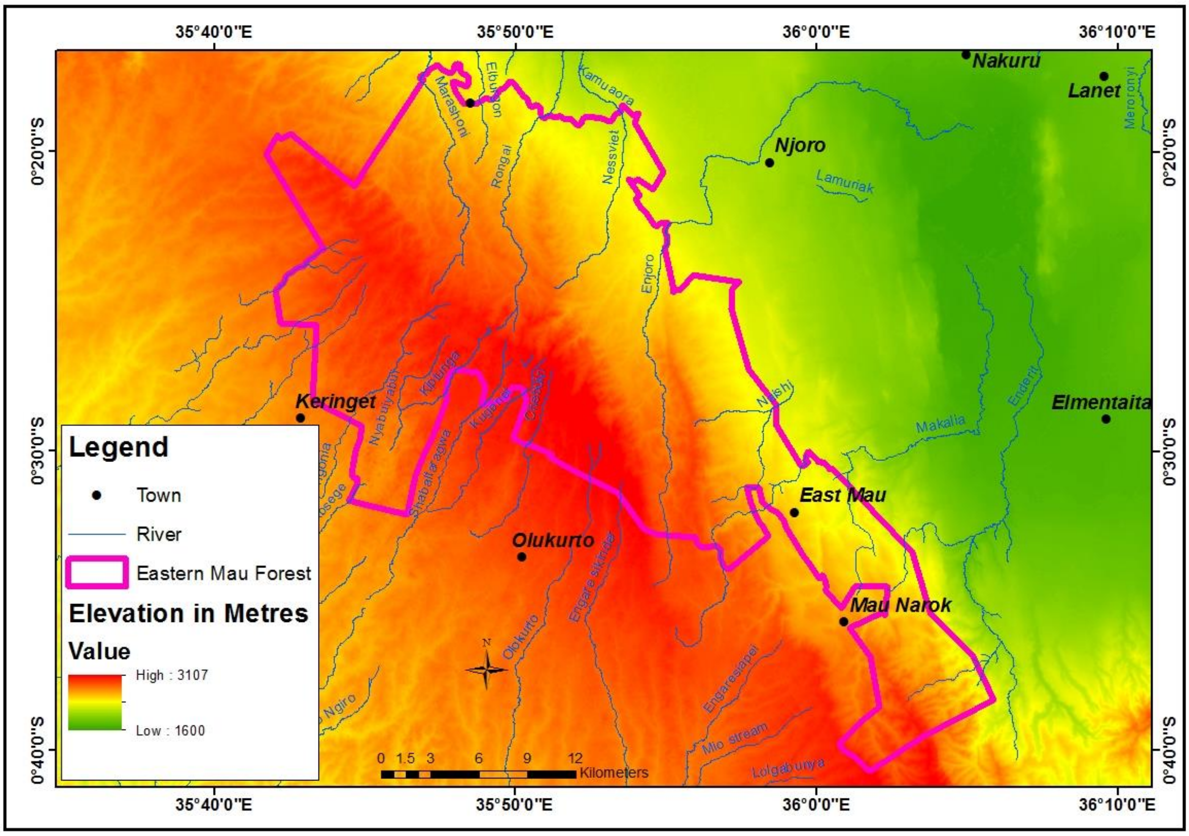

Figure 3.4: Eastern Mau Forest rivers (data source: Sok, KFS and NASA).

3.4. Vegetation Cover

The natural wooded vegetation cover of the Mau Forests complex can be broadly and roughly be classified as forest, woodland, bushland and wooded grassland (FAO, 2002). The vegetation cover in Eastern Mau Forest varies from grasslands to shrubland and forests. Based on the land cover interpretation of Landsat satellite image captured in January 2014 grassland covers 5,559 ha out of the total 65,889 ha covered by the entire area of study. Shrubland covers 1,255 ha, plantation forest 4,652 ha and indigenous forest 23,511 ha. The rest of the area is covered by cropland, built up area and bare ground as illustrated in *Table 3.1* and *Figure 3.5*.

Table 3.1: 2014 vegetation and other land cover types from Landsat image.

No.	Land Cover	Area in Hectares
1	Grassland	5559.32849
2	Shrubs	1254.65221
3	Plantation forest	4651.71872
4	Indigenous forest	23511.03218
5	Cropland	30836.66167
6	Built up area	73.00185
7	Bare ground	3.04533
	Total	**65,889.44045**

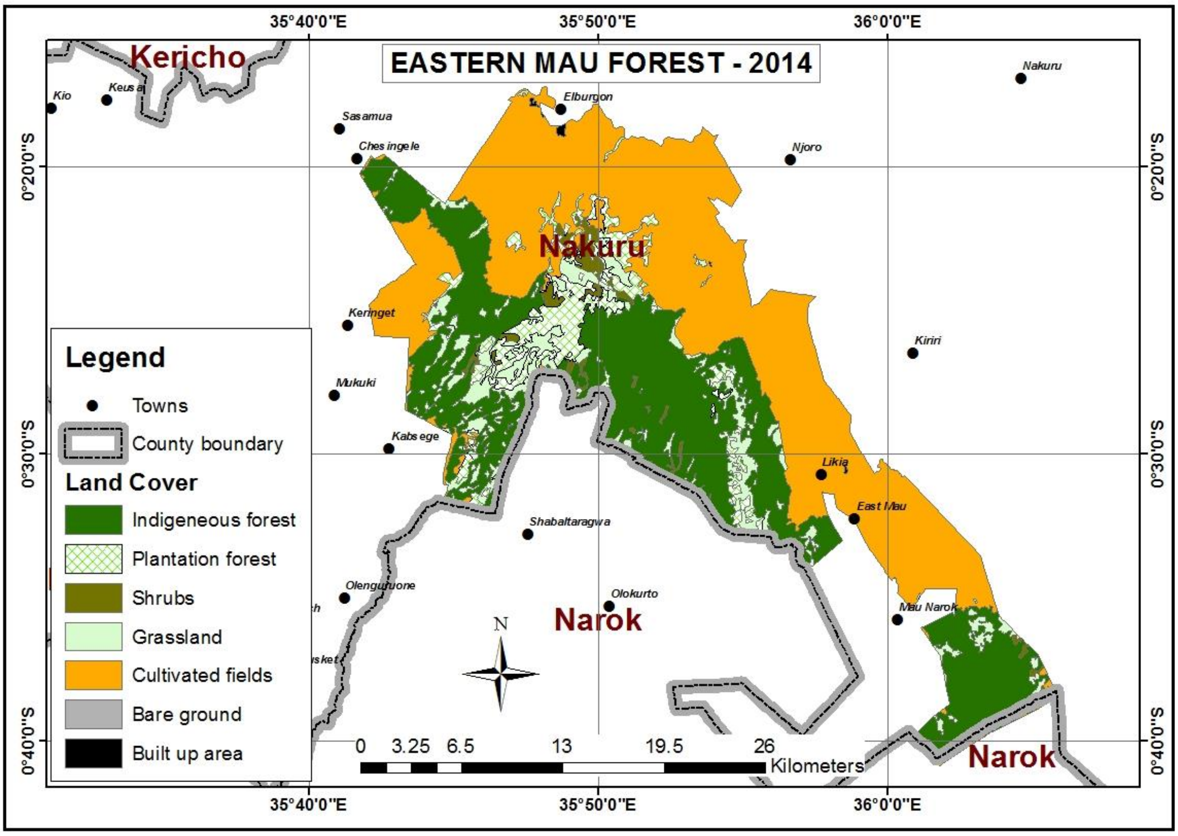

Figure 3.5: Eastern Mau Forest land cover from 2014 satellite images (data source: NASA).

3.5. Socio-Economic Activities

3.5.1. Population

According to the 2009 population census Rift Valley is the most populous region in Kenya with the overall population of 10,006,805 people and population density of 55. Nakuru County has 1,603,325 people with Molo Subcounty where Eastern Mau Forest is located having 542,103 people (KNBS, 2010). Population of the area covered by Eastern Mau Forest is as shown in *Figure 3.6* and *Table 3.2.*

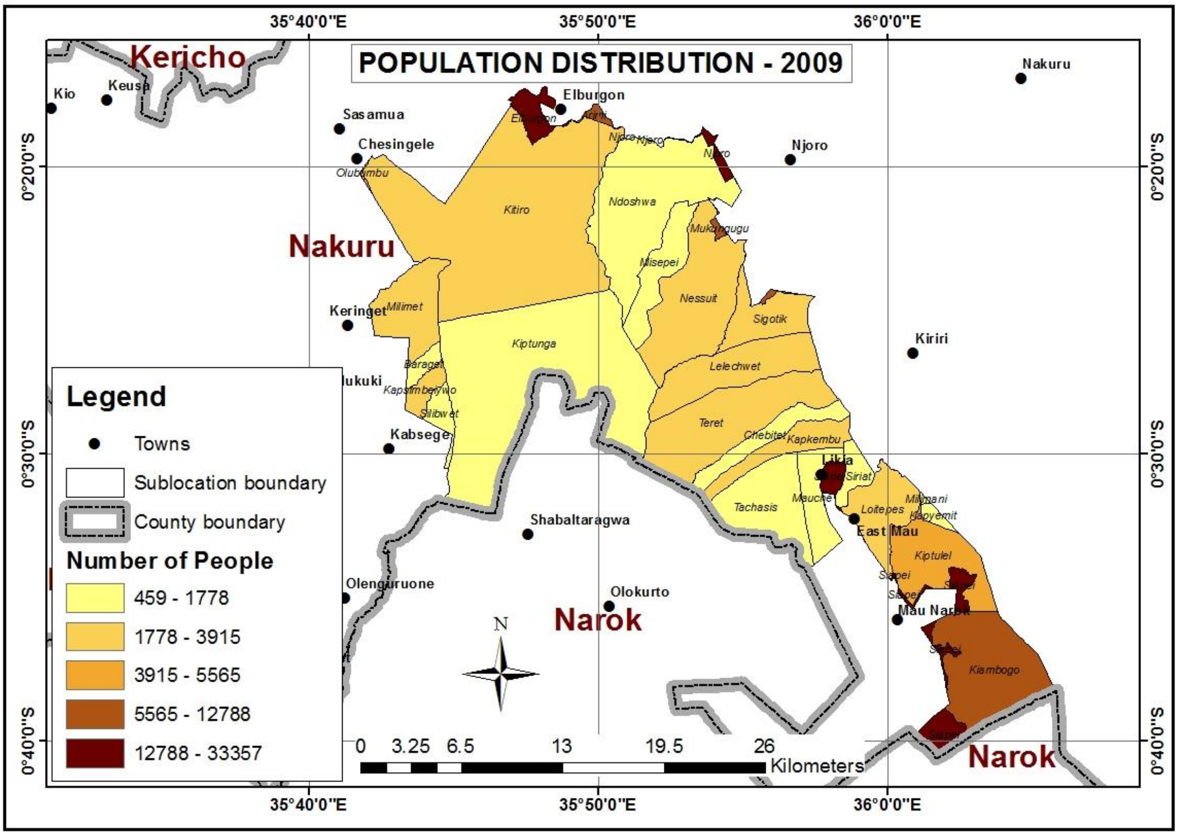

Figure 3.6: Population distribution in Eastern Mau Forest (Source: KNBS, 2009).

Table 3.2: Eastern Mau Forest population (Source: KNBS, 2009).

County	Division	Location	Sub-location	Area (Sq. Km)	Male	Female	Total	Density
Nakuru	Elburgon	Elburgon	Elburgon	53.54	16581	16073	32654	609.87
			Arimi	28.53	4075	4109	8184	286.82
		Mariashoni	Kiptunga	149.33	2147	1859	4006	26.83
			Ndoshwa	51.76	1976	1731	3707	71.63
			Kitiro	44.56	2496	2245	4741	106.40
	Gilgil	Kiambogo	Kiambogo	134.34	6964	6967	13931	103.70
	Njoro	Njoro	Njoro	90.03	19591	20079	39670	440.65
			Mukungugu	19.57	5559	5521	11080	566.09
		Nessuit	Nessuit	43.59	3687	3585	7272	166.83
			Misepei	17.72	1019	967	1986	112.08
			Sigotik	13.86	2223	2007	4230	305.14
	Keringet	Keringet	Milimet	35.86	4329	4186	8515	237.48
		Nyota	Olubumbu	20.48	3018	3054	6072	296.52
		Kapsimbeiywo	Kapsimbeiywo	25.41	2537	2652	5189	204.20
		Silibwet	Silibwet	23.61	1075	1027	2102	89.04
		Chebara	Baraget	10.89	918	931	1849	169.72
	Lare	Bagaria	Milimani	8.65	484	524	1008	116.50
			Kapyemit	8.66	723	786	1509	174.21
	Mauche	Mauche	Mauche	10.63	1424	1394	2818	265.09
			Tachasis	30.18	908	911	1819	60.26
		Teret	Teret	45.24	1788	1764	3552	78.52
			Lelechwet	26.53	2003	1872	3875	146.05
		Kapkembu	Kapkembu	11.52	1470	1389	2859	248.17
			Chebitet	12.20	1525	1541	3066	251.25
		Tuiyotich	Siriat	5.37	1227	1151	2378	443.05
			Loitepes	17.60	2352	2369	4721	268.26
	Mau Narok	Mau Narok	Siapei	141.41	15302	15497	30799	217.80
		Sururu	Kiptulel	25.21	4529	4427	8956	355.23

3.5.2. Economic Activities

The major economic activities practised in the Eastern Mau Forest area include crop cultivation, livestock rearing, saw milling, bee keeping and commercial selling of commodities. The main crops cultivated include maize, beans, Irish potatoes, tomatoes, onions, cabbages, citrus fruits and wheat *(Plate 3.1)*.

Plate 3.1: Wheat field in Tiritigoit area (source: author, date: 27/10/2014).

The most common livestock kept include cattle, sheep and goats. These animals are kept for meat, milk and skin. Saw milling is done in Elburgon town for timber production. The produced timber is used in carpentry for making of furniture and building of houses. Commercial selling of commodities is exhibited by the existence of numerous marketing and shopping centres in areas within and adjacent to Eastern Mau Forest. These centres include Njoro, Keringet, Mau Narok, Mauche, Likia, Teret, Nessuit, Sururu, Mathangauta, Kihingo and Elburgon *(Plate 3.2)*. Commercial selling in these centres is carried out in shops, hotels, open space markets, lodges, bars and restaurants.

Plate 3.2: Elburgon shopping centre (source: author, date: 30/10/2014).

CHAPTER FOUR

4.0. METHODOLOGY

4.1. Study Design

The study used mixed sample survey design involving purposive sampling of spatial data and cluster sampling of forest resource use data in Eastern Mau Forest area. In the purposive sample survey the data collected were on land cover types generated from Landsat satellite images between 1986 and 2014. Other spatial data were on Kenya forest boundaries, Kenya population data, 1:50,000 topographic maps, Kenya sub-location and county boundaries, Kenya Rivers and Kenya settlements necessary in the delimitation of the Eastern Mau Forest area on the satellite imageries. Purposive sampling was used to enable acquisition of data that captures land cover information on time series basis for land cover change detection. In the cluster sample survey of forest resource use the data collected were on the different ways of use of forest resources and drivers of land cover change in Eastern Mau Forest area. Data were collected based on 7 clusters from which different members were randomly interviewed. These clusters included: local households, Kenya Forest Service (KFS) officers, Community Forest Association (CFA) members, Community Based Organizations (CBO) members, religious leaders, local administrators and District Peace Committee (DPC) members. The resulting datasets were analysed using both spatial analysis techniques and geostatistical techniques to depict spatial-temporal land cover changes in Eastern Mau Forest.

4.2. Data Types and Sources

The data used in this study were of primary and secondary data types where primary data were on ground control points, land cover types and forest resource use. Primary data were collected in the Eastern Mau Forest area during field reconnaissance for ground control points and field validation for land cover types and forest resource use. Photographs of different land cover types and key informant interviews were also taken during primary data collection.

The GPS ground control points were selected on the basis of objects identified on the satellite imageries and the corresponding objects on the ground in the Eastern Mau Forest area for satellite images geo-rectification. Primary data on land cover types were collected for land cover validation of the preliminary satellite image interpretation. Forest resource use data were collected from 32 stakeholder interviews on the basis of forest resource use activities for identification of drivers of land cover change. The 32 stakeholders were randomly identified from 7 clusters namely local household elders, Kenya Forest Service, Community Forest Associations, Community Based Organizations, religious groups, local administrators and District Peace Committees in the Eastern Mau Forest and within 5km buffer area around the gazetted forest boundary.

Secondary data were acquired from already existing datasets covering the area of study and relevant to the study. These secondary data included spatial data in the form of Landsat imageries provided by the National Aeronautics and Space Administration (NASA) on the United States Geological Survey (USGS) website. The Landsat satellite images used were those captured by Landsat 5 Thematic Mapper (TM) sensor with seven spectral light channel image bands for 1986 and 1995 images, Landsat 7 Enhanced Thematic Mapper (ETM+) sensor with eight spectral light channel image bands for 2003 image, and Landsat 8 Operational Land Imager (OLI) sensor with eleven spectral light channel image bands for 2014 image. These image sensors were selected on the basis of their spatial resolution and available light channel image bands. The images from these three sensors have a uniform spatial resolution of 30 metres. They also have Green, Red and near Infrared image bands that are used for land cover information analysis. The image data were selected on the basis of amount of cloudy cover, season of the year and time interval. The selected images were those with less than 10 per cent cloudy cover, within January-February season and close to 10 year time interval between them. These images were used to generate land cover types and land cover change information.

Other spatial data were in the form of Kenya forest boundaries from Kenya Forest Service, population data from Kenya National Bureau of Statistics, and 1:50,000 topographic maps, sub-location and county boundary shapefiles, Kenya rivers shapefile and settlement shapefile from Survey of Kenya. Kenya forest boundaries data was for Eastern Mau Forest boundary delimitation and reconciling the observed forest boundaries with the legal forest boundaries. Kenya population data of 1989, 1999 and 2009 was used for identification of human-forest interactions. The 1:50,000 topographic maps of Keringeti, Njoro, Olenguruone, Mau Narok and Ol Doinyo Opuru were used for Eastern Mau Forest location while the sub-location and county boundary shapefiles were for administrative units identification. Kenya rivers shapefile and the settlement shapefile were selected on the basis of spatial representation of Eastern Mau.

4.3. Data Collection

4.3.1. Field Reconnaissance

Field reconnaissance (pilot survey) was carried out two weeks before actual field data collection. This was done for purposes of identifying ground control points corresponding to those identified on the satellite images for geo-referencing and geo-rectification of the images. Twelve ground control points were identified on the satellite images and X and Y coordinates input into a handheld GPS receiver for navigation and marking of the corresponding points on the ground. The pilot survey also enabled the researcher to introduce himself to the area of study. A letter of introduction *(Appendix I)* was obtained from the Department of Geography and Environmental Studies of the University of Nairobi before the start of the pilot survey. During the pilot survey the researcher identified two research assistants and introduced himself and the purpose of his mission to the Kenya Forest Service Officers whose areas of jurisdiction Eastern Mau Forest falls. He also introduced himself to some local administrators and identified places where to sleep while in the field. The researcher used the field reconnaissance to test the field questionnaire and land cover data collection form by identifying different land cover classes based on satellite images.

4.3.2. Target Population and Sample Size

The target population used in this study was of two types. The first type was that for providing information on the status of land cover while the second was for providing information on the drivers of land cover change. The Landsat satellite images used to provide land cover information for this study constituted the study target population for the first type which was composed of images acquired from 1986 to 2014. Initially, the planned target population was for images acquired from 1984 to 2014 but this was not possible due to lack of cloud free images. In some cases cloud free images were available but they were of different seasons and that would have given misleading results for land cover change detection. The 1984-2014 images had been selected for target population because the Landsat images that were captured before 1984 had a lower spatial resolution of 28.5 metres that is not ideal for comparison with the 30 metres spatial resolution of the images captured from 1984 to date.

The sample size from the first type of target population constituted of four Landsat image scenes acquired in January 1986, January 1995, February 2003 and January 2014. The sample size was to have four Landsat satellite image scenes with a uniform interval of 10 years between the images but this was not possible due to unavailability of good quality images falling in the same season. The satellite image interval that was used was therefore based on the available good quality images that were of the same season and close to 10 years between the images.

The second type of target population was selected on the basis of proximity to the forest, interaction with the forest, and use and conservation of forest resources. This target population was composed of different stakeholders from 7 cluster groups including local household elders, Kenya Forest Service (KFS) officers, Community Forest Association (CFA) members, Community Based Organizations (CBO) members, religious leaders, local administrators and District Peace Committee (DPC) members, all from an area within a 5 kilometre buffer around the gazetted Eastern Mau Forest boundary. Those beyond 5 kilometre buffer were not considered because areas beyond the buffer were covered by other forests like Eburu, Maasai Mau and Western Mau which may be unique in some ways. The sample size in this category was composed of 32 stakeholders that were selected from the 7 clusters and interviewed based on the location of land cover field validation points that were visited. Among the interviewed stakeholders 14 of them were elders from local households, 5 from KFS, 5 from CFAs, 3 CBO members, 2 pastors, 2 Assistant Chiefs and 1 member from District Peace Committee (DPC).

4.3.3. Data Collection Instruments

Field data collection involved use of different instruments. These instruments included land cover validation forms, field questionnaires, handheld GPS receiver, digital camera, GPS enabled android mobile telephone, satellite image map and internet. Land cover validation forms were used for recording different land cover types at the field sample points that were visited *(Appendix II)*. The recorded land cover type information was then used to validate the land cover classification from satellite imagery. The field questionnaires were used to record information on forest resource use and drivers of land cover change in Eastern Mau Forest as provided by respondents that were interviewed *(Appendix III)*.

Handheld GPS receiver was used for navigation to the ground control points based on the point coordinates from the corresponding points identified on the satellite images for geo-referencing and geo-rectification of the satellite images. It was also used for navigation to the sample land cover types for collection of land cover type information that was used for validating satellite image land cover classification. A digital camera was used to take photographs of all the points that were visited for land cover data validation. It was also used to take photographs during interviews on forest resource use and drivers of land cover change. The land cover photographs were used in validating land cover classification.

The GPS enabled android mobile telephone was used to record and create a web based back-up of all GPS points and photographs taken while in the field. The back-up was saved on *Kmacho* website which has provisions for online viewing and downloading of the points and photographs taken while in the field. The *Kmacho* online back-up had an additional advantage of accessing the collected data in case of any unfortunate eventuality where the GPS receiver and camera may be spoilt or lost. Satellite image map had an overlay of random sample points that were visited and land cover types at the points recorded to be used in satellite image classification. Internet was used for downloading the Landsat satellite images from the USGS website and for accessing the data saved on online *Kmacho* website.

4.3.4. Data Collection Procedure

4.3.4.1. Ground Control Points Acquisition

This process was done by picking twelve points on features that were seen to be appearing on all images. The features used to pick the points were road junctions *(Plate 4.1a)*. Images were displayed in ArcGIS 10.3 software and a point layer digitized on top of the identified twelve road junction points *(Plate 4.1b)*. Ground geographic coordinates of the digitized points were input into a handheld GPS receiver. Based on these coordinates the corresponding GCPs on the ground were navigated to and new GCPs marked and recorded in the GPS receiver while at the exact ground points to be used in satellite image geo-rectification.

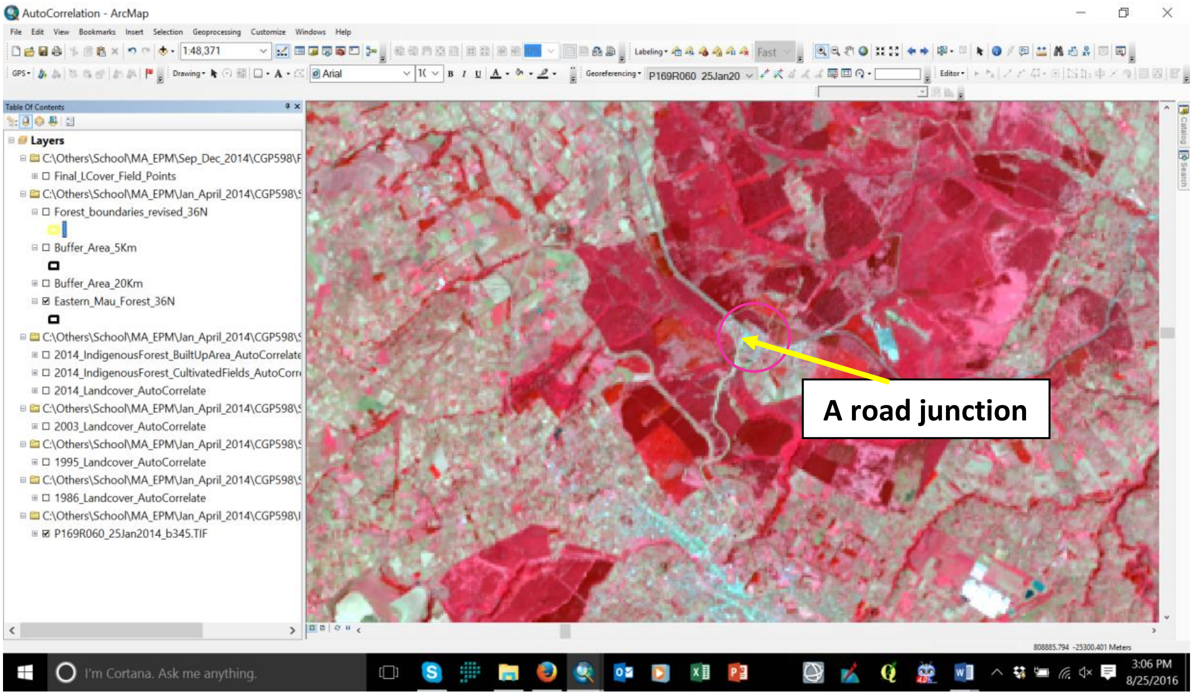

Plate 4.1a: A road junction for ground control point (source: ESRI ArcGIS).

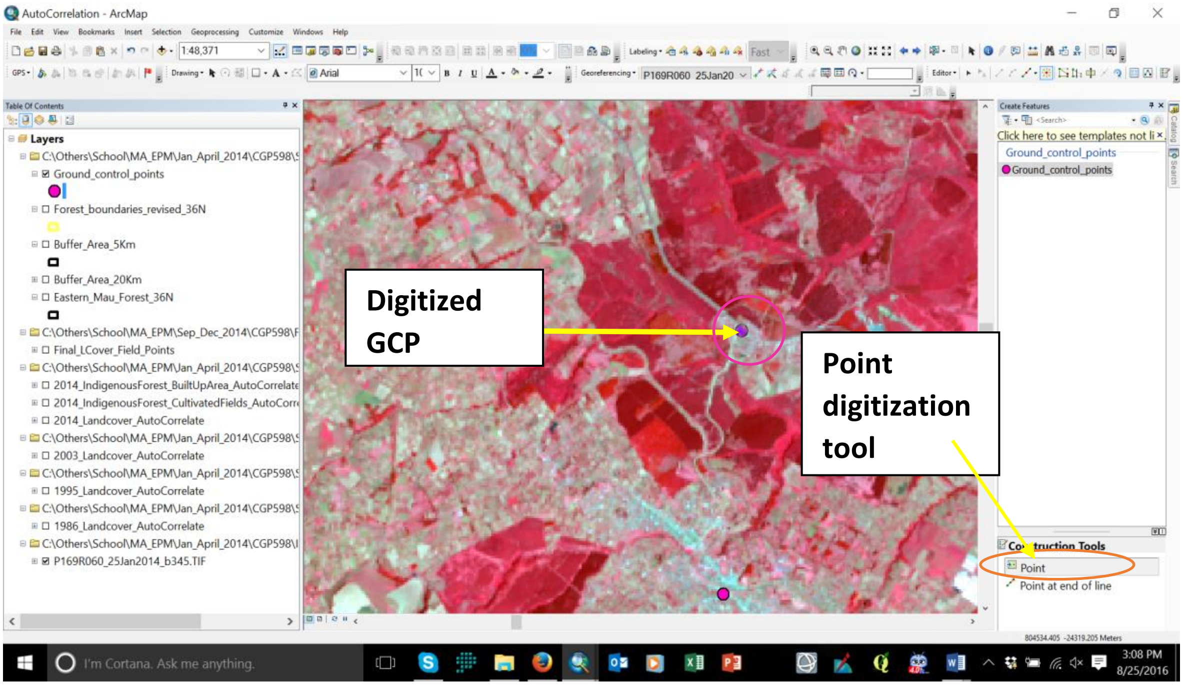

Plate 4.1b: Digitization of ground control points (source: ESRI ArcGIS).

4.3.4.2. Land Cover Validation Data Acquisition

Simple random sampling procedure was used in collecting data from the field. To carry out this procedure, 50 random points were generated within the area covered by Eastern Mau Forest in ArcGIS 10.3 software using simple random sampling tool under Data Management Tools *(Plates 4.2a and 4.2b)*. The generated points *(Figure 4.1)* were uploaded into a handheld GPS receiver that was used for navigation to the corresponding ground points while in the field.

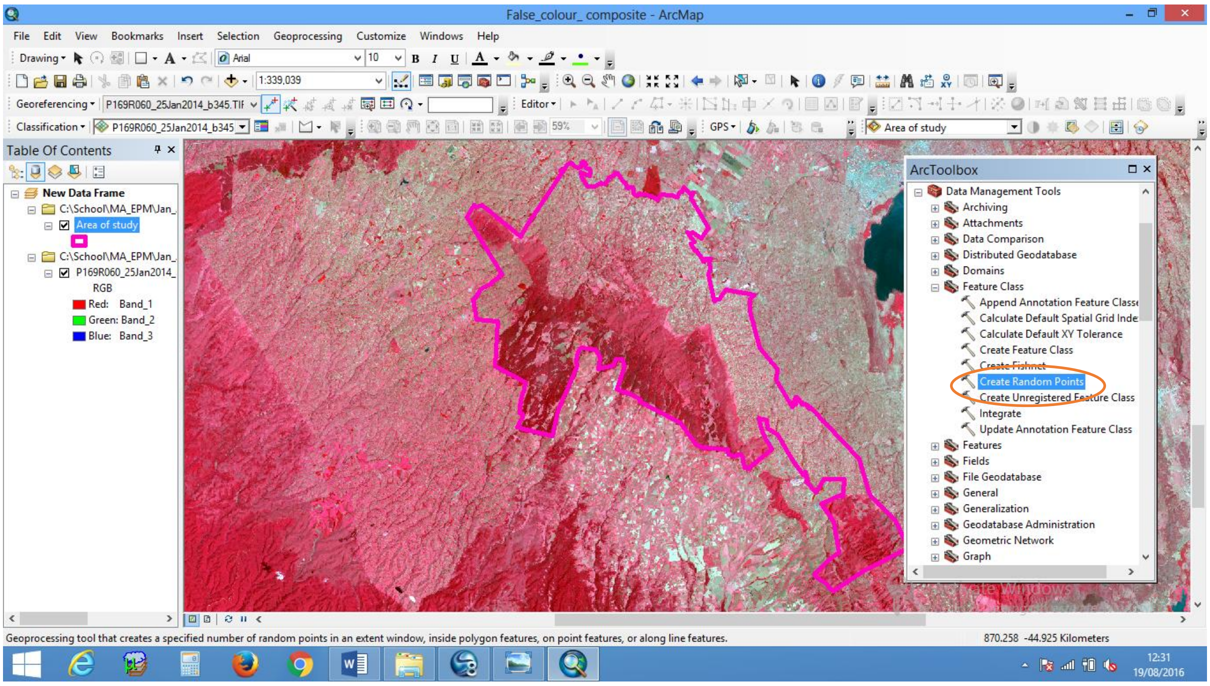

Plate 4.2a: Accessing random points generation tool (source: ESRI ArcGIS).

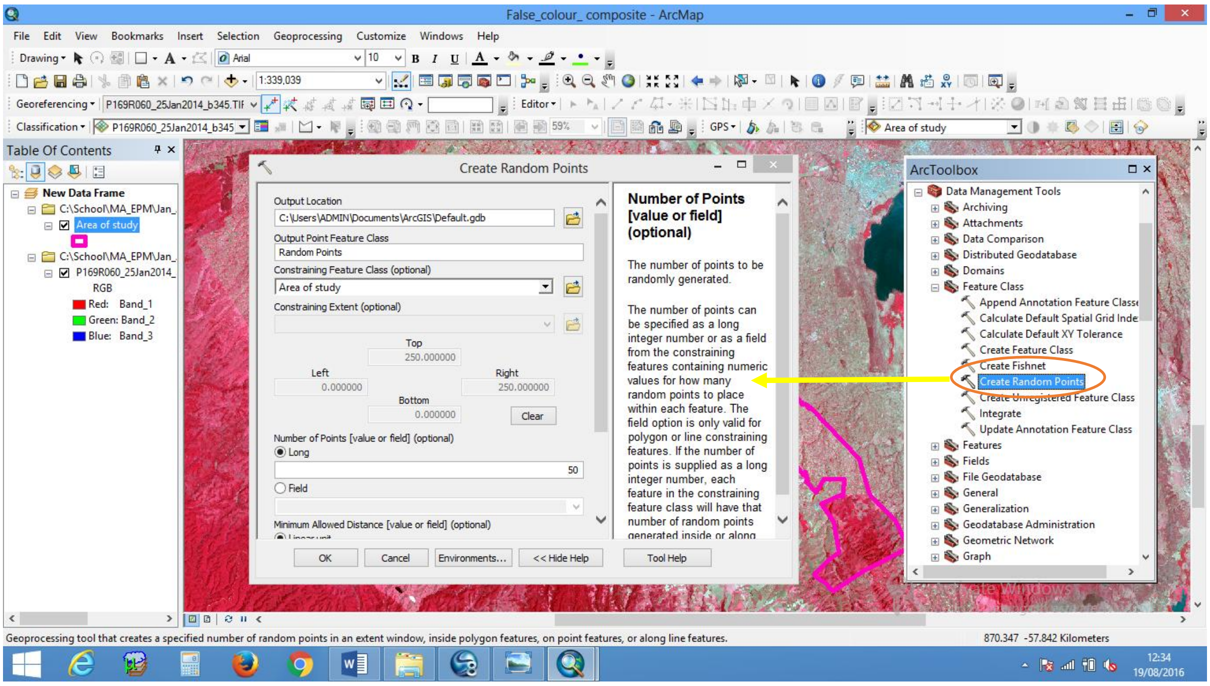

Plate 4.2b: Running random points generation tool (source: ESRI ArcGIS).

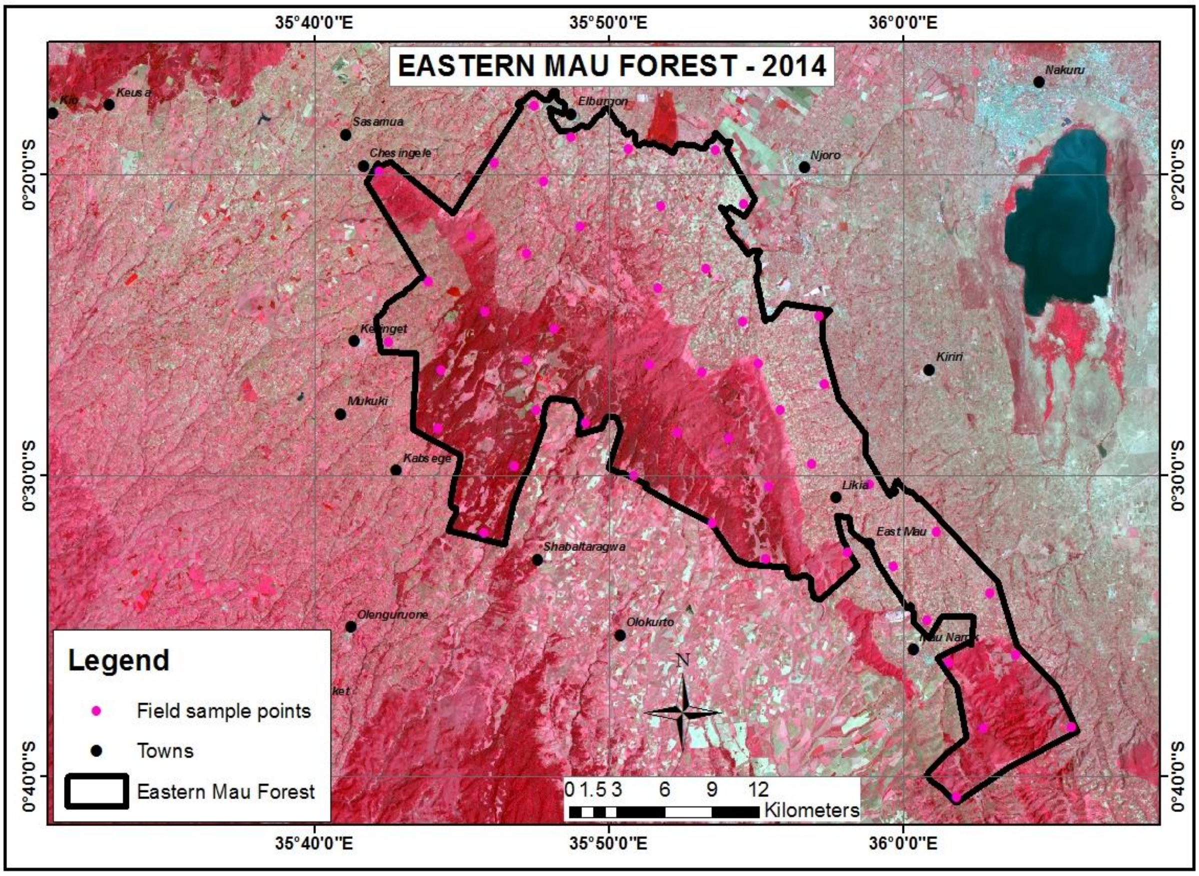

Figure 4.1: Field points overlaid on Landsat image of January 2014 (data source: NASA).

During the field survey all points were visited and land cover types observed and recorded in the land cover validation form *(Appendix II)*. Land cover GPS points were recorded in the handheld GPS receiver and photographs taken to be used in validating satellite image classification of different land cover types *(Plates 4.3, 4.4, 4.5, 4.6, 4.7 and 4.8)*. Another set of GPS points, photographs and descriptive information on the land cover was recorded in the android enabled mobile telephone and sent to the *Kmacho* website for storage.

Plate 4.3: Maize cultivated fields in Nessuit area (source: author, date: 27/10/2014).

Plate 4.4: Cedar plantation forest in Nessuit area (source: author, date: 27/10/2014).

Plate 4.5: Built up area and bare ground land cover types at Mathangauta shopping centre (source: author, date: 28/10/2014).

Plate 4.6: An open shrubland land cover type in Likia (source: author, date: 29/10/2014).

Plate 4.7: Grassland land cover type in Kiptunga (source: author, date: 30/10/2014).

Plate 4.8: Indigenous forest in Kongokolani area (source: author, date: 01/11/2014).

4.3.4.3. Forest Resource Use and Land Cover Change Drivers Data Acquisition

Key informants found in the areas where the sample points were falling were interviewed *(Plates 4.9 and 4.10)* based on the field questionnaire *(Appendix III)*. The interviewed informants gave information on the ways in which resources in the Eastern Mau Forest are utilized. They also gave information on the drivers of land cover change in Eastern Mau Forest. Some information about forest resources use and drivers of land cover change was acquired by the researcher through observations *(Plates 4.9 and 4.10)*.

Plate 4.9: An Ogiek elder in Tiritigoit area giving information on drivers of land cover change (source: author, date: 27/10/2014).

Plate 4.10: A Maasai elder's family in Kongokolani area after an interview on drivers of land cover change (source: author, date: 01/11/2014).

4.3.4.4. Satellite Image Data Acquisition

Landsat images are captured based on a predefined grid composed of array of paths and rows. Images were identified based on the path and row covered by the images. The Eastern Mau Forest boundary vector file was uploaded on United States Geological Survey (USGS) website and overlaid on Landsat satellite imagery grid to identify the images covering the area of study. Eastern Mau Forest is covered by path 169 and row 60 of the Landsat grid *(Figure 4.2)*. The start year of image acquisition was set as 1984 and all Landsat images acquired from 1984 to 2014 assessed and screened for suitability in terms of cloud free, seasonality and time interval between the four different years that had been chosen to be used in the study. Based on the screening and assessment that was done images that had less than 10% cloud cover, captured in the same season (January-February) and within close to 10 year time interval were identified, selected and downloaded *(Plate 4.11)*. The downloaded images were of January 1986, January 1995, February 2003 and January 2014 *(Figures 4.3, 4.4, 4.5 and 4.6)*.

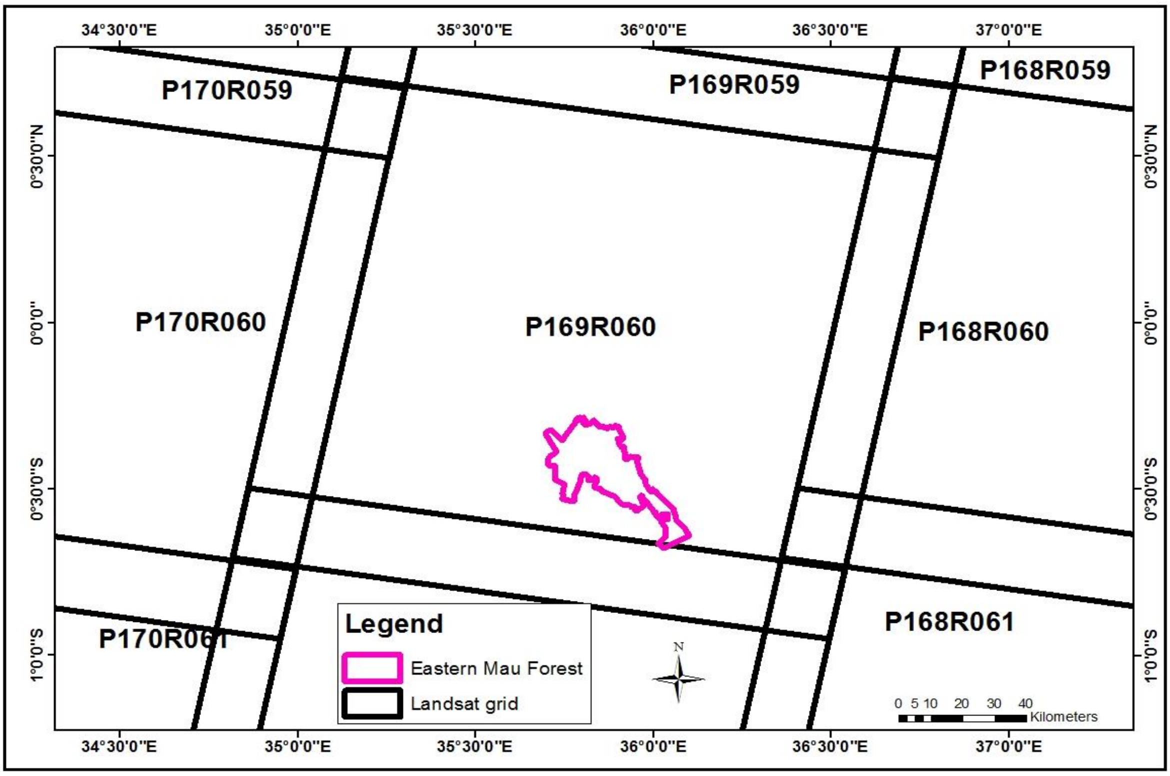

Figure 4.2: Landsat grid covering Eastern Mau Forest (data source: KFS and NASA).

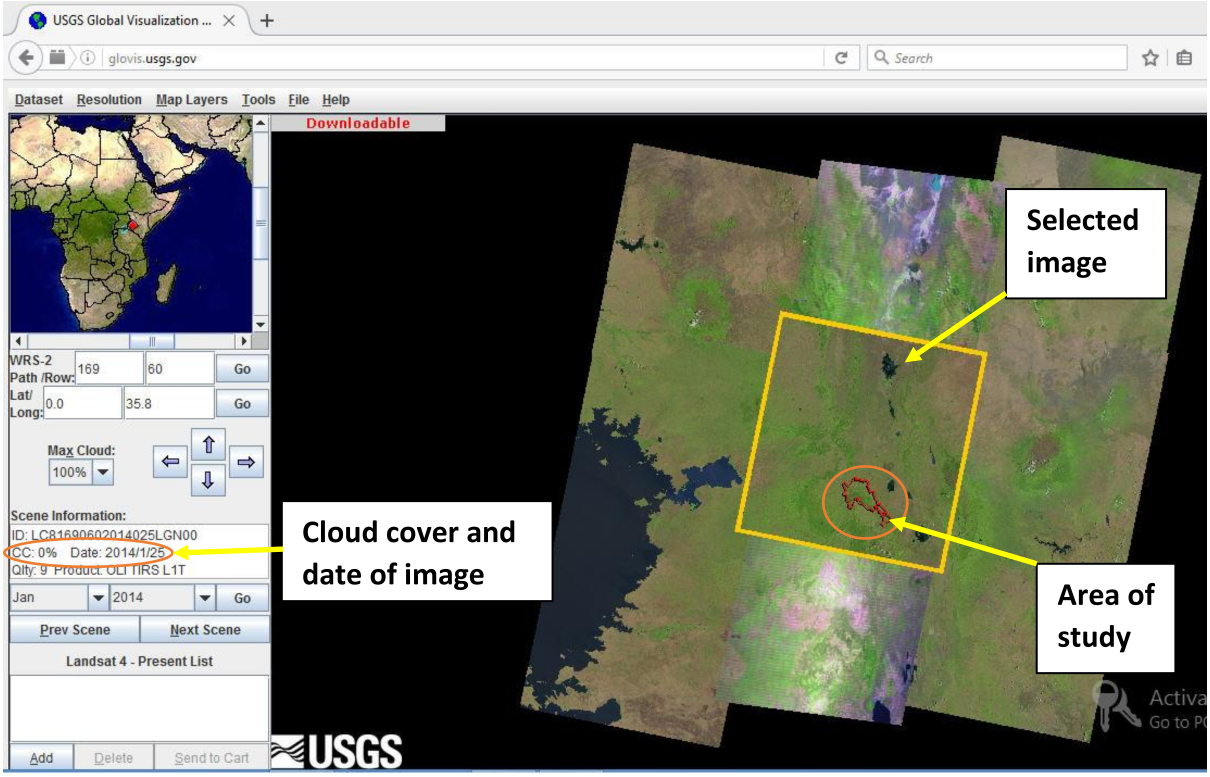

Plate 4.11: Landsat image of January 2014 on Glovis image viewer (data source: NASA).

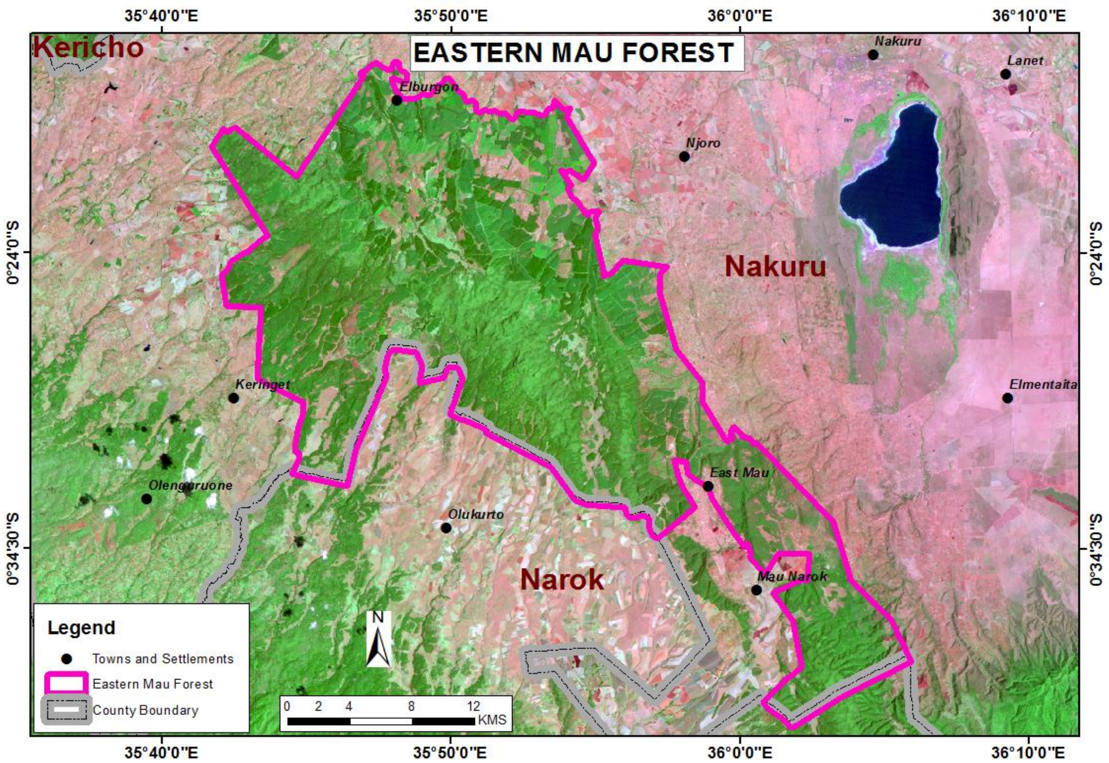

Figure 4.3: Landsat image of January 1986 (data source: KFS and NASA).

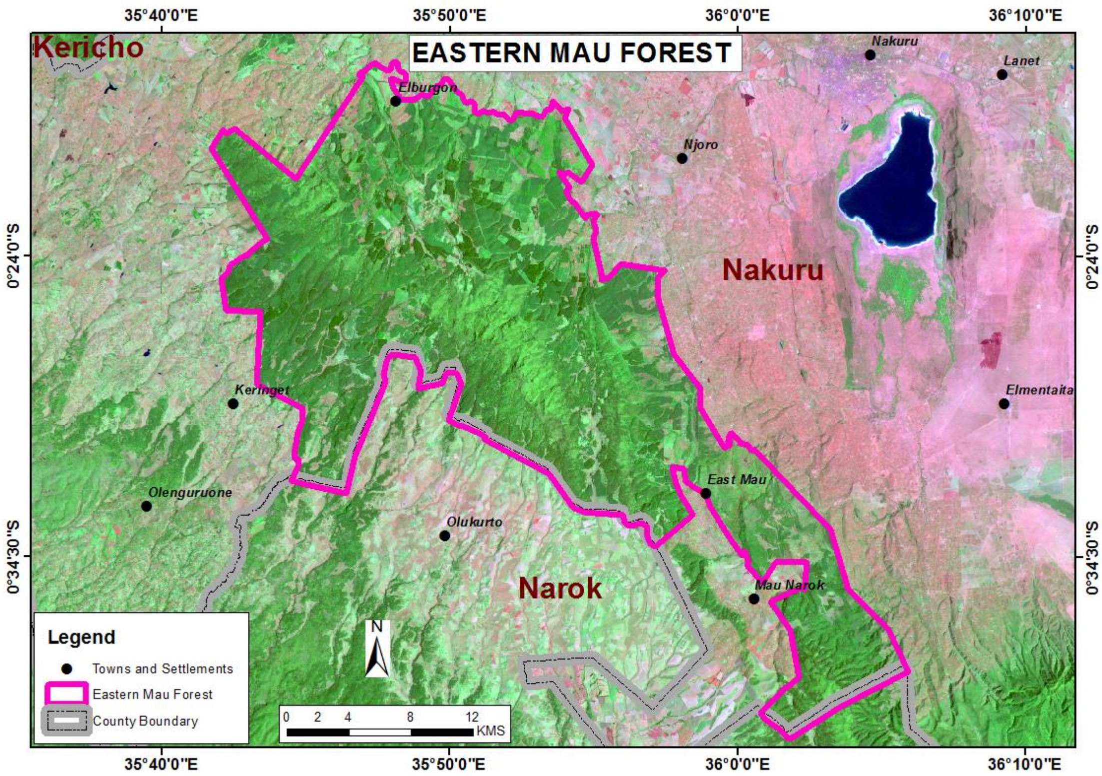

Figure 4.4: Landsat image of January 1995 (data source: KFS and NASA).

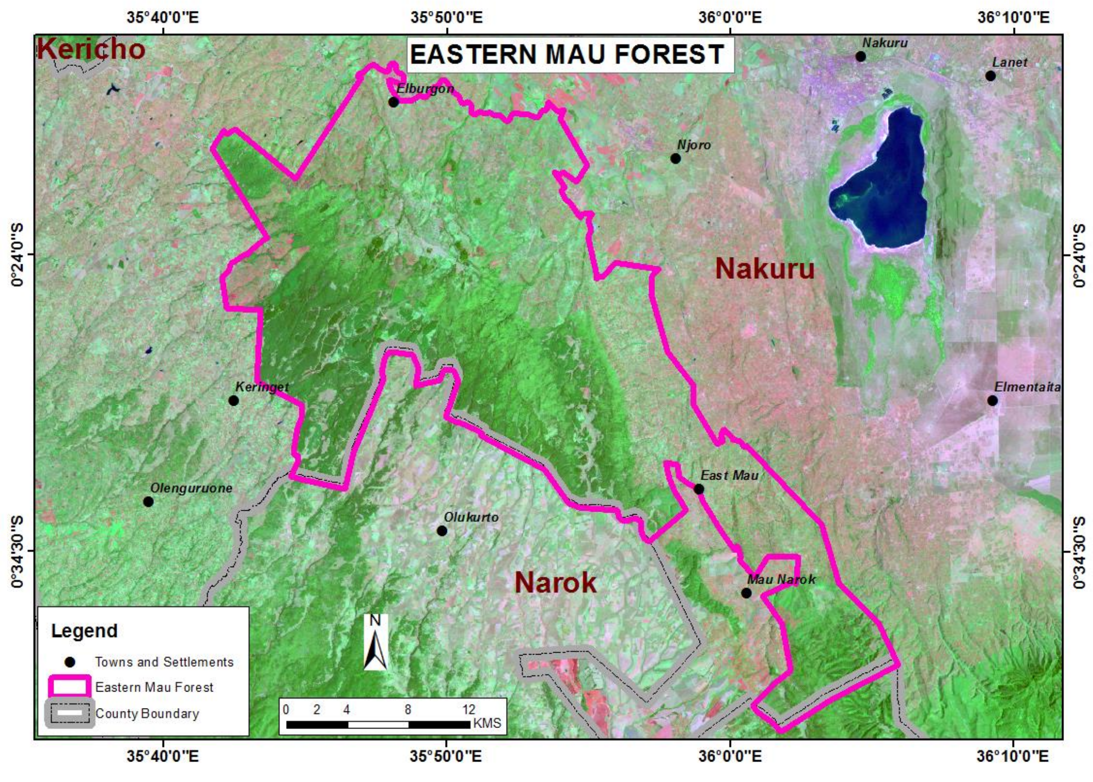

Figure 4.5: Landsat image of February 2003 (data source: KFS and NASA).

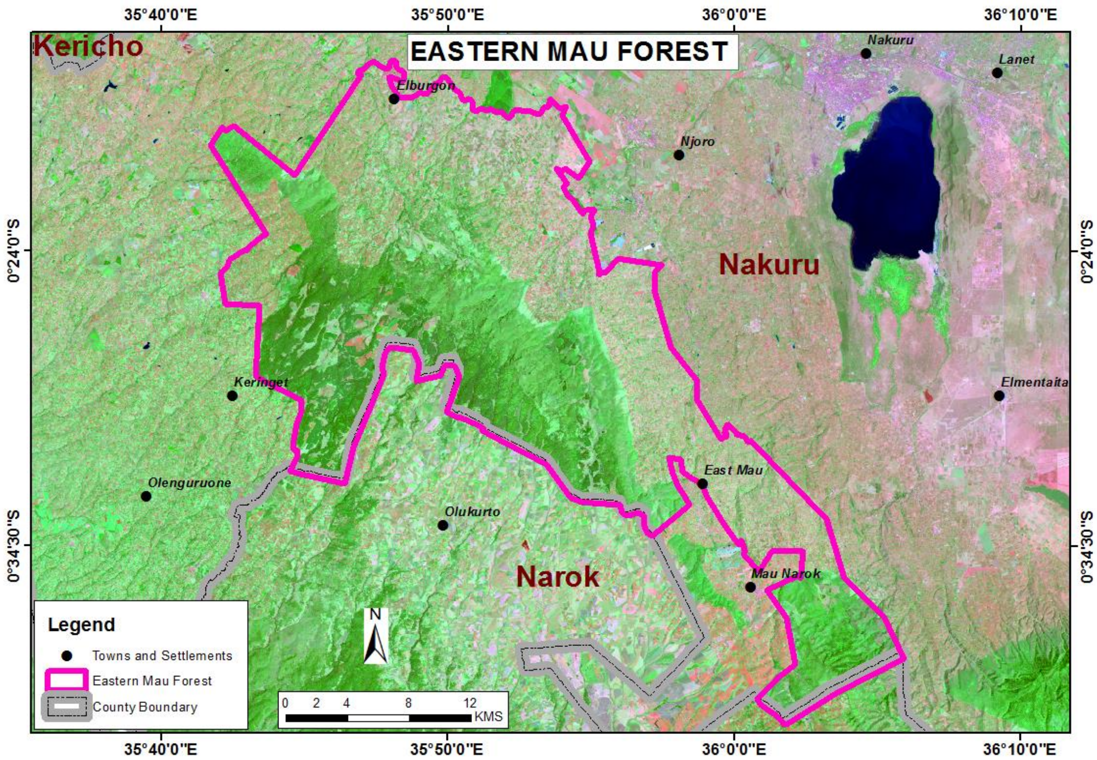

Figure 4.6: Landsat image of January 2014 (data source: KFS and NASA).

4.3.4.5. Other Spatial Data Acquisition

Other spatial data were acquired from already existing datasets by formally requesting for the data from different relevant and authorised custodians of spatial data in Kenya. Kenya forest boundaries were acquired from the Kenya Forest Service while population data was acquired from Kenya National Bureau of Statistics. The 1:50,000 topographic maps, sub-location and county boundary shapefiles, Kenya rivers shapefile and settlement shapefile were acquired from Survey of Kenya.

4.4. Data Processing

4.4.1. Field Data Processing

The different sets of data collected from the field were processed differently before data analysis. The ground control points that were recorded while on the ground were downloaded and displayed in a computer where they were found to be in geographic coordinate system. The satellite images that were to be geo-rectified using those ground control points were in projected coordinate system of UTM Zone 36 North. The control points were therefore projected to the satellite images coordinate system before they were used in the geo-rectification process.

Land cover validation GPS points were also downloaded and displayed in a computer. They were also found to be in geographic coordinate system. They were therefore projected to UTM Zone 36 North before they could be used to validate the land cover classification data generated from satellite images. The land cover field photographs were downloaded to a computer and renamed to bear the names of their respective GPS points for ease of their identification during land cover validation.

The forest resources use and land cover change drivers data were geo-linked to the field GPS points of the locations where they were collected. This was done by opening the attribute table of the GPS points in ArcGIS 10.3 and creating a table field in which to input the activities on the collected information *(Plate 4.12)*. Photographs on forest resources use and land cover change drivers interviews were also downloaded to a computer and renamed to bear the names of the places where interviews were conducted.

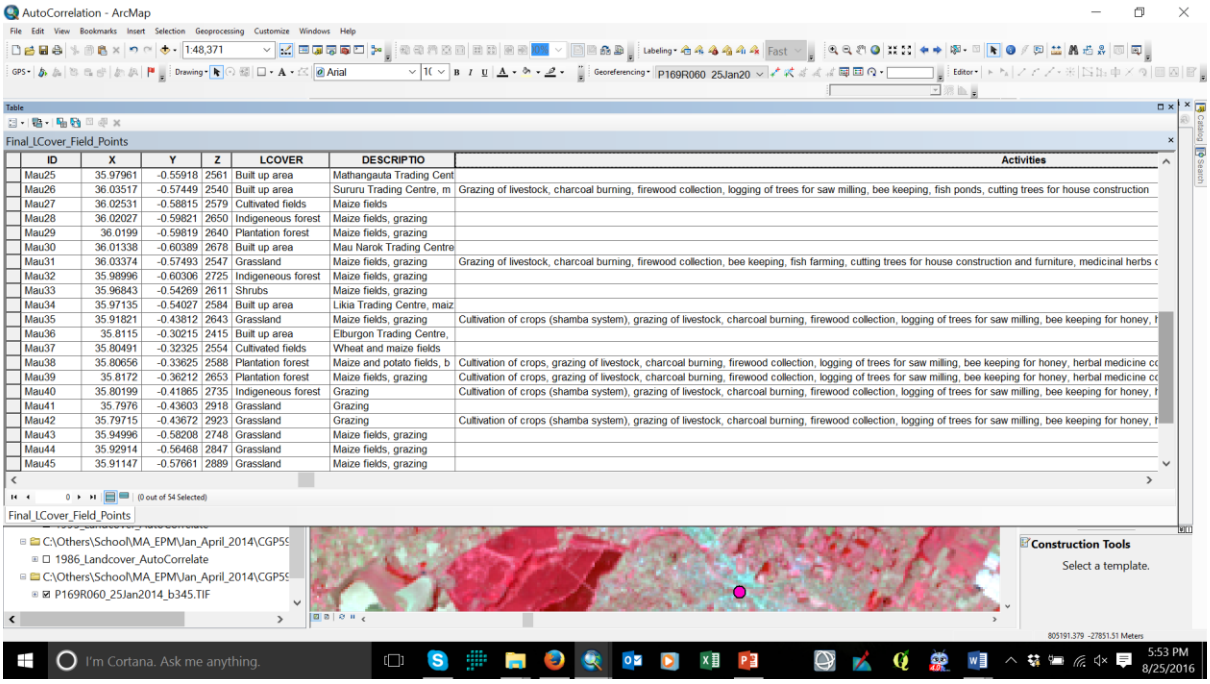

Plate 4.12: Forest resource use and land cover change drivers information (source: ESRI ArcGIS).

4.4.2. Satellite Image Data Processing

The satellite images that were downloaded from the USGS website were in form of compressed zip files bearing single image bands corresponding to different electromagnetic light channels. These were uncompressed before processing in readiness for interpretation and analysis. Image processing involved image layer stacking and image geo-rectification.

4.4.2.1. Image Layer Stacking

Landsat satellite images come as single raw image bands which represent different light channels of the electromagnetic spectrum. All ground features give grey colour reflectance of between white and black on a raw image band. To be able to clearly distinguish different features different light channel bands are combined to give colour composite images, a process referred to as layer stacking (image compositing).

This process involved combining three different image light channel bands to give the desired colour image for land cover classification. The combination of light channels was done in the same way red, green and blue light channels combine to give visible light, commonly known as RGB combination (R for red, G for green and B for blue light channels respectively). For purposes of interpreting and analyzing land cover false colour composites of bands 4, 3 and 2 were used for the 1986, 1995 and 2003 images captured by Landsat 5 and 7 sensors. That for 2014 was captured by Landsat 8 sensor and the band combination used to give a similar false colour composite was for bands 5, 4 and 3 which correspond to bands 4, 3 and 2 in Landsat 5 and 7. This was done by selecting and displaying the three image bands in ArcGIS 10.3 software *(Plate 4.13a)*. Image *band composite tool* under *Raster Processing Tools (Plate 4.13b)* was used to input the displayed image bands before running the process to create the colour composite image *(Figure 4.7)*.

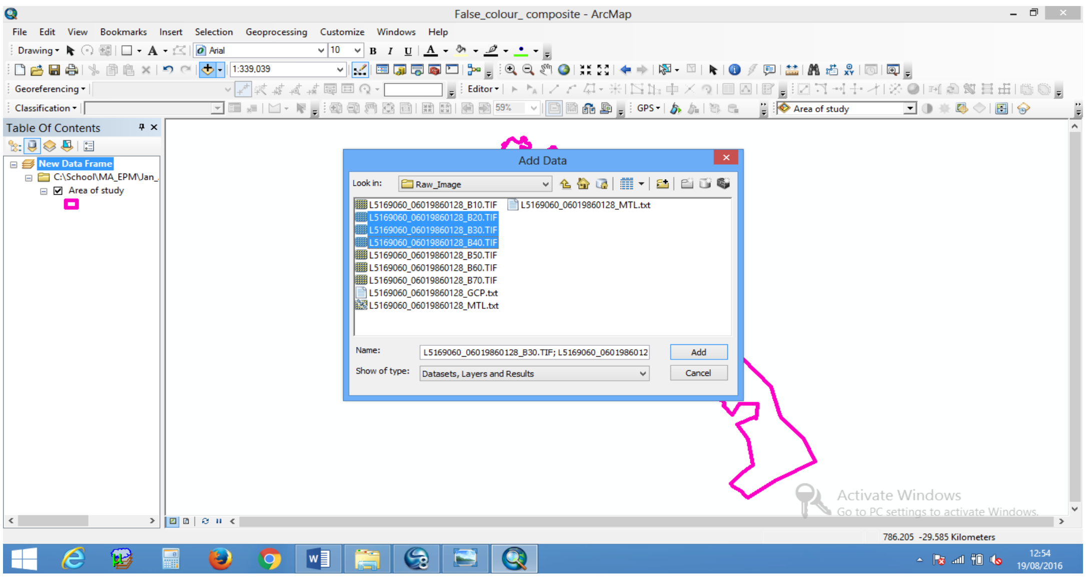

Plate 4.13a: Selection of image bands for layer stacking (source: ESRI ArcGIS).

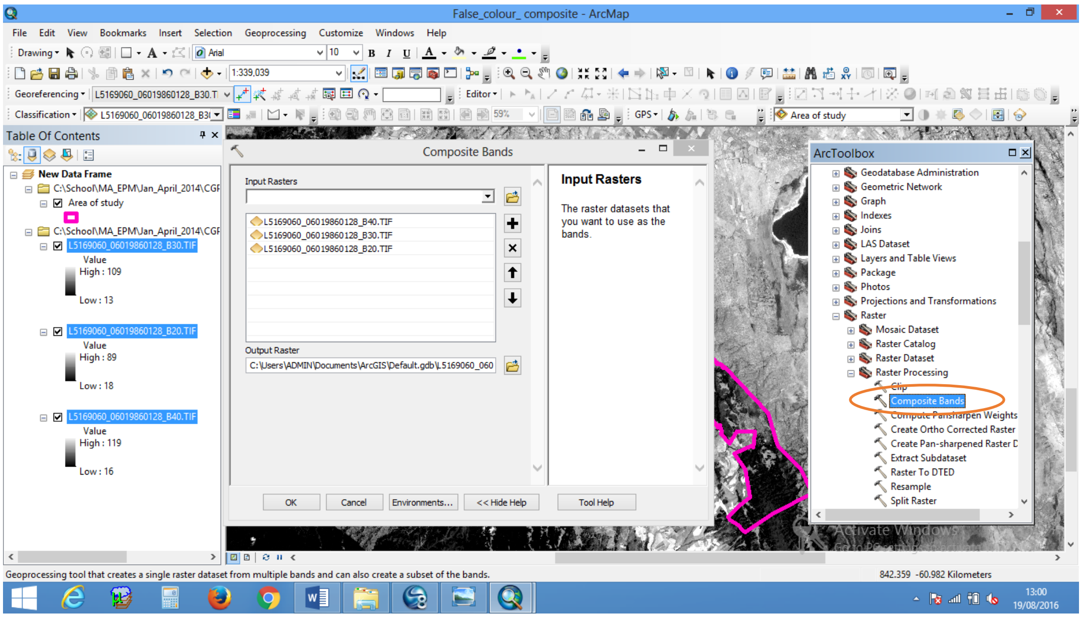

Plate 4.13b: Image band compositing tool (source: ESRI ArcGIS).

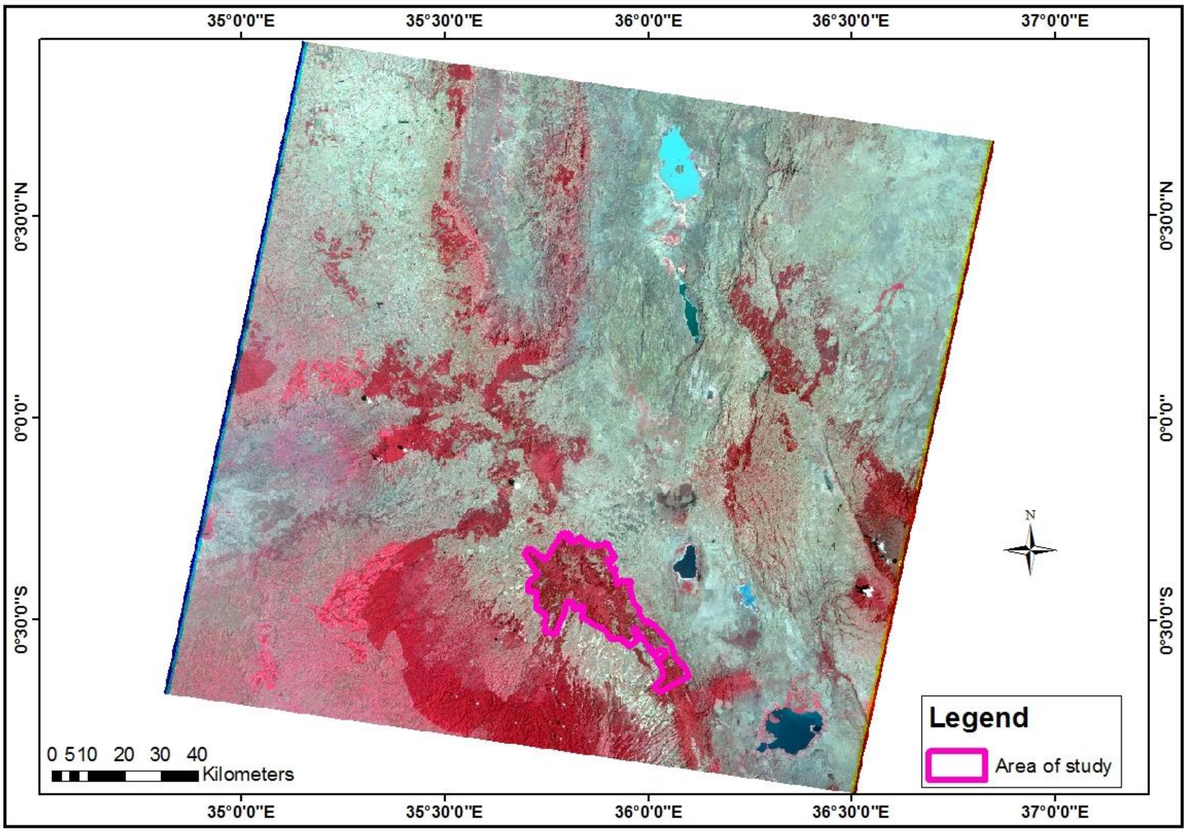

Figure 4.7: False colour composite image of the area of study (data source: KFS and NASA).

4.4.2.2. Image Geo-rectification

Different satellite images of the same area captured at different times tend to have some shift between them as a result of some differences in sensor flight heights at the time of data capture. To avoid having errors when carrying out change detection procedures the different images used were geo-rectified to ensure one on one image overlap and registration.

Each of the 1986, 1995, 2003 and 2014 images was displayed in ArcGIS software and *add control point* tool selected under image geo-referencing tools *(Plate 4.14a)* to assign new ground control points on the satellite images as captured on the ground. This was done by clicking on the add control point tool, right-clicking on the identified road junctions to display coordinate input window, and then input the coordinates recorded while on the ground *(Plate 4.14b)*. Image geo-rectification tool was then used to remove the shift that was between the images by moving all of them to exactly the same position as recorded by the GPS while on the ground. This was achieved by clicking on image geo-rectification tool *(Plate 4.14c)* to display a window for saving new images from geo-rectification process *(Plate 4.14d)*.

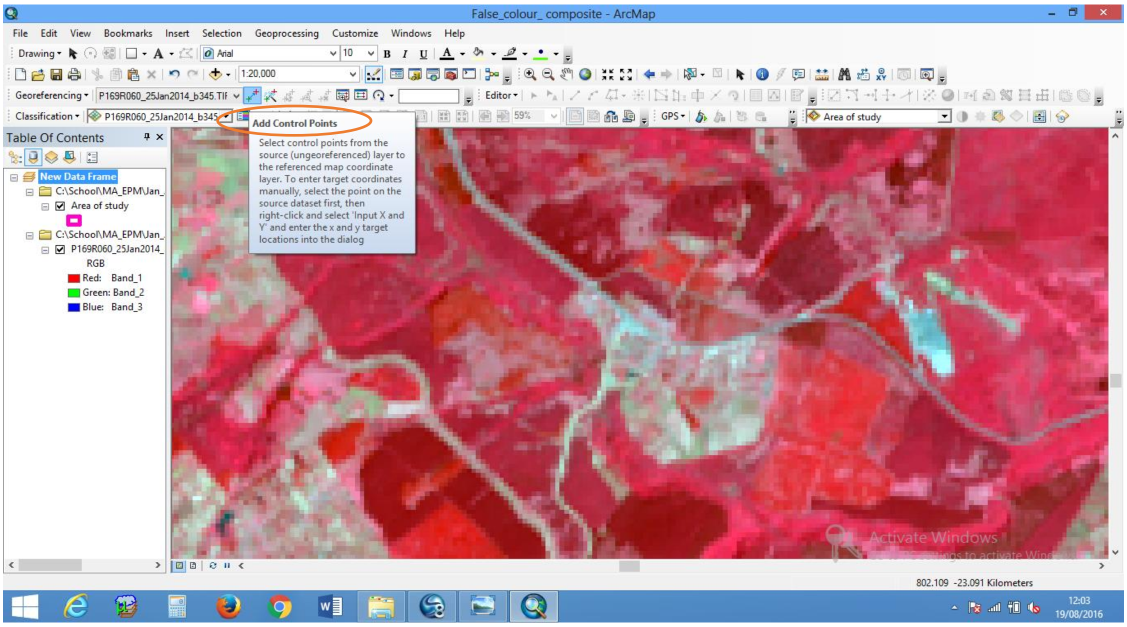

Plate 4.14a: Tool for adding ground control points (source: ESRI ArcGIS).

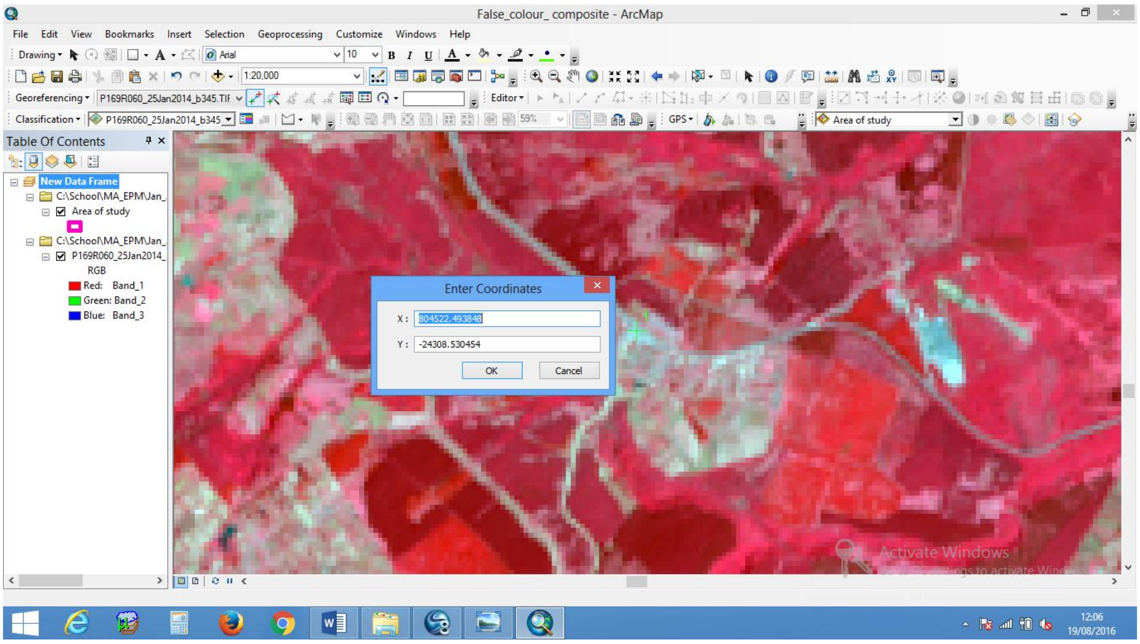

Plate 4.14b: Inputting ground control points coordinates for image geo-rectification (source: ESRI ArcGIS).

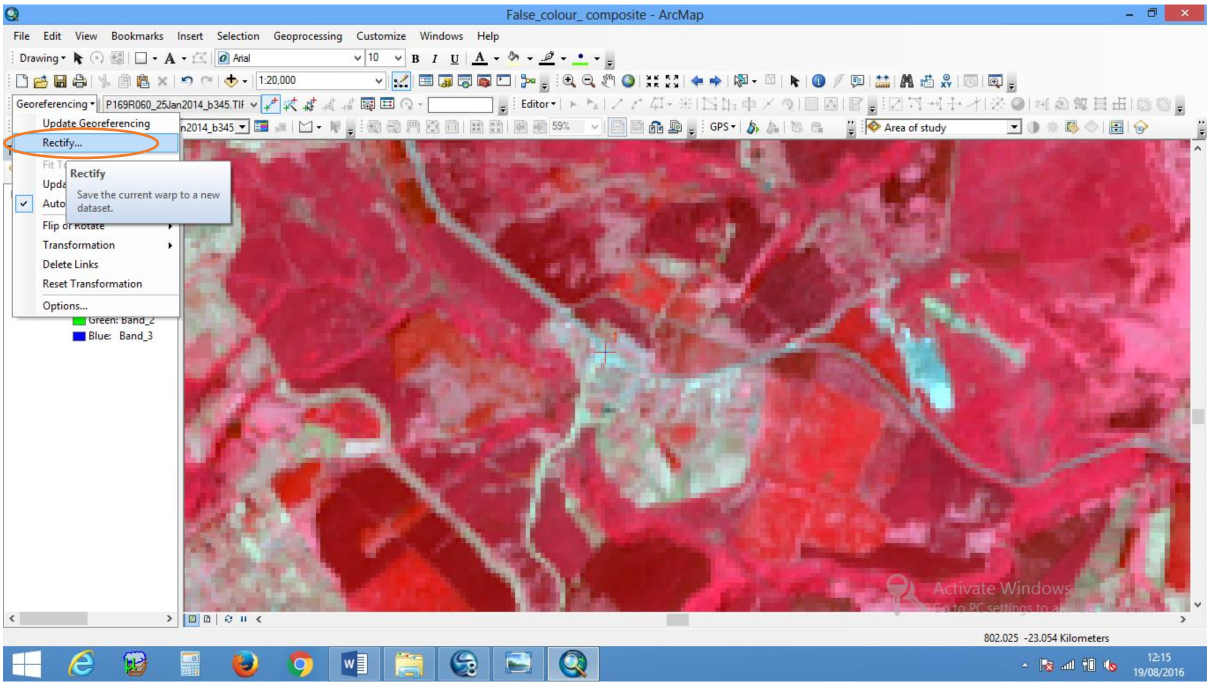

Plate 4.14c: Image geo-rectification tool (source: ESRI ArcGIS).

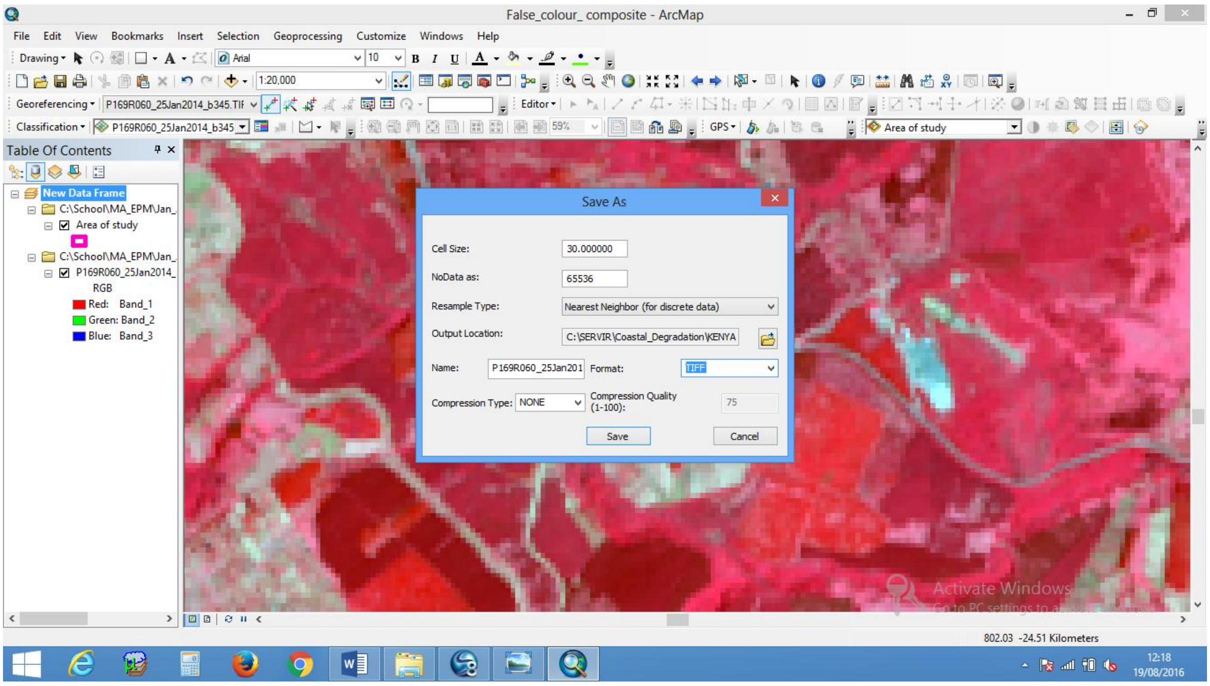

Plate 4.14d: Saving a geo-rectified image (source: ESRI ArcGIS).

4.4.3. Other Spatial Data Processing

Kenya forest boundaries, population, sub-location boundaries, county boundaries, Kenya Rivers and settlements datasets were acquired in geographic coordinate system. These datasets were therefore projected to the satellite images coordinate system of UTM Zone 36 North before they were used together with the images. The 1:50,000 topographic maps that were acquired from Survey of Kenya were not georeferenced. They were therefore ran through geo-referencing process before they were used.

Geo-referencing was done in ArcGIS 10.3 software by first displaying the Kenya topographic map sheets grid for identification of the coordinates to be used in geo-referencing. The grid layer name was right-clicked to open the attribute table for identification and selection of the topographic map sheets to be geo-referenced. The sheet selection was done in the attribute table and the selection was reflected on the sheets grid. The pointer tool was placed at the corners of the selected sheet on the grid and the coordinates to be used for geo-referencing were displayed at the bottom right corner of ArcGIS 10.3 display window *(Plate 4.15a)*. Geo-referencing was done by displaying the topographic maps and clicking the *add control points* tool at the topographic map sheets corners to input the geo-referencing coordinates *(Plate 4.15b)*. After inputting the four corner coordinates geo-referencing was ran by clicking on *Rectify tool (Plate 4.15c)* to create geo-referenced topographic map sheets.

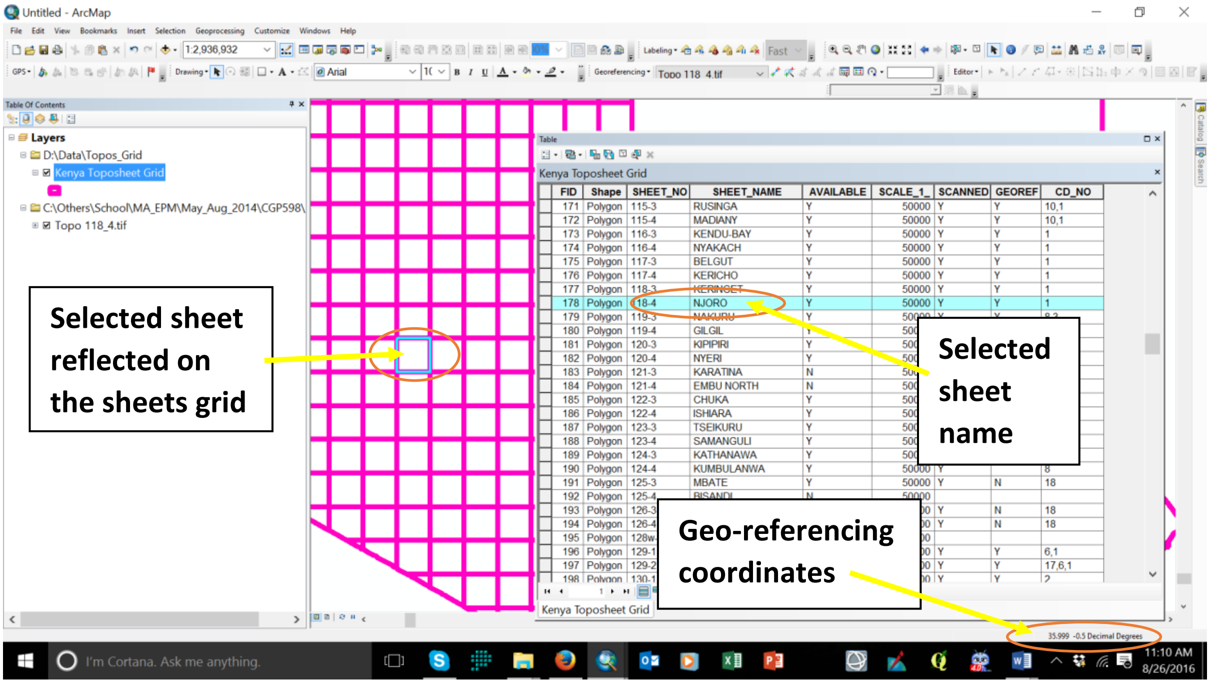

Plate 4.15a: Identification of geo-referencing coordinates (source: ESRI ArcGIS).

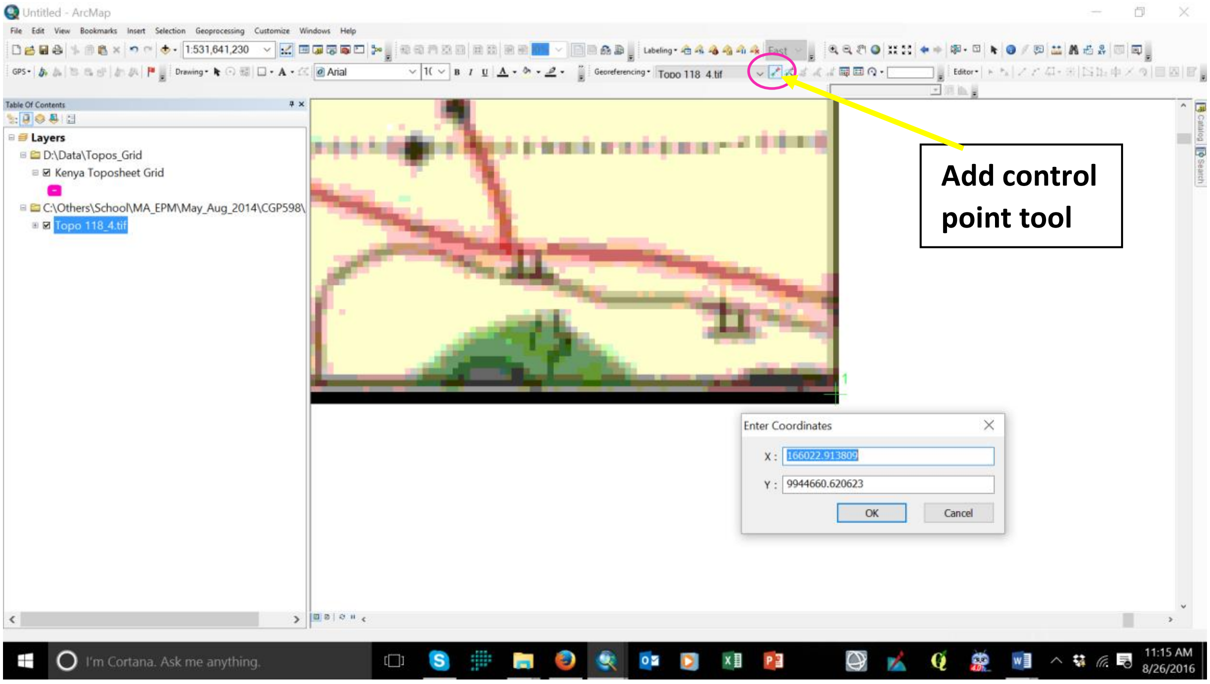

Plate 4.15b: Adding geo-referencing control points coordinates (source: ESRI ArcGIS).

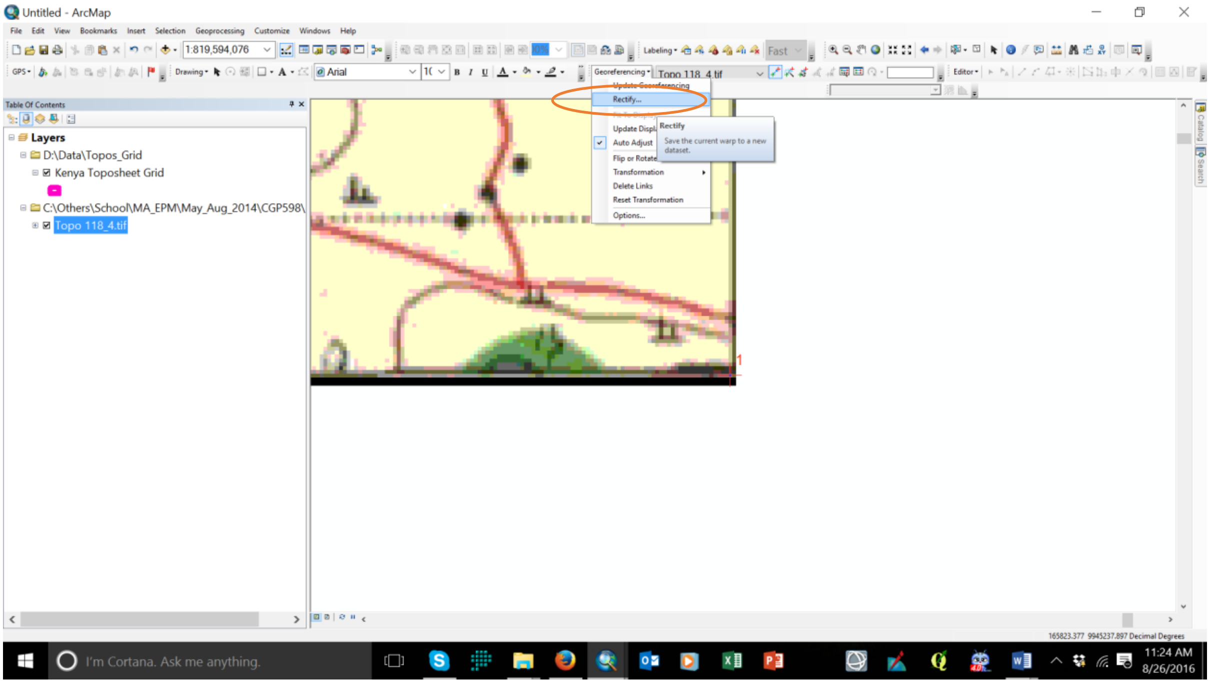

Plate 4.15c: Using rectify tool to geo-reference topographic maps (source: ESRI ArcGIS).

The geo-referenced map sheets were in geographic coordinate system and they were therefore projected to UTM Zone 36 North like the rest of the datasets. Projecting was done using *Project Raster* tool under *Data Management Tools* in ArcGIS 10.3 software *(Plate 4.16)*.

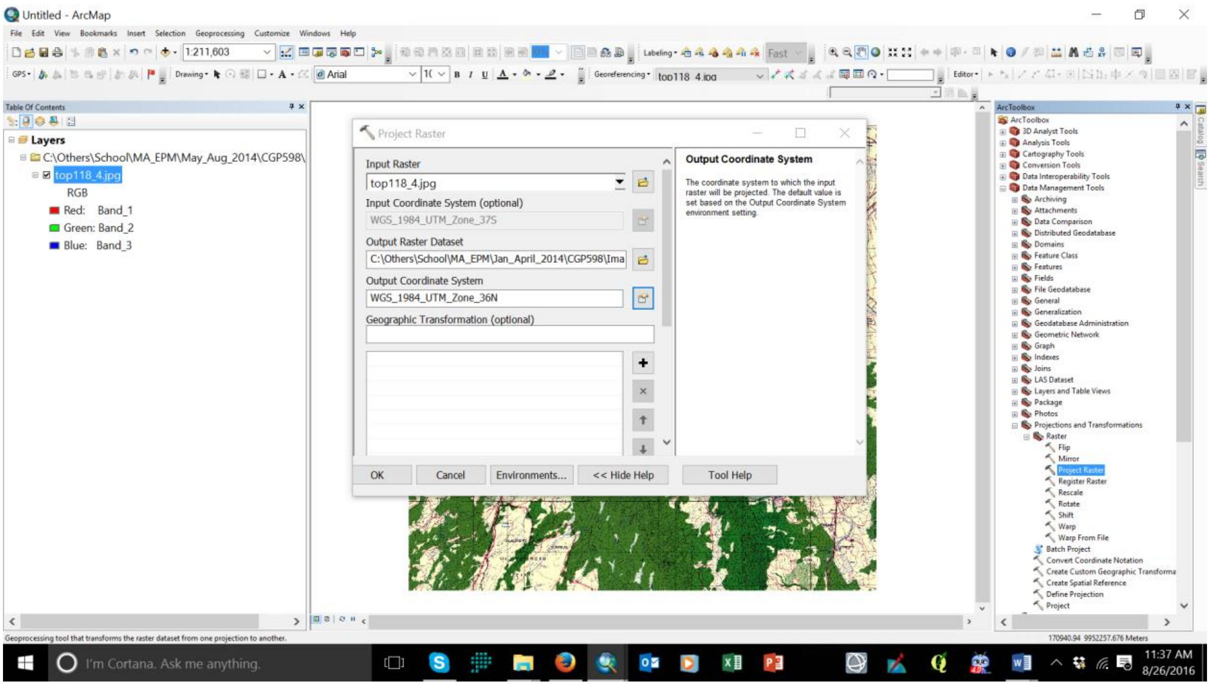

Plate 4.16: Projecting a topographic map sheet (source: ESRI ArcGIS).

4.5. Data Analysis Techniques

4.5.1. Spatial Analyses

4.5.1.1. Delimiting the Area of Study from the Satellite Imagery

Delimiting of the area of study was carried out by clipping of satellite images before interpretation and classification of different land cover types. Clipping of satellite images involved use of overlay spatial analysis function using a vector layer that defined the spatial extent of the study area. The overlay function used was arithmetic of multiplication option where the part of the image within the area of study was multiplied by one while that falling outside the area of study by zero.

Arithmetically, any number multiplied by one remains the same while a number that is multiplied by zero becomes zero. This led to the image parts in the area of study to retain their digital values while those outside the area of study were removed by acquiring a digital value of zero. This overlay spatial analysis enabled only the image parts within the bounds of the study area to be interpreted and analyzed which helped to reduce image processing time and storage space in the computer. The arithmetic multiplication overlay function was ran in ArcGIS 10.3 in *Data Management Tools* under *Raster Processing Clip tool* resulting into a clipped image *(Plate 4.17 and Figure 4.8)*.

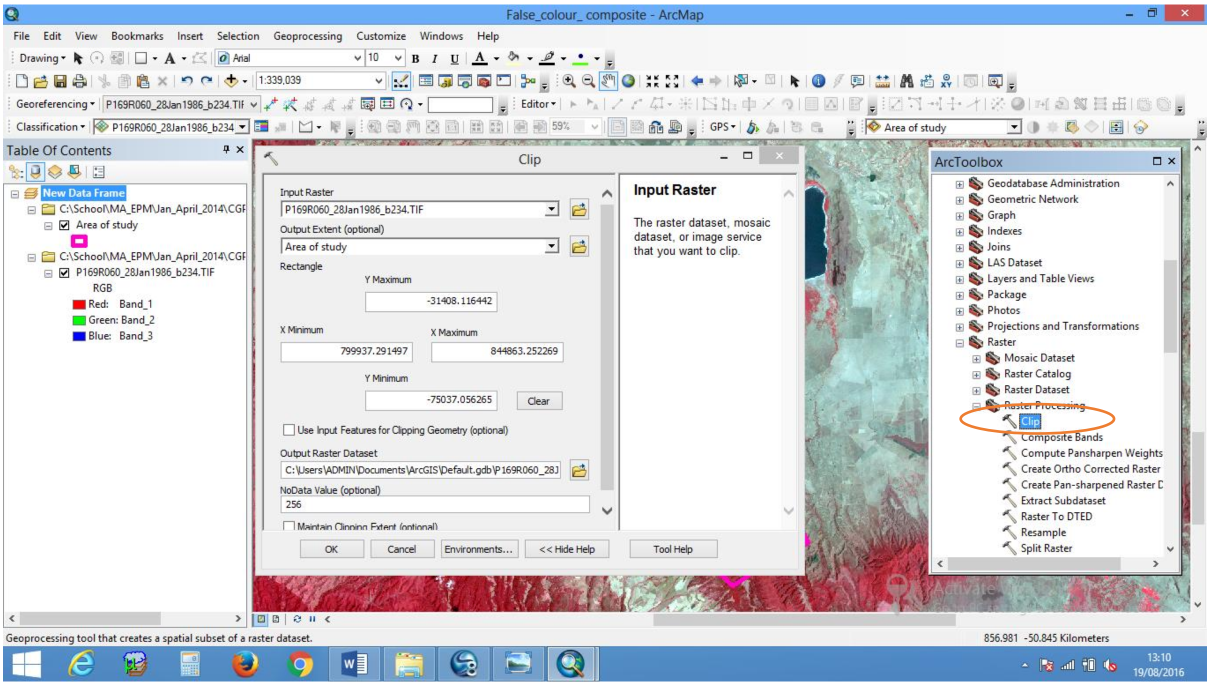

Plate 4.17: Image clipping tool (source: ESRI ArcGIS).

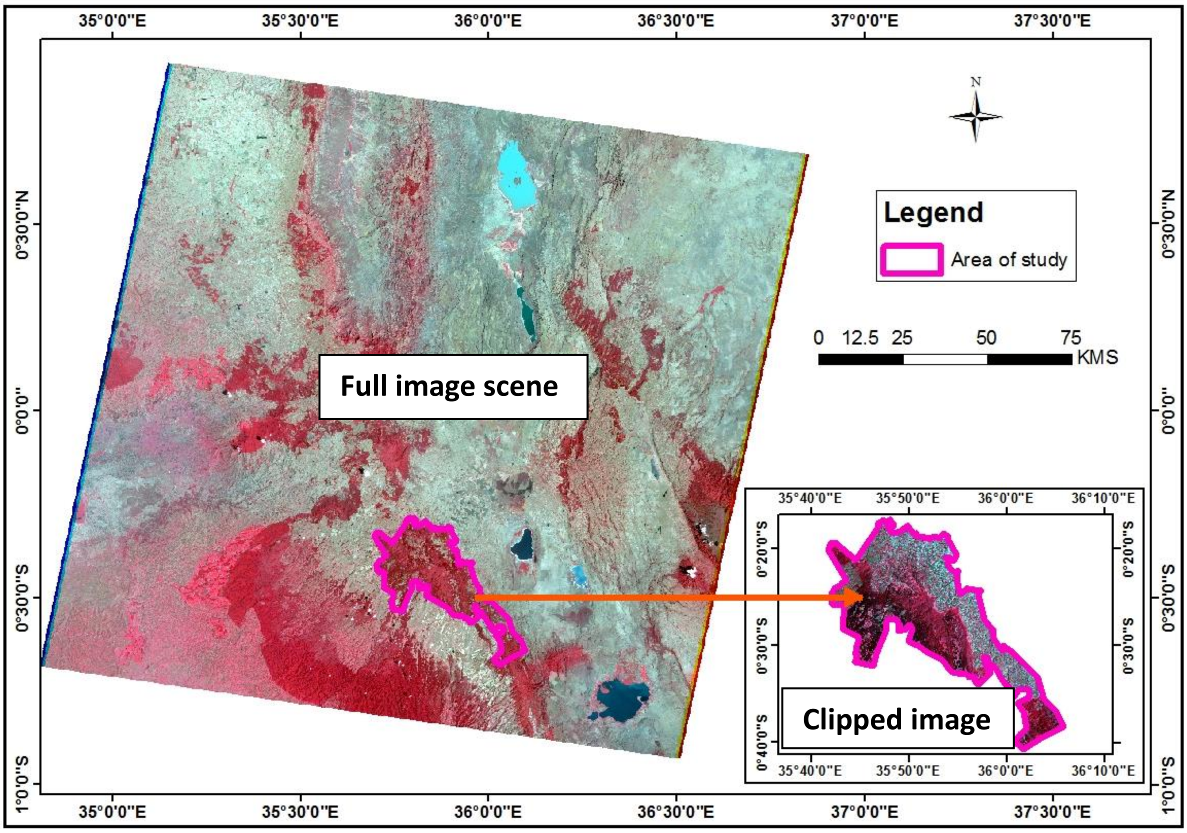

Figure 4.8: Full and clipped images of Eastern Mau Forest (data source: KFS and NASA).

4.5.1.2. Determination of Land Cover Classes

The clipped satellite images were analysed to determine the spatial extent of the different land cover types within the area of study. The different land cover classes had different spectral reflectances displayed as different image colours. This spatial analysis was based on interpreter guided supervised visual image interpretation and classification by computer digitization of polygons around spatially homogeneous areas of the images in ArcGIS 10.3 software. This was carried out by clicking on *Start Editing tool* to display *Create Feature Construction Tools* to get the *Polygon ditization tool (Plate 4.18a)*. The polygon digitization tool was then used to digitize polygons around different satellite image parts bearing homogenous colour reflectances and corresponding land cover types assigned to the polygons *(Plate 4.18b)* based on land cover types identified during field reconnaissance.

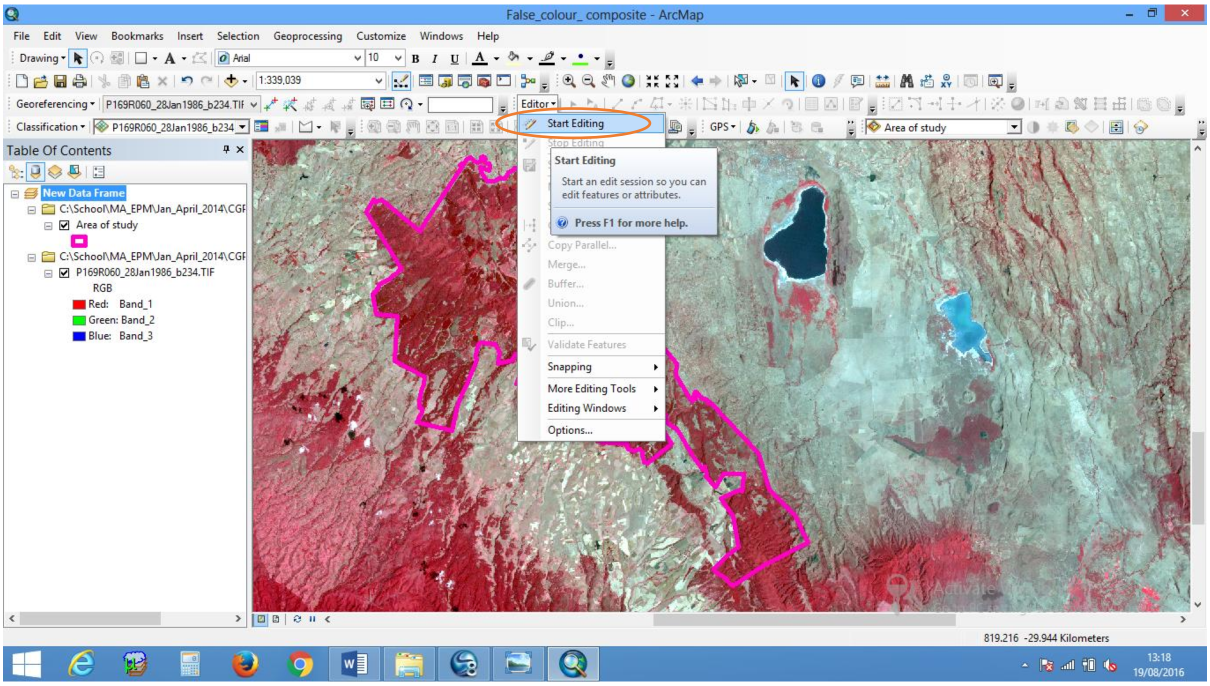

Plate 4.18a: Polygon digitization tool editor (source: ESRI ArcGIS).

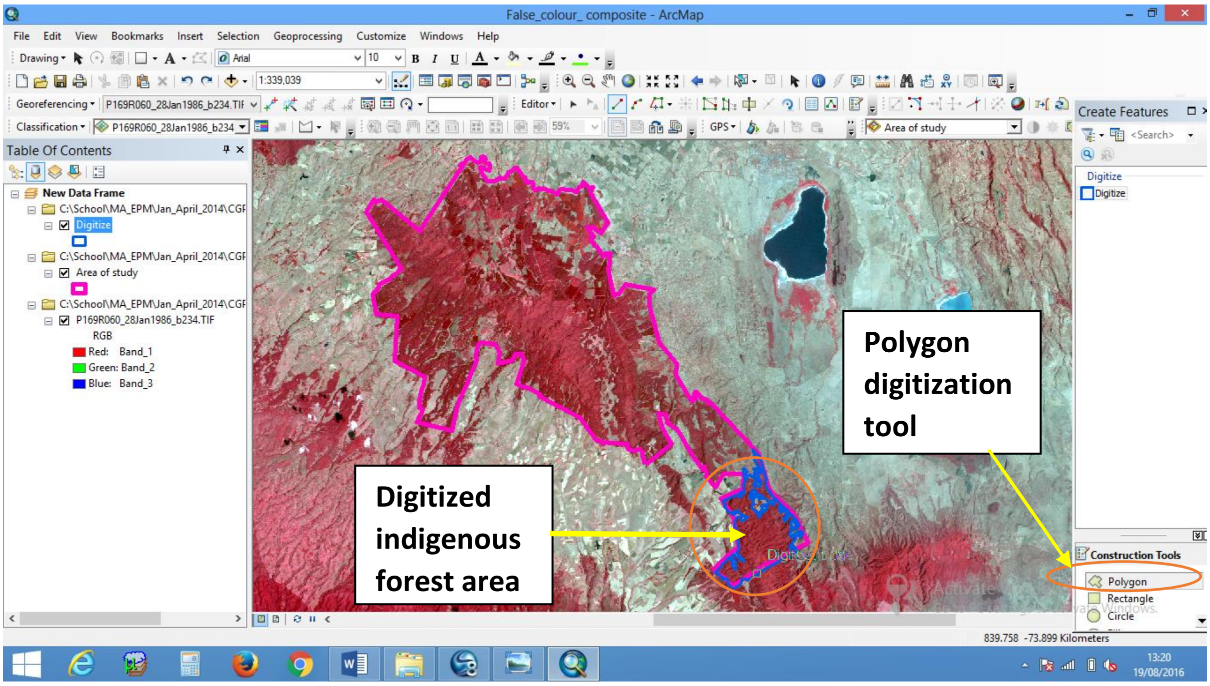

Plate 4.18b: Digitization of land cover classes (source: ESRI ArcGIS).

Field validation was carried out and points of different land cover types visited. Observations were made while at the points and the observed land cover types recorded in the land cover validation form *(Appendix II)*. GPS points were also saved in the handheld GPS receiver and photographs taken for ease of identification and classification of the different land cover classes. The saved GPS data was downloaded and overlaid on the land cover classification from the satellite images. Land cover data collection forms and photographs corresponding to different GPS points were referred to and changes made where classification was not correctly done. The different land cover classes that were identified during this spatial analysis include indigenous forest, plantation forest, grassland, shrubland, cultivated fields, bare ground and built up area. This spatial analysis gave rise to status of different land cover classes within the area of study for the different years under study (1986, 1995, 2003 and 2014).

4.5.1.3. Land Cover Change Detection

Land cover change detection was computed based on cross-tabulation analysis of areas of different land cover types for different years in IDRISI Selva software. To run the cross-tabulation classified land cover vector datasets of different years were converted to raster datasets. This was done using *Raster-Vector* conversion tool under IDRIS Selva *Reformat* tools *(Plate 4.19a)* that opened up Raster-Vector conversion window where conversion options were selected *(Plate 4.19b)*. The selected conversion options were vector to raster and polygon to raster options. The conversion generated raster layers of classified land cover types for different years *(Plate 4.19c)*.

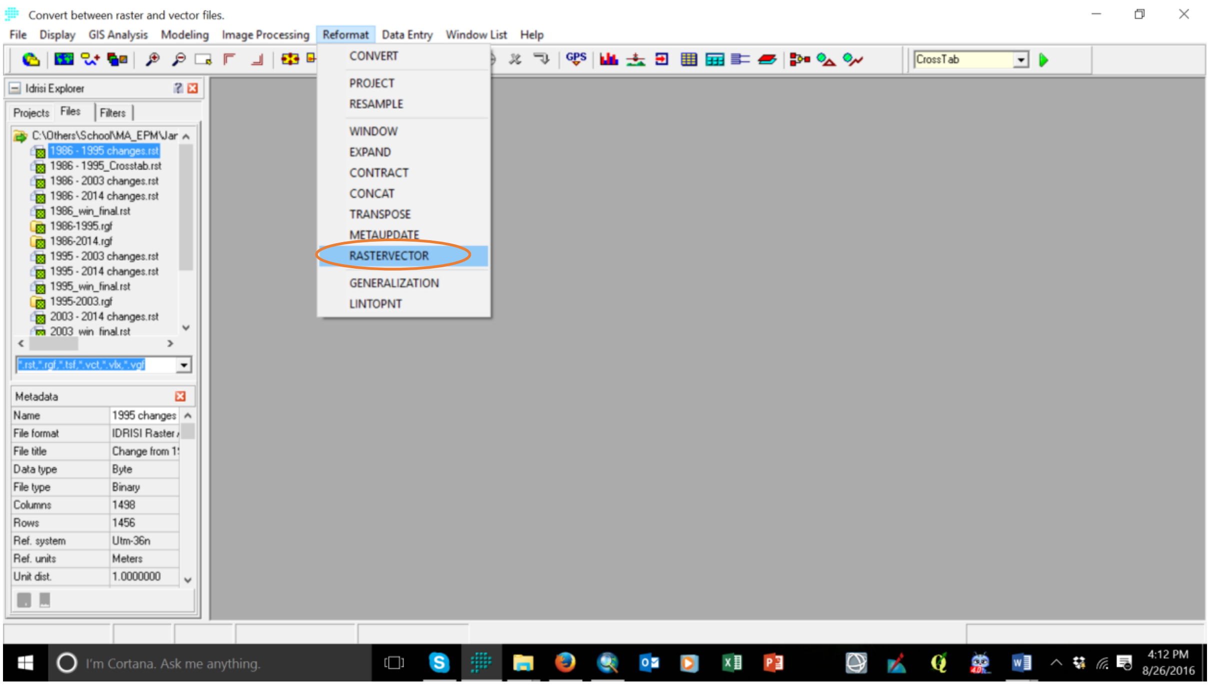

Plate 4.19a: Vector to raster conversion tool (source: Clark Labs IDRISI).

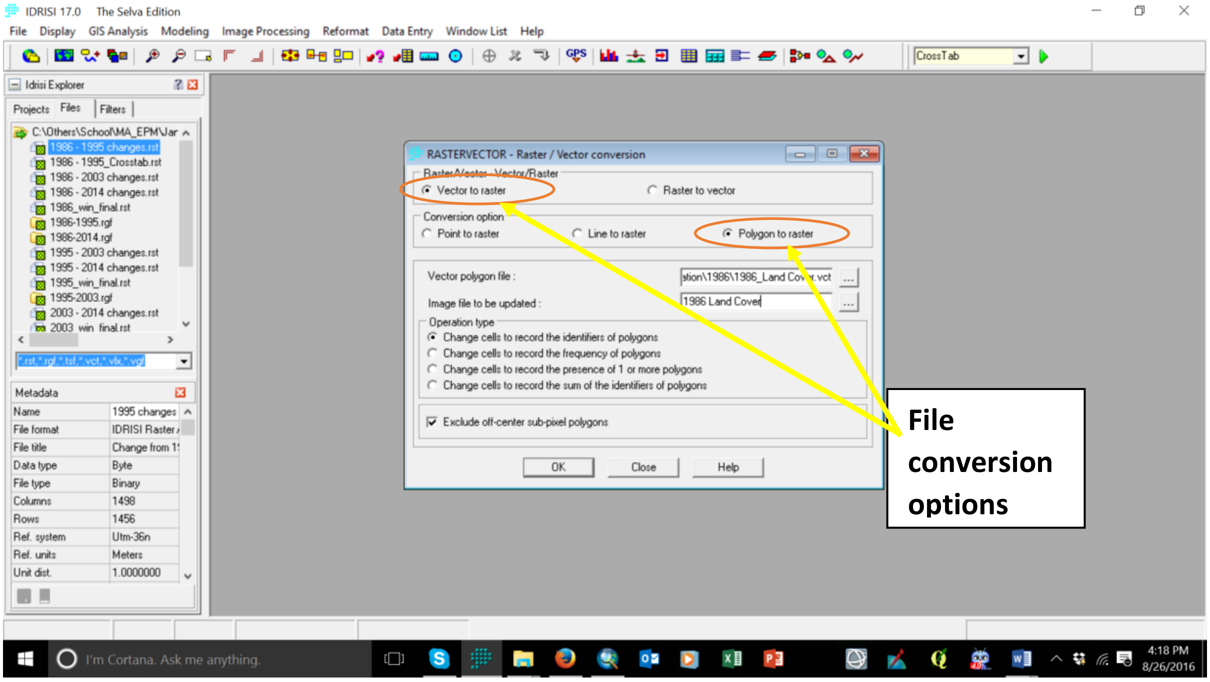

Plate 4.19b: Vector to raster conversion options (source: Clark Labs IDRISI).

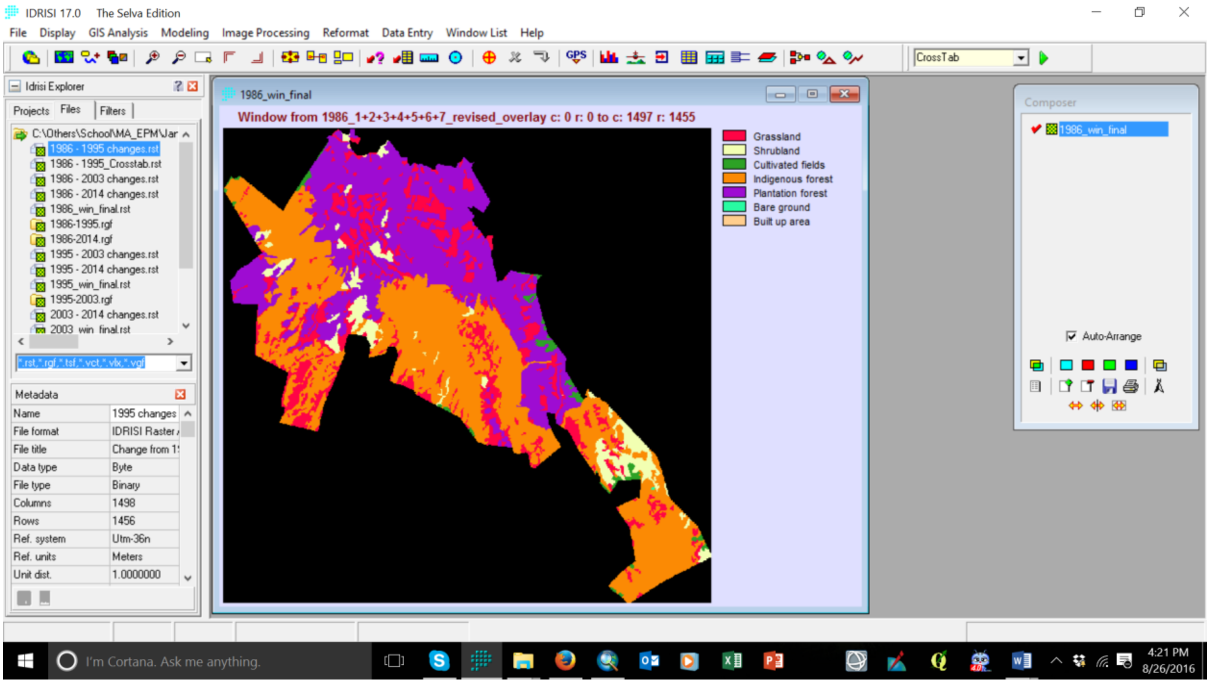

Plate 4.19c: 1986 land cover raster for Eastern Mau Forest (source: Clark Labs IDRISI).

The generated land cover raster files were ingested into *Land Change Modeler* under *Environmental Modeling* tools *(Plate 4.20a)* to run the cross-tabulation. The cross-tabulation was computed between two land cover layer parameters at a time *(Plate 4.20b)*. This change detection was computed to show which land cover types had changed, to which other types and by how much hectares. The changes computed were those of 1986-1995, 1995-2003, 2003-2014 and the overall change of 1986-2014.

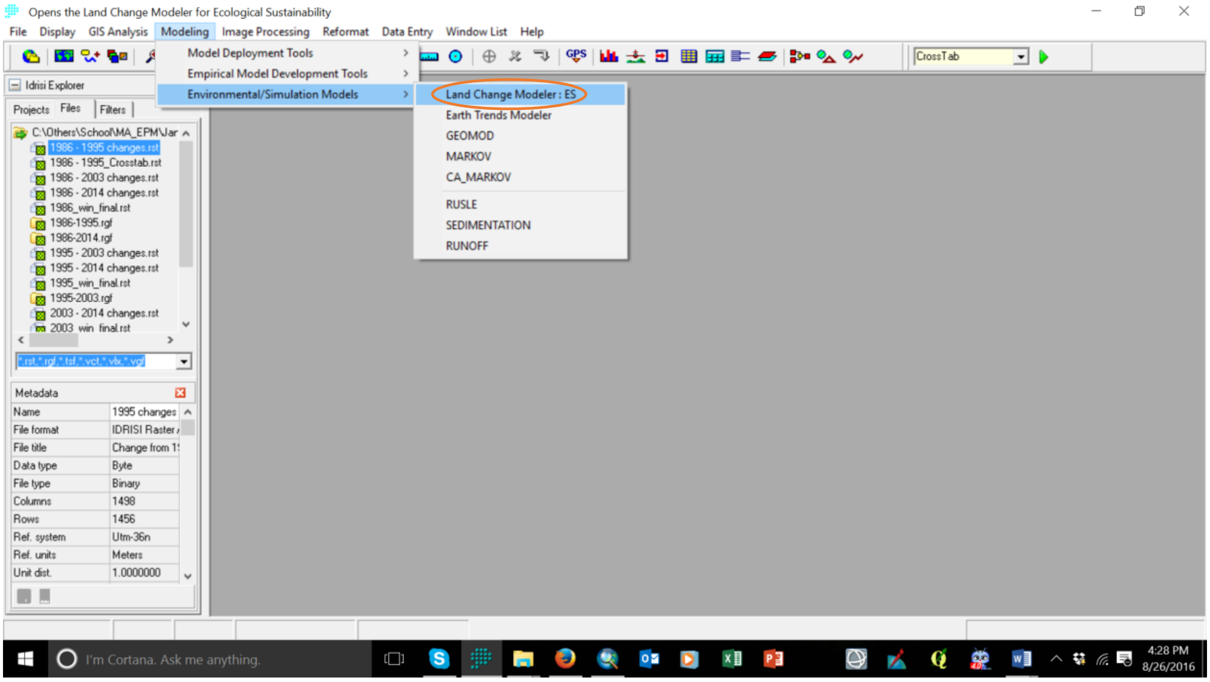

Plate 4.20a: Land cover change modeler (source: Clark Labs IDRISI).

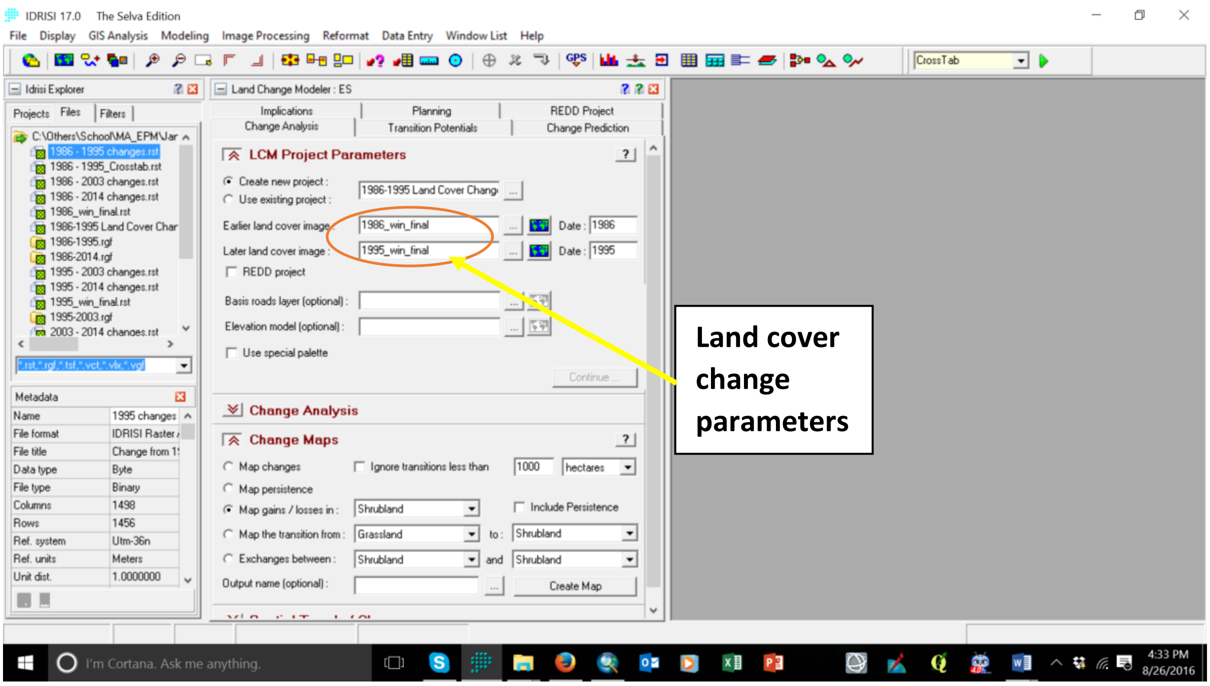

Plate 4.20b: 1986 and 1995 land cover change parameters (source: Clark Labs IDRISI).

4.5.2. Geostatistical Analyses

4.5.2.1. Determining Area of Land Cover Types

The areas covered by different land cover types for different years covered in the study were computed in hectares using a geostatistical tool for area computation based on attribute table analysis in ArcGIS 10.3 software. This was carried out using *Calculate Geometry tool* by right-clicking on the land cover layer name to open the attribute table *(Plate 4.21a)*, then right-click on the table area field to get the *Calculate Geometry tool (Plate 4.21b).* This tool provided different options for selecting the units of area computation where hectares option was selected. *(Plate 4.21c).*

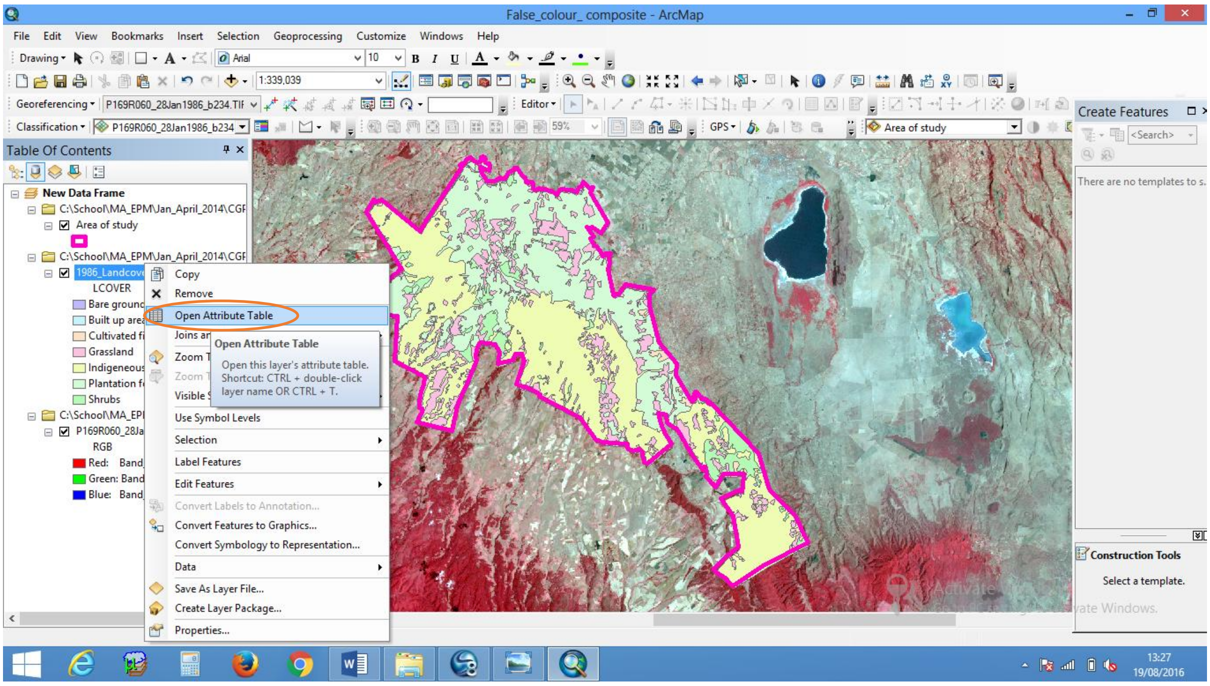

Plate 4.21a: Attribute table opening for land cover area computation (source: ESRI ArcGIS).

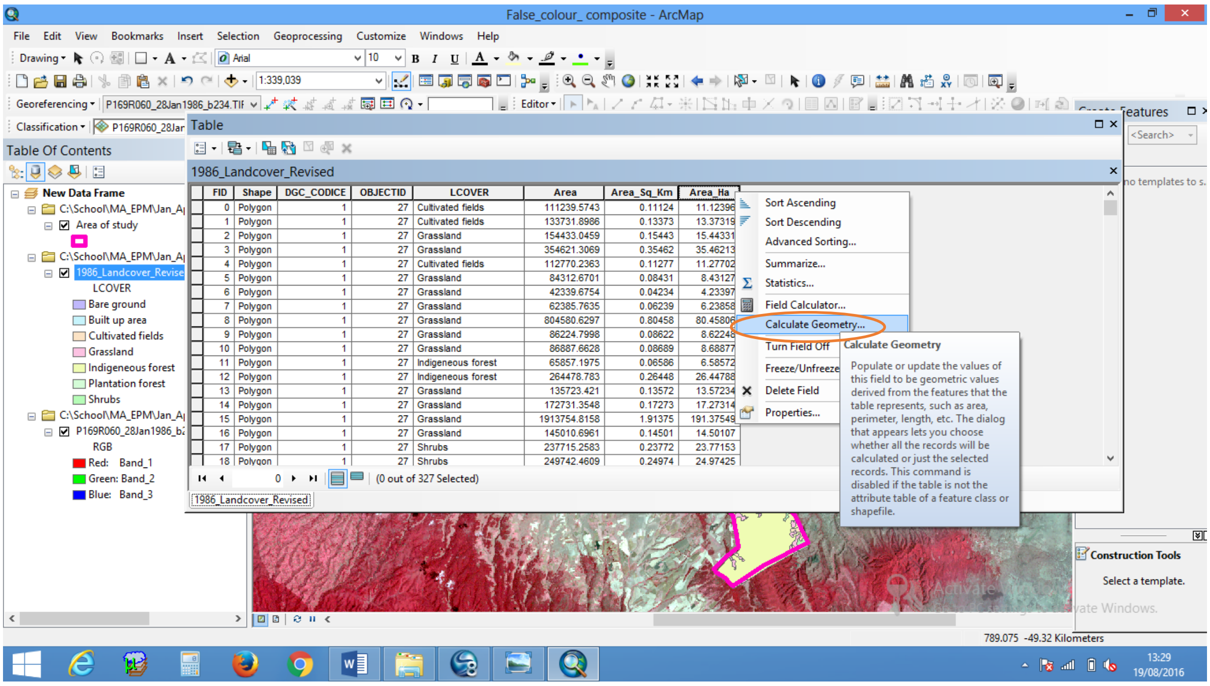

Plate 4.21b: Calculate geometry tool for land cover area computation (source: ESRI ArcGIS).

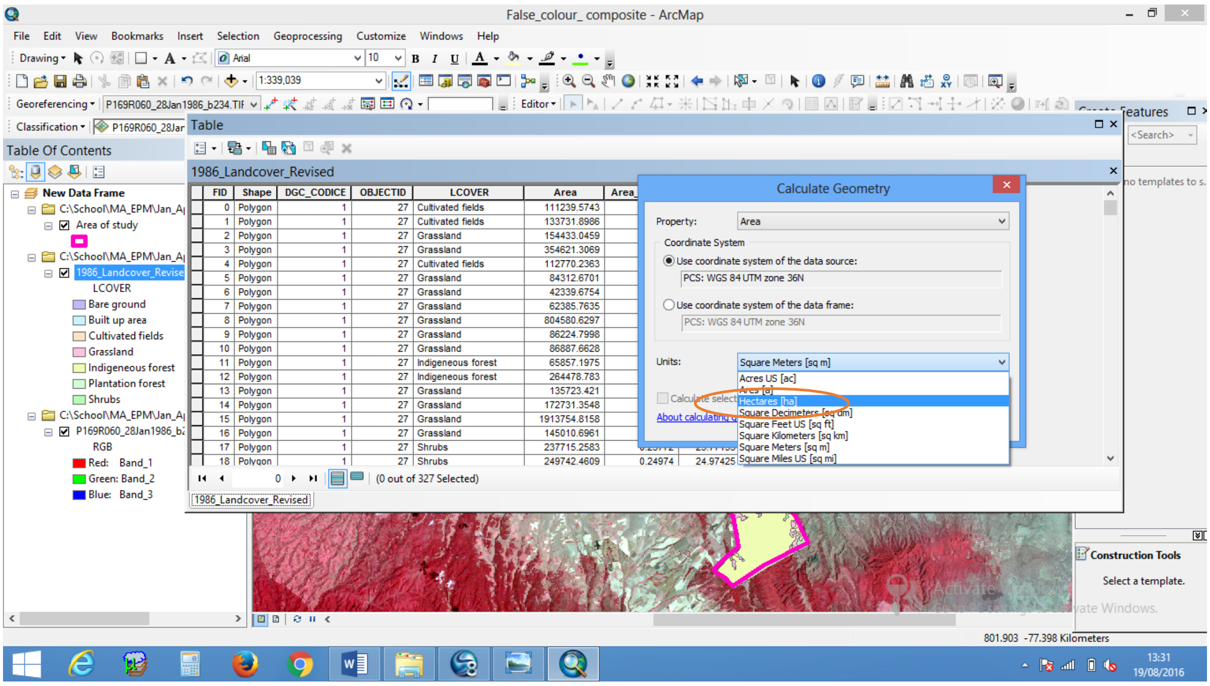

Plate 4.21c: Selecting units of area computation (source: ESRI ArcGIS).

4.5.2.2. Determining the Accuracy of Land Cover Classification

Accuracy in satellite image land cover classification is important as it determines the level to which the classification agrees with the reality on the ground. Accuracy assessment was carried out to determine how accurate land cover classification from the satellite images was done. This was achieved by getting field validated data and comparing it to the preliminary interpretation data using an error matrix that compared land cover on category by category basis. Four different statistics categories were computed from the error matrix, namely overall accuracy, producer's accuracy, user's accuracy and *Cohen's Kappa* statistic (*Kappa* index of agreement).

Overall accuracy gave the average accuracy obtained in the image interpretation and classification without giving accuracy in mapping independent land cover types. Overall accuracy was computed by dividing the number of correctly classified pixels in an image by the total number of pixels in the classified image.

Producer's and user's accuracies gave the level of accuracy in classifying different land cover types in terms of error of omission and error of commission respectively. Producer's accuracy determined the error in omitting some image pixels of any given land cover type during image classification. It depicted how accurate the image classification was done from the image interpreter's perspective. It was computed by dividing correctly classified pixels in any given land cover class by the total number of pixels for the same land cover class.

User's accuracy determined the error of commission during image classification. It gave the number of image pixels that were erroneously classified in any given land cover type. It looked at how accurate the classification was done from the user's perspective. It depicted how many image pixels on the map were actually what the classification said they were for every land cover type. User's accuracy was computed by dividing the number of correctly classified pixels in any given land cover class by the total number of pixels assigned to that particular class.

Cohen's kappa statistic *(K)* reflected the difference between actual agreement in classification and the agreement expected by chance (Jenness and Wynne, 2007). It was used to show the measure of agreement between preliminary interpretation of satellite image data and the field validated data. Kappa coefficient of agreement was computed by subtracting expected agreement from actual agreement then divided the result by one minus expected agreement. When there is total agreement K=1 and when there is no agreement K=0.

Cohen's kappa statistic *(K)* was computed using the statistic formula,

$$\frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_i + .x_{+i})}{N^2\sum_{i=1}^{r}(x_i + .x_{+i})}$$

In this formula,

r refers to the number of rows in the matrix,

x_{ii} refers to the number of observations in row i and column i,

x_{i+} refers to the total observations in row i,

x_{+i} refers to the total observations in column i,

N refers to the total observations in the matrix.

Accuracy assessment was computed based on *error (confusion) matrix* image processing tool in IDRISI Selva software under accuracy assessment tools *(Plate 4.22a)*. To run the error matrix field validated classified images were taken as the ground truth images while the unvalidated classified images were taken as the categorical map images in the error matrix analysis tool *(Plate 4.22b)*. The process generated four error matrices for classified images of 1986, 1995, 2003 and 2014.

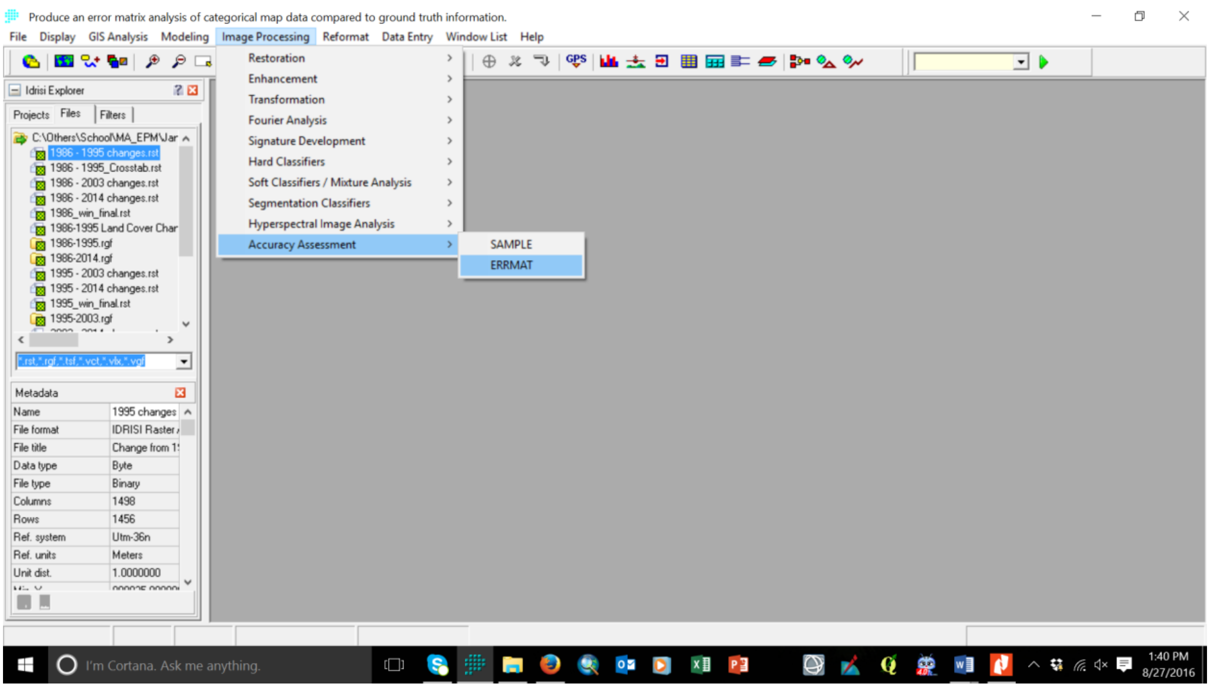

Plate 4.22a: Accuracy assessment tools (source: Clark Labs IDRISI).

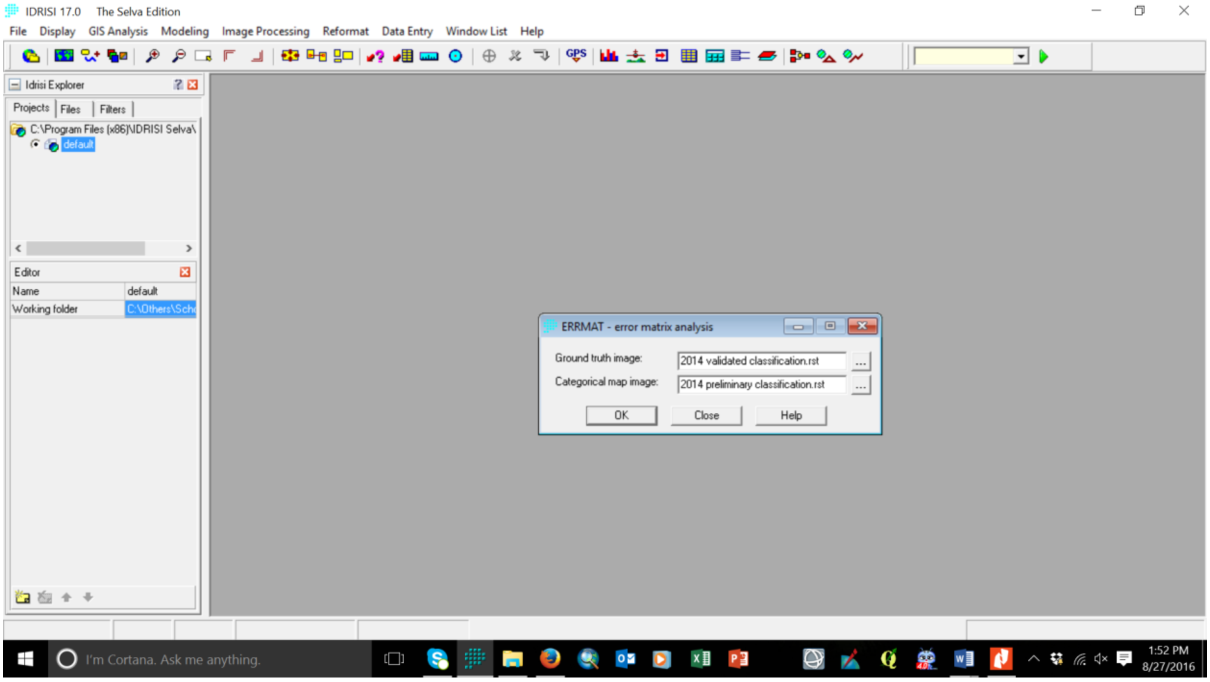

Plate 4.22b: Error matrix tool for accuracy assessment (source: Clark Labs IDRISI).

4.5.2.3. Testing Significance of Land Cover Change

The hypothesis on land cover change stated that there was no significant land cover change in Eastern Mau Forest between 1986 and 2014. Temporal (serial) autocorrelation was computed to determine if there were significance land cover changes by time series comparisons of the amounts of different land cover types in 2014 to those of 2003, 1995 and 1986. The four time series change in land cover was captured cumulatively in three different periods. The cumulative changes were 4531.54 hectares, 48481.56 hectares and 60092.72 hectares for 1986-1995, 1986-2003 and 1986-2014 periods respectively which revealed that land cover change occurred in Eastern Mau Forest between 1986 and 2014. Temporal autocorrelation was computed in a Microsoft Excel worksheet. From the Microsoft Excel computation of temporal autocorrelation,

r = 0.915078008, which is a strong positive autocorrelation.

An analogy was drawn between the autocorrelation coefficient and Pearson's product moment coefficient based on a table of critical values *(Appendix IV)*. This was carried out by first determining the degree of freedom, *df*, by subtracting 2 from the number of pairs, *N*, made by *X* and *Y* in *Table 4.1*. Therefore,

$df = 3 – 2 = 1$.

The r computation that was carried out gave a positive direction autocorrelation which, therefore, makes it a one tailed test. The standard level of significance (rejection) of 0.05 (95%) was chosen. At 0.05 significance level with 1 degree of freedom in this one tailed test the tabulated critical r = 0.988. The calculated r value is smaller than the tabulated r value, hence, there is no enough evidence to fail to reject the null hypothesis.

4.5.2.4. Testing the significance of Drivers of Land Cover Change

The hypothesis on the drivers of land cover change stated that the drivers of land cover change in Eastern Mau Forest did not have a significant impact on forest cover change that occurred between 1986 and 2014. The information collected during fieldwork and that which was generated from land cover area computation revealed that there are different land use activities, both inside and outside the area covered by Eastern Mau Forest, that lead to land cover change. These activities were increasing as settlements increased giving an indication that the people involved in land cover change activities were staying in the settlements within and outside Eastern Mau Forest. This shows that increase in settlements within and around the forest is one of the main drivers of land cover change in Eastern Mau Forest. Information collected from the field showed that resources extracted from Eastern Mau Forest were used in settlements that were both inside and outside the forest gazetted boundary. Those resources were used even in bigger towns like Nakuru which is close to 20 kilometres away from the forest.

Based on the interpretation of land cover 1986-2014 period indigenous forest land cover type was decreasing as built up area increased. It was therefore likely that the spatial decrease in indigenous forest was being caused by built up area increase. Spatial autocorrelation was computed to determine if drivers of land cover change had a significant impact on land cover changes in Eastern Mau Forest during 1986-2014 period.

This autocorrelation was based on *Moran's Spatial Autocorrelation (I)* algorithm,

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{i,j} Z_i Z_j}{\sum_{i=1}^{n} Z_i^2}$$

In this formula,

Z_i refers to the deviation of i from its mean,

Z_j refers to the deviation of j from its mean,

$W_{i,j}$ refers to the spatial weight between i and j,

n refers to the total number of features,

S_o refers to the aggregate of all the spatial weights,

The autocorrelation was based on both the observations made and the locations of those observations. From *Moran's I Spatial Autocorrelation* context the null hypothesis that was tested meant that land cover changes that were observed occurred by random chance and were not influenced by the existing drivers of land cover change. The *Moran's I* algorithm was used to show the spatial reduction in indigenous forest due to the location of built up area inside the forest and in a 20 kilometre buffer area around the forest, hence, distance between indigenous forest and built up area land cover types was used as a criterion for analysis. The computation was carried out in ArcGIS 10.3 software using *Spatial Autocorrelation (Moran's I)* tool under *Spatial Statistics Tools (Plate 4.23)* which gave the results in form of a report with *Moran's I* index values.

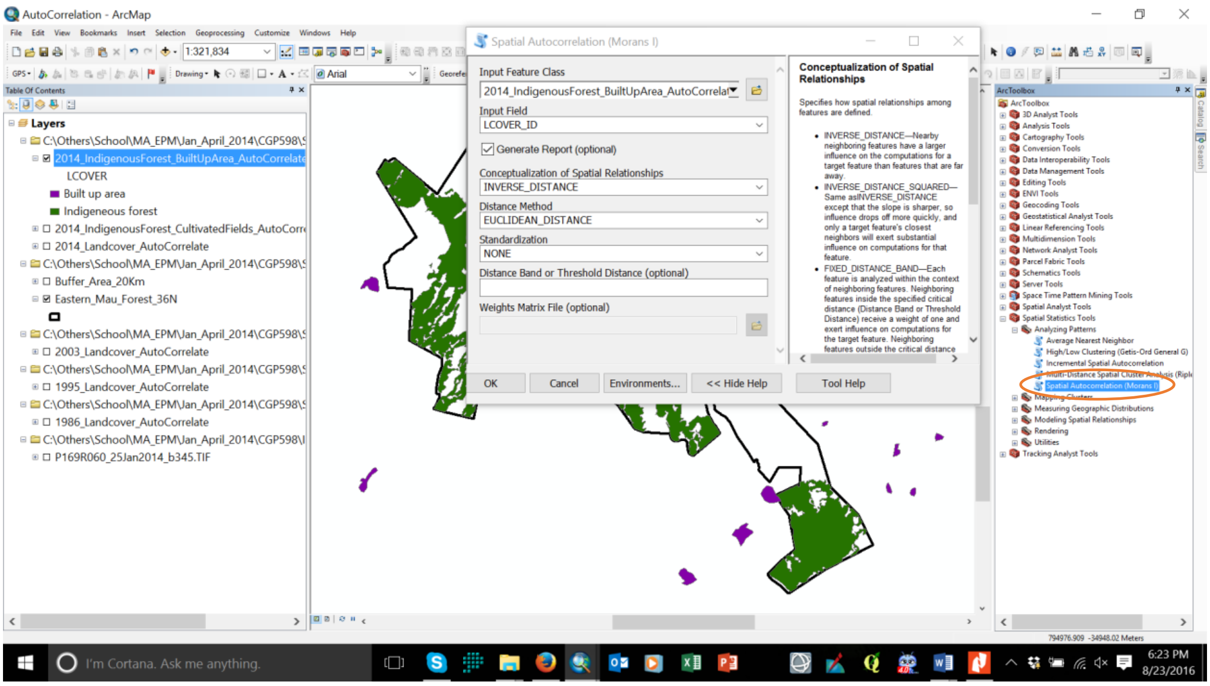

Plate 4.23: Moran's I distance based spatial autocorrelation tool (source: ESRI ArcGIS).

The *Moran's I Spatial Autocorrelation* tool evaluates whether the pattern expressed is clustered, dispersed or random. To evaluate the significance of the index, the *Moran's I*

Spatial Autocorrelation tool calculates the *Moran's I* index value which varies from -1 to +1. *Moran's I* index values near +1 indicate clustering while index values near -1 indicate dispersion. The value of the *Moran's I* index from the above spatial autocorrelation report is 0.351793. This value tends towards +1 which shows that the occurrence of land cover change in Eastern Mau Forest is due to clustering of drivers of land cover change within a distance that allows easy accessibility to the forest, hence, there is no enough evidence to fail to reject the null hypothesis.

4.5.2.5. Testing significance of Sustainable Ways of using Forest Resources

The hypothesis on the sustainable ways of using forest resources stated that there are no significant sustainable ways of using forest resources in Eastern Mau Forest. The information collected in the field and that which was generated from satellite image analysis indicated that there are different activities that depict unsustainable ways of using forest resources in Eastern Mau Forest. These activities lead to land cover change, especially change from indigenous forest to other land cover types. Key among the unsustainable ways of using forest resources is cultivation of crops in the forest.

Based on the land cover analysis of 1986-2014 period indigenous forest land cover type was decreasing as cropland increased. It was therefore likely that the spatial decrease in indigenous forest was being caused by cropland increase. From the *Moran's I Spatial Autocorrelation* context the null hypothesis that was tested meant that the land cover change that was observed occurred due to unsustainable ways of using forest resources and not by random chance. The *Moran's I* algorithm was used to show the spatial reduction in indigenous forest due to the adjacent location of cropland, hence adjacency of the two land cover types was used as a criterion. The computation was carried out in ArcGIS 10.3 software using *Spatial Autocorrelation (Moran's I)* tool under *Spatial Statistics Tools (Plate 4.24)* which gave the results in form of a report with *Moran's I* index values.

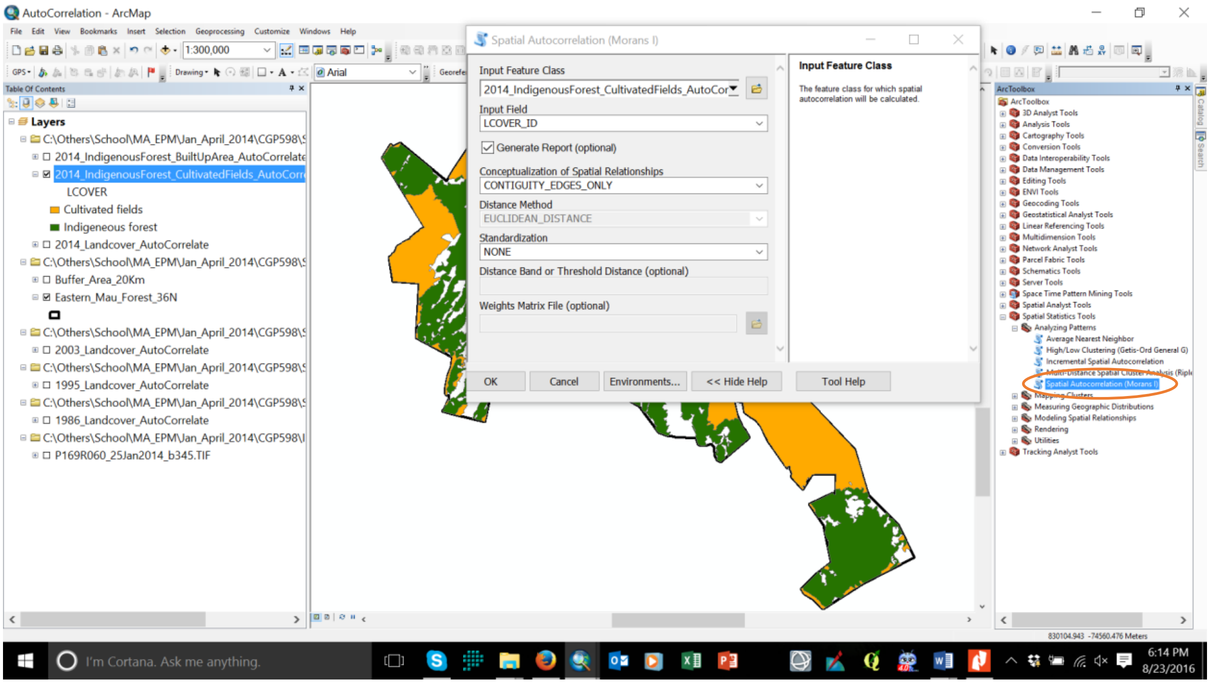

Plate 4.24: Moran's I adjacency based spatial autocorrelation tool (source: ESRI ArcGIS).

The value of the *Moran's I* index from the above spatial autocorrelation report is 0.309909. This value tends towards +1 which shows that the reduction of indigenous forest land cover in Eastern Mau Forest is due to the availability of unsustainable ways of using forest resources, hence, there is no enough evidence to reject the null hypothesis.

CHAPTER FIVE

5.0. RESULTS AND DISCUSSIONS

5.1. Land Cover Classification

Eastern Mau Forest land cover was classified into seven land cover classes based on Landsat satellite imagery analysis and field observation and validation. These land cover classes included indigenous forest, plantation forest, cropland, grassland, shrubland, built-up area and bare ground with indigenous forest as the dominant land cover type. The spatial extent of these land cover classes in the four different years was determined after field data validation was carried out. The area covered by each land cover type was computed in hectares *(Table 5.1)*.

Table 5.1: Eastern Mau Forest land cover area.

No.	**Land Cover**	**Area in Hectares**			
		1986	**1995**	**2003**	**2014**
1	Grassland	10741.69	9707.46	5796.09	5559.33
2	Shrubland	3596.71	2391.52	2439.73	1254.65
3	Plantation forest	22100.64	22079.21	7213.44	4651.72
4	Indigenous forest	28578.55	30057.70	25330.53	23511.03
5	Cultivated fields	844.70	1631.32	25069.95	30836.66
6	Built up area	18.60	13.68	34.13	73.00
7	Bare ground	8.55	8.55	5.57	3.05
	Total	**65,889.44**	**65,889.44**	**65,889.44**	**65,889.44**

The results from the analysis of the 1986 satellite image had indigenous and plantation forests as the dominant land cover types with most of the indigenous forest being on the western and southern parts and most of the plantation forest on the eastern part of Eastern Mau Forest. Cultivated fields as a land cover types was minimal in spatial coverage although it was more than built up area and bare ground land cover types *(Figure 5.1)*.

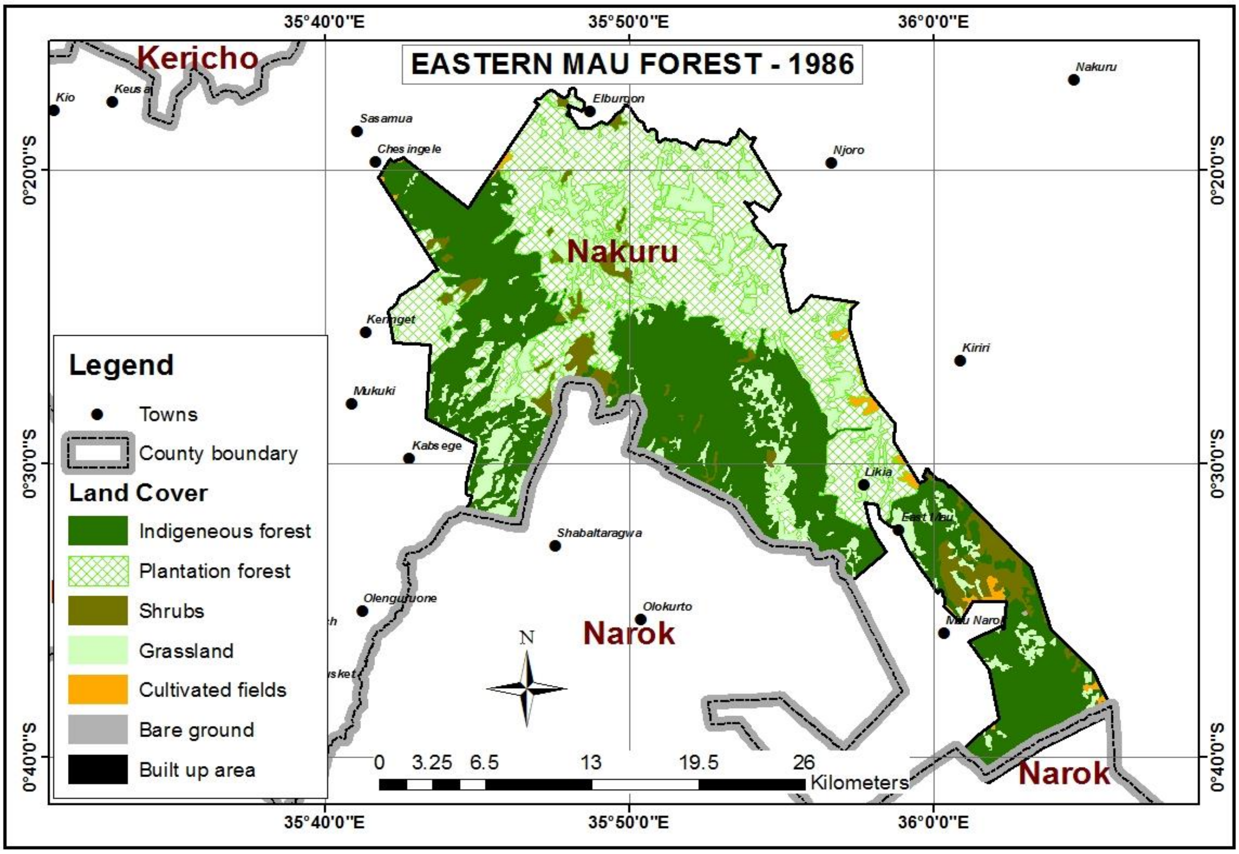

Figure 5.1: 1986 Eastern Mau Forest land cover (data source: NASA).

The 1995 satellite image analysis had indigenous and plantation forests as the dominant land cover types having increased and decreased by 1479.15 hectares and 21.43 hectares respectively as compared to 1986 spatial coverage. Cultivated fields land cover type had a noticeable increase in comparison to 1986 coverage especially on the eastern part of the area of study *(Figure 5.2)*.

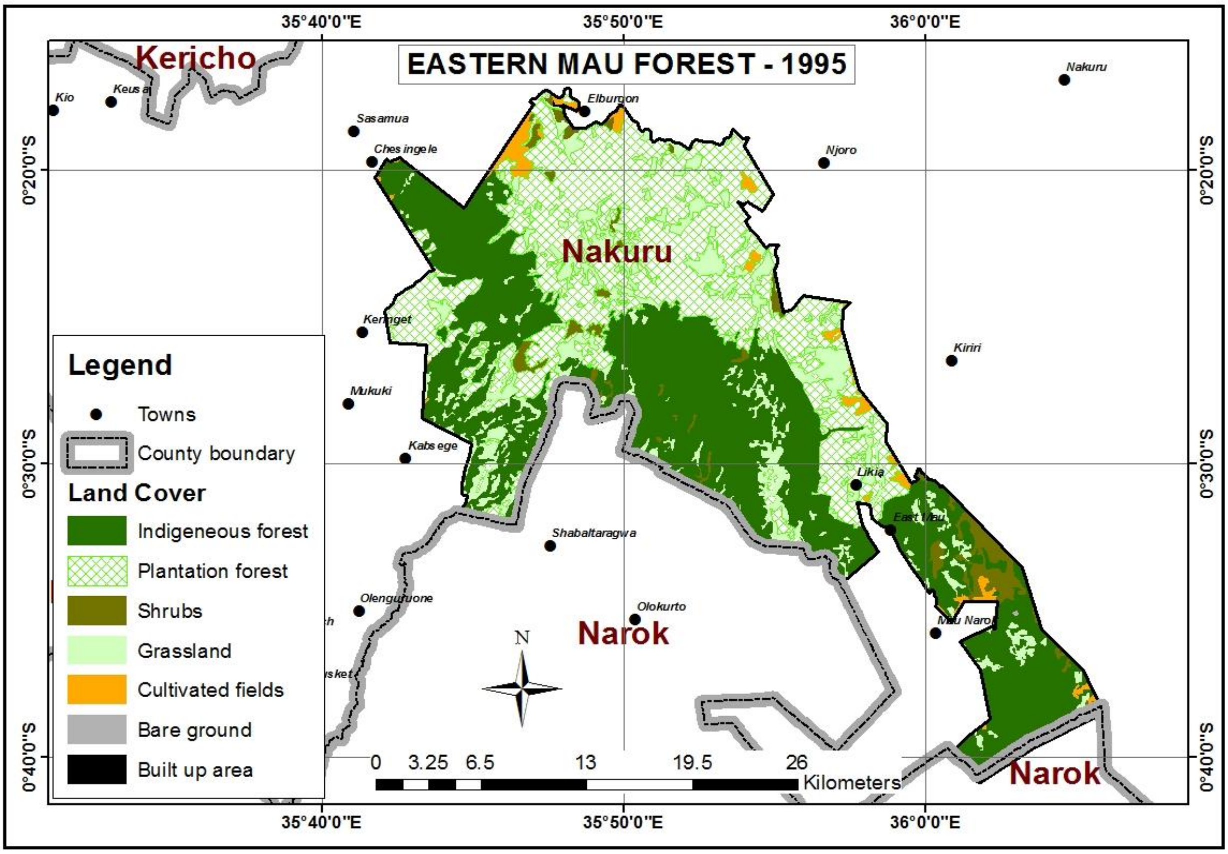

Figure 5.2: 1995 Eastern Mau Forest land cover (data source: NASA).

In 2003 plantation forest land cover type had a remarkable decline in spatial coverage with most of it having been replaced by cultivated fields. Other classes that had a decline due to replacement by cultivated fields were indigenous forest, grassland and shrubland. Cultivated fields had the most spatial increment and was second to indigenous forest in terms of dominance *(Figure 5.3)*.

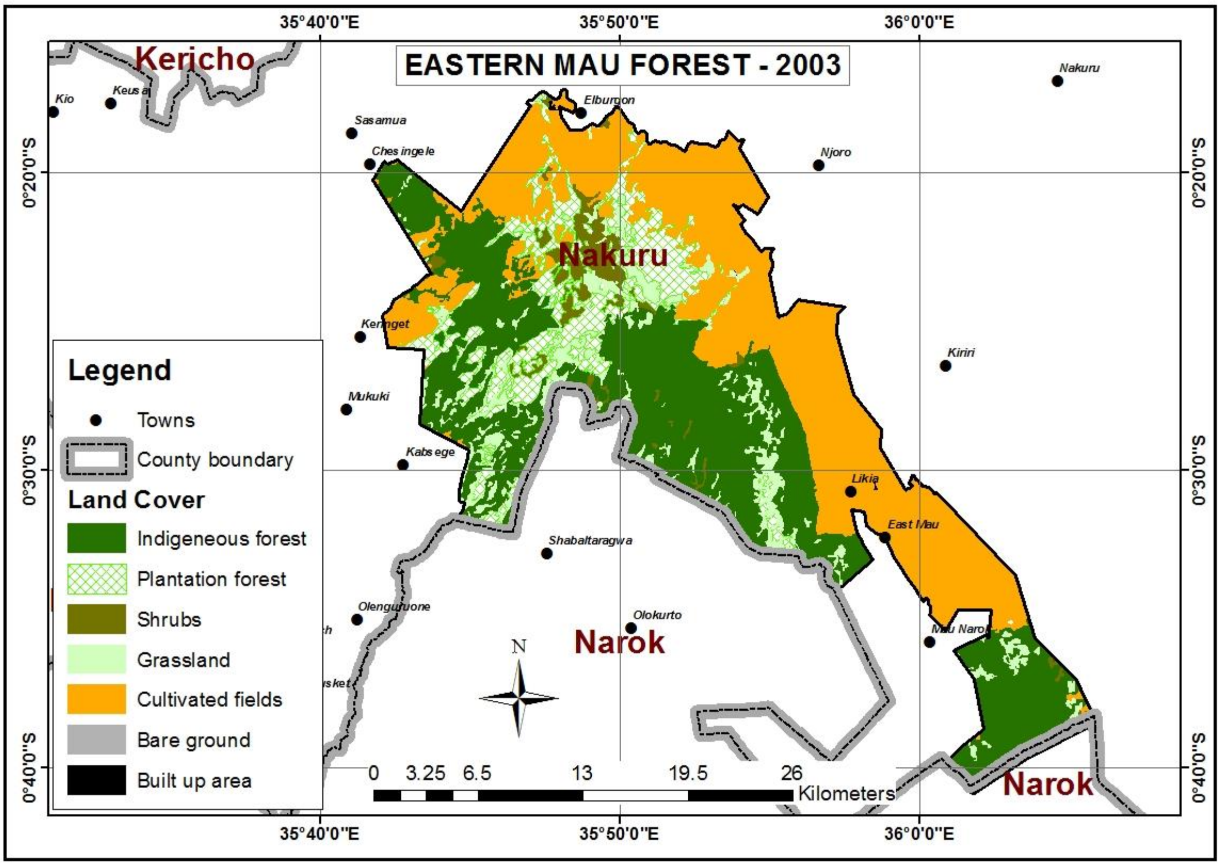

Figure 5.3: 2003 Eastern Mau Forest land cover (data source: NASA).

The 2014 analysis results had cultivated fields with continued spatial increment as the rest of the land cover classes declined spatially with an exception of built up area which also increased as compared to 2003 analysis *(Figure 5.4)*.

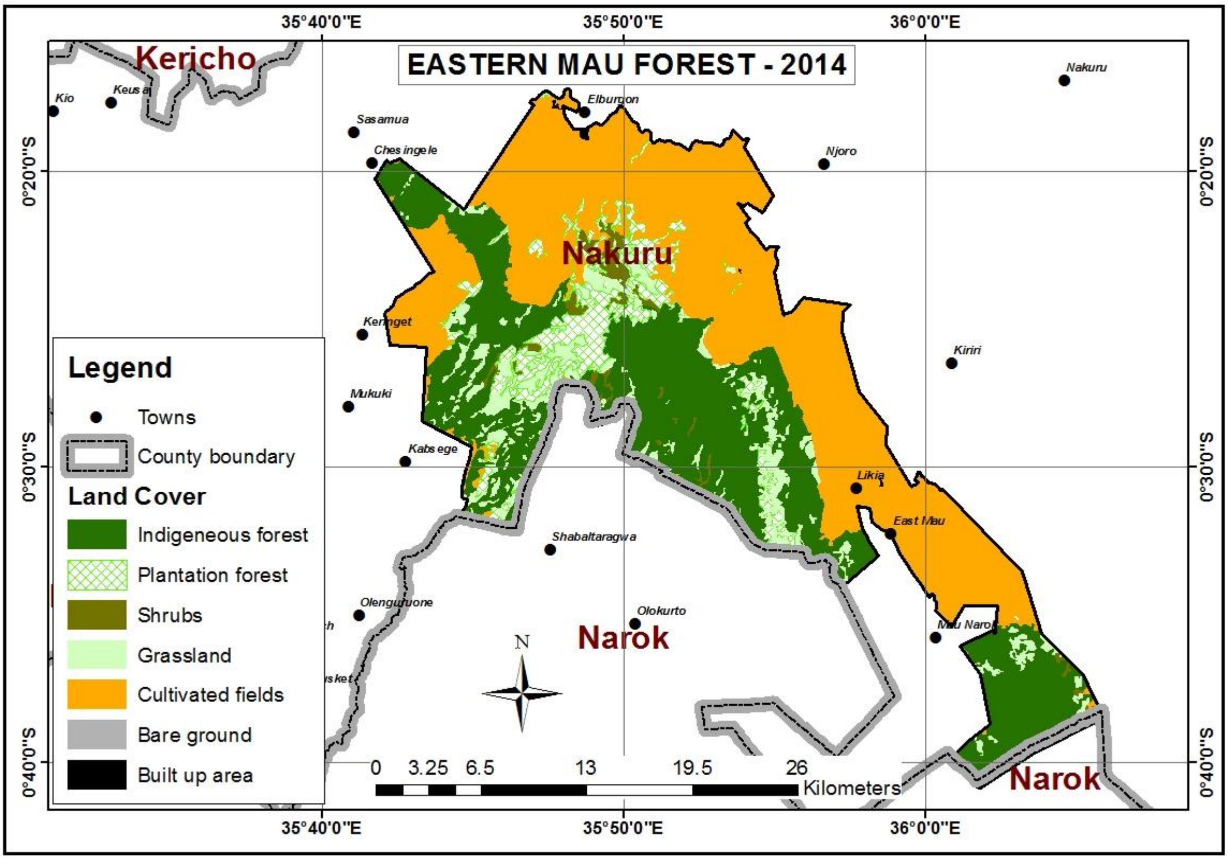

Figure 5.4: 2014 Eastern Mau Forest land cover (data source: NASA).

The percentage coverage of the different land cover classes in the area of study was also determined. Based on the results the most dominant class in 1986 was indigenous forest with 43%. The percentage coverages for other land cover types in 1986 were 34% for plantation forest, 16% for grassland, 6% for shrubland, 1% for cultivated fields and less than 1% for built up area and bare ground cover types *(Figure 5.5)*.

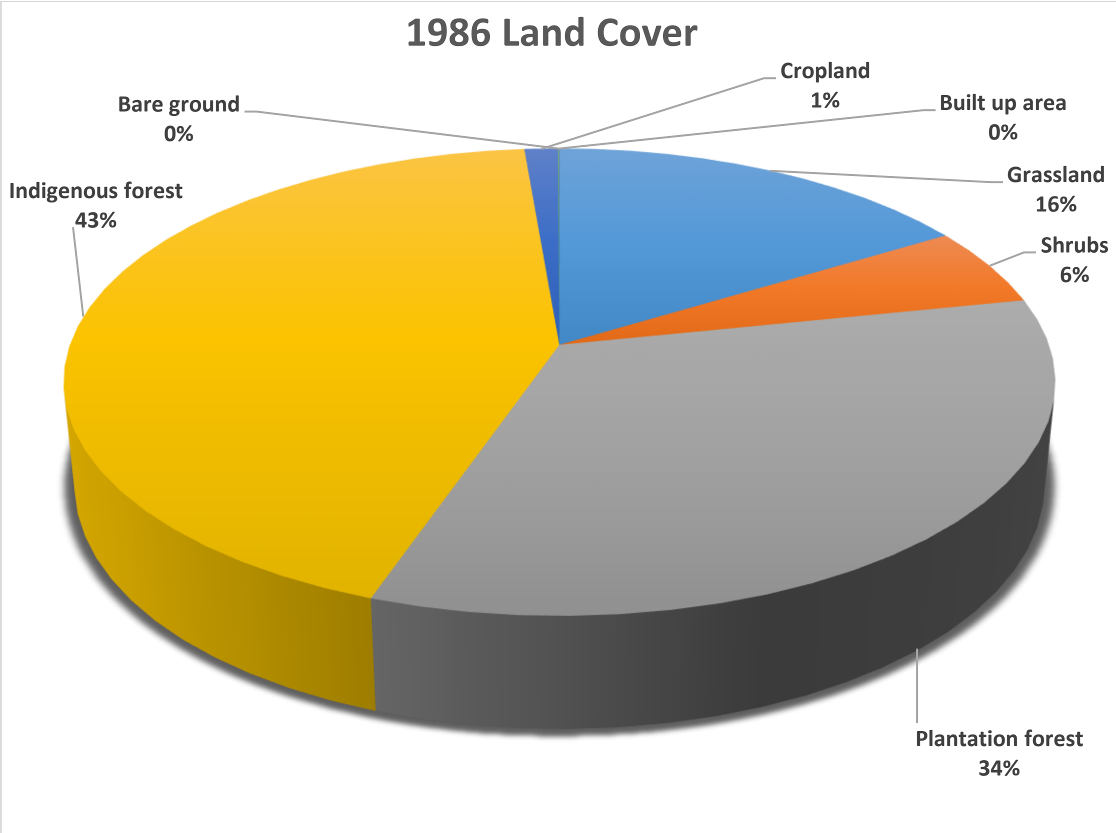

Figure 5.5: Percentage coverage of different land cover types in 1986.

Indigenous forest was still the most dominant land cover class 1995 having increased its percentage coverage to 46%. Plantation forest, grassland and shrubland cover types decreased to 33%, 15% and 4% respectively. Cultivated fields coverage increased to 2% while that for built up area and bare ground remained at less than 1% *(Figure 5.6)*.

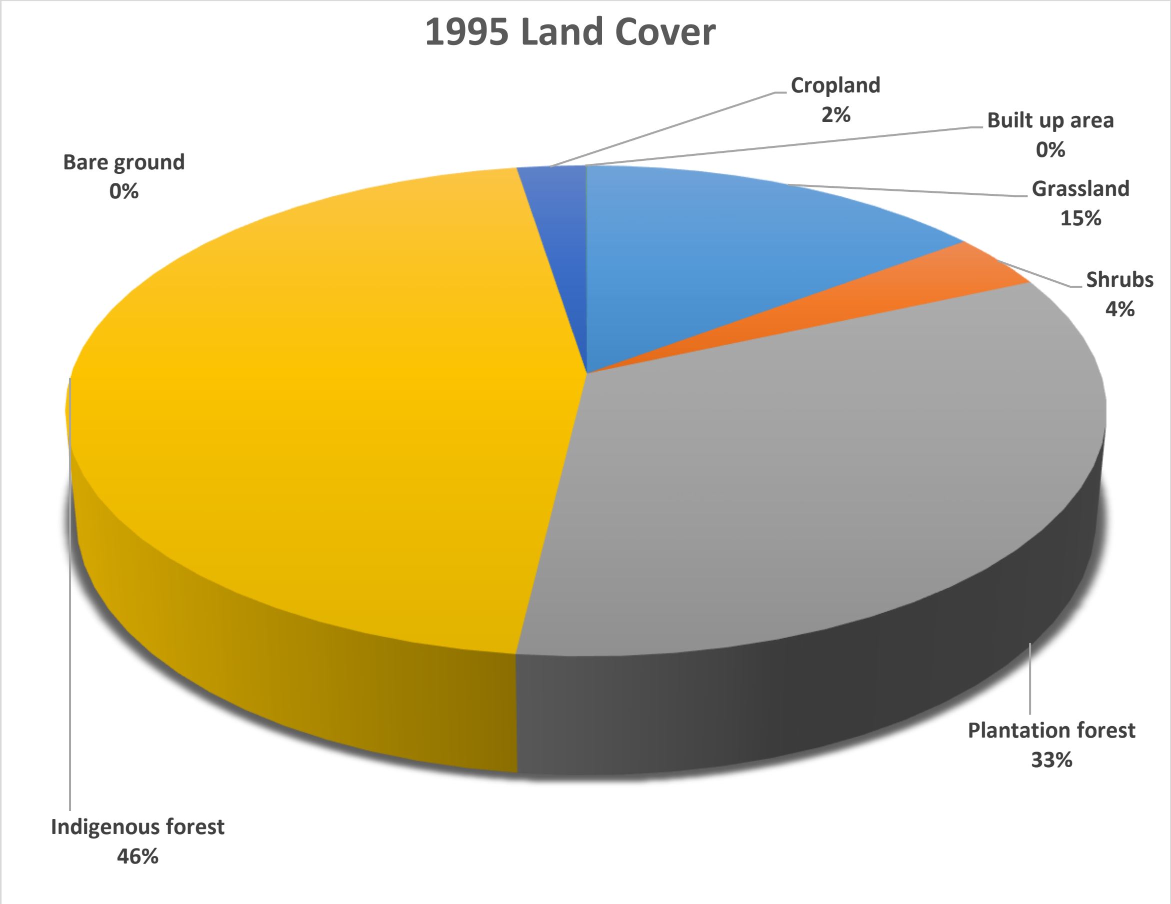

Figure 5.6: Percentage coverage of different land cover types in 1995.

In 2003 both indigenous forest and cultivated fields had a percentage coverage of 38% each. Plantation forest, grassland and shrubland were at 11%, 9% and 4% respectively. Built up area and bare ground were still at less than 1% each *(Figure 5.7)*.

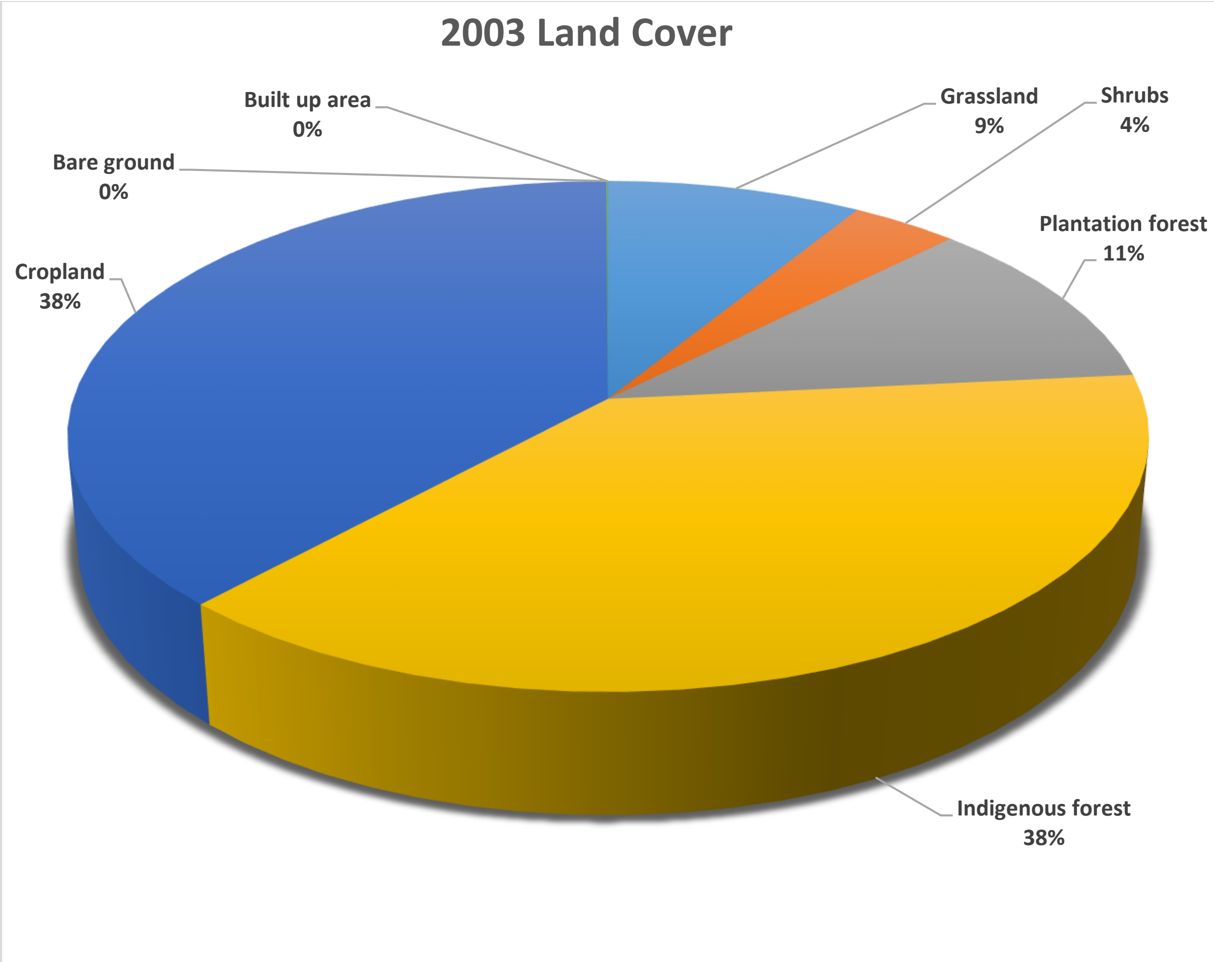

Figure 5.7: Percentage coverage of different land cover types in 2003.

The 2014 percentage coverage had cultivated fields as the most dominant land cover type with 47% spatial coverage. Indigenous forest, grassland, plantation forest and shrubland land cover types reduced to 36%, 8%, 7% and 2% spatial coverages respectively. Built up area and bare ground remained with less than 1% spatial coverage *(Figure 5.8)*.

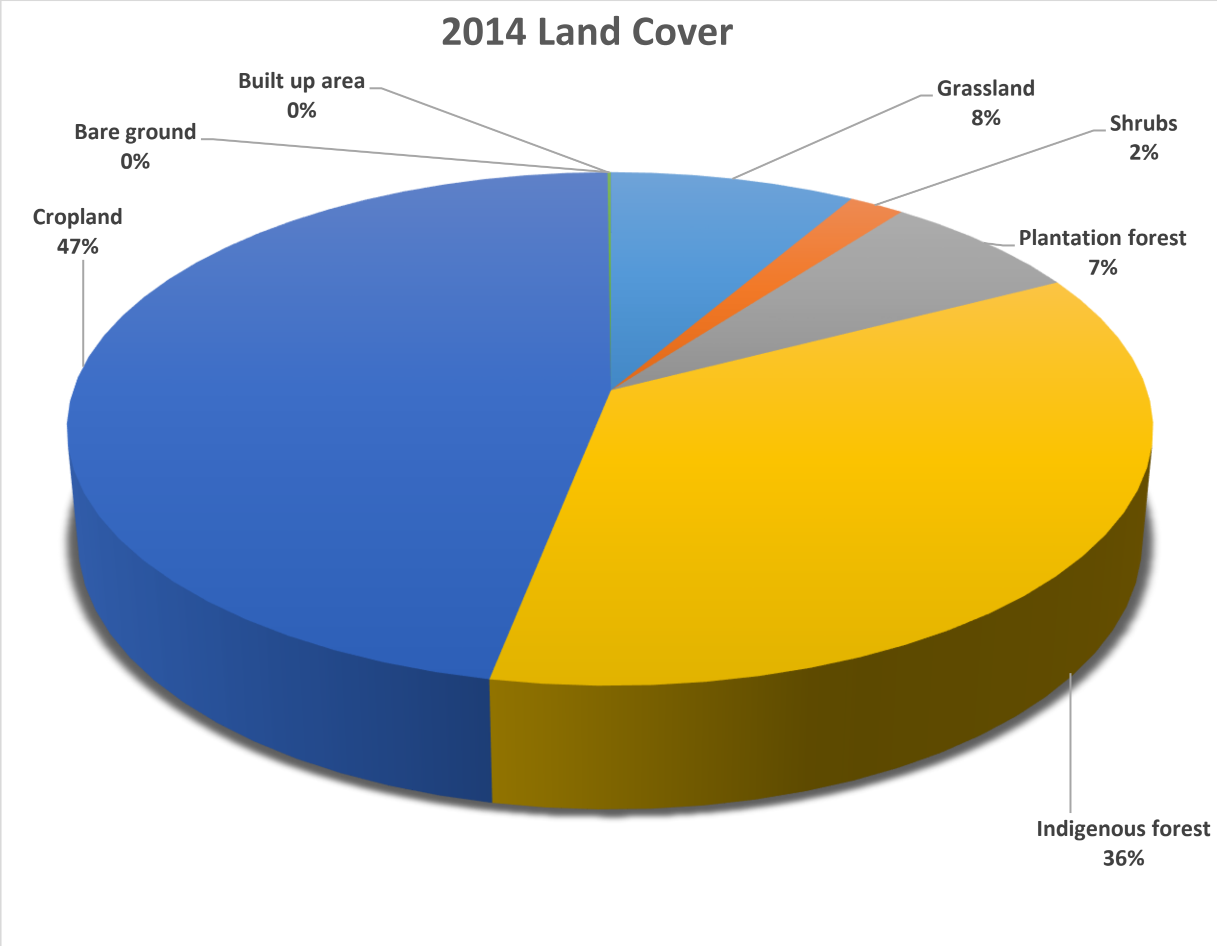

Figure 5.8: Percentage coverage of different land cover types in 2014.

5.1.1. Land Cover Classification Accuracy Assessment

Four different statistics categories were computed based on the error matrix in the accuracy assessment that was carried out. The computed statistics categories were producer's accuracy, user's accuracy, overall accuracy and Cohen's Kappa statistic (*Kappa* index of agreement). In the 1986 land cover classification producer's accuracy was 100 % for indigenous forest, cropland, grassland, shrubland and bare ground. It was 99.999 % for plantation forest and 99.226 % for built-up area. User's accuracy was 100 % for plantation forest, cropland, built-up area, shrubland and bare ground. Indigenous forest had 99.999 % while grassland had 99.993 %. Overall accuracy was 99.999 % while Kappa index of agreement was 1 *(Table 5.2).*

Table 5.2: Error matrix for 1986 land cover classification.

	Field Validated Data										
Preliminary Interpretation Data	**Land Cover Classes**	Grassland	Shrubland	Cultivated fields	Indigenous forest	Plantation forest	Bare ground	Built up area	**Total Pixels**	**Producer's Accuracy (%)**	**User's Accuracy (%)**
	Grassland	**119388**	0	0	0	0	0	0	119396	100	99.993
	Shrubland	0	**39986**	0	0	0	0	0	39986	100	100
	Cultivated fields	0	0	**9374**	0	0	0	0	9374	100	100
	Indigenous forest	0	0	0	**317490**	0	0	0	317491	100	99.999
	Plantation forest	0	0	0	0	**245552**	0	0	245552	99.999	100
	Bare ground	0	0	0	0	0	**97**	0	97	100	100
	Built up area	0	0	0	0	0	0	**204**	204	99.226	100
	Total Pixels	119388	39986	9374	317490	245553	97	212	**732100**		
	Overall Classification Accuracy = (732,091/732,100) x 100 = 99.999 %										
	Overall Kappa Statistic = (0.99999-0.33)/(1-0.33) = 1										

In the 1995 classification producer’s accuracy was 100 % for indigenous forest, plantation forest, cropland, grassland, shrubland and bare ground. Built-up area had 75.84 %. User’s accuracy was 100 % for indigenous forest, plantation forest, shrubland, built-up area and bare ground. Grassland had 99.98 % while cropland had 99.92 %. Overall accuracy was 99.995 % while Kappa index of agreement was 0.9999 *(Table 5.3)*.

Table 5.3: Error matrix for 1995 land cover classification.

	Field Validated Data										
Preliminary Interpretation Data	**Land Cover Classes**	Grassland	Shrubland	Cultivated fields	Indigenous forest	Plantation forest	Bare ground	Built up area	**Total Pixels**	**Producer’s Accuracy (%)**	**User’s Accuracy (%)**
	Grassland	**107839**	0	0	0	0	0	0	107861	100	99.98
	Shrubland	0	**26573**	0	0	0	0	0	26573	100	100
	Cultivated fields	0	0	**18123**	0	0	0	0	18137	100	99.92
	Indigenous forest	0	0	0	**333934**	0	0	0	333934	100	100
	Plantation forest	0	0	0	0	**245385**	0	0	245385	100	100
	Bare ground	0	0	0	0	0	**97**	0	97	100	100
	Built up area	0	0	0	0	0	0	**113**	113	75.84	100
	Total Pixels	107839	26573	18123	333934	245385	97	149	**732100**		
	Overall Classification Accuracy = (732,064/732,100) x 100 = 99.995 %										
	Overall Kappa Statistic = (0.99995-0.34)/(1-0.34) = 0.9999										

In the 2003 classification producer's accuracy was 100 % for indigenous forest, plantation forest, cropland, grassland, shrubland and bare ground. Built-up area had 70.50 %. User's accuracy was 100 % for indigenous forest, plantation forest, shrubland, built-up area and bare ground. Cropland had 99.97 % while grassland had 99.96 %. Overall accuracy was 99.99 % while Kappa index of agreement was 0.9998 *(Table 5.4)*.

Table 5.4: Error matrix for 2003 land cover classification.

	Field Validated Data										
Preliminary Interpretation Data	**Land Cover Classes**	Grassland	Shrubland	Cultivated fields	Indigenous forest	Plantation forest	Bare ground	Built up area	**Total Pixels**	**Producer's Accuracy (%)**	**User's Accuracy (%)**
	Grassland	**64435**	0	0	0	0	0	25	64460	100	99.96
	Shrubland	0	**27086**	0	0	0	0	0	27086	100	100
	Cultivated fields	0	0	**278543**	0	0	0	88	278631	100	99.97
	Indigenous forest	0	0	0	**281415**	0	0	0	281415	100	100
	Plantation forest	0	0	0	0	**80179**	0	0	80179	100	100
	Bare ground	0	0	0	0	0	**59**	0	59	100	100
	Built up area	0	0	0	0	0	0	**270**	270	70.50	100
	Total Pixels	64435	27086	278543	281415	80179	59	383	**732100**		
	Overall Classification Accuracy = (731987/732,100) x 100 = 99.99 %										
	Overall Kappa Statistic = (0.99985-0.31)/(1-0.31) = 0.9998										

The 2014 classification had producer's accuracy of 100 % for indigenous forest, cropland, shrubland and bare ground. Grassland had 99.70 %, plantation forest had 95.29 % while built-up area had 81.60 %. User's accuracy was 100 % for plantation forest, grassland, built-up area and bare ground. Cropland had 99.90 %, indigenous forest had 99.68 % while shrubland had 89.83 %. Overall accuracy was 99.62 % while Kappa index of agreement was 0.9941 *(Table 5.5)*.

Table 5.5: Error matrix for 2014 land cover classification.

	Field Validated Data										
Preliminary Interpretation Data	**Land Cover Classes**	Grassland	Shrubland	Cultivated fields	Indigenous forest	Plantation forest	Bare ground	Built up area	**Total Pixels**	**Producer's Accuracy (%)**	**User's Accuracy (%)**
	Grassland	**61581**	0	0	0	0	0	0	61581	99.70	100
	Shrubland	0	**13933**	0	0	1578	0	0	15511	100	89.83
	Cultivated fields	183	0	**342674**	0	11	0	150	343018	100	99.90
	Indigenous forest	0	0	0	**261238**	843	0	0	262081	100	99.68
	Plantation forest	0	0	0	0	**49210**	0	0	49210	95.29	100
	Bare ground	0	0	0	0	0	**34**	0	34	100	100
	Built up area	0	0	0	0	0	0	**665**	665	81.60	100
	Total Pixels	61764	13933	342674	261238	51642	34	815	**732100**		
	Overall Classification Accuracy = (729335/732,100) x 100 = 99.62 %										
	Overall Kappa Statistic = (0.9962-0.36)/(1-0.36) = 0.9941										

5.2. Land Cover Change

The spatial-temporal land cover change in Eastern Mau Forest between 1986 and 2014 was determined by interpreting and analysing Landsat satellite images. The dominant land cover type in the years covered was indigenous forest but cropland was increasingly becoming dominant especially in the former plantation forest. The explanation for the increased cropland was largely in terms of increasing population pressure that lead to increased need for food supply. Land cover change in Eastern Mau Forest was computed to show which land cover types had changed, to which other types and by how much. The changes computed were of 1986-1995, 1995-2003, 2003-2014 and 1986-2014 periods. The changes between 1985 and 1995 are as illustrated in the land cover change matrix in *Table 5.6*. The unchanged amount of specific land cover classes during this period are in the major diagonal of the matrix. During this period 7354.89 hectares of grassland did not change while 3390.03 hectares changed to other land cover classes. 1637.19 hectares of shrubland did not change while 1961.55 hectares changed to other land cover classes. For plantation forest 18933.57 hectares did not change while 3166.2 hectares changed to other land cover classes. Indigenous forest had 28409.31 hectares unchanged with 165.23 hectares changing to other classes. Cultivated fields had 802.62 hectares unchanged with 41.04 hectares changing to other classes. 17.01 hectares of built up area changed to other classes but 2.07 hectares did not change. Bare ground land cover type did not have change.

Table 5.6: Land cover change matrix for Eastern Mau Forest between 1986 and 1995.

1986	**1995**							
	Land Cover Class	Grassland	Shrubland	Plantation forest	Indigenous forest	Cultivated fields	Built up area	Bare ground	**Total Change (Hectares)**
	Grassland	**7354.89**	252.81	2406.06	605.61	124.29	1.26	0	10744.92
	Shrubland	228.24	**1637.19**	630.90	1023.75	68.94	9.72	0	3598.74
	Plantation forest	2067.12	466.65	**18933.57**	0.09	631.98	0.36	0	22099.77
	Indigenous forest	35.10	17.91	108.54	**28409.31**	3.68	0	0	28574.54
	Cultivated fields	20.16	0	5.58	15.30	**802.62**	0	0	843.66
	Built up area	0	17.01	0	0	0	**2.07**	0	19.08
	Bare ground	0	0	0	0	0	0	**8.73**	8.73
	Total Change (Hectares)	**9705.51**	**2391.57**	**22084.65**	**30054.06**	**1631.51**	**13.41**	**8.73**	**65889.44**

In the 1995-2003 period 4801 hectares of grassland did not change while 4903.56 hectares changed to other land cover classes. 578.52 hectares of shrubland did not change while 1813.05 hectares changed to other land cover classes. For plantation forest 6444.81 hectares did not change while 15639.84 hectares changed to other land cover classes. Indigenous forest had 24987.96 hectares unchanged with 5065.78 hectares changing to other classes. Cultivated fields had 1547.10 hectares unchanged with 83.97 hectares changing to other classes. 2.97 hectares of built up area changed to other classes but 10.44 hectares did not change. Bare ground had 5.13 hectares changing to other classes but 3.6 hectares did not change *(Table 5.7)*.

Table 5.7: Land cover change matrix for Eastern Mau Forest between 1995 and 2003.

1995	**2003**								
	Land Cover Class	Grassland	Shrubland	Plantation forest	Indigenous forest	Cultivated fields	Built up area	Bare ground	**Total Change (Hectares)**
	Grassland	**4801.00**	696.78	500.85	130.68	3562.02	13.23	0	9704.56
	Shrubland	34.83	**578.52**	268.38	17.82	1488.96	3.06	0	2391.57
	Plantation forest	780.21	1073.25	**6444.81**	190.89	13593.33	2.16	0	22084.65
	Indigenous forest	127.26	65.70	2.07	**24987.96**	4870.75	0	1.71	30055.45
	Cultivated fields	54.90	23.49	0	0	**1547.10**	5.58	0	1631.07
	Built up area	0	0	0	0	2.97	**10.44**	0	13.41
	Bare ground	0	0	0	0	5.13	0	**3.60**	8.73
	Total Change (Hectares)	**5798.20**	**2437.74**	**7216.11**	**25327.35**	**25070.26**	**34.47**	**5.31**	**65889.44**

The 2003-2014 period had 4044.69 hectares of grassland unchanged with 1754.46 hectares changing to other classes. 1085.58 hectares of shrubland did not change while 1352.16 hectares changed to other land cover classes. For plantation forest 3375.63 hectares did not change while 2786.94 hectares changed to other land cover classes. Indigenous forest had 22849.83 hectares unchanged with 2477.96 hectares changing to other classes. Cultivated fields had 24592.41 hectares unchanged with 476.46 hectares changing to other classes. 2.97 hectares of bare ground changed to other classes but 2.34 hectares did not change. Built up area did not have change. *(Table 5.8)*.

Table 5.8: Land cover change matrix for Eastern Mau Forest between 2003 and 2014.

2003	**2014**							
Land Cover Class	Grassland	Shrubland	Plantation forest	Indigenous forest	Cultivated fields	Built up area	Bare ground	**Total Change (Hectares)**
Grassland	**4044.69**	101.07	360.09	277.47	1014.66	1.17	0	5799.15
Shrubland	94.86	**1085.58**	294.03	2.07	961.20	0	0	2437.74
Plantation forest	746.01	44.82	**3375.63**	262.71	2786.94	0	0	7216.11
Indigenous forest	486.09	0	508.95	**22849.83**	1482.92	0	0	25327.79
Cultivated fields	187.11	22.50	109.08	119.34	**24592.41**	37.71	0.72	25068.87
Built up area	0	0	0	0	0	**34.47**	0	34.47
Bare ground	0	0	0	0	2.97	0	**2.34**	5.31
Total Change (Hectares)	**5558.76**	**1253.97**	**4647.78**	**23511.42**	**30841.10**	**73.35**	**3.06**	**65889.44**

Aggregate land cover change per land cover class between 1986 and 2014 was also computed. This aggregate land cover change was the total change from a given land cover type to other land cover types. From the aggregate change computation plantation forest changed by 19,007.91 hectares, grassland by 7,227.54 hectares, indigenous forest by 6,052.32 hectares, shrubland by 3,008.79 hectares, cultivated fields by 57.96 hectares, built up area by 11.97 hectares and bare ground by 5.94 hectares *(Table 5.9).*

Table 5.9: Aggregate land cover change in Eastern Mau Forest between 1986 and 2014.

Category	**Land Cover**	**Change in Hectares**
1	Plantation forest	19007.91
2	Grassland	7227.54
3	Indigenous forest	6052.32
4	Shrubland	3008.79
5	Cultivated fields	57.96
6	Built up area	11.97
7	Bare ground	5.94
	Total	**35372.43**

The changes of area covered by different land cover types between 1986 and 2014 were of different magnitudes including from 28578.55 hectares to 23511.03 hectares for indigenous forest, 22100.64 hectares to 4651.72 hectares for plantation forest, 3596.71 hectares to 1254.65 hectares for shrubland, 10741.69 hectares to 5559.33 hectares for grassland, 844.70 hectares to 30836.66 hectares for cropland, 18.60 hectares to 73.00 hectares for built up area and 8.55 hectares to 3.05 hectares for bare ground. The results indicated that during the period 1986-2014, cropland and built up area increased by 29,991.96 hectares (97.26%) and 54.40 hectares (74.52%) respectively while plantation forest, shrubland, bare ground, grassland and indigenous forest decreased by 17,448.92 hectares (78.95%), 2,342.06 hectares (65.12%), 5.50 hectares (64.33%), 48.25% and 17.73% respectively. The most dominant class in 1986 was indigenous forest with 43% which reduced to 36% in 2014. Cultivated fields class that was only 1% in 1986 was the most dominant in 2014 with 47%. Plantation forest had a coverage of 34% in 1986 which reduced to 7% in 2014. Grassland and shrubland were at 16% and 6% in 1986, and 8% and 2% in 2014 respectively. Built up area and bare ground cover types were less than 1% each, both in 1986 and 2014.

5.3. Drivers of Land Cover Change

Land cover change in Eastern Mau Forest is caused by different drivers. Key among these drivers are politics and weak legislations that are not implemented. These two are key because they create an environment that enables other drivers that are observed to thrive. It is a requirement by the Forest Act Cap 385 that for forest land to be allocated to people it should first be de-gazetted and this should only happen if it in the public interest. Illegal forest allocations continue to happen in spite of this Forest Act being in place. For instance, according to the Ndungu report, 1812 hectares of forest land in Kiptagich area of Mau Forest were excised for resettlement of Ogiek community but ended up in the hands of prominent individuals and companies (Amnesty International, 2007). This amounts to being illegal and irregular allocation of forest land. Likia area has been experiencing allocation of forest land just before general elections. In Mesipei Sub-location of Nessuit Location, just before the 2013 general elections, there were some people who settled on the forest land where others were previously evicted. This happened under the watch of Kenya Forest Service that is supposed to ensure implementation of forest policies but could do nothing because it was happening on orders from senior politicians. In some cases, those who are allocated forest land because of political motivations establish plantation forests in areas that were previously indigenous forest which degrades the native state of the forest. Lack of policies on sharing of benefits from forest resources hampers efforts to conserve forests. This happens because locals feel deprived of the forest resources benefits thereby destructing the forest in retaliation.

The land cover change drivers that occur as a result of politics and weak legislations as observed in Eastern Mau Forest include cultivation of forest land, construction of settlements, grazing of livestock in the forest, charcoal burning, illegal logging, and allocation of forest land to commercial saw milling companies. Eastern Mau Forest land cover classification and analysis had more intact indigenous forest on the western side than on the eastern side which was an indication of having more drivers of land cover change on the eastern side than on the western side. Increase in cropland as a driver of land cover change was more on the eastern side than on the western side. Similarly, built up area as a driver of land cover change was more on the eastern side than on the western side as illustrated in *Figure 5.9*.

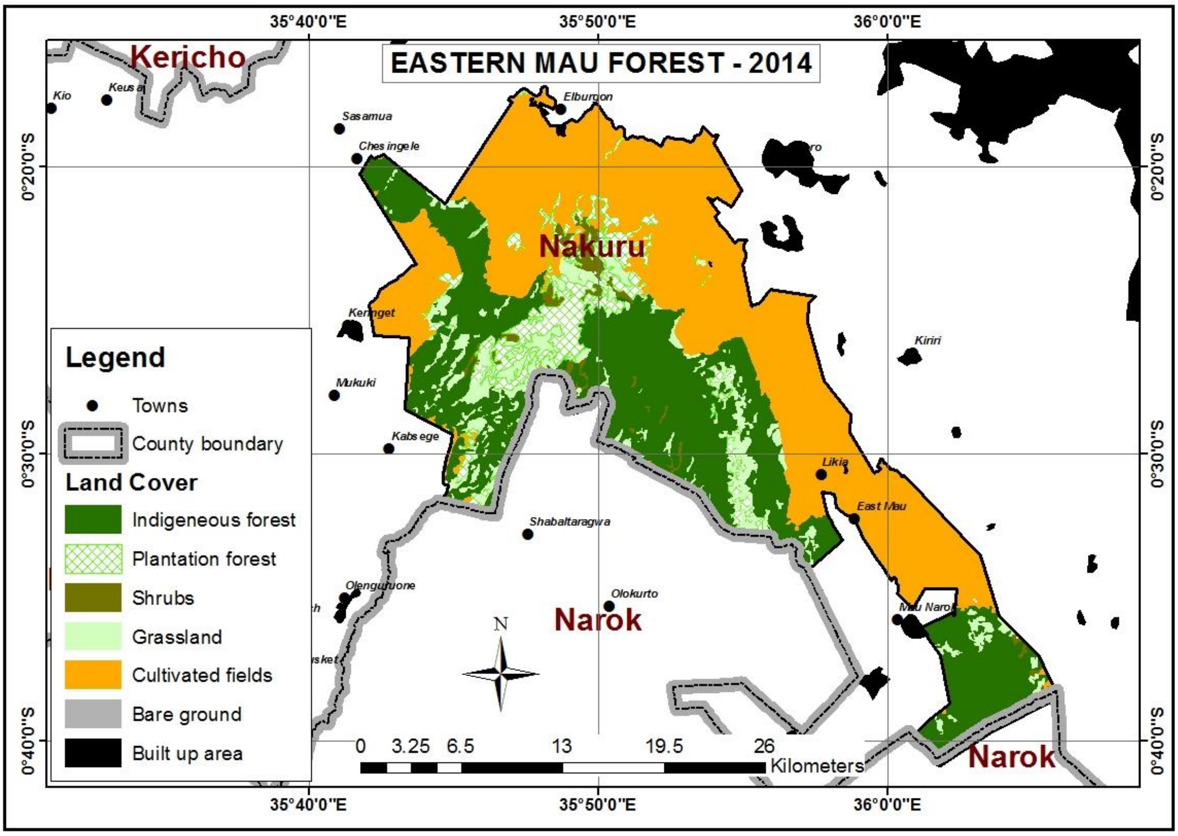

Figure 5.9: Distribution of drivers of land cover change (data source: NASA).

Cultivation of forest land increased over the years as can be seen from the satellite image interpretation results. This is as a result of the government allowing people to cultivate forest land as well as illegal forest land cultivation and illegal selling of forest land that is converted to agricultural land. Settlements are increasingly put up by increasing population as well as the increasing nearby towns/shopping centres. These settlements have a big influence on the land cover change in Eastern Mau Forest. Results from land cover analysis showed that parts of Eastern Mau Forest that are next to towns and shopping centres have a land cover type of cultivated fields and not indigenous forest. These settlements include Elburgon, Mau Narok, Keringet, Nessuit and Likia. Residents and hotels in Nakuru, Elburgon, Mau Narok and Njoro towns rely on charcoal, firewood and timber from Eastern Mau Forest. Saw millers in the same towns are supplied with trees from Eastern Mau Forest. Forest trees are cut for constructing the settlements leading to forest cover change. Also, people who stay in these settlements make use of forest products like charcoal and firewood which encourages illegal charcoal burning and firewood collection from the forest.

Grazing is done both on site and off site where animals graze inside the forest and grass is cut and transferred to other places for feeding livestock respectively. This encourages burning of grass in the forest during dry season to enable regeneration of good pasture in the rainy seasons. The burning of grass ends up burning forest trees thereby causing forest degradation/destruction although this is considered to have a minimal impact as compared to charcoal burning and honey harvesting that cause more forest burning. Culture of natives staying in the forest leads to forest cover change. This is because the culture of surviving on hunting and gathering is now changing with the changing times where hunters and gatherers have now turned to cultivation of forest land for food. This kind of culture negatively impacts on the forest as it makes forest to be more susceptible to destruction due to cultivation.

Drivers of land cover change have been increasing with time. There were only 844.70 hectares of cropland in 1986. This area increased to 1631.32 hectares, 25069.95 hectares and 30836.66 hectares in 1995, 2003 and 2014 respectively. On the other hand, there were 18.60 hectares of built up area in 1986 which reduced to 13.68 hectares in 1995 and then increased to 34.13 hectares and 73.00 hectares in 2003 and 2014 respectively. The 1995 reduction in the built up area was just two years before the general elections of 1997 while the 2003 and 2014 increase was just one year after the 2002 and 2013 general elections. This indicated that increase in the built up area as a driver of land cover change in Eastern Mau Forest has some relationship with the Kenyan general elections.

5.3.1. Population and Land Cover Change

Land cover change occurred in form of conversion of some land cover categories to different other categories. The land cover change in Eastern Mau Forest increased as human population density increased. The explanation for this land cover change was largely in terms of increasing population pressure. Kenya censuses are based on administrative boundaries of Sub-location level as enumeration areas. The 1989 census was based on less number of Sub-locations as compared to the 1999 and 2009 censuses. This was because some Sub-locations were split into other more Sub-locations after 1989 census. Therefore, some 1999 and 2009 population density data were combined to be in conformity with 1989 data. The comparison of 1989, 1999 and 2009 census data showed a general increase in population density in the area of study *(Table 5.10).*

Table 5.10: Eastern Mau Forest population density trend (Source: KNBS, 1989, 1999, 2009).

1989 Location	1989 Sub-location	1999/2009 Location	1999/2009 Sub-location	1989 Population Density	1999 Population Density	2009 Population Density
Elburgon	Elburgon	Elburgon	Elburgon	464.36	443.756	497.60
			Arimi			
Mariashoni	Kiptunga	Mariashoni	Kiptunga	18.46	3.98	26.83
	Ndoshwa		Ndoshwa	12.35	21.33	71.63
	Kitiro		Kitiro	35.47	16.46	106.40
Kiambogo	Kiambogo	Kiambogo	Kiambogo	44.98	101.78	103.70
Njoro	Njoro	Njoro	Njoro	248.53	390.50	463.05
			Mukungugu			
	Nessuit	Nessuit	Nessuit	177.76	83.78	179.43
			Misepei			
			Sigotik			
Molo South	Keringet	Keringet	Milimet	51.59	126.58	204.10
		Nyota	Olubumbu			
		Kapsimbeiywo	Kapsimbeiywo			
		Silibwet	Silibwet			
		Chebara	Baraget			
Lare	Naish	Bagaria	Milimani	232.40	187.12	145.41
			Kapyemit			
Kihigo	Likia/Teret	Mauche	Mauche	72.43	96.063	157.52
			Tachasis			
		Teret	Teret			
			Lelechwet			
		Kapkembu	Kapkembu			
			Chebitet			
		Tuiyotich	Siriat			
			Loitepes			
Mau Narok	Siapei	Mau Narok	Siapei	64.07	139.49	217.80
	Kianjoya	Sururu	Kiptulel	338.58	218.74	355.23

Out of the 35,372.43 hectares land cover change that occurred in Eastern Mau Forest in the 1986-2014 period 30,054.96 hectares were of conversion from other land cover types to cropland *(Table 5.11)* which was an indicator that more food was required as a result of population density increase. This clearly shows that there is a relationship between population increase and land cover change especially the change of other land cover types to cultivated fields land cover type.

Table 5.11: Land cover change in Eastern Mau Forest between 1986 and 2014.

Category	**Land Cover Change**	**Hectares**
1	Shrubland to grassland	262.17
2	Cultivated fields to grassland	9.18
3	Indigenous forest to grassland	616.05
4	Plantation forest to grassland	1153.98
5	Grassland to shrubland	402.75
6	Cultivated fields to shrubland	22.50
7	Plantation forest to shrubland	238.77
8	Grassland to cultivated fields	5493.60
9	Shrubland to cultivated fields	2033.82
10	Indigenous forest to cultivated fields	5192.64
11	Plantation forest to cultivated fields	17316.99
12	Bare ground to cultivated fields	5.94
13	Built up area to cultivated fields	11.97
14	Grassland to indigenous forest	463.05
15	Shrubland to indigenous forest	257.04
16	Cultivated fields to indigenous forest	7.38
17	Plantation forest to indigenous forest	262.17
18	Grassland to plantation forest	850.23
19	Shrubland to plantation forest	443.43
20	Cultivated fields to plantation forest	18.90
21	Indigenous forest to plantation forest	243.36
22	Indigenous forest to bare ground	0.27
23	Grassland to built-up area	17.91
24	Shrubland to built-up area	12.33
25	Plantation forest to built-up area	36.00
	Total	**35372.43**

During this period some land cover types decreased in spatial coverage while other increased. Those that decreased include grassland, shrubland, plantation forest, indigenous forest and bare ground. Those that increased were cropland and built up area. Cropland increased from 844.70 hectares to 30,836.66 hectares while built up area increased from 18.60 hectares to

73.00 hectares. Just like cropland increase conversion of other land cover types to built-up land cover was an indicator of need for more settlements due to population density increase.

5.4. Trends in Land Cover Change

The trend of land cover change in Eastern Mau Forest between 1986 and 2014 is different for different land cover types. Some land cover types increased in size in terms of area covered spatially while others decreased *(Figure 5.10)*. Land cover classes that increased in size include cultivated fields and built up area. Those that decreased include indigenous forest, plantation forest, shrubland, grassland and bare ground. Some land cover types had a continuous increasing trend, others had a continuous decreasing trend while others had a trend of both increasing and decreasing.

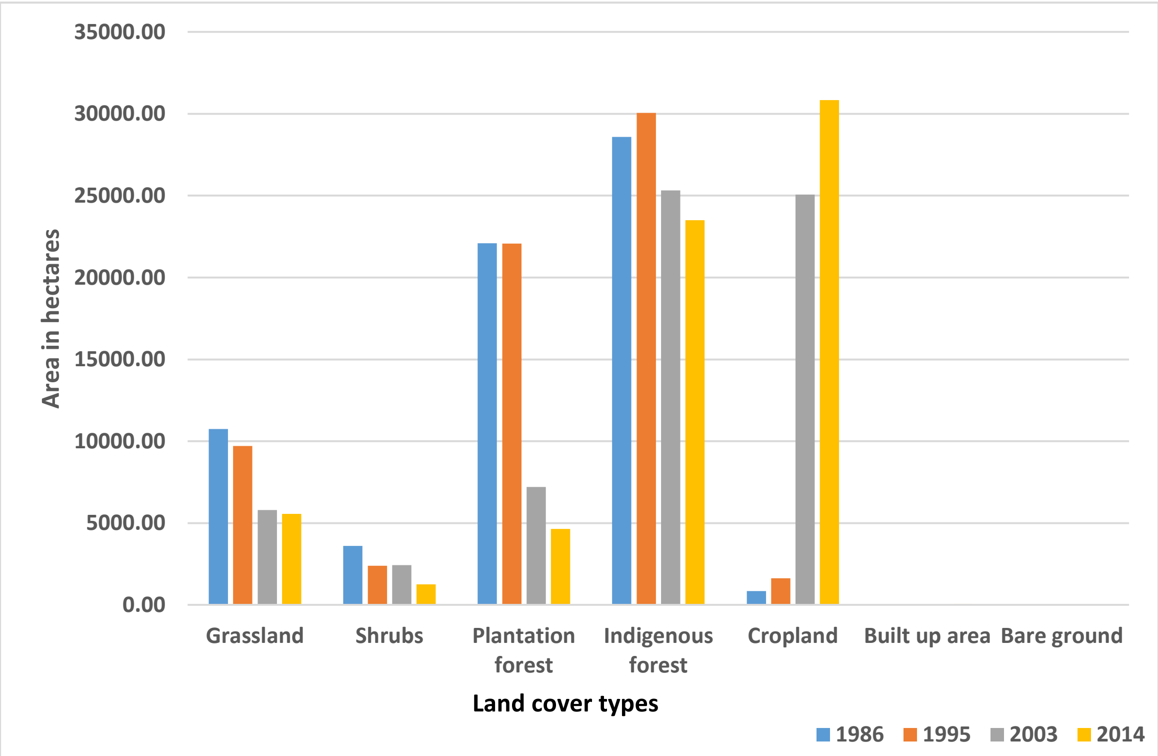

Figure 5.10: Area covered by different land cover types in hectares.

Cultivated fields had a continuous increasing trend between 1986 and 2014. Plantation forest, grassland and bare ground land cover types had a continuous decreasing trend. Indigenous forest increased from 1986 to 1995 then decreased from 1995 to 2014. Shrubs decreased from 1986 to 1995, increased from 1995 to 2003 and then decreased from 2003 to 2014. Built up area decreased from 1986 to 1995 then increased from 1995 to 2014. Based on the land cover change trend in the 1986-2014 period it is noticeable that the land cover classes that increased in spatial coverage between 1986 and 1995 were indigenous forest and cultivated fields with indigenous forest gaining from shrubland conversion to forest in the area bounded by longitude $35^{0}50^{'}$E going westwards. Cultivated fields gained from conversion of plantation forest and grassland land cover types especially on the eastern part of the area of study *(Figure 5.11)*.

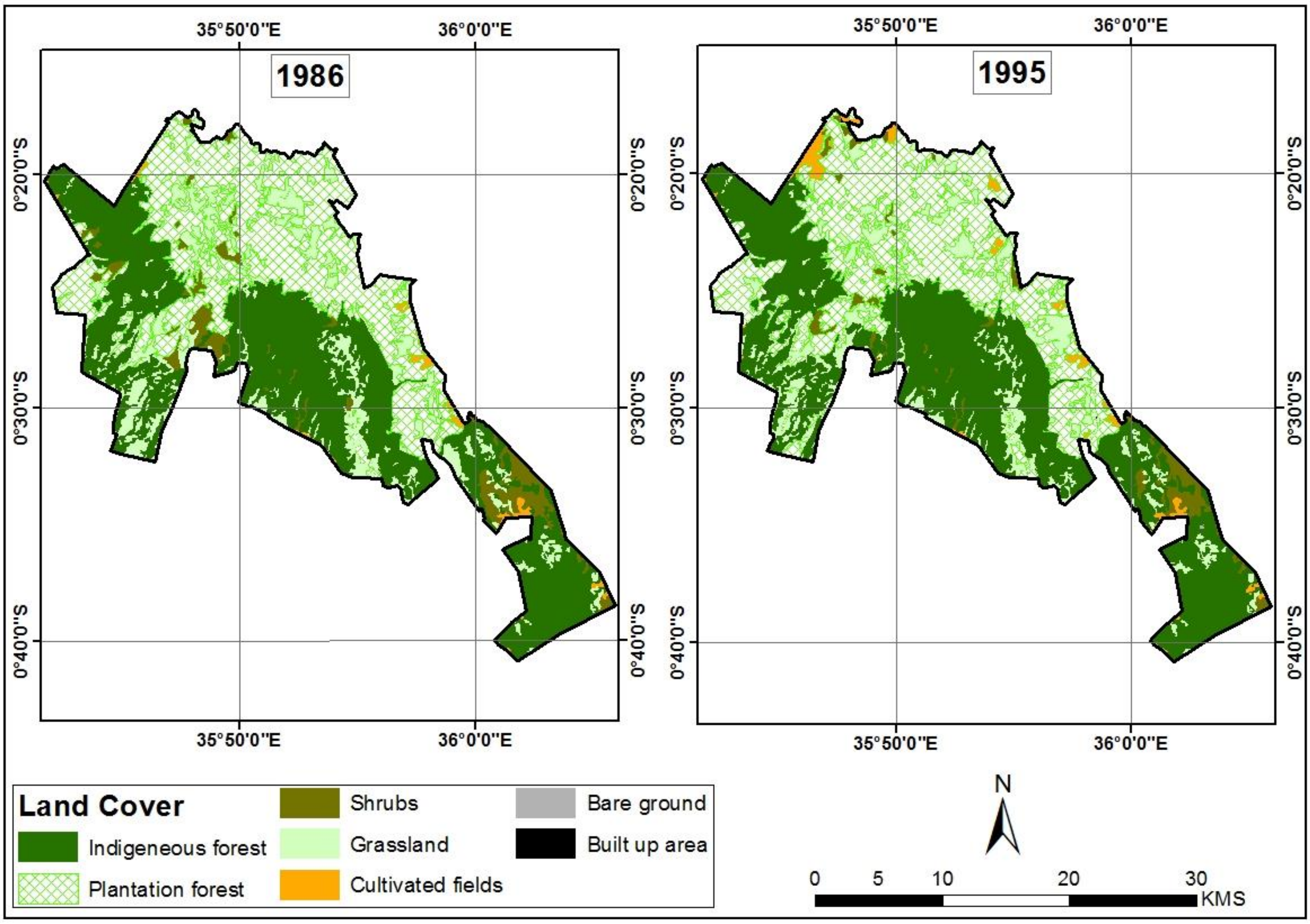

Figure 5.11: Eastern Mau Forest 1986-1995 land cover change (data source: NASA).

In the 1995-2003 land cover change trend built up area and cultivated fields increased in spatial coverage. Built up area gained from grassland, cultivated fields, shrubland and plantation forest conversion. Cultivated fields gained from conversion of plantation forest, indigenous forest, grassland and shrubland land cover types especially on the eastern part of the area of study *(Figure 5.12)*.

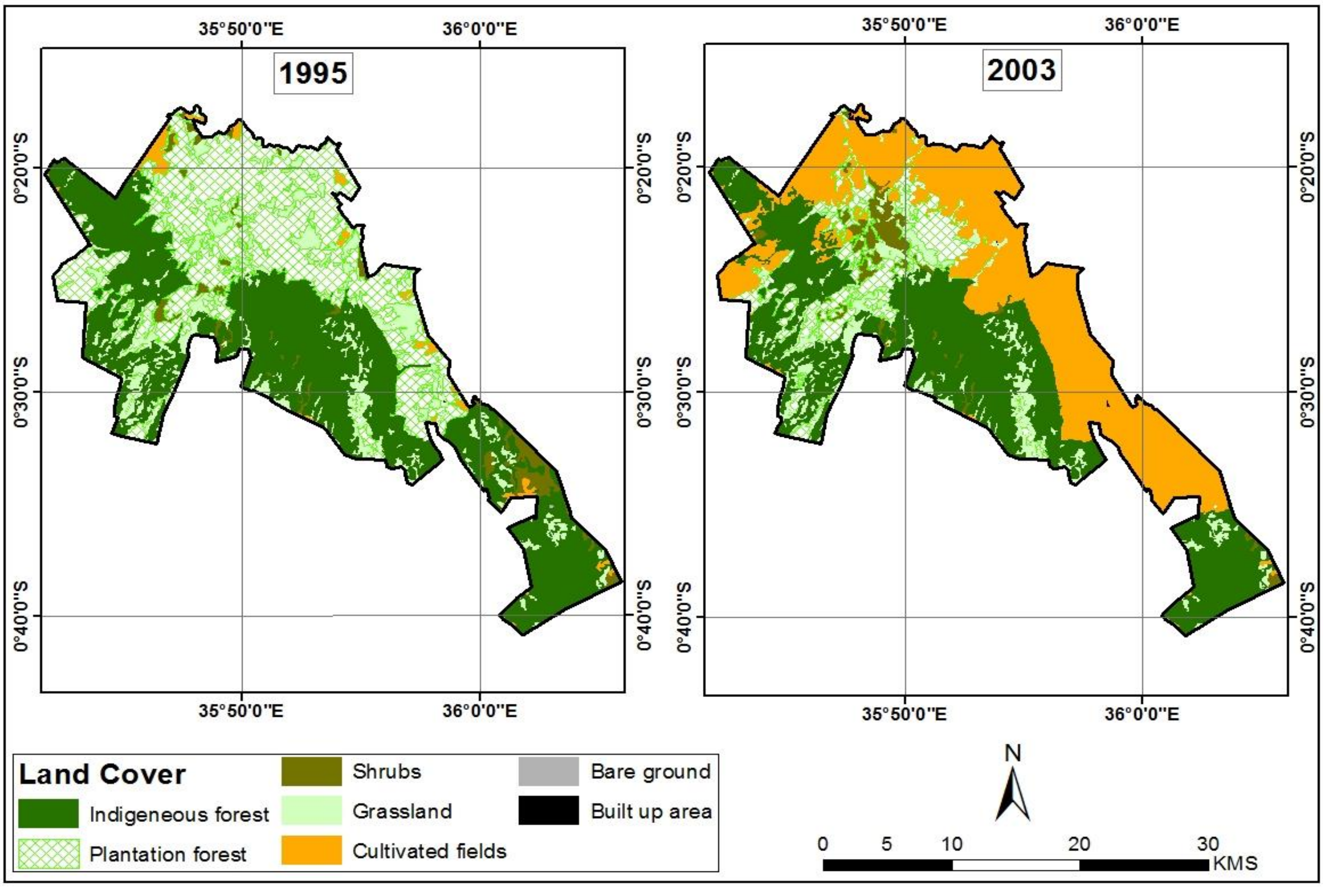

Figure 5.12: Eastern Mau Forest 1995-2003 land cover change (data source: NASA).

Just like in the 1995-2003 land cover change the 2003-2014 change had only built up area and cultivated fields with an increase in spatial coverage. The remaining land cover classes decreased in their spatial coverage. Built up area gained from grassland and cultivated fields while cultivated fields gained from conversion of plantation forest, indigenous forest, grassland, shrubland and bare ground land cover types especially on the eastern part of the area of study *(Figure 5.13).*

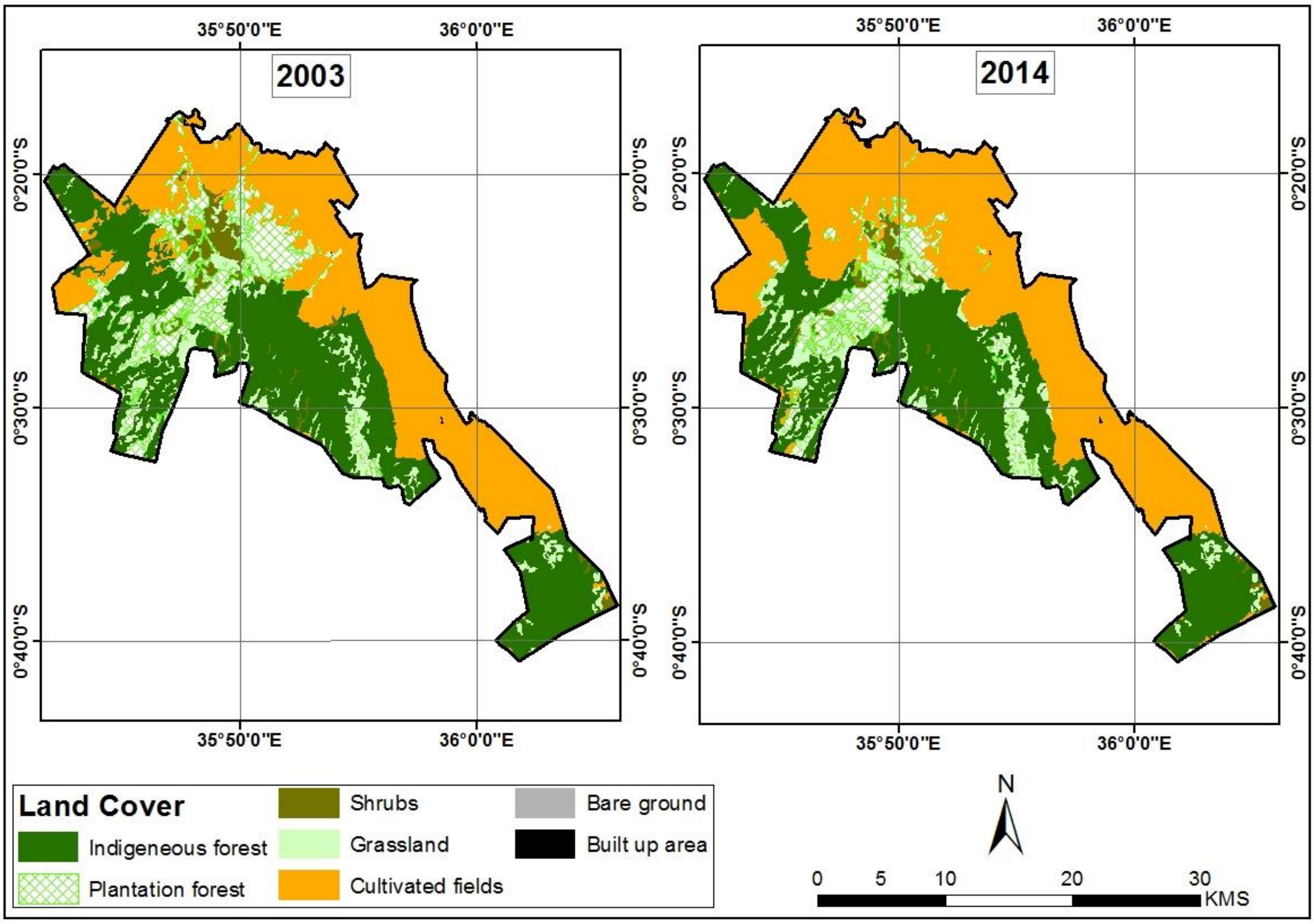

Figure 5.13: Eastern Mau Forest 2003-2014 land cover change (data source: NASA).

The overall land cover change between 1986 and 2014 had plantation forest, grassland and bare ground with a decreasing trend that was continuous throughout that period. Indigenous forest, shrubland and built up area had a trend that was both decreasing and increasing between the different study period years. It is only cultivated fields land cover type that had a continuously increasing spatial coverage in the 1986-2014 period *(Figure 5.14).*

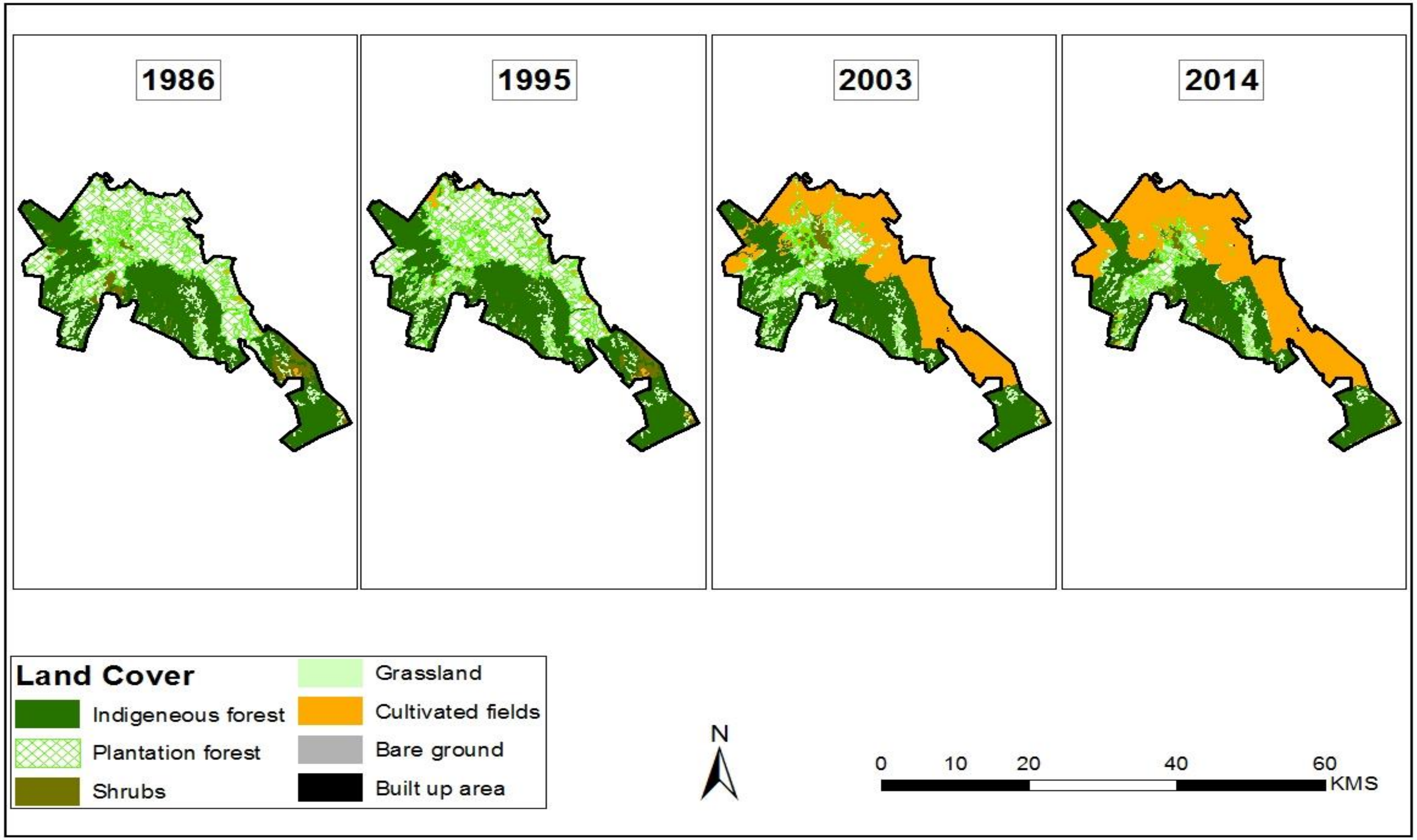

Figure 5.14: Eastern Mau Forest 1986-2014 land cover change trend (data source: NASA).

5.5. Hypotheses Testing

Three null hypotheses were tested to determine if there was significant land cover change in Eastern Mau Forest between 1986 and 2014; determine if the drivers of land cover change have a significant impact on forest cover change; and determine if there are significant sustainable ways of using forest resources in Eastern Mau Forest. The hypothesis on the determination of land cover change significance stated that there was no significant land cover change in Eastern Mau Forest between 1986 and 2014. This hypothesis was tested based on temporal (serial) autocorrelation which measures a parameter of the same variable over time by computing the correlation of each observation with the next observation. Based on the amount parameter of spatial land cover change variable the amount of change cumulatively increased with time between the different years of study. The amount of spatial land cover change between 1986 and 1995 was 4531.54 hectares. In 2003 and 2014 the amount of change had increased to 48481.56 hectares and 60092.72 hectares respectively (*Table 5.12).*

Table 5.12: Cumulative land cover change and periods of change between 1986 and 2014.

No.	**Years of Change**	***X*** **(Period of Change in Years)**	***Y*** **(Cumulative Land Cover Change in Hectares)**
1	1986 - 1995	9	4531.54
2	1986 - 2003	17	48481.56
3	1986 - 2014	28	60092.72

A time series autocorrelation was computed based on the cumulative land cover change values using Microsoft Excel autocorrelation function. The computed value was a strong positive autocorrelation of r = 0.915078008. A time series plot on the trend of land cover change was also generated from the Microsoft Excel function. The overall trend on the time series plot is that land cover change continued to increase as years progressed from one period of change to another *(Figure 5.15)*. The null hypothesis was therefore rejected based on the strong positive autocorrelation that indicated that significant land cover change had occurred in Eastern Mau Forest between 1986 and 2014.

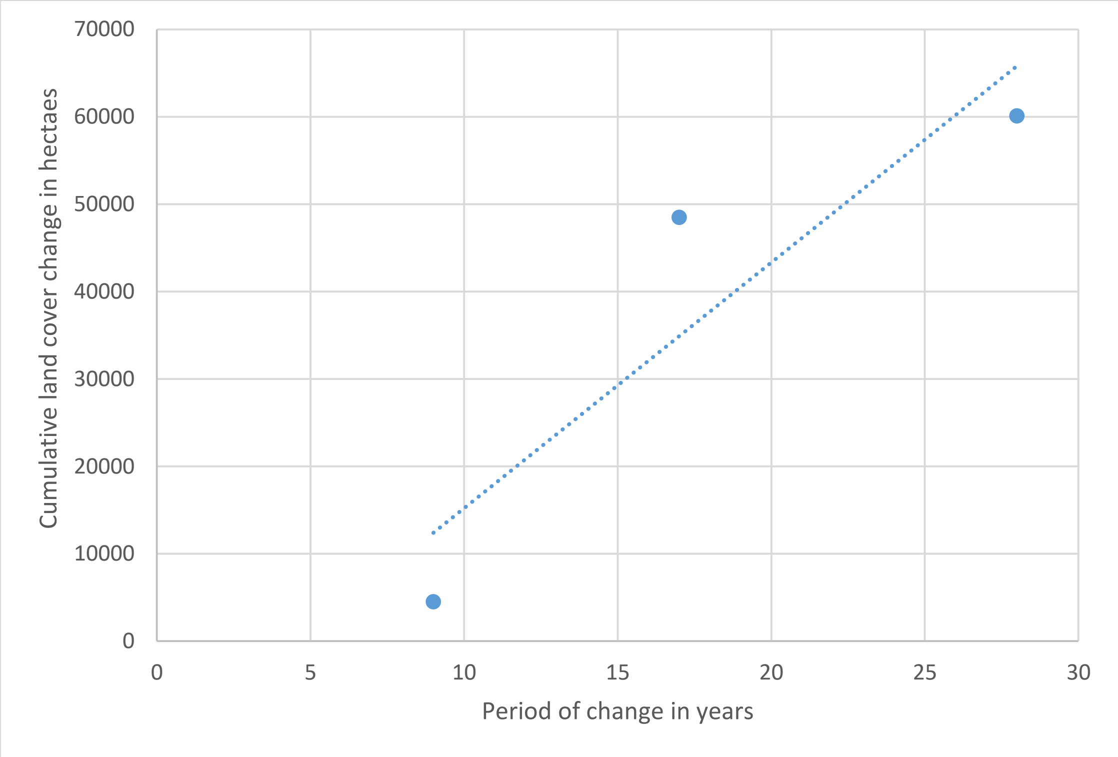

Figure 5.15: Time series plot of serial correlation in the 1986-2014 period.

The hypothesis on the determination of the significance of the impact of drivers of land cover change stated that the drivers of land cover change in Eastern Mau Forest did not have a significant impact on forest cover change that occurred between 1986 and 2014. It meant that land cover changes that were observed occurred by random chance and were not by the drivers of land cover change. This hypothesis was tested using *Moran's I* spatial autocorrelation algorithm which computes the autocorrelation based on the observations made and the locations of those observations. It was observed that land cover change was increasing as settlements increased. This was an indication that expansion of settlements was one of the most significant drivers of land cover change because forest trees were cut to create room for settlement construction and provide material for construction. Also, people who stay in the available settlements are involved in activities that contribute to other drivers of land cover change. For instance, they are involved in crop cultivation which was also observed to be another most significant driver of land cover change. Therefore, expansion of settlements contributes to increase of drivers of forest cover change.

The spatial autocorrelation was used to determine if the spatial reduction in forest cover occurs as a result of having settlements inside the forest and in locations outside the forest but in close proximity to the forest. Distance between forest cover and settlements was therefore used as a criterion for analysis. *Moran's I* spatial autocorrelation results are in form of an index report with values between -1 and +1. Values near +1 indicate clustering while those near -1 indicate dispersion. The resultant report from this spatial autocorrelation test had a *Moran's I* index value of 0.351793 *(Plate 5.1)* which tends towards +1 and shows that the occurrence of forest cover change in Eastern Mau Forest is due to clustering of drivers of land cover change in close proximity to the forest, hence, there is no enough evidence to fail to reject the null hypothesis. The null hypothesis was therefore rejected on the basis of having evidence of drivers of land cover change inside and close to the forest.

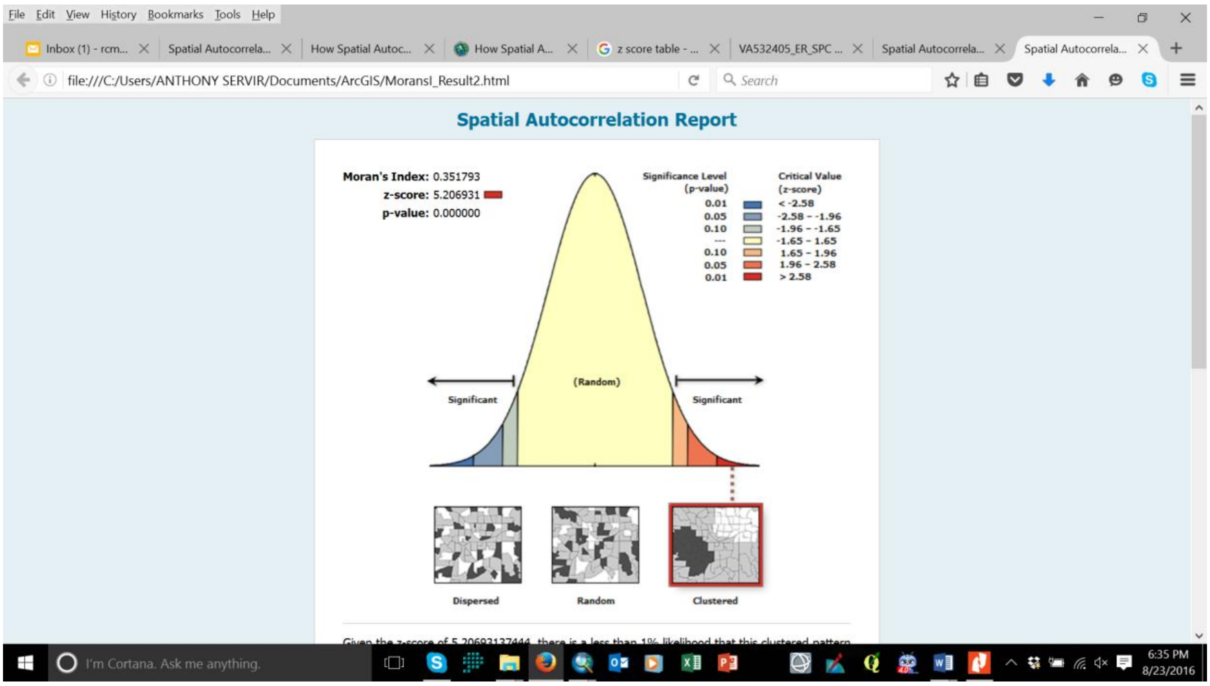

Plate 5.1: Indigenous forest and drivers of land cover change autocorrelation (source: ESRI ArcGIS).

The hypothesis on the determination of the significance of sustainable ways of using forest resources stated that there are no significant sustainable ways of using forest resources in Eastern Mau Forest. It meant that land cover changes that were observed occurred due to unsustainable ways of using forest resources and were not by random chance. This hypothesis was also tested using *Moran's I* spatial autocorrelation algorithm. It was observed that land cover change was increasing as unsustainable land use activities in the forest increased. The most conspicuous activity was conversion of forest land to cropland. This was an indication that expansion of cropland into the forest was one of the most unsustainable ways of using forest resources in Eastern Mau Forest.

The spatial autocorrelation was used to determine if the spatial reduction in forest cover occurs due to expansion of unsustainable forest resource use. Adjacency of indigenous forest and cropland was used as a criterion for analysis of autocorrelation between forest cover reduction and cropland increase. *Moran's I* spatial autocorrelation report from this test had an index value of 0.309909 *(Plate 5.2)* which tends towards +1 and shows that reduction of indigenous forest in Eastern Mau Forest is due to availability of unsustainable ways of using forest resources, hence, there is no enough evidence to reject the null hypothesis.

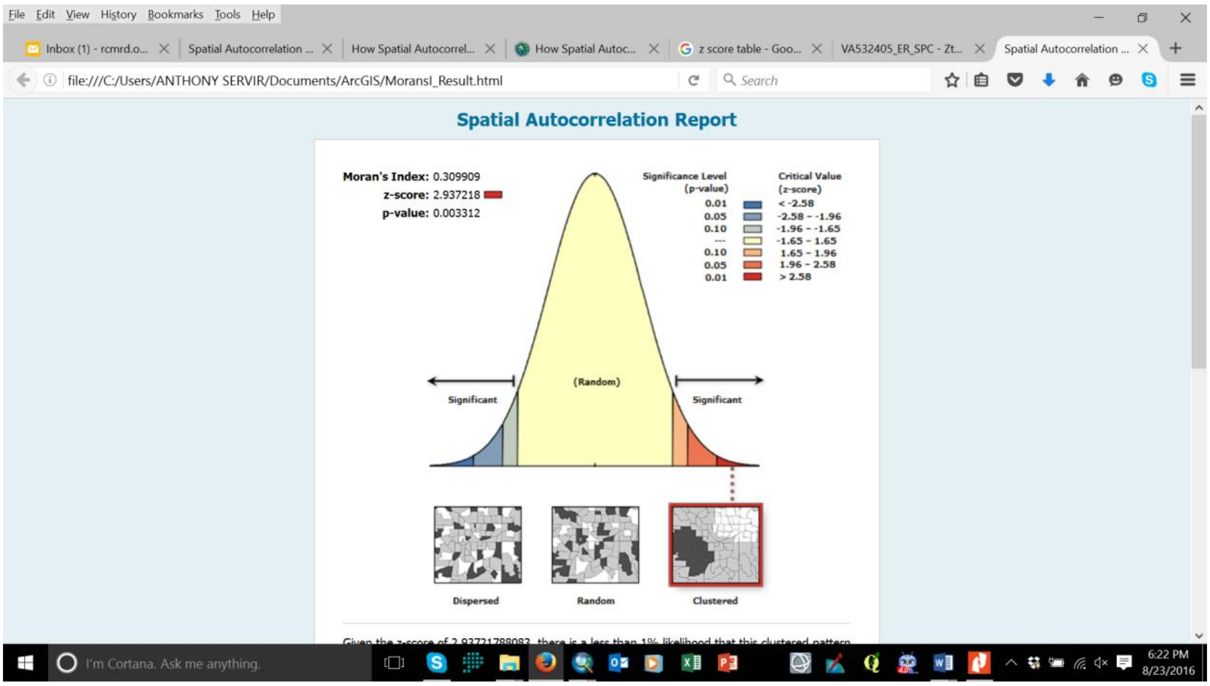

Plate 5.2: Indigenous forest and unsustainability forest resource use autocorrelation (source: ESRI ArcGIS).

CHAPTER SIX

6.0. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1. Summary

The study had three specific objectives namely: to determine land cover change in Eastern Mau Forest between 1986 and 2014; to determine the drivers of the land cover change; and to determine sustainable ways of using forest resources. The variables in the objective on land cover change were type and amount of change in terms of space and time. Those in the objective on drivers of land cover change were the forces that cause land cover change while those in the objective on sustainability were the ways in which forest resources are used. Land cover change variables were tested based on serial autocorrelation which gave the result of a strong positive autocorrelation of 0.915078008 indicating occurrence of land cover change. Drivers of land cover change variables were tested based on *Morans I* spatial autocorrelation which gave a positive index of 0.351793 indicating clustering of drivers of land cover change next to the forest. Variables on sustainability of forest resource use were also tested based on *Morans I* spatial autocorrelation which gave a positive index of 0.309909 indicating availability of unsustainable ways of using forest resources.

Land cover change analysis was done for 1986, 1995, 2003 and 2014 based on classification of Landsat satellite images and field data validation. Land cover classification had seven land cover types namely indigenous forest, plantation forest, shrubland, grassland, cropland, bare ground and built up area. The analysis revealed that between 1986 and 2014 cropland and built up area increased in spatial coverage while indigenous forest, plantation forest, shrubland, grassland and bare ground reduced.

Drivers of land cover change in Eastern Mau Forest were identified during field data validation. The identified drivers include increase in crop cultivation, increase in settlements, grazing of livestock, policies that allow people to settle on forest land and cultures that encourage people to stay in the forest. There were a lot of conversions of indigenous forest and plantation forest land cover types to cropland between 1995 and 2014. It was also during the same period that there was a lot conversion of plantation forest to settlements. Census data of 1999 and 2009 that is covered within the same period revealed that there was population increase in the area covered by Eastern Mau Forest during this period. This population increase led to increase in demand for food and housing consequently leading to increase in cropland and construction of settlements respectively.

The information collected during fieldwork revealed that there are different activities that depict unsustainable ways of using forest resources in Eastern Mau Forest. These activities lead to land cover change, especially change from indigenous forest to other land cover types. The identified unsustainable forest resource use ways in Eastern Mau Forest include cultivation of crops on forest land, settling of people on forest land, introduction of plantation forests with unfavourable exotic tree species, grazing of livestock in the forest, logging, firewood extraction and illegal charcoal burning. The forest resources usage was likely to be unsustainable if cropland expansion were to remain unchecked. Expansion of settlements adds more pressure to the forest resources that are relied on for their construction. Similarly, it leads to need for more food hence increasing conversion of forest land to cropland.

6.2. Conclusions

This study came up with three conclusions based on its findings. One of the conclusions is that if the trend of land cover change in Eastern Mau Forest is not checked it is likely that some land cover types will disappear especially those that are considered to be more important in sustaining environmental stability in terms of provision of ecosystem services like indigenous forest. In the long run, this may lead to climatic and environmental catastrophes.

Having policies and legislations that govern management of natural resources is not enough if they are not implemented as expected. This is especially in cases where policy and legislation implementation is compromised by politics like it happens in Kenya where powerful politicians allocate public forest land to people especially those inclined to their political and tribal affiliations just before the general allocations as a way of campaigning for votes without consideration the impact such actions on the environment.

Technology has proved to be very important in solving different challenges including those that are environmental in nature. Geo-information technology provides tools for generating information on the changes in the environment based on location and spatial extent. It is therefore important that if sustainable development is to be achieved this technology should be embraced by most stakeholders as an integral platform for providing environmental changes information.

6.3. Recommendations

The study provided the following recommendations based on the conclusions made:

1. On the land cover change trend that was observed in Eastern Mau Forest the study recommended that:
   i. Resettlement activities be reduced or eliminated in the Eastern Mau Forest area in order to reduce or stop cropland expansion. The authority concerned must come up with a policy that should end resettling people on forest land and prohibit settlements at the forest boundaries.
   ii. There is need to carry out continuous studies on land cover change in Eastern Mau Forest as a way of ensuring that up to date information on the changes that are taking place is made available to the relevant authorities for the necessary mitigation measures.

2. On the implementation of policies and legislations that govern management of natural resources the study recommended that:
   i. The law should be very strict on politicians who allocate public forest land to their political cronies if sustainable development goals are to be achieved. Such politicians should be made to pay tough penalties and be restricted from holding public office.
   ii. It is important to continuously invest in campaigns that educate citizens on the importance of conserving the environment and future challenges that come with degradation of the environment.

3. On the use of geo-information technology in providing information for management of environmental resources the study recommended that:
   i. There is need to have legislations that will make geo-information technology to be a compulsory part of education curriculum for those pursuing studies that are related to the environment.
   i. There is need to explore on ways of how geo-information skills can be imparted on all those that are involved in conservation and management of the environment.

REFERENCES

1. Adoyo, J. W. and Wangai, C. I. (2012). KENYA Political, Social and Environmental Issues (Nova Science Publishers, Inc.).
2. Akotsi, E. F. N., Gachanja, M. and Ndirangu, J. K. (2006). Changes in Forest Cover in Kenya's 'Five Water Towers' 2003-2005.
3. Amnesty International. (2007). Kenya - Nowhere to go: Forced Evictions in Mau Forest. Briefing Paper, May 2007.
4. Ayuyo, I. O. and Sweta, L. (2012). Land Cover and Land Use Mapping and Change Detection of Mau Complex in Kenya Using Geospatial Technology. International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064.
5. Better Globe (2009). Miti Issue No. 3 (2009). The Tree Business Magazine for Africa. A publication of Better Globe, Nairobi.
6. BirdLife International. (2015). Important Bird Areas factsheet: Mau forest complex.
7. China, S. S. (1993). Land Use Planning using GIS. PhD thesis, University of Southampton.
8. Cihlar, J. (2000). Land Cover Mapping of Large Areas from Satellites: Status and Research Priorities. Canada Centre for Remote Sensing, Ottawa K1A 0Y7, Canada.
9. Diallo, Y., Hu, G. and Wen, X. (2009). Applications of Remote Sensing in Land Use/Land Cover Change Detection in Puer and Simao Counties, Yunnan Province, China. Journal of American Science.
10. FAO (2002). Tropical Secondary Forest Management in Africa: Reality and Perspectives, Kenya Country Paper.
11. FAO (2009). Food and Agriculture Organization of the United Nations. Crop evapotranspiration: Guidelines for computing crop water requirements – FAO Irrigation and Drainage paper 56, Rome, Italy.
12. FAO (2012). Food and Agriculture Organization of the United Nations. State of the World's Forests (FAO), Viale delle Terme di Caracalla, 00153 Rome, Italy.
13. GoK (2007). Kenya Vision 2030. Government of the Republic of Kenya, 2007.
14. GoK (2008). Government's Report on Mau Complex and Marmanet Forests: Environmental and Economic Contributions, Current State and Trends.
15. GoK (2009). Report of the Government's Task Force on the Conservation of the Mau Forests Complex.

16. Guthiga, P. (2009). Opportunity Costs of Conservation: The Case of Protected Area Management in the Kakamega Forest, Western Kenya. Environment for Development (EfD) Policy Brief Paper.
17. ISRIC/FAO-UN. (1995). Procedures for Soil Analysis. Technical Paper 9. (5th edition).
18. Jenness, J. and Wynne, J. J. (2007). Cohen's Kappa and Classification Table Metrics.
19. Karanth, K. K. (2010). Interactions between Protected Areas and their Surroundings in Human-Dominated Tropical Landscapes: Biological Conservation Paper.
20. KFMP. (1994). Kenya Forestry Master Plan Project (Kenya Forestry Master Plan Development Programmes).
21. KFWG. (2001). Kenya Forests Working Group. Excision and settlement in the Mau Forest. Kenya Forest Working Group report, Nairobi, Kenya.
22. KFWG (2010). Analysis of the Implementation of the Forests Act 2005. Policy Brief No. 4. 2010. Kenya Forests Working Group (KFWG), Nairobi.
23. KFWG (2013). On-Going Review of Forest Sector Management: Opportunities for Improved Governance. Policy Brief No. 6. 2013. Kenya Forests Working Group (KFWG), Nairobi.
24. Kundu, P. M. (2007). Application of Remote Sensing and GIS techniques to evaluate the impact of land use and land cover change on stream flows: The case for River Njoro catchment in Eastern Mau-Kenya. PhD Thesis. Egerton University, Kenya.
25. Lambin, E., and Geist, H. (2007). Causes of land use and land cover change.
26. Lillesand, T. M. and Kiefer, R. W. (2000). Remote Sensing and Image Interpretation (4th edition). John Wiley, New York.
27. Maingi, J. K. and Marsh, S. E. (2001). Assessment of environmental impacts of river basin development on the riverine forests of eastern Kenya using multi-temporal satellite data. Arizona Remote Sensing Center, University of Arizona, Tucson, Arizona 85750, USA.
28. Malgorzata, V. W. (2010). Data acquisition and integration Remote Sensing. Land Surveying, Geodetics and Cartography. Eredeti [ISBN][ISSN].
29. McArthur, E. D. and Kitchen, S. G. (2007). Shrubland Ecosystems: Importance, Distinguishing Characteristics, and Dynamics. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
30. NEMA (2008). State of the Environment Report for Uganda 2008. National Environment Management Authority (NEMA), Kampala.

31. Olang L. O. & Kundu P. (2011). Land Degradation of the Mau Forest Complex in Eastern Africa. A Review for Management and Restoration Planning.
32. Owido, S. F. O., Chemelil, C. M., Nyawade, F. O. & Obadha, W. O. (2003). Effects of Induced Soil Compaction on Bean (Phaseolus vagaries) Seedling Emergence from a Haplic phaeozen soil. Agriculture Tropica. ET subtropica.
33. Pearce, D. W. (2002). The Economic Value of Forest Ecosystems: DOI: 10. 1046/j. 1526-0992.2001.01037.x.
34. Pellikka, P., Clark, B., Hurskainen, P., Keskinen, A., Lanne, M., Masalin, K., Nyman-Ghezelbash and Sirvio, T. (2004). Land Use Change Monitoring Applying Geographic Information Systems in the Taita Hills, SE-Kenya.
35. Pfeifer, M., Burgess, N. D., Swetnam, R. D., Platts, P. J., Willcock, S., Marchant, R. (2012). Protected Areas: Mixed Success in Conserving East Africa's Evergreen Forests. PLoS ONE 7(6): e39337. doi: 10. 1371/journal.pone.0039337.
36. Quaddus, M. A. and Siddique, M. A. B. (2001). Modelling sustainable development planning: a multicriteria decision conferencing approach. Environment International.
37. Rawat, J. S. and Kumar, M. (2015). Monitoring land use/cover change using Remote Sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India.
38. Reis, S. (2008). Analyzing Land Use/Land Cover Changes Using Remote Sensing and GIS in Rize, North-East Turkey. Aksaray University, Faculty of Engineering, Department of Geodesy and Photogrammetry.
39. REMA and UNEP (2009). Rwanda State of the Environment and Outlook Report. Rwanda Environment Management Authority (REMA)/United Nations Environment Programme (UNEP), Nairobi.
40. Rimal, B. (2005). Application of Remote Sensing and GIS, Land Use/Land Cover Change in Kathmandu Metropolitan City, Nepal. Faculty of Earth Science and Environmental Management Institute of Geography, University of Wroclaw.
41. Sam, M. (2000). The Grassland Biome. University of California Museum of Paleontology.
42. Shalaby, A. and Gad, A. (2010). Urban Sprawl Impact Assessment on the Fertile Agricultural Land of Egypt Using Remote Sensing and Digital Soil Database, Case Study: Qalubiya Governorate. National Authority for Remote Sensing and Space Sciences, Egypt.

43. Sombroek, W. G., Braun, H. M. H. &van der Pouw, B. J. A. (1980). The explanatory soil map and agro-climatic zone map of Kenya. Report No. E. 1, Kenya Soil Survey, Nairobi, Kenya.
44. Spruyt, C. (2011). Changing Concepts of Nature and Conservation Regarding Eastern Mau Forest. A Case Study of the Mariashoni Ogiek.
45. Svizzero, S. and Tisdell, C. (2014). Economic Theory, Applications and Issues. Theories about the Commencement of Agriculture in Prehistoric Societies: A Critical Evaluation. Working Paper No. 68. The University of Queensland.
46. Tiffen, M., Mortimore, M. and Gichuki, F. (1994). More people, less erosion: environmental recovery in Kenya, London: ODI.
47. UNCED (1992). United Nations Sustainable Development. United Nations Conference on Environment and Development Report.
48. UNEP (2006). Africa Environment Outlook 2. United Nations Environment Programme (UNEP), Nairobi.
49. UNEP (2007). Water Towers of Eastern Africa: Policy Issues and Vision for Community-Based Protection and Management of the Environment.
50. UNEP (2009). Kenya: Atlas of Our Changing Environment. United Nations Environment Programme (UNEP), Nairobi.
51. UNEP, FAO and UNFF (2009). United Nations Environment Programme, Food and Agriculture Organization of the United Nations and United Nations Forum on Forests Secretariat: Vital Forests Graphics.
52. UNEP (2012). How Much Forest Cover in Kenya? A surprisingly difficult question to answer. United Nations Environment Programme.
53. USDA (2008). United States Department of Agriculture. USDA Forest Service: Valuing Ecosystem Services. Version 1.
54. WCED (1987). Our Common Future. World Commission on Environment and Development (1987). Oxford: Oxford University Press.
55. World Commission on Environment and Development (1987). Brundtland Report: Our Common Future. Oxford: Oxford University Press.
56. World Bank (2007). Strategic Environmental Assessment of the Forests Act 2005. The World Bank, Nairobi.
57. WRI (2007). Nature's Benefits in Kenya: An Atlas of Ecosystems and Human-Well Being. World Resources Institute (WRI), Washington D. C.

APPENDICES

Appendix I: Letter of Introduction

UNIVERSITY OF NAIROBI

Department of Geography & Environmental Studies

Telephone: +254 2 318262
Extension: +28016
Fax: +254 2 245566

P.O. BOX 30197-00100
NAIROBI
KENYA

3 October 2014

TO WHOM IT MAY CONCERN

This is to confirm that **Mr. Antony Oduya Ndubi** (Reg. No. C50/60306/2013) is a postgraduate student at the Department of Geography and Environmental Studies, University of Nairobi. He is pursuing his Master of Arts Degree in Environmental Planning and Management and is currently undertaking a research project on **"Spatial and temporal analysis of land cover change: Impact of resource use conflict in Eastern Mau Forest".**

Any assistance accorded to him will be highly appreciated.

Yours faithfully,

CHAIRMAN
Department Of Geography
and Environmental Studies
UNIVERSITY OF NAIROBI

Dr. Stella Mukhovi
Ag. Chair, Department of Geography & Environmental Studies

Appendix II: Land Cover Data Collection Form

LAND COVER DATA COLLECTION FORM

Form number-------------------

A. GENERAL INFORMATION

1. Area Name………
2. Sub-location……………………………………………………………………………………………………….
3. Location…….
4. Date……..
5. Time……..
6. GPS Position: Easting (X-Coordinate)…………………………………………………………………….

   Northing (Y-Coordinate)………………………………………………………………

   Elevation/Altitude (meters)….……………………………………………………….

B. LAND COVER INFORMATION

7. Land cover type...
8. Is land cover homogeneous? …..
9. If there is agriculture, which crop is grown? ....
10. Specify if agriculture is large or small scale..
11. Genera remarks:

    ……….

    ……
    ……
    ……
    ……
    ……
    ……
    ……
    ……
    ……
    ……

Appendix III: The Field Questionnaire

Antony Oduya Ndubi
P. O. Box 632 – 00618
Nairobi

Dear Sir/Madam,

Re: Field Data Collection

I am a student in the Department of Geography and Environmental Studies in the University of Nairobi pursuing a Master's degree in Environmental Planning and Management. I am required to carry out field data collection on land cover types and drivers of land cover change in Eastern Mau Forest Reserve as part of my research work for my studies.

QUESTIONNAIRE.

Questionnaire number--------------------

A. GENERAL INFORMATION

12. Area Name………

13. Sub-location……

14. Location……

15. Date……

16. Who is the interviewee? …………………………………………………………………………………

B. FOREST RESOURCE USE INFORMATION

17. Which livelihood activities are practiced in the forest?

………

………

………

………

………

………

18. Which livelihood activities are practiced outside the forest but have impact on the forest?

………

………
………
………
………
…………………… ……………………………………………………………………………………………………

19. Who are the forest resource users?

………

………
………
………
………
………

How do they make use of forest resources?

………

………
………
………
………
………

20. When did the local forest resource users settle there?

………

………
………
………
………

21. Are there any conflicting interests between the different forest resource users?

………

………
………
………
………

22. If yes, what are the impacts of the conflicting interests on the forest resources?

………

………
………

………

………

23. General remarks:

………

………

………

………

………

………

Appendix IV: Correlation Coefficient r Critical Values Table

Table of Critical Values for Pearson's *r*

	Level of Significance for a One-Tailed Test					
	.10	.05	.025	.01	.005	.0005
	Level of Significance for a Two-Tailed Test					
df	.20	.10	.05	.02	.01	.001
1	0.951	0.988	0.997	0.9995	0.9999	0.99999
2	0.800	0.900	0.950	0.980	0.990	0.999
3	0.687	0.805	0.878	0.934	0.959	0.991
4	0.608	0.729	0.811	0.882	0.917	0.974
5	0.551	0.669	0.755	0.833	0.875	0.951
6	0.507	0.621	0.707	0.789	0.834	0.925
7	0.472	0.582	0.666	0.750	0.798	0.898
8	0.443	0.549	0.632	0.715	0.765	0.872
9	0.419	0.521	0.602	0.685	0.735	0.847
10	0.398	0.497	0.576	0.658	0.708	0.823
11	0.380	0.476	0.553	0.634	0.684	0.801
12	0.365	0.457	0.532	0.612	0.661	0.780
13	0.351	0.441	0.514	0.592	0.641	0.760
14	0.338	0.426	0.497	0.574	0.623	0.742
15	0.327	0.412	0.482	0.558	0.606	0.725
16	0.317	0.400	0.468	0.542	0.590	0.708
17	0.308	0.389	0.456	0.529	0.575	0.693
18	0.299	0.378	0.444	0.515	0.561	0.679
19	0.291	0.369	0.433	0.503	0.549	0.665
20	0.284	0.360	0.423	0.492	0.537	0.652
21	0.277	0.352	0.413	0.482	0.526	0.640
22	0.271	0.344	0.404	0.472	0.515	0.629
23	0.265	0.337	0.396	0.462	0.505	0.618
24	0.260	0.330	0.388	0.453	0.496	0.607
25	0.255	0.323	0.381	0.445	0.487	0.597
26	0.250	0.317	0.374	0.437	0.479	0.588
27	0.245	0.311	0.367	0.430	0.471	0.579
28	0.241	0.306	0.361	0.423	0.463	0.570
29	0.237	0.301	0.355	0.416	0.456	0.562
30	0.233	0.296	0.349	0.409	0.449	0.554
40	0.202	0.257	0.304	0.358	0.393	0.490
60	0.165	0.211	0.250	0.295	0.325	0.408
120	0.117	0.150	0.178	0.210	0.232	0.294
∞	0.057	0.073	0.087	0.103	0.114	0.146