UNIVERSITY OF NAIROBI

LIVELIHOODS EXPANSION IMPACTS ON CARBON SEQUESTRATION: A CASE STUDY OF MAU FOREST COMPLEX

BY

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Declaration

I declare that this thesis is my original work and has not been submitted elsewhere for research. Where other people's work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements. I am conscious that the incorporation of material from other works or a paraphrase of such material without acknowledgement will be treated as plagiarism, subject to the custom and usage of the subject, according to the University Regulations on Conduct of Examinations.

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Dedication

I want to dedicate this thesis to my family, more specifically to my kids Kent Kamau and Neysa Ng'endo. When they read this thesis many years to come, I want them to know they can only be better than their mother. I've already set the pace for them.

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I want to thank the SERVIR program, a program supported by United States Agency for International Development (USAID) and National Aeronautical Space Administration (NASA), which provided me funding to undertake my masters studies. They created an opportunity to uplift me and to them I owe this Masters. I want to thank the Regional Centre for Mapping of Resources for Development (RCMRD) management for providing a suitable and enabling environment that saw me through my studies. I want to thank the System Land based Emissions Estimation (SLEEK) program, I managed the Land Cover Change component for them between 2015 and 2016 as a partnership between RCMRD where I work, Department of Resource Surveys and Remote Sensing (DRSRS), Kenya Forest Service (KFS) and Survey of Kenya (SOK). Through SLEEK we were able to develop very good datasets on land cover that I have relied on as input data.

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Abstract

Forest ecosystems provide direct-tangible benefits such as fodder and tree parts for animals, whole trees for timber, firewood and charcoal provides livelihoods for the local communities, whilst the indirect-intangible benefits such as carbon sequestration, groundwater recharge, air quality, soil formation etc. are insurmountable. The forest ecosystem however, is being threatened by climate change and livelihood expansions such as: expanding cropland areas, pastoralism, timber harvesting, and charcoal trading. With projections showing increasing populace in the Sub-Saharan Africa, these threats to forest ecosystems are likely to be exacerbated. Mau Forest Complex (MFC) a vital forest ecosystem faced with a lot of these challenges, and deforestation hotspot at that. This study focused on three key objectives: to determine the land cover changes (1990-2018) that had taken place, to determine the factors driving livelihood expansion into the MFC and to determine the carbon sequestration losses due to the land conversions. The study administered 200 household surveys from communities living around the MFC, a focused group discussion and five key informant interviews to determine the drivers of livelihoods expansion around the MFC. Additionally, analysis of Landsat satellite images was used to determine the land cover conversions that had occurred. This information was used as primary data in the Agriculture Land Use (ALU) software to estimate associated losses in carbon sequestration.

This research determined that there has been a 12.63% reduction in forest cover category which is a 33% reduction of the forest cover in the study area between 1990 and 2018. It was also determined that within the same timeframe there was a 31.68% increase in the cropland area, most of which were land converted from forestlands and grasslands. The periods of highest deforestation rates between 1990 and 2010 recorded at 12%, coincided with forest excisions that had been granted by the government in 1990 and 2001. The study determined that the greatest threat to carbon sequestration capacity of the MFC had been land conversion to cropland areas. A sequestration capacity loss of -5,053.884Gg/yr. was determined to occur between 1990 and 2018. The study recommended the need for abating actions to be taken now rather than later. Involvement of all key stakeholders: governments, communities, local authorities, researchers, NGOs was paramount to understand how their livelihoods expansion impacted the environment, and actions that needed to be taken, to positively conserve and improve on their ecosystem for sustainability of the environment, their livelihoods and their future.

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List of Acronyms

AFOLU	Agriculture Forestry and Land Use
AGB	Above Ground Biomass
ALU	Agriculture Land Use
BGB	Below Ground Biomass
CHIRPS	Climate Hazards group InfraRed Precipitation with Station data
CIFOR	Centre for International Forestry Research
CO_2	Carbon dioxide
CFA	Community Forest Association
CSA	Climate Smart Agriculture
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DRSRS	Department of Resource Surveys and Remote Sensing
EIA	Environmental Impact Assessment
EMCA	Environmental Management and Coordination Act
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GIS	Geographic Information Systems
GHG	Greenhouse gases
GOK	Government of Kenya
GPS	Global Positioning Systems
HWSD	Harmonized World Soil Database
IPCC	Intergovernmental Panel on Climate Change
KCC	Kenya Cooperative Creameries
KII	Key Informant Interview
KFS	Kenya Forest Service
KWTA	Kenya Water Towers Agency
LC	Land Cover
LULUCF	Land Use Land Cover and Forest Change
MFC	Mau Forest Complex
N_2O	Nitrous Oxide
NASA	National Aeronautical Space Administration

NDC	Nationally Determined Contribution
NGO	Non-Governmental Organization
RCMRD	Regional Centre for Mapping of Resources for Development
REDD	Reduced Emissions from Deforestation and Degradation
SDG	Sustainable Development Goals
SLEEK	System for Land based Emissions Estimation in Kenya
SOC	Soil Organic Carbon
SSL	Secure Socket Layer
UN	United Nations
UNFCCC	United Nations Convention on Climate Change
USAID	United States Agency for International Development

Chapter 1. Introduction

1.1 Introduction

Chapter one is an introductory chapter that provided background knowledge on the benefits of forests. It highlighted some of the threats and challenges that forest ecosystems face, narrowing down to the specific challenges experienced in the Mau Forest Complex as a result of expanding livelihoods. It defined the research problem and justified why this research was necessary. The chapter also defined the scope and location of the research. It further stated the questions that the research was looking to answer and developed a hypothesis around these questions. It listed the objectives that were required to fulfil the research purpose, to either prove or nullify the hypothesis. Further, it gave a brief overview of the methodological approach that was be applied by the research.

1.2 Background

Forests are important to the local residents for their physical, social and economic well-being (Ouko et al., 2018). Derived ecosystem benefits from forests include provision and cultural services that provide a direct human benefit. Other indirect benefits include support and regulatory services, such as restoration of soil fertility, climate regulation, carbon sequestration and air quality. Direct benefits are a source of livelihood to these communities as they provide tree parts and forage for their domestic animals and water for domestic use, farming and livestock. The forest ecosystem for these communities is a lifeline for pastoralism and agriculture. Additionally, the forests are a source of energy with majority of people in these communities relying on either charcoal or fuelwood (Ouko et al., 2018). The communities also rely on the forests for traditional medicine from roots, leaves, tubers, tree barks, bulbs, and seeds (Muhati et al., 2018). Land use change (changes resulting from settlement expansions and agricultural expansions and some even being illegal encroachment), climate change, and unsustainable use of resources have been determined as the major driving force behind declining provision of ecosystem services (Muhati et al., 2018).

Forests play a key role in the global carbon budget, accounting for 50% (350–600 Gt C),of carbon stored in vegetation globally (Brinck et al., 2017). Forest ecosystems harbour 67.3% of the global terrestrial plant species (Huang et al., 2018). They provide essential livelihoods and environmental services and are a key mitigation for climate change (Oldekop et al., 2020).

Tropical forests play a critical role in global climate regulation. Environmental benefits accounts for 28% of income at houshold levels in rural livelihoods 77% of which are associated with natural forests (Angelsen et al., 2014). These benefits notwithstanding we find that global forests has reduced from 4.28 billion hectares to 3.99 billion hectares between 1990 and 2015 (Moon and Solomon, 2019). The deforestation rates in Africa are observed to be five times the global average. (Bowker et al., 2017). These losses attributed to demands for timber and fuel, and conversion of forest to pasture and agriculture (Bowker et al., 2017). Tropical deforestation contributes significantly to increases in anthropogenic atmospheric CO_2 concentration that may lead to global warming (Jhariya et al., 2014).

The Mau Forest Complex (MFC), in Kenya is considered one of the major water towers and therefore a key ecosystem supporting functions of fauna and flora regulation, climate regulation as well as carbon sequestration. Mau Forest Complex is one of Kenya's top five major water towers: The Aberdares, Mt. Elgon, Cherengani Hills, Mau Forest Complex and Mt. Kenya. Water towers are vital national assets that provide; water storage, groundwater recharge, control of soil erosion, river flow regulation, flood mitigation, water purification, and reduced siltation of water bodies, nutrients cycling and soil formation, conservation of biodiversity, climate regulation, carbon storage, and sequestration (Mwangi et al., 2020) The water tower has been faced with several changes that have led to destruction and losses emanating from deforestation to pave way livelihoods related to agriculture, pastoralism, charcoal and fuel trade among others.

Several conversions have taken place in the Mau since 1990 for either settlement through excisions, tea farms or other agricultural ventures as well as logging for timber and charcoal firewood (Force, 2009). The consequential effect of land conversions is that the sequestration capacity of the forest is reduced. Even with the best restoration efforts, the same sequestration capacity may never be fully restored. Reforestation efforts do not necessarily fully restore forest biomass or carbon sequestration (Gibson et al., 2011).

Carbon Sequestration is the process that enables vegetation to synthesize carbon dioxide in the atmosphere and store this as carbon in form of biomass within their trunks, leaves, branches, and roots. A lot of carbon is also stored in the soils. This attribute enables woody products to act as carbon sinks. A process that enables offsetting sources of carbon dioxide from sources such as: forest fires, deforestation, and fossil fuel emissions, to the atmosphere.

1.3 Problem Statement

The major threats to biodiversity conservation in the MFC are human-related: agriculture, settlement, encroachment, illegal grazing, logging for timber and charcoal production. Poor law enforcement also contribute to the degradation of forest areas and the loss of biodiversity (Mutune, 2018). "An estimate of 50,000 cattle graze in the forest daily (Force, 2009)", making pastoralism and illegal grazing another driver of deforestation and degradation.

Deforestation and degradation through the abstraction of wood, clearing of forests for agriculture and settlement areas and other livelihoods significantly reduce carbon sequestration capacity especially in cases where whole trees have been removed. If left unabated, even with restoration, the environment could be permanently changed and may not be able to sustain human, animal and plant life as we know it. Agricultural expansion though very important to feed the growing populace has been greatly associated with the land conversation of forest area to create more agricultural lands. This has been responsible for forest fragmentation as more and more land is required to increase food production (Chaplin-Kramer et al., 2015). These land conversions have so far been seen to tremendously impact water resources notable from drying boreholes, rivers, and lakes (Gichuhi, 2014). Settlements in such locations are unsustainable in the long run, as water resources are declining very fast and will in the future be unable to support these populations (Mutugi and Kiiru, 2015a).

Further, agricultural practices that encourage full tillage of land, which is practised all over Africa including the MFC, have been known to expose the land to oxidation leading to increased CO_2 being released as the carbon stored within the soil is disturbed through tillage. In the US for instance, current practices where full till is applied release 9.4 Tg of CO_2 while a no till system only releases 2.2 Tg of CO_2 (Bernacchi et al., 2005).

Whereas we have many researchers have been looking at individual components of drivers of deforestation, and/ or land cover conversions as separate research areas, there's very little research that addresses how these drivers affect carbon sequestration. This research prioritized bridging this gap in knowledge on the impacts of livelihoods expansion on carbon sequestration within the MFC.

1.4 Research Questions

1. What are the land cover changes that have taken place in the Mau Forest Complex?
2. How has expansion of livelihoods driven land cover changes in the Mau Forest Complex?
3. What are the changes in carbon sequestration as a result of livelihood expansions?

1.5 Hypothesis

It is perceived that the greatest threat to forest conversion in the tropics is agriculture. This has led to deforestation, degradation and forest fragmentation. Forest loss eventually leads to loss in carbon sequestration and biodiversity loss. The hypothesis made for this research therefore is that agricultural as key sector in the economy in Kenya can only provide mutual benefit to the forest ecosystem.

1.6 Aim and Objectives

The main aim of this study was to determine how changes in livelihoods had impacted carbon sequestration in the MFC. The specific objectives were to:

1. Determine the land cover status and changes that have taken place in the MFC between 1990 and 2018.
2. Determine factors driving livelihood expansions to forest areas in the MFC.
3. Determine the carbon sequestration changes resulting from these land conversions.

1.7 Justification of the study

Mau Forest Complex is vital national assets that provides climate regulation, water storage, groundwater recharge, river flow regulation, flood mitigation, control of soil erosion and reduced siltation of water bodies, water purification, conservation of biodiversity, carbon storage and sequestration, nutrients cycling and soil formation (Mwangi et al., 2020). The MFC ecosystem is been significantly threatened by expansion of livelihoods related to agriculture, encroachment, charcoal trading, timber harvesting, pastoralism and illegal grazing among others leading to unsustainable deforestation and degradation of the ecosystem. There's little research that links the impacts of these livelihood activities to carbon sequestration losses, or water quality for instance. These consequential impacts can significantly exacerbate impacts of climate change within this region and downstream to other populations that rely on the MFC ecosystem.

1.8 Significance of the study

There's significant evidence that show human activities have significantly influence weather and climate patterns as shown by increments in hot extremes are being experienced all over the world in figure 1.1 (Ming et al., 2021). In light of the Paris climate agreement to reduce global temp increments to less than 1.5 degrees Celsius, high targets have been set by countries to reduce and maintain this temp target. Increasing carbon sequestration capacity, is a significant mitigation strategy that is being adopted by countries towards this.

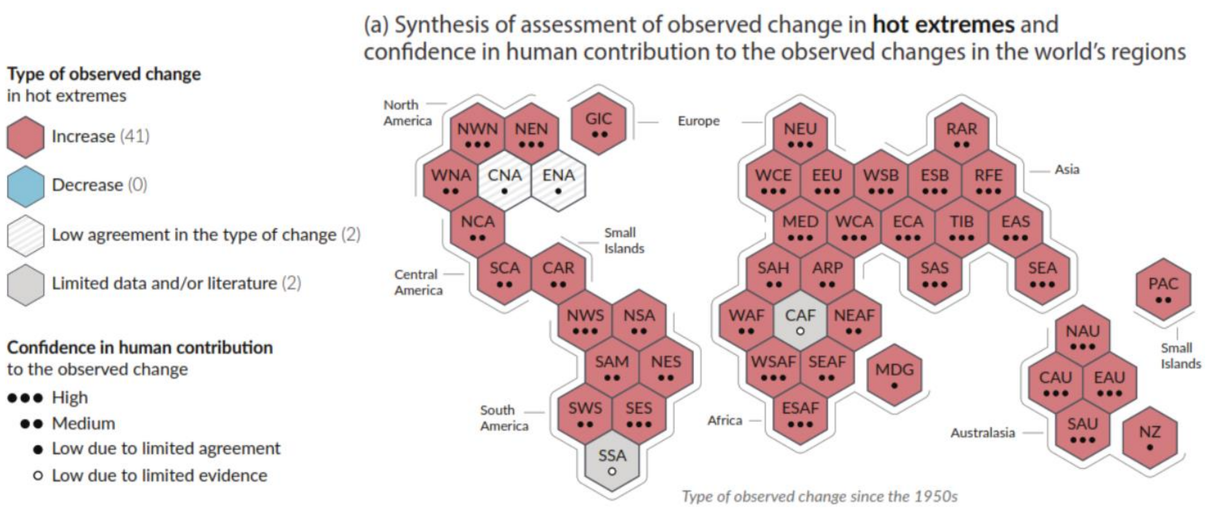


Figure 1.1: Human contributions to Hot Extremes (Source IPCC AR6)

Further, SDG 15.2 whose main target is "to promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally by 2020" puts a high target on countries to ensure that they manage their forests sustainably. This will not only guarantee the preservation of biodiversity but also increase carbon sequestration capacity thereby reducing the effects of climate change (UN, 2015).

1.9 Scope of Research

This research looked at two main themes: carbon sequestration and livelihoods. The main theme being carbon sequestration and how these have been impacted by expansion of livelihoods emanating from land conversions within and around Mau Forest Complex (MFC) between 1990 and 2018. Livelihoods addressed by the study were: agriculture (tea farming, and subsistence crops farming), pastoralism, firewood abstraction, charcoal burning, and timber harvesting. Albeit the situation in Mau has been experienced by other water towers and forest ecosystems this research limited its study area to the MFC mostly because of time and resource constraints.

1.10 Overview of the Methodological Approach

This study applied qualitative and quantitative methods in achieving its objectives. The qualitative and quantitative methods were applied in determining the factors driving the expansion of existing livelihoods into forest land: agriculture (both cropping and livestock keeping), firewood abstraction, charcoal burning, and timber harvesting were determined through literature review, survey questionnaires, interviews with key informants and a focused group discussion as the key drivers.

Quantitative methods were applied in making an analysis of how much carbon sequestration was lost over time due to the land conversions taking place as a result of livelihood expansions. Earth observation data was used considerably well in monitoring above ground biomass/ carbon sequestration (Stringer et al., 2012). A basis for which land cover data derived from Landsat data was considered for this study to determine land cover conversions that had taken place from 1990 to 2018. Land cover data was used in determining forest areas lost to other livelihoods such as agriculture, deforestation, and degradation due to timber harvesting and charcoal burning. Land cover data are intervention tools that help managers better understand, measure and manage their landscapes. To realize landscape changes over different time spaces, land cover data for several years are needed. Land cover was determined through analysis of satellite data (Baldyga et al., 2008). Information gained from such data can be utilized to gauge management decisions made in the past and guide management decisions for the future. ALU software, which is a GHG accounting tool was used in computing sequestration gains and losses across changing land covers. Nationally, the Kenya Forest Service has been utilizing land cover maps developed for Kenya in different time periods to determine prioritization of reforestation measures as well as the development of National Forest Reference Emissions Level used in measurements and verification of Reduced Emissions from Deforestation and Degradation activities (REDD).

The interlinkage between forest coverage and carbon sequestration is one that is rather direct with forest being one of the CO_2 sequestrants besides soils and the oceans thereby providing a key role in climate regulation. This, therefore, means that the relationship between carbon sequestration capabilities and forestry one that is directly correlated. Current approaches used in predicting the impacts of agricultural expansions require that total land area converted is assessed against impacts on biodiversity per unit area. This generally assumes a linear relationship between impacts and land area (Chaplin-Kramer et al., 2015).

Chapter 2. Literature Review

2.1 Introduction

This chapter reviewed literature on different livelihoods and their impacts of the forest ecosystem starting from a global and regional perspective to a local perspective of what is happening specifically to the Mau Forest Complex and the livelihoods involved. It looked at the effects on land use changes on carbon sequestration either in increasing the carbon emissions or in accumulation of carbon pools. These land uses were also assessed in terms of how they affected the forest cover and finally emphasizing that replanted forests (secondary forests) more often than not, do not have same sequestration capacity as primary forests.

Forests play a significant role in carbon sequestration but they can also contribute to increased carbon emissions. They contribute to increasing carbon emissions when tree(s) whole/ parts are burnt/ or when forest fires occur, to emit carbon dioxide (CO_2) and non-CO2 emissions i.e., carbon monoxide (CO), nitrogen oxides and methane or when they decay (dead wood) like all living organisms, the decay process releases carbon dioxide into the atmosphere hence increasing the carbon emissions. Further, a reduction in carbon sequestration capacity, means that the ecosystem has less sink capacity for removals, and thus will have higher accounts of carbon emissions being reported.

2.2 Impacts of Agriculture and other livelihoods on deforestation and carbon sequestration from a Global and Regional perspective

It is estimated that globally in the next 40 years, growth in agricultural land could reach between 200 and 300 million ha (Chaplin-Kramer et al., 2015), most of which will be in Sub-Saharan Africa and Latin America. Studies done on the effects of agricultural expansion on carbon storage noted that forest fragmentation had a strong effect on carbon storage, and a conversion of 10% of forest land lost could lead to 50% of carbon storage loss (Chaplin-Kramer et al., 2015). Agriculture was estimated to account for 90% deforestation in the tropical forests according to (James, 2006). This was attributed to the fact that forest land was considered to be fertile for agriculture, much like a good dose of fertilizer within the tropics. The dependence on ‘natural’ fertilizer (natural system for fertility restoration) in the tropics was preferred due to unavailability and high costs of mineral fertilizers. So then farmers continued to clear more forests for agriculture as their lands productivity decline (James, 2006).

Tropical forests within Brazil Legal Amazon recorded deforestation on 18.9 million hectares in just six years, between 2000 and 2006. A loss also resultant of livelihood expansions, attributed to global demand for soybean oil, soybean meal especially in China, and the majority to pasture for cattle (Barona et al., 2010). In Sub-Saharan Africa, 80% of the population relied on charcoal as their source of energy, this made charcoal trade a major source of livelihood especially within the rural populations (Zulu and Richardson, 2013). The Guinea Rain Forest had reduced to 113,000 Km^2, which was 18% of its original size due to the expansion of smallholder agriculture. On the contrary, harvested area of Cocoa, Oil Palm and Cassava increased to 68,000 Km^2 (Gockowski and Sonwa, 2011). In study done on tropical forests for the period 2010-2014, it was noted that expansion of agriculture and tree plantations into forests contributed to emissions of approximately 2.6 gigatonnes carbon dioxide per year (Pendrill et al., 2019)..

2.3 Effects of Livelihoods on the Ecosystems of Mau Forest Complex

Majority of the communities living around the Mau Forest Complex depend of Agriculture (85%), livestock keeping (14%) and forest resources (Charcoal, Timber, Herbs, Honey) as their main source of livelihood (Kong'ani, 2016). Mau Forest Complex, a major source of water in Kenya, had experienced a 32% decrease in forest cover and a 203% increase in agriculture in the Mara River Basin just between 1973 and 2000 (Masese et al., 2012).

The original inhabitants of the MFC the Ogieks were hunters and gathers, and had a very symbiotic and balanced relationship with the forest hardly causing any significant alteration in coverage. The migrant communities, however, now practiced farming and settlement had been observed to be overexploiting the forest for its resources (Masese et al., 2012). This had led to degradation and deforestation and affected water recharge both in quality and quantity. Destruction of the forest had led to decreased water volumes and levels in the rivers and lakes that depend on it (Mutugi and Kiiru, 2015a). In 2015, Lake Nakuru had decreased in area by close to 100m radius due to the decreased water levels in the perennial rivers feeding it that come from the MFC. The hydro plant on Sondu Miriu river had also been affected by decreased water levels (Mutugi and Kiiru, 2015b).

Research done in 2014 by indicated that local communities living around the MFC also depend on the forest for firewood, charcoal, timber, medicinal herbs, and fodder for animals. She noted that 105 kg of firewood was collected from the forest every week, timber harvesting was at 4.9 cf/year, 3.99 kgs of honey per week, 65.7 kgs of fodder per week and 5 sacks of other farm products are collected every week (Chepngeno, 2014).

2.4 Effects of Land Use Changes on Carbon sequestration

A study done in SOC in agroforestry systems indicated that SOC decreased from 26 to 24 in a land use change from forest to agroforestry; while a transition from agriculture to agroforestry, SOC in increases from 26 to 40, while conversions from grassland to agroforestry only show SOC increments from 9 to 10 (De Stefano and Jacobson, 2018). A separate study done in 2016 for Nigeria indicated that 50% of Soil Organic Carbon (SOC) was found at depth of 0-30cm. As land conversions take place and more of the top is removed or depleted, then a significant part of SOC is lost (Akpa et al., 2016). A meta-analysis done in tropics showed that the highest losses of Soil Organic Carbon (SOC) was due to land conversions from primary forest into croplands, -25% SOC lost when converted to perennial croplands and -30% SOC lost when converted to annual croplands. The study noted that conversions of forests to grasslands for instance only led to a 12% decrease in SOC. It further determined that secondary forests stored less SOC than primary forests (Don et al., 2011).

On the other hand, Above ground biomass (AGB) stores were accumulated in woody stocks, branches and leaves over time and they determined carbon accumulation from primary production. The net balance of the carbon is highly influenced by disturbances that result in carbon losses such as human use, land use change, fire, and mortality. AGB plays a vital role in livelihood activities of this research’s interest such as pastoralism, fuelwood, timber harvesting, and charcoal production (Stringer et al., 2012). AGB is affected by direct human influences such charcoal harvesting as was experienced in the MFC, a number one cause of both degradation and deforestation is smallholder agriculture that causes deforestation and fragmentation of the forest also experienced in the MFC. These disturbances contribute to a reduction in both AGB and Soil Organic Carbon (SOC) (Stringer et al., 2012).

The key to realizing local and global benefits in tropical agriculture would be significantly achieved through agricultural intensification, change of farming practices to include improved fallow management; reduction of cropland area while at the same time ensuring much more intensified agricultural production; adoption of agroforestry systems at national and local levels; shift of cropping practices such as expansion of fallow land to restore lost soil carbon; reduction in rates of deforestation and land use conversions of forest lands in general; diversification of forest species composition; diversification of livelihoods and proper valuation of ecosystem services to ensure maximum benefits to the communities that rely on them (Albrecht and Kandji, 2003).

Agroforestry systems through Climate Smart Agriculture and reforestation were viable options for restoring lost carbon due to deforestations. However, it’s worth noting that these measures do not have the same sequestration potential as primary forests. Alternative energy sources such as renewable energy would also reduce the dependencies of firewood and charcoal wood.

2.5 Livelihood Impacts on Forest Cover

A study conducted in 2014 on the forest clearing in rural livelihoods, indicated that in the case for Africa, 78.8 % of cleared forest land was used for croplands, 2% was used for pasture, 1.3 % was left non cultivated and only 17.3% was replanted (Babigumira et al., 2014). Livelihood impacts such as agricultural expansions on forest cover are summarized as shown in table 2.1 in a study done to indicate how different livelihoods affect forest densities (Sunderlin et al., 2005).

Table 2.1: Different Livelihoods and their Impacts on Forest Cover

Table 2.1: Different Livelihoods and their Impacts on Forest Cover				
Livelihood type	Associated attributes of forest use			
	Main Forest use	*Forest Use*	*Derived Value from usage*	*Income value as derived from Forest use*

A. Hunting and gathering	Food and Medicinal plants: This was done through collection of forest resources.	High	Use Value: High Exchange Value: Low	High
B. Fallow Farming	Restoration of Agricultural lands Creates market centres for forest products	Medium	Use Value: Medium Exchange Value: Medium	Medium
C. Agricultural encroachment in the forest outskirts	Creation of new agricultural lands Creation of market centres for forest products	Low	Use Value: Low Exchange Value: High	Low

The sustainable use of forest resources became very key especially at a time when the whole globe is struggling with issues of climate change due to anthropogenic greenhouse gases. Unsustainable use of the forest meant that much of the carbon sinks created by forestry would be lost. This, therefore, meant that the existence and expansions of livelihoods should not be done at the expense of forest systems.

2.6 Research Gap

Several research studies on the Mau Forest Complex have looked at the land use land cover changes taking place, the political effects on the social economics, the land degradation effects of the different livelihoods taking place around the complex (Olang and Kundu, 2011, Kweyu et al., 2020, Chaudhry, 2021, OYIEKO, 2021). Most of these studies relied on remote sensing technology to monitor the land cover changes that have taken place either through classification of the landcover on a temporal basis or on proxy indicators such as Normalised Difference Vegetation Index (NDVI). They have also relied on quantitative methods such as household surveys to determine the drivers of land cover changes. But there is very little literature that is available on quantified sequestration losses resulting from degradation and deforestation. Further, land cover change monitoring is a continuous process that needs to be done periodically. The drivers of change could also keep varying from one time to another.

Chapter 3. Study Area and Methods

3.1 Introduction

Chapter three started with a description of the study area based on its physical location, the biophysical properties, the physiography, drainage and the socio-economic, administrative and regulatory framework. The next part of this chapter gave a conceptual framework of this research's focus and what it proposed to achieve. Using a demonstration of factors affecting carbon sequestration with one pathway showing the status quo, and the alternative pathway which brought into perspective the need for intervention measures to deliver better environmental outcomes. Further, the research expounded on the methods it applied to achieve its three objectives coming from desktop studies done, Household surveys and the methods of data analysis. Lastly, it summarized the outputs of each and every objective and the interconnection in a data synthesis section.

3.2 Study Area

3.2.1 Location and Description

The Mau Forest Complex (MFC) is located on the western shoulder of the East African Rift. It lies between the coordinates of: top-left (35^{o} 1' 5.45"E and 0^{o} 18' 23.45"N) and the bottom-right (36^{o} 14' 28"E and 1^{o} 4' 13.89"S). It's considered to be the largest closed-canopy (Forest whose leaves are continuous from tree to tree and are multi-layered) forest ecosystem in Kenya. MFC is the considered to be of the largest remaining closed canopy forest within the Eastern Africa. MFC is also the main catchment area for 5 main lakes: Lake Nakuru, Lake Natron, Lake Turkana, Lake Baringo, and the Trans-boundary Lake Victoria (Olang and Fürst, 2011). The study area location is shown in figure 3.1.

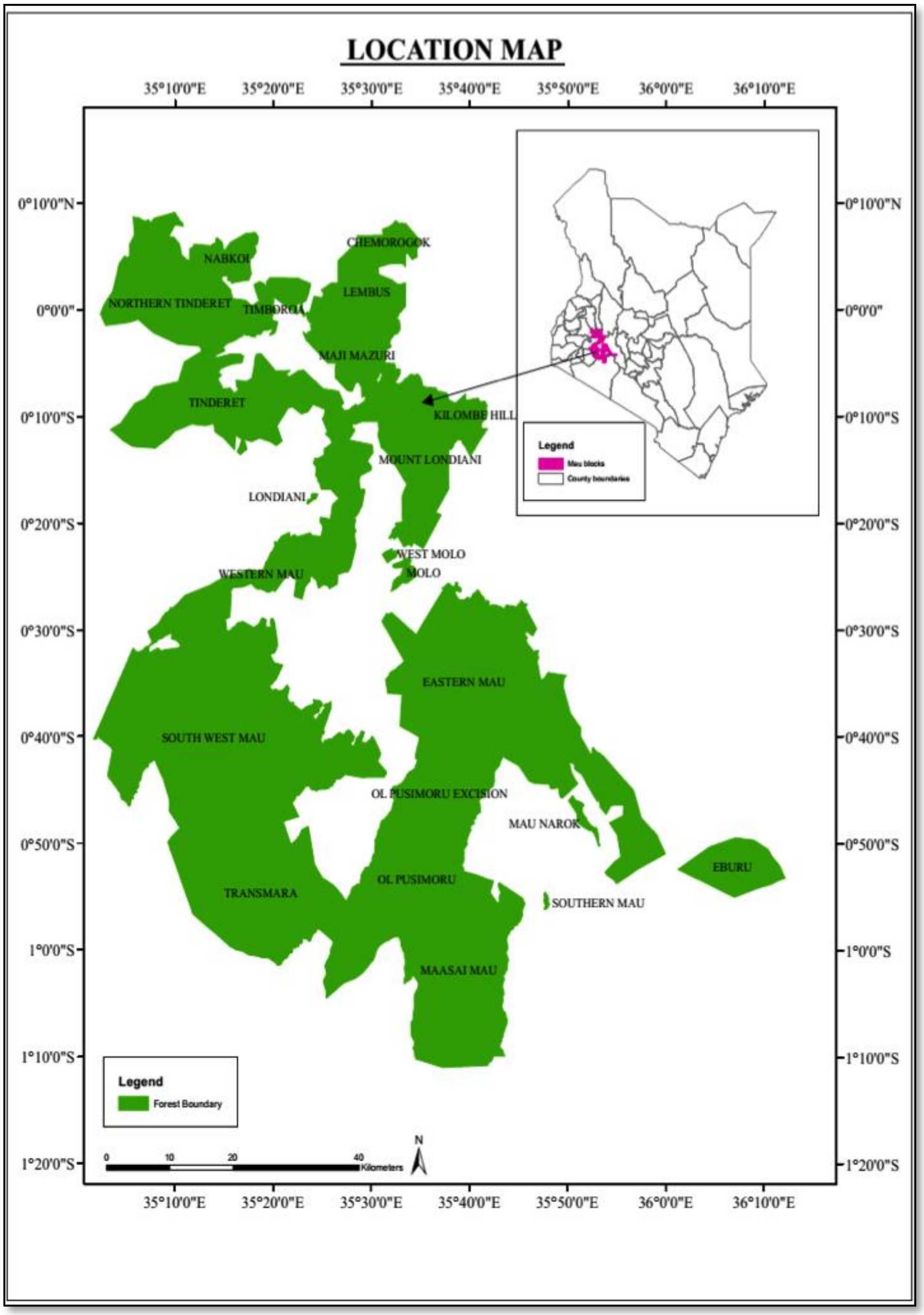


Figure 3.1 Mau Forest Complex (source Kenya Water Towers Agency, 2019)

3.2.2 Biophysical Setting

The climate of the MFC is generally cold to hot and humid weather conditions, with soil temperature ranges from 16˚C to 25˚C and air temperatures ranges from 10˚C to 30˚C. It has mean annual rainfall of 1300 mm experienced during the short rains that occur from November to December and the long rains occurring from April to May. The mean annual rainfall increases with increasing altitude (Rwigi, 2014).

The MFC comprised of diverse flora. At altitudes of below 2,300 meters, vegetation is mostly: grassland vegetation mixed/ bamboo /forest. At higher altitudes, above 2,300 meters, we find the Western Montane forests (Olang and Kundu, 2011). The vegetation around water features such as lakes and rivers are usually a mix of shrubs, dense bush and acacia trees.

Land use changes resultant from increased demand for settlement in the area have led to encroachment of up to 29,000 ha of previous forest areas (GOK, 2009). Former largescale farmland had been fragmented into smallholder farms through subdivision (Olang and Kundu, 2011). In Sebiens (Ngondu) and Wright (Njokerio) the large flower farms, wheat farms and commercial dairy farms had currently been subdivided into subsistence farm plots and grazing plots. This had caused a lot of land fragmentation (Olang and Kundu, 2011).

There are 8 conservation areas linked to the MFC (South Turkana National Reserve with a scenic landscape, Lake Baringo which is an important bird area, Lake Nakuru, a Ramsar site since 1990, Lake Natron, the main breeding grounds for flamingos in East Africa, Maasai Mara, famous for the great wild beast migration, Serengeti National Park, a world heritage site and Kakamega Forest National Reserve which is the last remaining portion of the Guineo-Congolian forest ecosystem) and provide employment for at least 400,000 people in the informal sector and 6000 in the informal sector (GOK, 2009).

MFC also provided other invaluable ecosystem services such as water storage, river flow regulation, flood mitigation, groundwater recharge, control of soil erosion and reduced siltation of water bodies, water purification, conservation of biodiversity, climate regulation, carbon storage, and sequestration, nutrients cycling and soil formation (Lambrechts et al., 2003, Mwangi et al., 2020).

The MFC lies between altitudes 2,000m and 2,600m above the sea level, on the western slope of the Mau Escarpment. The slopes range from 2% in the plains to more than 30% in the foothills (Olang and Kundu, 2011). MFC is the main catchment area for 12 rivers: Njoro, Sondu, Molo, Nderit, Naishi, Kerio, Ewaso Nyiro, Mara, Nyando, Yala, Makalia, and Nzoia that drain into five major lakes: Baringo, Turkana, Natron, Nakuru, and the Trans-boundary

Victoria (Olang and Kundu, 2011). Most of its water is received from rainfall that gets to serve the rivers and lakes in its catchment. The major physiography of the forest complex, figure 3.2, comprise of the escarpments, hills, rolling land and plains.

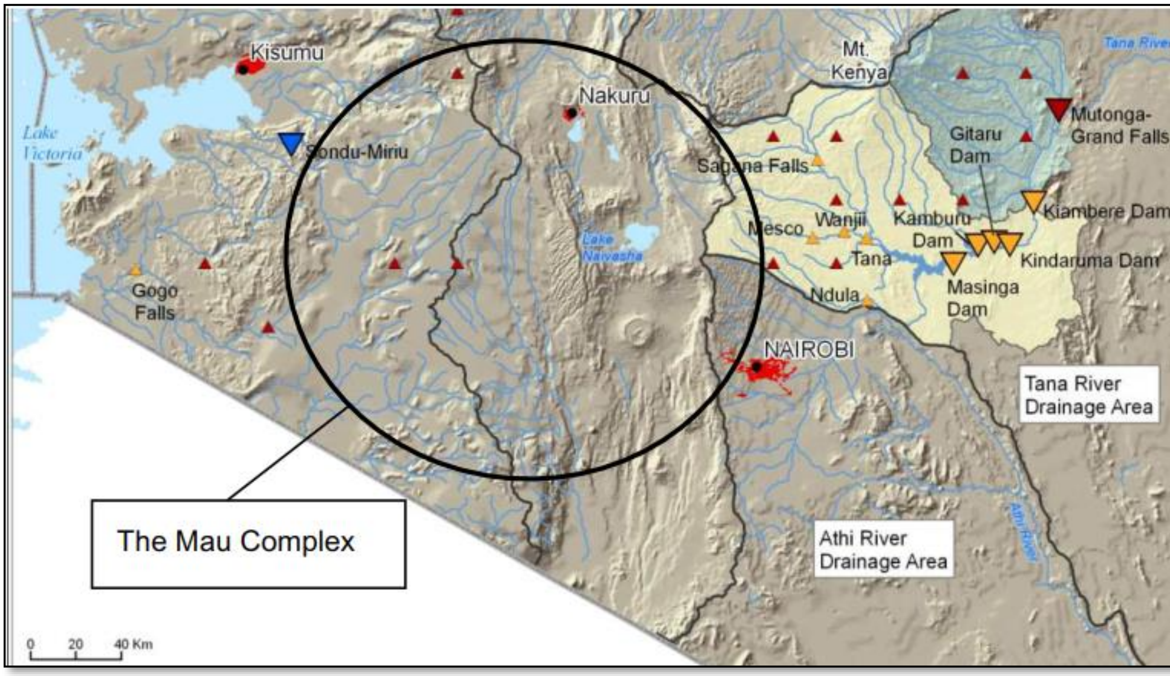


Figure 3.2: Mau Forest Complex Physiography and Drainage- source, (Wallis, 2008)

Biophysical vulnerabilities of the MFC are mostly anthropogenic due to the human activities in the area. Illegal abstraction of forests leading to deforestation, fragmentation, and loss of biodiversity. Encroachments of the forest areas by unplanned settlements. Excisions that have contributed to a 25% loss of forest area (Force, 2009).

3.2.3 Socio-Economic Setting

The Ogiek community is scattered around the MFC though there have been recommendations to resettle them in alternative locations to secure long-term biodiversity conservation. The 2001 excision by the Kenyan government tried to achieve this purpose mostly for the resettlement of the Ogiek and victims of the 1990 clashes. The Ogieks are documented to be hunters and gatherers. The Maasai community who are mostly livestock herders (pastoralists) occupy the Maasai Mau Trust lands.

The MFC provides a microclimate that enables tea farming to thrive in the area. The tea sector provides 50,000 jobs and the livelihoods of 75,000 small holder farmers, together with supporting 645,000 dependants (Force, 2009). Market value of the tea and tourism sector is about Kshs. 20 billion annually (TIONY, 2016). Additionally, rivers flowing from the MFC through 478 sub- locations and a population of at 5.5 million people, is able to support other subsistence agriculture including livestock (GOK, 2009). Rice production which is also supported by the MFC catchment areas brings in about Kshs. 1 billion annually (GOK, 2009).

The river catchments of the MFC are a lifeblood to major conservancies that are tourist destinations such as the Lake Nakuru National Park and the Maasai Mara National Reserve. In 2007, revenues from park fees in Maasai Mara and Lake Nakuru National parks were Kshs. 650 and Kshs. 513 million respectively not to mention the other conservancies that equally collect revenue (GOK, 2009).

The economic benefit of the energy hydro-energy potential of the MFC and its catchment is estimated at 500 megawatts, an amount equal to 40% of installed electricity capacity in Kenya by 2016 (TIONY, 2016). People living at a 5 km radius of the of the forest boundary are also able to practice other forms of livelihoods such as pastoralism, medicine extraction and charcoal harvesting (GOK, 2009). Economic value derived from different livelihoods is more than Kshs 20 Billion annually (TIONY, 2016), water supply to its environments in both rural and urban areas not included.

Overexploitation of forest resources and unplanned settlements puts the economic dependencies and the biological diversity at risk in the long term. This is even more aggravated since alternative livelihoods have not been provided. There's also need to actively involve the community in developing solutions for the forest conservation and restoration. Further, the need to have value-addition services to the forest products will lead to more economic benefits with much lessor extraction.

3.2.4 Administrative context:

Legal boundaries in 22 blocks of the forest reserves exist and are properly described. However, boundaries of the blocks affected by the 2001 excisions have not been determined.

There's a lack of harmonization of records between what is preserved by the Kenya Forest Service and records held by the Survey of Kenya. The 22 forest blocks are yet to be surveyed or issued with Land title deeds. Additionally, some of the trust lands, Maasai Mau Trust land had not been gazetted. Further to this84% of the boundaries on the northern blocks are visible on the ground whereas 57% of the boundaries on the Southern blocks are visible, an effect of the 2001 excision (Force, 2009).

3.2.5 Regulatory Framework:

Environmental Management and Co-ordination Act, No. 8 (EMCA) which was enacted 1999 but effected from January 14, 2000, is an overhaul of varying environmental legislation and provisions that impact on conservation and management of forests. One of the requirements of EMCA is that any change in land use should be subjected to an Environmental Impact Assessment (EIA) to ensure that there is sufficient scientific consideration of the social, economic and ecological implications. If EMCA was to be implemented in its entirety then we can be guaranteed that biodiversity will be protected. However, flaws and laxity in its implementation occurs, greatly to the community’s detriment (Force, 2009).

Forest Act of 2005, establishing the Kenya Forest Service, gave KFS a mandate over all forests and their protection in the country. The Mau Forests Complex Authority was established to coordinate and oversee the management of the complex. This was done through a board of directors comprising representatives of the main stakeholders, including the economic sectors directly dependent on the goods and services of the Mau Forests Complex (Force, 2009).

3.3 Methodology

3.3.1 Introduction

The methods applied in this research were both qualitative and quantitative. Objective one, sought to determine land cover changes that had taken place between 1990 and 2018 using GIS and remote sensing technology which is a form of quantitative research. This objective determined the land cover changes that had taken place over time for different years.

Objective two sought to determine the drive behind livelihood expansions to forested areas by applying qualitative and quantitative methods. To achieve this objective, a literature review was carried out to understand the existing livelihoods that were likely to affect forestry and carbon sequestration. This was further affirmed through successive household surveys. Survey questionnaires were administered to 200 households around the MFC based on a two-step sampling technique to get their perspective on the kind of livelihoods they practiced and the interaction of these livelihoods with the forest. This objective was also used to determine if sub-national priorities had aided or hindered conservation efforts being done at national level. Five key informant interviews were conducted with the community chief, a representative from Kenya Water Towers Agency, a representative from Kenya Forest service agency. Two representatives from State Department of Agriculture declined to participate in any conversations regarding the MAU forest, for this reason an alternative representative from the county of Nakuru was interviewed, finally one representative from the private sector such as Center for International Forestry Research (CIFOR) that do a lot of research related to forestry. This helped to gain a better understanding of the problems surrounding MFC and the measures that had been taken to solve them. A focused group discussion was also conducted with an integrated group of participants (10 participants mainly small holder farmers, businessmen and livestock keepers) in the community to also get their perspective on the existing livelihoods and how and why they affect forestry and hence carbon sequestration. This study was limited to 1 FGD due to limited resources.

The last objective underpinned both objectives one and two. It sought to determine using quantitative methods, the losses and/or gains related to carbon sequestration resulting from the livelihood expansions to forest land and what this meant for the country as a whole.

3.3.2 The Conceptual Framework

The conceptual framework was adopted from (Abdollahbeigi, 2020) that stipulated that climate change and carbon sequestration is naturally affected by climatic factors such as solar radiation, earth rotation, ocean volatility etc: both historical and the current that inevitably keep changing. Environmental factors such as diseases, insects, landslides, volcanic eruptions etc. also affect carbon sequestration. Environmental factors can result from natural or anthropogenic influences. Human related activities on the ecosystem (anthropogenic factors) also influence carbon sequestration. Livelihood related activities such as uncontrolled settlements and encroachments, overexploitation of forest resources, agricultural expansion into forested areas, lack of enforcement of existing policies etc that lead to deforestation and degradation ultimately influence carbon sequestration. Anthropogenic factors, unlike the other factors (climatic and environmental) that had a slow change response had been seen to be accelerating at unprecedented scales, and influencing both the climatic and the environmental factors. Humans had a role to play in controlling the rate of influence of these anthropogenic factors. If no action was taken, then more and more negative effects on the environment such as forest degradations and deforestation, uncontrolled developments, just to mention will persist. A pathway that fed into the status quo where ecosystem benefits would continue to depreciate, and climate change effects would increasingly lead to loss of livelihoods and lives. This research, however, sought to provide an alternative pathway by determining factors driving livelihood expansions to forested areas and relating this with the subsequent losses in carbon sequestration. Bringing into perspective the impacts of uncontrolled and unsustainable actions on the environment and forest in particular on carbon sequestration. This research provided recommendations that if implemented could lead to better management of forest resources, sound policies, and ultimately with a better ecosystem we could have improved livelihoods, and in essence slow down the rate at which these anthropogenic effects were affecting carbon sequestration. The flowchart of this conceptual framework is captured in figure 3.3.

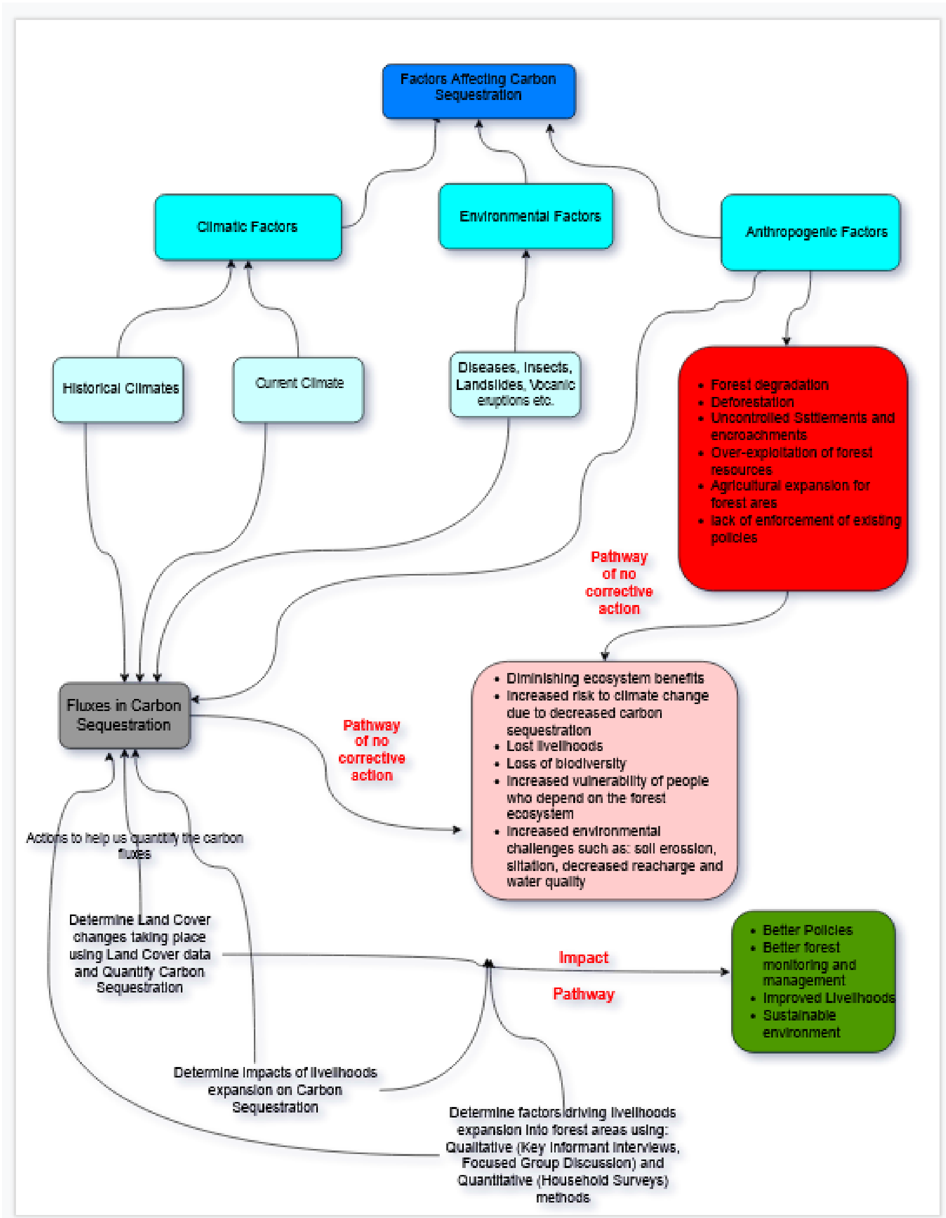


Figure 3.3: The Conceptual Framework showing factors affecting carbon sequestration, the pathway should the status quo remain and the alternative pathway provided by this research.

3.3.3 Objective 1: Land Cover (1990-2018) Development

Desktop studies were done primarily to identify sources of Earth Observation (EO) imagery to be used in the analysis process. Landsat images were used to develop land cover maps for the years 1990, 2000, 2010 and 2018. Landsat images are collected by a joint program of National Aeronautics and Space Administration (NASA) and the United States Geological

Survey (USGS). Their data is available as open data for all users through their open data portal that is hosted and managed by the USGS (https://earthexplorer.usgs.gov/).

GIS and Remote sensing methods were applied to develop land cover data for the years 1990, 2000, 2010 and 2018. The first step: '***Data Acquisition stage***, was to acquire Landsat imagery from the USGS open portal. The images for the study area were selected from path/rows P169R060 and P169R061, based on quality criteria that required the images only for the dry season (Jan-Feb) or (Jul- Aug) within the years 1990, 2000, 2010 and 2018. The images also had minimal cloud cover (10% and below), for this study area, the month of February in each year provided the least clouds. In cases where there were clouds and shadows, additional Landsat images overlapping the cloud and shadows would be required to fill the data gaps. Images that met these criteria were downloaded, one for each representative year.

The '***Pre- Processing stage*** required the downloaded data to be clipped in ArcGIS using the AOI shapefile that is bound to the spatial extents' coordinates indicated in Chapter two, after which all the clouds and shadows were masked from the imagery. NASA provides with each image a single band product labelled '***cfmask***'. This is an automated mask produced during NASA data processing that indicates pixels affected by cloud and shadow. Masking the downloaded Landsat image using the '***cfmask***'enables elimination of all cloud and shadows. This was done in ArcGIS.

The Cloud masked image datasets were reprojected in ArcGIS using the projection tool within Raster tab in ArcGIS. Reprojection required that initial projection (default global datum of WGS 84) is set and the projection parameters for Arc 1960 are set. (The reprojection parameters for Arc 1960 are: - Datum: Arc 1960, Spheroid: Clarke 1880 RGS, UTM Zone: 37s, Scale Factor: 0.99960, and False Easting: 500,0000). This would be done for all the images. Arc 1960 is the datum used by the Kenyan government as recommended by the Survey of Kenya. Reprojection helped in correct placement of imagery to its actual physical location on the ground, it also enabled overlaying of other datasets such as boundary data that were already in this projection system. It applied parameters that minimized distortions that may be present. All this was done in ArcGIS. ArcGIS is a commercial GIS software developed by Esri Inc.

The next step was to correct all images post re-projection for terrain artefacts. Terrain Illumination Correction (TIC) is a process that removes the effect of slope and aspect on images to ensure that we have a consistent digital signal regardless of which sun angle the satellite sensor collected the image from. TIC correction requires a knowledge of the slope and aspect of each pixel (from a Digital Elevation Model (DEM)), and knowledge of the solar position at the time of overpass (from Landsat acquisition data). The SRTM 30m DEM produced by NASA was used. The other data collection parameters such as sun angle are embedded within the Landsat image metadata. TIC was carried out using a closed access python script ***Ter_Correct.Exe***, provided by Commonwealth Scientific and Industrial Research Organisation (CSIRO). After Terrain correction, Reprojection was done again to ensure that the Arc 1960 datum was maintained.

Once the '***Pre-processing stage*** was completed then the images were ready to move into the next phase which is the '***classification Stage***. Note that Quality Assurance (QA) was done at each and every stage. QA checks ensures that the outputs received at every preliminary stage is what is expected. And in case it is not then the process is repeated to check for the sources of errors. Within the 'Pre-processing' stage, an output was developed that mosaicked all the images (P169R060 and P169R061) for the study area to be used for visualization and comparison with the final classification output. Each year would then end up with one Mosaicked image covering the entire study area for the years of interest (1990, 2000, 2010 and 2018). The Mosaicking was done in ArcGIS within the raster tab.

The '***Classification stage*** was done using a remote sensing Software called ENVI. ENVI is a commercial software developed by David Stern, University of Colorado. Classification is the process of assigning a land cover class (or class probability) to each image pixel. This can be automictically generated through unsupervised classification, where we assign number of classes required and a classification model is used to assign the pixels into their most suitable class within the study area. This research used supervised classification that required that development "***Training sites***." Using Envi, similar pixels, based on expert knowledge, were assigned to a training site (Class). The number of Classes used in a study area depends on detail of Land Cover categorization that is required. This research used the Intergovernmental Panel on Climate Change (IPCC) recommended land Cover categories. Once the training sites are collected, the next step was to run the classification using an appropriate classification algorithm that would then assign the remaining pixels to their suitable land cover class. Rand Forest (RF) was the classifier chosen for this research. Random forest is a machine learning algorithm first developed and patented by Leo Breinman and Adele Cutler (Breiman, 2001).

RF fits a large number of separate trees, each to a randomly selected subset of the training data. Each pixel is given a class label from each tree, and the relative frequencies of a pixel's class allocations from the multiple trees are used as measures of classification confidence. The RF runs about 50 iterations (more iterations can be set; this meant more time for the classification process, yet beyond a certain number of iterations once confidence is achieved then more iterations are not required. Tests done revealed that 50 iterations were sufficient to achieve good confidence of classification) until convergence was achieved. Typically, map results are displayed using only the 'most common' class label for each pixel. The confidence measures become important in the subsequent multi-temporal classification processing. The RF procedure also produces summarised indicators of classification accuracy derived from the training data. The classification outputs were then confirmed through a QA process. Once classification satisfaction was achieved, the outputs were mosaicked to form landcover for the area of interest. This process was repeated for all the years (1990, 2000, 2010 and 2018) of interest.

The next stage which is the '***Validation stage*** utilized randomly stratified sample points generated within ArcGIS. These were then loaded in Google Earth pro which is an open-source app developed by Google containing High-Resolution (HR) imagery. The points were interpreted using the imagery to record the land cover category they fall into. A process that is usually referred to by remote sensing experts as ***Reference data collection***. Each point utilized imagery of the dates that corresponded with the land cover imagery date. In this case a set of 4 validation points was collected for the years 1990, 2000, 2010, and 2018. Where no HR images were available then the available low-resolution images were used. There were no HR images available for 1990 for instance. These validation points once interpreted were loaded into ENVI and used against the mosaicked classification outputs to verify the accuracy level of the land cover outputs. The results usually come out in a matrix table showing users accuracy, producers' accuracy, the overall map accuracy and a kappa co-efficient.

Acceptable Overall accuracy for the land cover data is threshold at 75% for good practice in remote sensing (Anderson, 1976). Where:

1. ***Overall accuracy:*** Proportion of the total number of correctly classified pixels
2. ***Kappa coefficient:*** (Measure of chance classification) Probability that the classification results were not arrived at through random assignment of pixels to classes.

Note. The definition of the land cover categories used in the 'classification stage' can be obtained in Appendix A1. These are the land cover definition adopted and used by the national government of Kenya. The IPCC categorization is recommended for purposes or Greenhouse gases reporting and national communications to provide standardization across the globe. It consists of 6 land cover classes: forestland, grassland, cropland, wetland, settlement and otherland. Countries are encouraged to subcategorize the IPCC classes as is appropriate or the national circumstance. Also, note that the settlement category was not classified for this study. The settlement category utilises a separate approach in classification where it is derived from higher resolution imagery and overlaid on the Land cover. Since our study is significantly focused on vegetation, the extra effort for deriving this class was not necessary. A summary of the data analysis steps used in generating the land cover and change data is indicated in figure 3.4.

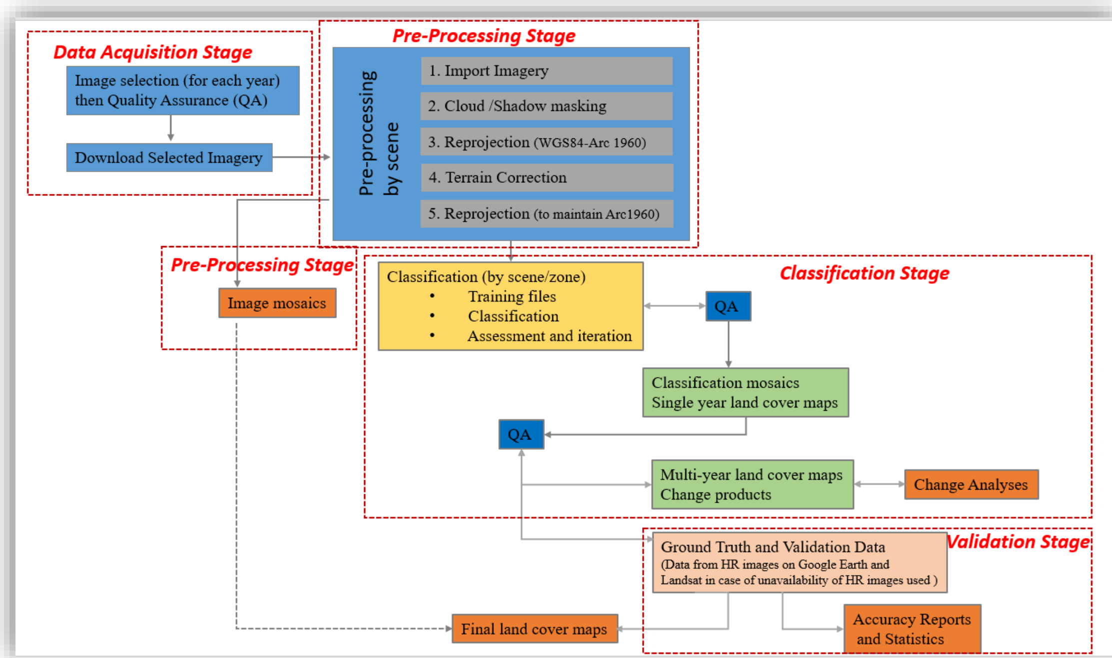


Figure 3.4: Schematic Workflow of processes used in developing the Land Cover Maps

Data Analysis

The land cover changes were determined from the cross tabulation using the raster calculator in ArcGIS for the 1990 and 2018 land cover maps. The outputs from this were further analysed using Excel tables to assess the land cover change dynamics and develop graphs and statistics. Using ArcGIS, different change scenarios were developed into PDF maps to enhance visualization of the changes that needed to be highlighted by this research.

3.3.4 Objective 2: Drivers of Deforestation and Land Conversions in MFC

Literature review was conducted to determine the livelihoods within and around the MFC. These livelihoods were captured in chapter 1 as: farming, pastoralism, charcoal trading, bee keeping just to mention.

Qualitative Research methods: FGD and KII

Qualitative research methods were used to understand the feelings, values, and perceptions that were underling and influenced perceptions of different stakeholders towards livelihood interactions with the forest. A combination of two qualitative research methods i.e., Key Informant Interviews (KIIs) and Focus Group Discussion (FGD) were used address inherent limitations associated with application of single methodologies and hence obtain relevant information necessary for making value-added recommendations.

Key Informant Interviews (KIIs)

Key Informant Interviews involved one-on-one interviews with people that were conversant and worked on issues of the Mau and/or interact with the communities within Mau or had lived and were aware of the history of the forest. The aim was to obtain in-depth perspective on their level of engagement with the study area using the KII guide provided in Appendix: A4-. These stakeholders provided critical information with regards to their perceptions about MFC particularly between 1990 and 2018. Five KII were conducted with respondents from: community chief, representative from Kenya Water Towers Agency, representative from Kenya Forest service agency, representative from the County of Nakuru and finally one representative from the private sector such as CIFOR. It was also anticipated to get opinions from the State department of Agriculture but the two participants declined to comment on the subject.

Data collected was in the form of opinions, perceptions, experiences and recommendations that were both quantifiable and qualifiable. The KII adopted the approach stipulated in figure 3.5.

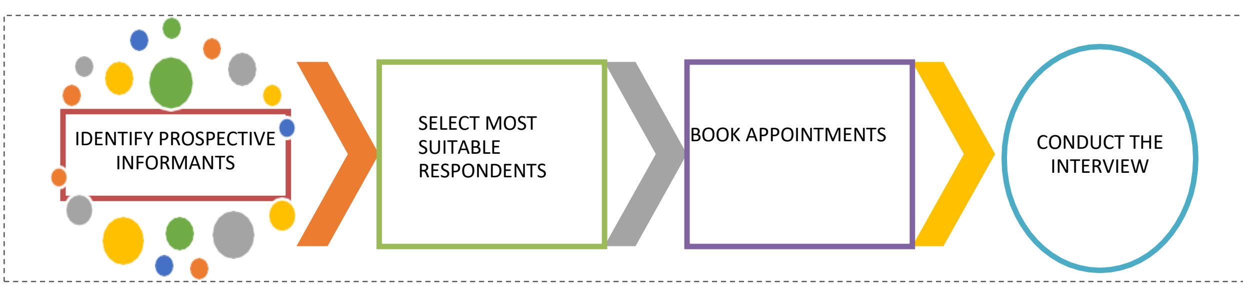


Figure 3.5: KII Approach

Focus Group Discussion (FGD)

Focus Group Discussion is an interactive discussion led by a moderator to discuss a given topic. The main purpose of the FGD in this study was to determine respondents' attitudes, feelings, beliefs, experiences and reactions in a way that would not be feasible using other research methods.

Compared to individual interviews, which an individual's opinions, attitudes and feelings, focus groups elicit a multiplicity of views and emotional processes. The target group for the FGD was Mau area residents drawn from the general public that engaged in the livelihoods (farmers, pastoralists, beekeepers, charcoal traders) that interact with forestry. This allowed this research to get views and perceptions of the target group towards the existing livelihoods and their interactions with forestry.

A FGD was conducted with 10 participants from Molo, on the 13th July, 2019 at Green Garden lodge. Information obtained from this approach was triangulated with the both KIIs and Household survey findings.

Selection for the FGD

The following steps were followed: -

Step 1: Designing recruitment questionnaire

Guided by this research's objectives, a recruitment questionnaire was developed. The recruitment questionnaire was primarily based on gender inclusivity, age (to have knowledge of the forest history), occupations that interact with forestry (farmers, pastoralists, scientists, community leaders, hunters and gatherers, charcoal traders etc.) and willingness to participate in the FGD.

Step 2: Identifying the study sampling points

Community chiefs and relevant authorities were consulted to guide in selecting an appropriate location for the FGD. Molo Centre was identified as a central location by most of the chiefs consulted.

Step 3: Recruitment

Recruitment was done at the household level using the left hand rule and a skip pattern of 5 houses (Cochran, 2007). The research team randomly recruited participants for the FGD using a screening guide to ensure that the right group was recruited for participation. During the recruitment process, contact details of the respondents were collected for making follow ups.

Step 4: FGD Session

During the FGD session, a guide was used (Appendix A3). It comprised of predominantly open ended, deep-probing questions that kept the respondents most engaged. Ten FGD respondents had been recruited, for ease of control (when the group becomes too big it becomes difficult to manage) and budgetary constraints. Group dynamics were checked to minimize any form of bias due to dominance. The group setting was arranged to allow for free roundtable discussion for about two hours. This discussion was recorded on a Dictaphone for transcription and referencing.

Quantitative Research methods: Household Surveys

Household surveys were used to measure the extent of respondent responses and allowed for the data collected to be analysed quantitatively. Face to face interviews were applied since they are more effective than other data collection methods (such as calls or email responses). Targeted participants were visited in their household and sampling was done based on a two-stage sampling technique. In stage 1, the minimum sample count was identified based on Cochran's formula in Eq. 3.1 while in stage 2, a proportional distribution of the samples was drawn to ensure all age brackets were represented.

A semi-structured questionnaire that can be referenced from Appendix A2 was used through the aid of the smart phone-based kobo toolbox. Kobo toolbox is an open-source software application developed by the Harvard Humanitarian Initiative (Evrendilek et al., 2004). It can be installed on any smart phone. Kobo toolbox enables you to transcribe interview questions and generate forms for data collection. It automatically and immediately submits data collected via SSL (Secure Socket Layer where there's continuous internet connectivity, alternatively, offline collection can be done and submitted to the database later on when internet can be accessed. It analyses, manages data collected and generates reports based on feedback from the field. Further it has geocoding ability making it possible to view, from a centralized place, the location of data collection.

Sampling

A two-stage sampling technique was used, which ensured that every eligible respondent had an equal chance of being selected.

Stage 1: Stratification of target respondents

In this stage, the minimum size of the target respondents was identified using Equation 3.1 through which a sample of **200** respondents was drawn.

$$n = \frac{z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2}$$

Equation 3.1: Equation for determining the sample size (Cochran formula)

Where

- **Z** is the z score (95% confidence Interval for a level of confidence of 95%, z = 1.96)
- **ε** is the margin of error (**7%** is used due to budgetary constraints normally 5% error is preferable but this would have doubled our sample size)
- **n** is population size (196)
- **p̂** is the population proportion (a Variance of 50% is used when unknown we use **p̂** = 0.5)

Normally a margin of error of ±5% at 95% confidence level is acceptable based on industry standards, ±7% also within acceptable standards was used in our study to minimize sample size that was within the projects budget. For our study area the minimum **n** value is ***196*** with a 95%confidence interval, I rounded to the nearest hundred and worked with **200** samples instead.

Stage 2: Sampling by category

This stage involved proportional distribution of the proposed sample to the different age brackets.

Systematic Sampling method

Selection of the S_{hi} *s*ampled household can be expressed through Equation 3.2;

$$S_{hi} = R_h + [I_h \times (I-1)] \text{ for } I = 1, 2, 3, 4, \ldots\ldots\ldots\ldots\ldots\ldots, n_h \quad \textit{where}$$

Equation 3.2: Systematic Sampling method

- S_{hi} = Section of the *h*th household
- Rh= Random start of strata
- Ih = sampling interval for households (calculated based on the target sample and the total population)

Quantitative survey is the most appropriate method in situations where the survey objective is to cover a large number of cases. Here, the objective was to cover a sample that was representative of the universe/ random population. The survey is also the most appropriate design applied in situations where there is need to collect a lot of information that can be used to increase the understanding of a given situation as well as for generalization purposes. Quantitative method is advantageous as it allows for the comprehensive accumulation and aggregation of statistical data that is easy to analyse and interpret. The statistical representation allows for segmentation and sub cluster analysis of the data collected.

Household survey for this research was conducted between 9th and 18th July 2019 with the communities around the Mau Forest Complex. The exact locations for where the 200 households' surveys were to be collected was further segmented based on wards (the smallest administrative units in that area) that had experienced the highest deforest incidences. This led us to designate the 8 wards as the data collection points. The allocation of the number of surveys in each of the 8 priority wards was assigned based on the size of ward as a fraction of the required sample count of 200. The allocations in each ward was as indicated: Kuresoi (20 interviews), Molo (40 interviews), Subukia (21 interviews), Eldoret South (20 interviews), Narok North (39 interviews), Narok South (20 interviews), Eldama Ravine (20 interviews) and Kipkelion (20 interviews). The guiding questions in Appendix A2 were administered to the selected participants in the wards. Figure 3.6 shows a map of locations and number of interviews in each location and figure 3.7 a detailed spatial image of the data collected in Molo town.

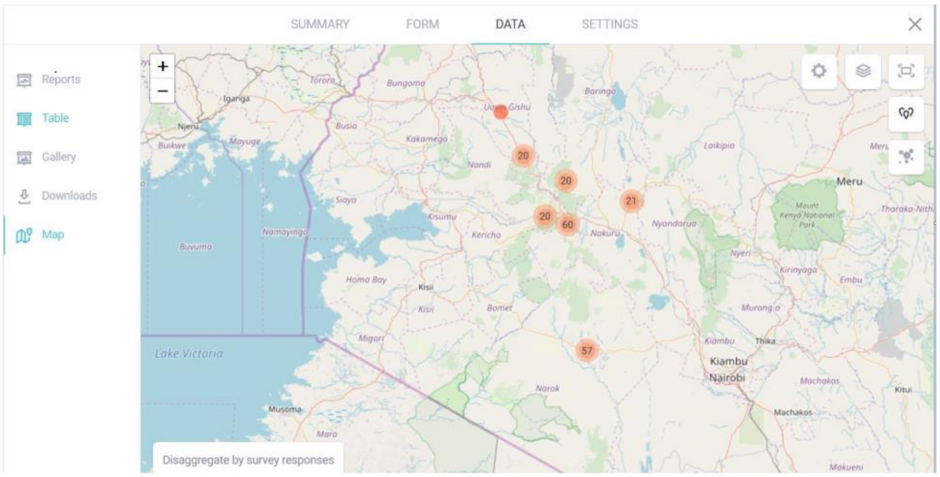


Figure 3.6: Picture showing survey locations and the number of surveys within these locations: Kuresoi (20), Molo (40), Subukia (21), Eldoret South (20), Narok North (39), Narok South (20), Eldama Ravine (20) and Kipkelion (20)

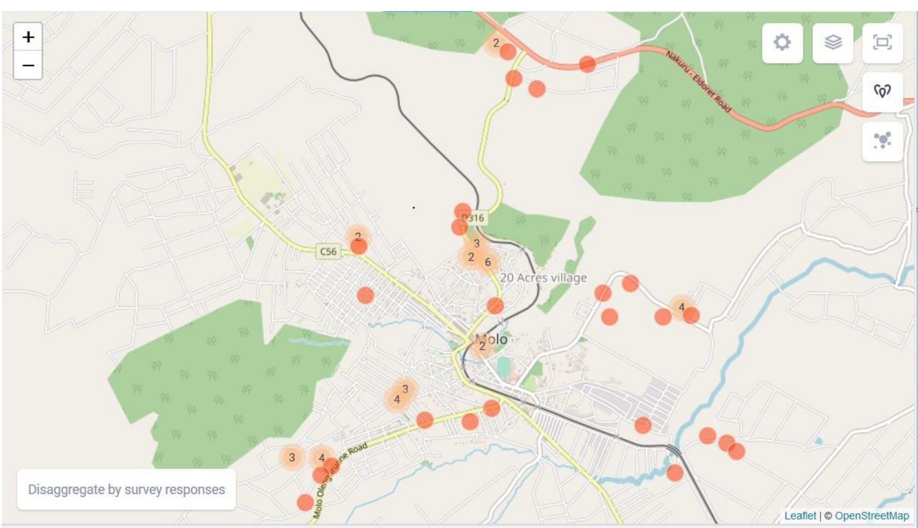


Figure 3.7: Expanded Picture showing the distribution of survey participants (orange dots) within Molo Location

Data Analysis

The transcribed data from the KII and the FGD was thematically analysed and the key findings used for this research.

The Household surveys were analysed using Microsoft Excel, frequency and trend analyses for all variables was conducted and clustered based on proposed perception themes. A deeper exploration of key findings was done by disaggregating the gender and age. These disaggregated data was visualized using clustered bar charts for comparisons between overall distributions, geographic distributions, and gender and age-group distributions.

3.3.5 Objective 3: Quantification of Carbon Sequestration

Agriculture and Use tool (ALU) for GHG Inventory accounting was used in determining the carbon sequestration gains and losses between 1990 and 2018. The ALU software is an open-source software developed by Colorado State University, Natural Resource Ecology Laboratory to calculate for GHG emissions from the Agriculture, Forestry and Land use Sector (https://www.nrel.colostate.edu/projects/alusoftware/home). It was built based on the IPCC (Intergovernmental Panel on Climate Change) 2006 and IPCC 2013 guidelines for GHG accounting and continues to be updated whenever new updates are required either to remove bugs within the software or take into consideration new accounting guidelines being provided by the IPCC. The software is able to generate reports, conduct quality assurance and enable mitigation actions to be accounted for in the calculations as well. It requires data in three stages: the primary data which primarily was a record of land cover transitions obtained using analysis of data in Objective ne (activity data), secondary data which was a record of disturbances, land management practices, the maturity stage or age of vegetation and residue management, and finally the emission factors.

Data Analysis

GIS and Remote sensing methods and ALU GHG software was used in computing the Carbon sequestration fluxes between 1990 and 2018. Figure 3.8 shows an image of the ALU software.

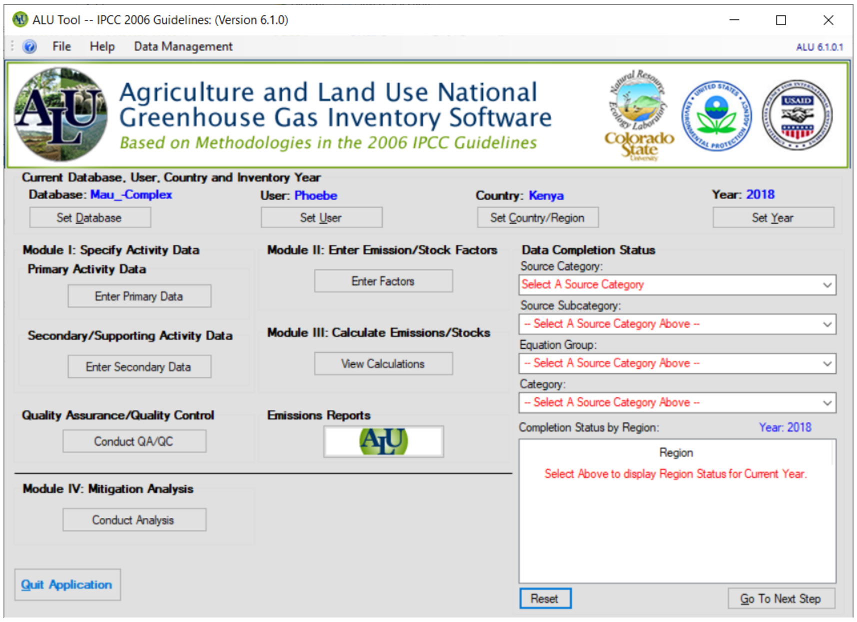


Figure 3.8: ALU GHG Inventory Software developed by Colorado State University, Natural Resource Ecology Laboratory

For the carbon sequestration losses/gains estimations activity data (primary activity data) from land cover transitions was required, the change matrix was used to derive the primary data. Other datasets required included: climate type (the study area was entirely within the tropical montane), ecological zone (the study area was entirely within the tropical mountain system) both obtained from the IPCC portal (http://www.ipcc-data.org/). Soil data was obtained from the Harmonised World Soil Database (HWSD). The area of study is covered by three soil types: high activity clay- 27%, low activity clay- 49% and volcanic mineral- 39%). Different soil types contain varied Soil Organic carbon. The HWSD data enables us to track the appropriate SOC associated with each soil type. The spatial location of these was intersected with the land cover change data in a GIS environment. Tier 1 emission factors (Module II) were obtained from IPCC 2006 guidance document (Change, 2006).

For secondary data the following-assumptions were made due to lack of disaggregated data the study area level. This was also informed by expert knowledge:

a) The distribution of land conversions was equivalent to the soil type as derived from HWSD for this region;

b) Annual crops had a maturity of 50% as mature and 50% not mature;

c) The study area had three cropping seasons (based on period required for maturity) in which wheat (4 months), cereals (2-3 months) and maize (2-3 months) were rotated for the entire region;

d) Sequestration losses were calculated based on either gain or losses from 1990 therefore referring to 1990 as the baseline;

e) Perennial cropland had a 50% maturity and that only tea is grown as a perennial crop since this is what could be mapped from remote sensing techniques used in this study;

f) Forest age for the study area was 80% greater than 20years and 20% below or equal to 20% considering that this is mostly natural forest;

g) There were no occurrences of disturbance (fires, or diseases). Note that this is not to infer a lack of occurrence but the data on fire occurrences and the exact areas affected by these fires at this scale was not available;

h) That grassland areas were degraded as 10% showing improvement, 40% being moderate, 40% being degraded and 10% remaining as the nominal;

i) Tillage within cropland areas assumed to have full till, i.e., 100% tillage; and

j) Residue removal is 100%.

The sources/sinks in the land use section used are biomass carbon stocks (AGB and BGB) and Soil Organic Carbon (SOC).

The sources of biomass carbon in this case being, forestland remaining as forestland or land conversions to forestland. This was derived by the below Equation 3.3 and Equation 3.4. Note that gain loss method was in all cases used to derive the change in Biomass Carbon Stocks.

$$dCG = A * Gtot * CF$$

Equation 3.3: Biomass Carbon Stocks due to Forestland

Legend:

Abbreviation	**Description**	**Units**	**Type**
dCG	Annual Increase in Biomass Carbon Stocks	(tonnes C/yr)	Equation Result
A	Forest Area	(ha)	Quantity Value

Gtot	Average Annual Increment in Biomass	(tonnes dm/ha/yr)	Calculated Factor
CF	Carbon Fraction of Dry Matter for Forest Type	(tonnes C/tonnes dm)	Factor Value

And;

Gtot = Gw * (1 + R)

Equation 3.4: Average Annual Increment in Biomass for Forestland

Legend:

Abbreviation	**Description**	**Units**	**Type**
Gtot	Average Annual Increment in Biomass	(tonnes dm/ha/yr)	Equation Result
Gw	Average Annual Above-ground Biomass Growth	(tonnes dm/ha/yr)	Factor Value
R	Ratio Below: Above-ground Biomass (Forest Type)	(tonnes dm/tonnes dm)	Factor Value

The other source of Biomass Carbon Stocks is perennial croplands. This source is determined through the equation 3.5.

dCG = A * G

Equation 3.5: Biomass Carbon Stocks from Perennial Croplands

Legend:

Abbreviation	**Description**	**Units**	**Type**
dCG	Annual Increase in Biomass Carbon Stocks	(tonnes C/yr)	Equation Result
A	Cropland Area	(ha)	Quantity Value
G	Cropland Biomass Carbon Accumulation Rate	(tonnes C/ha/yr)	Factor Value

Soil Organic Carbon was determined through equation 3.6.

$$SOC = A * SOCref * Flu * Fmg(avg) * Fi(avg)$$

Equation 3.6: Determining Soil Organic Carbon

Legend:

Abbreviation	**Description**	**Units**	**Type**
SOC	Mineral Soil Organic C Stock	(tonnes C)	Equation Result
A	Cropland Area	(ha)	Quantity Value
SOCref	Reference Soil Organic C Stock	(tonnes C/ha)	Factor Value
Flu	Soil C Stock Change Factor for Land Use	(index)	Factor Value
Fmg(avg)	Weighted Average Factor for Management Regime	(index)	Calculated Factor
Fi(avg)	Weighted Average Factor for Input	(index)	Calculated Factor

Note that Global warming Potential AR4 (2007) described in table 3.1 was used in calculating the CO_2 equivalents of the sequestration data.

Table 3.1: Global Warming Potential AR4 (2007)

IPCC WG1 AR4 (2007)	
Carbon Dioxide (CO_2)	1
Carbon Monoxide (CO)	0
Methane (CH_4)	25
Nitrogen Oxides (NO_x)	0
Nitrous Oxide (N_2O)	298

Note also that to convert from Carbon Stocks to CO_2 Equivalent equation 3.7 was used.

$$CO_2 \text{ Equivalent} = (\text{Biomass Carbon Stocks} * 44)/12$$

Equation 3.7: Converting Between Biomass carbon and CO_2 Equivalent

The sequestration capacity lost as a result of deforestation was quantified using Equation 3.8

Value	**Formula**
Total area (in Ha) Converted=236,195	=FC Area + FG Area + FO Area+ FW Area (Refer Change Matrix i.e. FC Forest to Cropland, FG Forest to Grassland, FW Forest to Wetland)
Biomass Carbon Stocks Under FF Area (in Ha)	= XX Gg Carbon stock change
Biomass Lost due to Deforestation	$= ((Total\ Area \frac{Coverted}{Total} Area\ of\ Forest\ remaining\ Forest) * Biomass\ Carbon\ Stocks\ in\ FF) - Biomas\ Stocks\ in\ FC$
CO_2 Equivalent of Sequestration Capacity Lost=	$=$ Biomass Lost due to Deforestation $* 44/12$

Equation 3.8: Set of Equations for Determining the carbon sequestration capacity lost due to deforestation

Data Synthesis

Data developed through objective one enabled understanding the trends of land cover changes over the study period and gain knowledge of which land cover category was responsible for the greatest land conversions particularly of forest land to another category. Further the data from objective one was utilised as primary data in objective three. This enabled the calculations of the carbon sequestration losses. Data obtained through objective two was used to determine the drivers of deforestation and also as a means of validating that the land cover changes determined scientifically were actually taking place on the ground.

Chapter 4. Results and Discussion

4.1 Introduction

This chapter presented the findings of the three research objectives. Section 4.2 were the results showing the land cover changes that had taken place within the study area and discussed the drivers of this change based on the analysis done. Section 4.3. presented the results from the Household survey, FGD and the KII and presented the findings of what these groups considered to be drivers of land cover changes, and discussed these findings. Section 4.4. Presented the outputs of the carbon sequestration based on the quantification methods used in determining how much carbon sequestration had been lost due to the deforestation activities and lastly discussed what these findings meant.

4.2 Land Cover and Land Cover Change Coverage

4.2.1 Accuracy of the Land Cover outputs

All the land cover outputs met the minimum required thresholds for accuracy with the least (2018) having an accuracy of 76.5 and the highest (1990) an accuracy of 85%. The accuracy levels for the land cover outputs used in this study is indicated in table 4.1.

Table 4.1: Accuracy Measure for the Map

Year of Map	Kappa Coefficient	% Overall Accuracy of Map
1990	0.76	84.99%
2000	0.74	83.02%
2010	0.75	82.39%
2018	0.74	76.52%

4.2.2 Change coverage for Land Cover for 1990-2018

Visual Representation of the change occurrences

Visual change analysis of the land cover outputs showed forest cover had been decreasing in each successive decade of analysis from 1990 to 2018. A close look at the forest cover of 1990 compared with what is observed in the successive decades (2000, 2010 and 2018) showed significant deforestation on the South Eastern Forest lands. On the other hand, the cropland area had been increasing rapidly within the same time frame. This effect was very apparent when we looked at the grassland areas (‘yellow’) surrounding the Mau Forest Complex in all previous years (1990, 2000 and 2010). By 2018, most of the previous grassland zones (‘yellow’) in 1990 had been converted to cropland areas (‘pink’). Refer to figure 4.1.

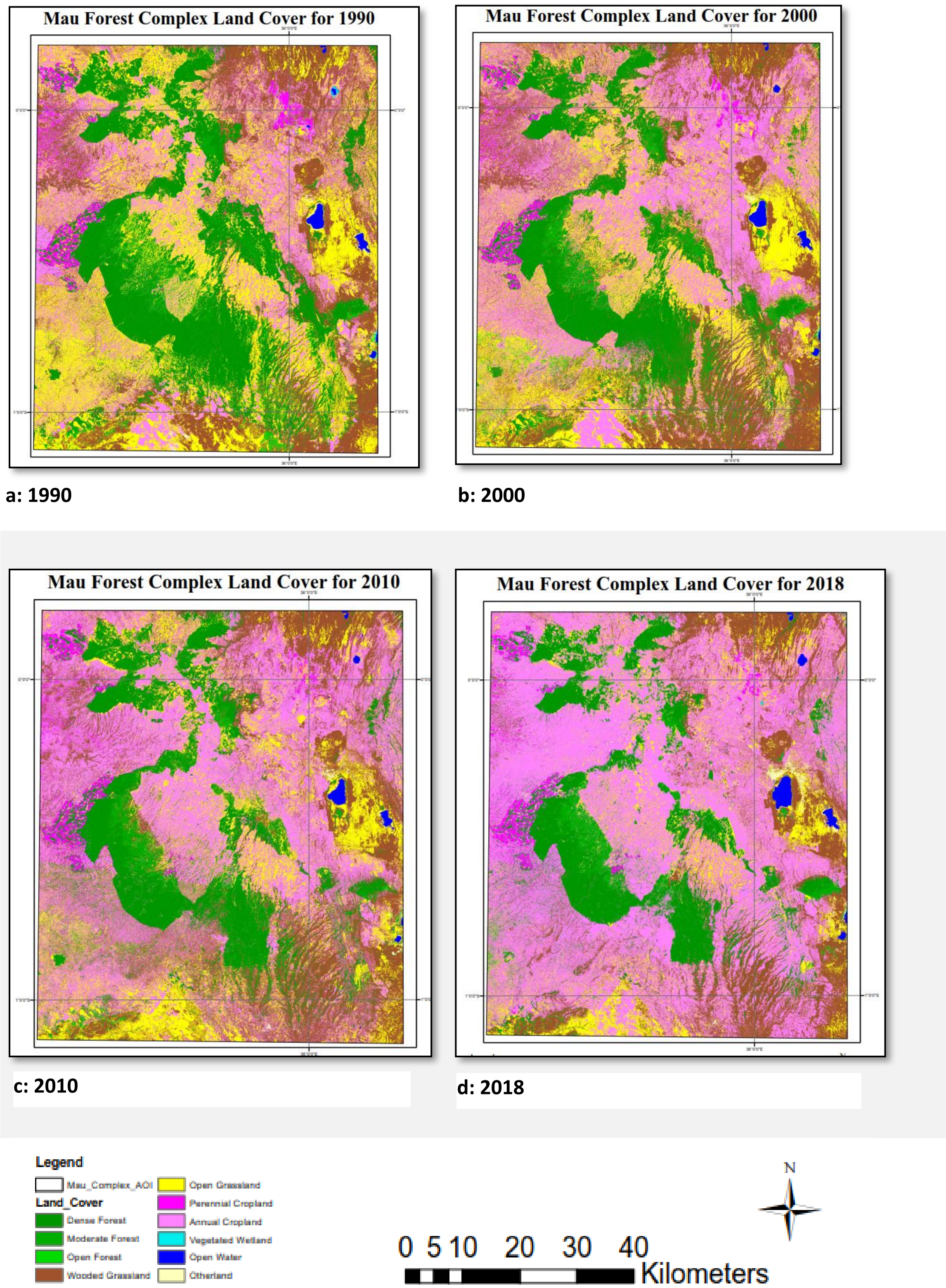


Figure 4.1: Land Cover maps for: a) 1990, b) 2000, c) 2010 and d) 2018

Proportions of the Land cover coverage

Forestland reduced by 12% between 1990 and 2010. This rapid deforestation trend however changed in the next decade of assessment (2010-2018), where a 2% decrease in forest cover area was recorded. Cropland area increased by 16% between 1990 and 2010 and further increased by 15% between 2010 and 2018, while the grassland area decreased by 10% between 1990 and 2010 and witnessed a further 13% decrease between 2010 and 2018.

Wetland area maintained the same consistency between 1990 and 2010, 0.45% in 1990, 0.42% in 2000 and 0.40% in 2010, but a strange occurrence of 50% increase was noticed between 2010 and 2018, this prompted a further investigation. The otherland area is also seen to bounce between the years, from 0.28% in 1990 to 0.17% in 2000, 0.27% in 2010 and a significant increase to 0.69% in 2018. The increments in otherland area are consistent with literature findings that show increased land degradation due to a number of climatic and anthropogenic factors.

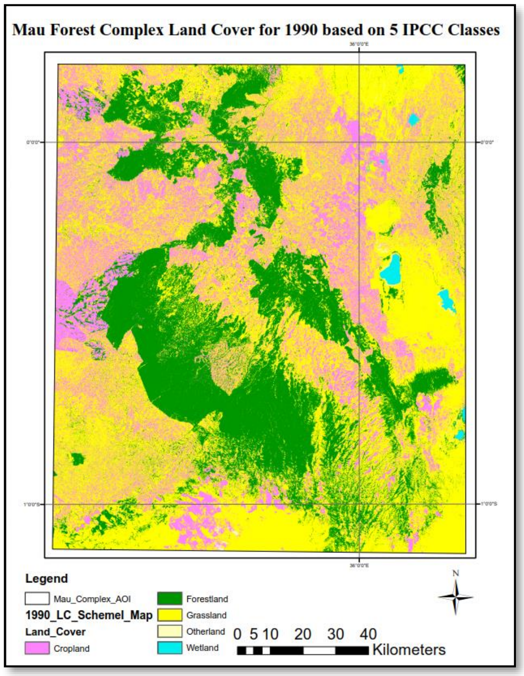
Table 4.2 shows the Acreage of each land cover in hectares and the proportions they occupy within the study area of the land covers transitions presented for the years 1990, 2000, 2010 and 2018. The Land Cover proportions are also presented for each year as percentages of the total study area.

Table 4.2: Table showing Acreage and percentages of Land Covers in Different years

Land Cover	1990 Area in HA	2000 Area in HA	2010 Area in HA	2018 Area in HA	% in 1990	% in 2000	% in 2010	% in 2018
Forestland	485187.21	367089.84	347876.82	311920.20	25.95	19.63	18.60	16.68
Grassland	958844.25	892126.44	782096.67	528383.43	51.28	47.71	41.82	28.26
Cropland	412291.35	599664.24	727378.56	1004687.55	22.05	32.07	38.90	53.73
Wetland	8472.33	7927.74	7519.77	12011.85	0.45	0.42	0.40	0.64
Otherland	5153.76	3140.64	5077.08	12945.87	0.28	0.17	0.27	0.69
Total	**1869948.90**	**1869948.90**	**1869948.90**	**1869948.90**				

IPCC Land Cover Change between 1990 and 2018

The IPCC Land Cover was used to determine the land cover changes that occurred between 1990 and 2018. This is shown in figures 4.2a and 4.2b were used to develop the change matrix.



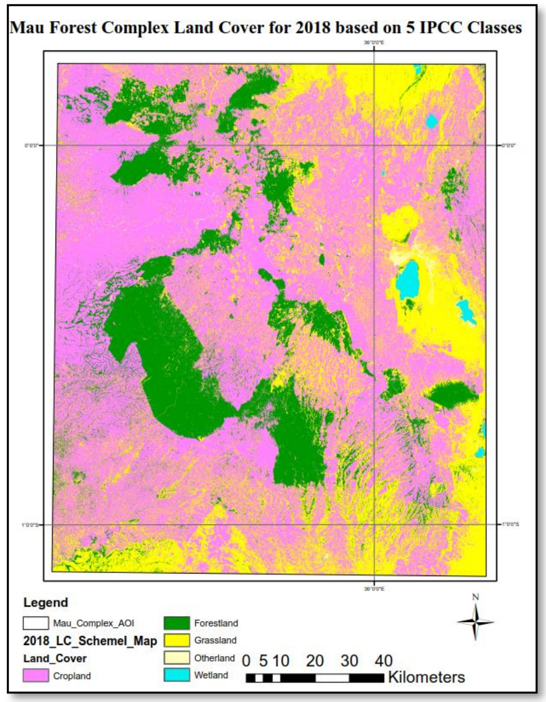


Figure 4.2a: IPCC Land Cover for 1990 **Figure 4:2b IPCC Land Cover for 2018**

Land Cover Change Matrix for 1990 and 2018

The land conversions: grassland to cropland areas at 28%, and forestland to cropland at 8.43% and further forestland to grassland at 4.13% have the highest magnitude besides the land categories that did not change or stayed the same over this study period. Note that this change matrix also provides input data for calculation the carbon sequestration for objective 3.

Cumulatively, from table 4.3, it was determined that there has been 12.63% forest loss equal to a 33.3% reduction of the original forest area from 1990 to 2018, these being conversions of forestland in 1990 to mainly croplands and grasslands in that order.

Table 4.3: Land Cover Change Matrix between 1990 and 2018

Change	Change occurrence in Full	Attribution	Area_Ha	% of Land Conversion
GC	Grassland to Cropland	Land cover Change	525,836	28.12
GG	Grassland remaining as Grassland	No Change	372,234	19.91
CC	Cropland remaining a Cropland	No Change	319,180	17.07
FF	Forest Remaining as Forest	No Change	248,992	13.32
FC	Forest to Cropland	Deforestation	157,590	8.43
FG	Forest to Grassland	Deforestation	77,283	4.13
CG	Cropland to Grassland	Land cover Change	76,241	4.08
GF	Grassland to Forest	Regrowth	49,624	2.65
CF	Cropland to Forest	Land cover Change	13,088	0.70
GO	Grassland to Otherland	Land cover Change	8,508	0.45
WW	Wetland remaining a Wetland	Land cover Change	7,360	0.39
CO	Cropland to Otherland	Land cover Change	3,134	0.17
GW	Grassland to Wetland	Land cover Change	2,643	0.14
OG	Otherland to Grassland	Land cover Change	2,267	0.12
OC	Otherland to Cropland	Land cover Change	1,506	0.08
FW	Forest to Wetland	Deforestation	821	0.04
OO	Otherland remaining as Otherland	No Change	783	0.04
CW	Cropland to Wetland	Land cover Change	649	0.03
WC	Wetland to Cropland	Land cover Change	576	0.03
OW	Otherland to Wetland	Land cover Change	539	0.03
FO	Forest to Otherland	Deforestation	501	0.03
WG	Wetland to Grassland	Land cover Change	359	0.02
WF	Wetland to Forest	Land cover Change	157	0.01
OF	Otherland to Forest	Land cover Change	59	0.00
WO	Wetland to Otherland	Land cover Change	20	0.00
Total			1,869,950	

Figure 4.3 gives a visual perspective of this cumulative forest loss (in red) for the study period, 1990-2018.

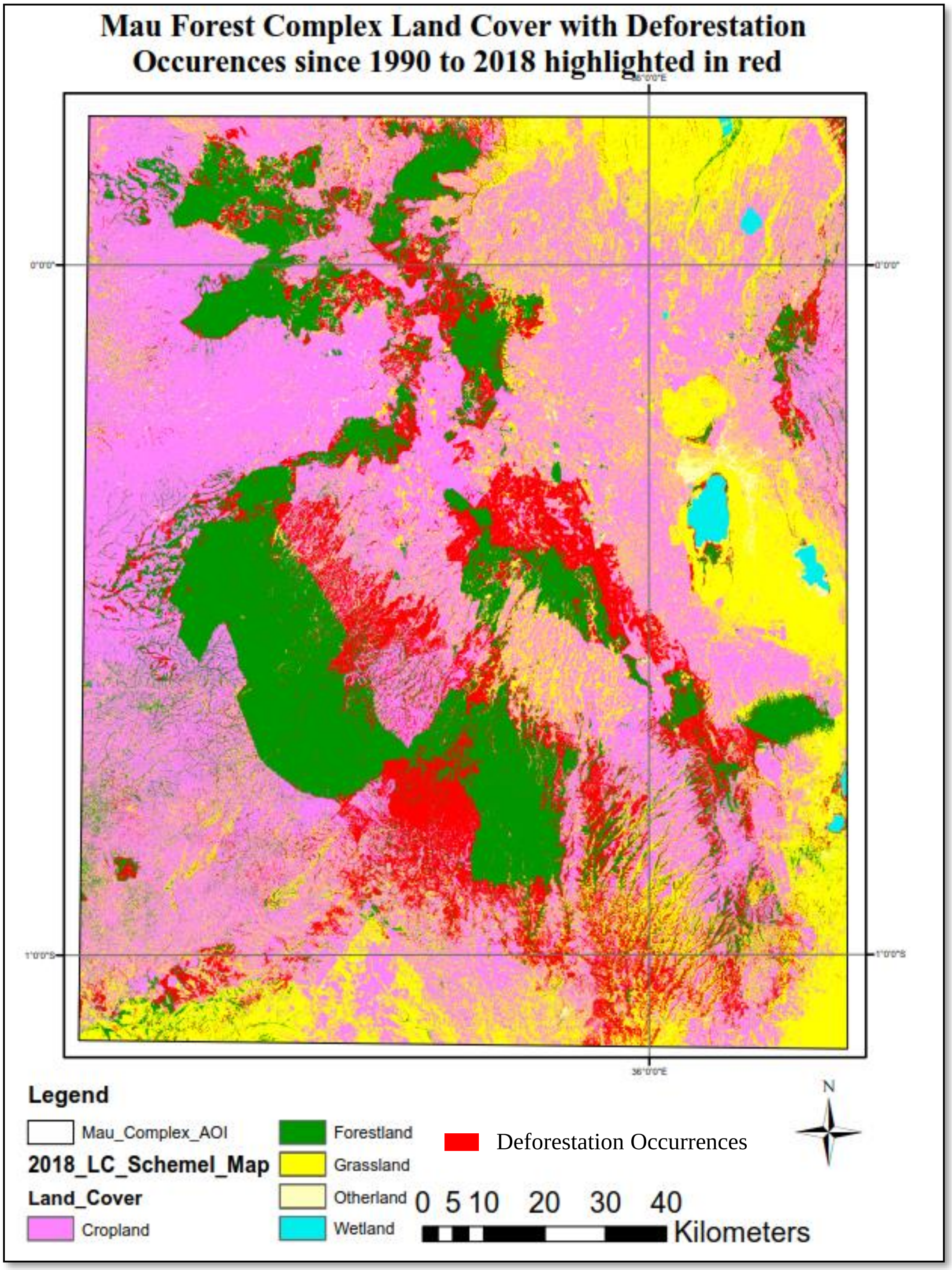


Figure 4.3: Map highlighted in red 33.3% forest loss since 1990

It was also determined that cropland area increased by 31.68% from 1990 to 2018. Figure 4.4 gives a visual perspective of the new (converted) cropland areas that were previously not there in 1990. A portion of the “new cropland area’’ locations are consistent with areas that in 1990 were occupied by forestland.

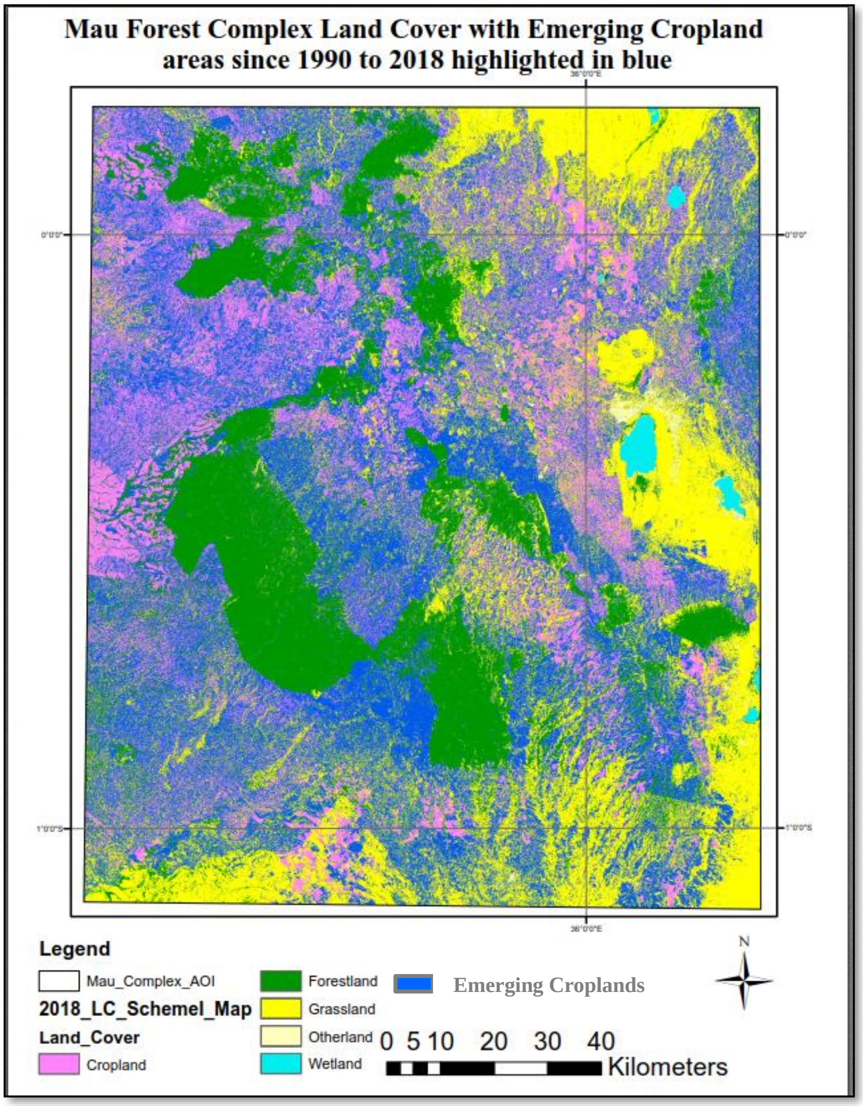


Figure 4.4: Map highlighting in blue 31.68% emerging cropland areas since 1990

Results of the open water cover using data from CHIRPS

The percentages of the wetland category moving from 0.45% in 1990, 0.42% in 2000 and 0.40% in 2010, and then 0.64% in 2018, a 50% increase between 2010 and 2018 led us to further investigate the unexpected increase. Note that for this study area, there are no marshlands or natural vegetated wetlands, therefore the entire wetland category is occupied by open water bodies. Using locations within the six open water point locations (P1, P2, P3, P4, P5 and P6) in the study area, all towards the eastward side, CHIRPS (Climate Hazards group Infrared Precipitation with Station data) data were obtained for the area to investigate the rainfall patterns between 1990 and 2018. CHIRPS data is a blended satellite-station bias corrected rainfall forecast dataset (https://www.chc.ucsb.edu/data/chirps).

The findings show that 2018 received the one of highest rainfall (ranging from 1247 (P6) at the lowest water point to 1353mm at the highest water point (P3) compared 716 at the lowest water point (P6) and 966mm at the highest point (P4) in 1990) this gave us clarity on the 50% increase in area occupied by the wetland area compared to what is recorded in 1990. This is shown in figure 4.5, that captured the annual rainfall patterns and increasing trends of rainfall between 1990 and 2018 for each point location. The dotted lines being the trends lines (Linear P1…. Linear P6) for each point and the solid lines being the annual rainfall patterns from the annual rainfall average indicated in a dot at the year of coincidence.

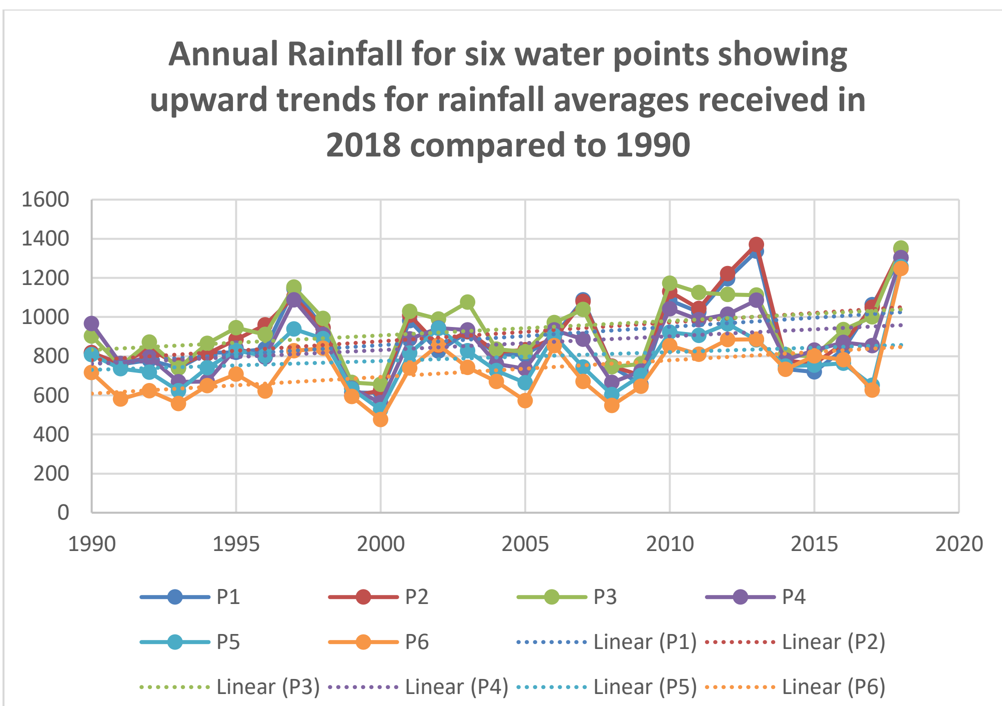


Figure 4.5: Annual Rainfall (mm) for six water points all showing upward trends for rainfall averages received in 2018 compared to 1990

4.2.3 Discussion on the findings from Land Cover Analyses

This research has determined that the main driver of deforestation and land conversion for this study area is the expansion of agricultural lands. It also found that cropland area increased by 31.68% between 1990 and 2018, 12.68% of these coming from forested lands, and the 19% from grasslands. A groundtruth survey done by the Permanent Presidential Commission on Soil Conservation revealed that 44,502.77 ha of forest had been excised in the MFC between 1995 and 1999 (Matiru, 1999). Similarly, other researchers determined that the main driver for deforestation in the tropics is agriculture (Houghton, 2012, Ndubi, 2016, Bowker et al., 2017, Muhati et al., 2018).

This research also noted that the rapid change in forest cover between 1990 and 2010 which was recorded at 12% and 2% between 2010 and 2018 respectively, coincides with forest excisions that had been granted by the government in 1990 and 2001 to resettle populations that had been affected by political violence. This makes lack of political goodwill another significant contributor in aiding deforestation activities. Kweyu et al., 2020 had similar findings noting that in the same study area there had been great forest loss around 1995 and 2005. These losses he attributed to forest excisions that were politically instigated, migrations resulting from multi-party politics that resulted from tribal clashes seeing population displacement into areas around the MFC. (Kweyu et al., 2020).

This research determined also that the increments in rainfall received significantly contributed to land cover changes around water bodies leading to unusual land use change with the wetland category recording a 50% increase in surface area between 2010 and 2018. Other research indicated that increased siltation and sediment load into the water bodies also lead to increments in surface area of water bodies (Zekarias et al., 2021). Though this research only confirmed one source of increment in surface area of the waterbodies, rainfall, we anticipate that conversions of forestland to croplands will increase runoff erosion and lead to increased siltation and sedimentation into the lakes and this could further cause increments in to the surface area of the lakes. Thereby causing increased flooding events and threaten the wetland ecosystem (Zekarias et al., 2021). The otherland category essentially does not contain any biomass or soil organic carbon, so did not in any way cause the sequestration capacity to fluctuate. Otherland is land that has lost all its capability of productivity. Refer to Appendix A1.

4.3 Drivers of deforestation resulting from livelihood expansions

4.3.1 Introduction

The household surveys as well as the Key Informant interviews revealed that the main driver for deforestation is agriculture. These were done either through encroachment into the forest or settlement locations for the new farms and farmers.

Community profile and existing livelihoods within the MFC

The survey determined the ethnic dynamics of the communities living around the Mau have since changed and it is no longer dominated by the Maasais and Ogieks only. Kikuyus are now the dominating tribe at 35% followed by Kalenjins at 20%, the Maasais at 16%, Kisiis' at 12% and 17% by other tribes. Note that 71% of the population interviewed had been living in the area for at least 10 years with 45% having lived there for more than 20 years and 21% for more than 30 years which means they could provide reliable and critical details of what had been happening in the Mau region. Most (92%) of this population was also involved in farming as a source of livelihood and 6% in livestock keeping, 6% of them were into business as small-scale traders, 1% indicated that they were "jua-kali" artisans (traders working in open air with no formal market structures).

4.3.2 Drivers of deforestation determined from the Household Survey and the Focus Group Discussion.

39% of the community felt that forest had reduced in size while 20% felt it had remained the same, and 41% felt that the forest area was increasing. This could in effect relate to the duration of stay because our research revealed that the greatest loss occurred between 1990 and 2010. This means that only those, who'd lived there for at least 20 years could have observed this change. They confirmed that this loss in forest was attributed to tree cutting (49%), land grabbing/encroachment (12%), human settlement (27%), and charcoal burning (14%), loss of rain/ climate change (4%) and forest fires (1%).

The conservation initiatives in the region had only been noticed by a small percentage 39% of respondents with 61% feeling nothing was being done. This finding was confirmed by 54% of the population that felt that there had been a decline in water resources. They (66%) indicated that they had been experiencing poor rainfall and 17% indicated that the dry seasons are now are prolonged.

The research revealed that 75% of the population using firewood as their source of energy and 49% using charcoal. This energy was preferred because it is cheap and readily availability. The worrying bit is that 64% of those using either charcoal/ firewood indicated they had no intention of changing to alternative sources of energy. This was attributed to the high cost of alternative energy sources either in setting up or routine payments. However, despite this over-reliance on the forest resources they did not see the forest as diminishing resource and still felt that it shall be in existence perpetually in spite of their livelihoods. A significant part of the population has been involved in reforestation (51%) notably in the last 5 years (2014-2019) with 82% of those engaged confirming this.

Majority (79%) of this population were poor famers living on monthly income of less than US dollars (USD) 300 per month. Many of them (65%) of the population had family sizes between 1 and 4 kids. This broadened the spectrum on why theses dynamics of deforestation were occurring, the encroachments, use of charcoal etc. It was promising though that 93% of them have either had access to TV, the internet or newspapers which meant that they could be informed on the issues that needed to be publicized about Mau and the government efforts in addressing them.

The 10 participants in the FGD were mostly small-scale farmers who sell their produce, or laborers who work in farms for pay as little as USD 2 daily. They lease land for farming for as much as USD 160 annually and were required to have a minimum lease period of 3 years, which many of them could afford. They also relied on forest resources such as firewood for their own utility and for sale. Majority of residents had been resettled there after the 1992 political clashes but the new settlement was not ready to accommodate them: lacking social services, job opportunities just to mention. Land was unaffordable. There were very few factories to work in and the others that used to be there like Kenya Cooperative Creameries

(KCC) was closed in the 90s. They had to team up into multiple families to purchase land and subdivide amongst themselves. The only available sources of livelihood they are left with is farming and resources of the forests such as firewood and timber. They indicated that they used to have two pyrethrum factories that since closed down. The change in weather patterns could no longer allow for pyrethrum, a cash crop, to grow in Molo. They also had a railway line that enabled them trade their produce in Kisumu, this transport system malfunctioned.

They believed that the government had a hand in the deforestation since the saw milling factories in Molo were owned by rich people who could only be given permits to cut down trees by the government. Politicians in the 1990s also contributed to deforestation by allocating forest land to their wealthy political allies. They mentioned that politicians had been using the forest land to gain political mileage. Initial buyers had been told that the land allocated was temporary but they had since sold the land to second and third owners who had built permanent structures. Due to this fact every time there had been notices for eviction, politicians would politicize the evictions this land to gain political mileage by stopping the evictions. They also indicated that some foreigners too like presidents from Uganda and South Sudan had been allocated some of the land.

The government having been pushed by the greater public gave a directive in 2018 to stop deforestation and banned cutting of trees in the MFC. By 2019 at the time of the FGD, only two companies, TimSales and Rai Ply, were permitted to cut trees. The FGD determined that deforested land was mostly used for farming and because the community perceived deforestation as a lesser evil because it provided them with a source of livelihood. They also indicated that they had been engaged in reforestation activities during the rainy season. This corroborated the findings of household survey.

The farming community felt they had not impacted the forest since they observed regulations such as observing riparian reserves restrictions and planting trees whenever they could, to replenish what they had taken. They confirmed that majority of the community used firewood as their main source of energy since it is what most people could afford. However, since the 2018 ban they had experienced difficulties in getting the fuel wood. In some cases, they were allowed by the forest guards to collect tree parts that fell off for as long as they were not cutting the trees.

The government to some degree had been seen to support conservation and reforestation. Those allocated forest land for farming on rotational basis were required to plant trees and were provided seedlings by the government. Some few NGOs too had also been involved in reforestation and educating farmers on conservation. The forest guards assigned by the government also aided in protecting the forests by arresting anyone involved in illegalities. They also pointed out that the communities were watch guards to corrupt forest guards and reported such matters when they made observations. They also recognized that the tree cutting ban had contributed greatly to conserving the forest.

Some of the locations where deforestation had taken place were identified by the community including Molo which were seen more as settlement schemes than forestlands. These areas in the 90s used to be all forested. One of the participants is quoted, “I don’t think there is anything called Mau Forest because from Kiptunga forest to Mau Summit there is no forest. The forest is in Koibatek. The forest land was given out all the way from Olenguruone to Mau, there is no forest. All we have are schemes and people farm and have built homes.” The community supported eviction of all people within the forestland and indicated that those living there should be resettled elsewhere. Some pictures captured during the FGD session are shown Plates: 1-3.

Plates 1: FGD in Session, at Green Garden Lodge in Molo, on the 13th July 2019.

Plates 2: FGD in Session, at Green Garden Lodge in Molo, on the 13th July 2019.

Plates 3: Group picture with the FGD Participants, at Green Garden Lodge in Molo, on the 13th July 2019.

4.3.3 Drivers of deforestation from the Key Informants perspective

Kenya Forest Service was involved in mapping the forest on a regular basis to monitor the changes taking place not just in MFC but in other areas as well. They recognized and were aware of the challenges that MFC was facing such as illegal logging, encroachment, over abstraction of forest resources. They had a forest protection unit with rangers whose main job was to protect the forest from illegal logging and illegal activities within the forest area. They worked with Community Forest Associations (CFA) who were community members/groups gazetted by government to take care of the forest. The Associations were registered. They indicated that the greatest challenge they faced as an institution was evicting the natives of the forests (the Ogieks) and the squatters of the forest who had been living within the forest and its environs for years, some who had been involved in deforestation and charcoal burning. They indicated that the government had played a role in increasing deforestation due the vested political interest of the government of the day and the sensitivity and laxity in resettlement. They recommended working through the CFA to plant more trees, educating the community members of the benefits of forests and especially the need to conserve indigenous trees since these were the ones responsible to maintain the water tower.

The Kenya Water Towers Agency was involved in conducting research that informed solutions provided for the protection of water towers and the issues they faced. Issues such as land cover changes, social and economic dynamics and changes in river flows. They were aware of the issues affecting MFC and documented such issues whenever they were observed. Some of the notable and documented issues included deforestation, encroachment, livestock grazing and how that had affected the structure of vegetation around the forest leading to erosion as observed in the southern Mau region. They had a directorate that conducts research to inform policy, forest and ecosystem conservation. They worked with other agencies to protect the forest. Agencies such as KFS, KWS and the County government. They had however been involved in restoration activities that they implemented through the community such as tree planting, whereby they provided seedlings to the community. They also engaged the community in educating them on conservation and providing them with alternative livelihood options such as providing them with bee hives and work with them to promote sustainable management practices such as agroforestry. A lot of what they do is done with the community, they encouraged the community to harvest water and worked with them to put out fires whenever they occurred.

The greatest challenge that KWTA faced was limited resources and so they were only able to work in priority areas. They also faced a similar challenge as that indicated with KFS where politics come to play whenever evictions of squatters and those encroaching the forest came up. They acknowledged that the government had tried to address the issue of deforestation. The formation of their agency was one such effort that was made in 2012 so that they could address issues affecting the water towers such as deforestation, degradation, encroachments. Some of the solutions they had been providing through partnerships with other agencies included development of ‘an eco-system conservation management plan’ that provided a range of activities that could be prioritized in areas facing high deforestation and degradation and the intervention measures to be undertaken in those areas. They also recommended inclusion of Public Private Partnerships with companies such as Keringet (bottled water company) to work together in protecting the forest.

At the community level, the Chief’s office was involved in sensitizing the community to conserve and protect the forest. They held monthly barazas (community gatherings) with the community to sensitize them on sustainable management and use of the forest. The chief’s office was aware of illegal deforestation for timber and charcoal burning taking place in the forest. Some of the challenges they faced included lack of power to arrest or even take action on offenders. They could only work through other government agencies to enforce and sensitize the community. They acknowledged government effort in trying to address the deforestation issues and indicated that the tree cutting ban of 2018 had significantly helped. However, on the ground there were also corrupt government officials who allow this ban to be breached. They would like be empowered to take action when such illegalities happen. As it is then, they could only report occurrences but more often than not, no action was taken after their reporting. They had been provided with motor cycles to patrol and this had helped greatly in patrolling but they felt that vehicles too would make their patrolling much easier. The other challenge raised was on siltation of river beds, which was now affecting river flows. It was pointed out that the community needed more education on the tree species to be planted to avoid this issue. Alternative farming practices needed to be observed near water bodies.

The Research Production Unit at the County of Nakuru had been working with World Vision to educate the community in forest conservation by encouraging communities around the MFC to get their animals out of the forest and practice more zero grazing in a bid to reduce forest and land degradation and reduce the pressure on the forest complex. The farmers were trained on growing and conserving their own fodder to reduce the reliance on the vegetation and feed from the forest. They were also trained on ways to increase fodder productivity to meet the demand of their livestock. The unit had limited information with regards to the challenges facing Mau save for what was commonly available from the newspapers on the eviction matters. Some of the challenges they had faced is resistance by the community with the alternative feed for their animals. The community sometimes still preferred to go to the forest.

The changes in weather patterns made it challenging for the community, though trained, to depend on rainfed planted fodder, leaving the farmers with little alternatives for their livestock but to go back to the forest. Some of the recommendations made included the government marking the boundaries of MFC and making this publicly available so that anyone within the boundaries was aware that they were encroaching. The receding forest had made the boundaries difficult for the community to realize since to them forest land was only that with trees. He proposed use of satellite data in tracking encroachments and deforestation. Empowering of government agencies such as KWS to control access to the forest. He also proposed that milling and timber harvesting companies should be compelled to replace the trees they take out of the forest. The county took cognizance of the role that MFC played in water restoration and noted that from stories told by those who had been there longer, the deforestation had affected the rainfall quantities and changed the weather pattern significantly. Rivers emanating from the forest had dried up and in others there was declined river flows.

CIFOR had been involved in conducting capacity building for the communities around the MFC in forest and water management. They were familiar with the issue of declining forest cover in the MFC due to encroachments, degradation from forests fires and population pressure. The pressure on the forest had been affecting the water supply, rivers emanating from the Mau had reduced in water quality and quantity. CIFOR was working with the CFAs to train them on forest and water conservation. They also worked with the community in restoration of riparian forests. Some of the challenges they faced in providing solutions included having a limited scope of work for such a huge forest area. The worked in specific places with targeted communities. CIFOR also faced challenges to bring all the stakeholders on board since the conservation matters had many stakeholders. The challenge sometimes being that the different stakeholders had different priorities and interests.

CIFOR felt the government had done quite a lot. There are forest and water acts which provided for community participation. The government had created authorities responsible for forest and water management. The government agencies they had worked with had committed to implementing the interventions they had proposed. The government had also created an environment for conversations and interventions to be heard and made. CIFOR encouraged participatory forest management that involved working with the community as one of the key tools that would ensure that conservation efforts were realized. Other tools proposed was gender inclusion in conservation, having more women involved. They also felt that there was need have more engagements with all relevant stakeholders.

4.3.4 Discussion on the drivers of deforestation

The household survey, Focus Group Discussion and the Key Informant Interviews provided a lot of insight on the drivers of deforestation, what was being done at different levels of government to address the issue of deforestation and degradation, the stakeholders involved and much more importantly, the community involvement in restoration, conservation, and cessation of deforestation. The community was a centerpiece that could not and should not be ignored. All conservation efforts must involve the community.

This research determined that small holder agriculture, livestock keeping, timber harvesting and charcoal trading are the key drivers of deforestation in the MFC. Allocation of forestland to small scale farmers (excisions) had significantly impacted the Mau Forest. In 2001 alone, 61,023 ha of the forest was excised, this is 14% of MFC in total. The Eastern block by 54%, 35,301ha and the Southern Western Block by the 27%, 22,797 ha (Albertazzi et al., 2018).

This research, also determined that poverty, though not largely mentioned by other researchers, was also a driver of deforestation. Many of the communities living around Mau are poor communities living on USD 2 per day to fend for their needs. They did not have alternative livelihoods making it very difficult for the status quo to change. Further, these communities relied heavily on timber for housing, using charcoal and fuelwood as their main source of energy (75% of the population). They could not afford alternative energy sources. Unless supported by government and private sector in the initial set up costs of alternative energy.

Ndubi's research done in 2016 also came to the conclusion that 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 in the Eastern Mau are the main drivers of deforestation in the Mau Forest (Ndubi, 2016).

This research determined that though the government is blamed for laxity in implementation of policies, there was a lot that they and other stakeholders were doing on the ground to combat deforestation. The government's greatest challenge was the eviction of those who had encroached forestland. The implementation of the evictions required a lot of wit since it involved human lives. Tree planting activities and community involvement had been felt at community level in the last 5 years. Some of the initiatives implemented to conserve forest identified through this research included: tree cutting ban of 2018; tree planting by several stakeholders: KFS, KWTA, CIFOR, and CFAs; alternative sources of livelihoods such a bee keeping as encouraged by KWTA; use of Rangers and forest protection units; community involvement in some of initiatives for conservation, tree planting, watch guarding; sensitization and education of the community on the benefits of the forests, the need to conserve the forest, sustain use and management of the forest and water; research to inform policy decisions and interventions; alternative feed for animals to reduce pressure on the forest; agroforestry; policy formulation and acts of parliament that protect the forest; and formation of Authorities mandated to conduct research that informs policy such as KWTA.

This research determined, in summary, that the drivers of deforestation and degradation in the MFC were: forest excisions; poverty; corruption; overexploitation of forest resources;

encroachments for human settlement; bad politics; agriculture; livestock grazing in forest land; charcoal burning; timber harvesting; lack of alternative energy sources; laxity in implementation of policies; population pressure; climate change and change in weather patterns; and forest fires.

This research determined the effects of deforestation to be: loss of biodiversity in flora and fauna; forest degradation; change in rainfall patterns; prolonged dry season and droughts; increased vulnerability of communities; drying rivers; change in quality and quantity of water sources; siltation; soil erosion; change in climate; and change in poor yields for the location due to change in climate. The findings of this research concurred with conclusions reached by other researchers as further elaborated. Deforestation around the MFC results in increased soil erosion, sedimentation which in turn caused decreased water quality and quantity and eutrophication (Chrisphine et al., 2016). The destruction also caused biodiversity loss for the ecosystem they sustained.

The presence of pollutants into the lake created an imbalance in the ecosystem (Chrisphine et al., 2016). Household surveys done around MFC in the deforested areas indicated decline in precipitation resulting into lower water discharge into the rivers and lakes being served by the catchment (Hesslerová and Pokorný, 2010). Climate and Land use Change models done on the MFC catchment using PRECIS regional climate model and land use data from Landsat indicated that the area had become warmer and wetter since the 1970s, while stream flow showed a decreasing trend (Rwigi, 2014). Other researchers had found that deforestation was affecting the climate of MFC hence affecting the food productivity of the area, increased warming had led to poor yields (Kitheka, 2019). Further the deforestation had led to climate change, climate variability and unpredictable seasons which threatened food production and livelihoods of the farmers in area (Kitheka, 2019).

4.4 Outputs of Carbon Sequestration capacity of the study area

The output of Carbon Stock change calculations indicated that the area of study was still a net sink with the sequestration capacity of -7,563.508 Gg per year of CO_2 with an uncertainity of ±65.08 Gg per year. Note. The negative sign on CO_2 equivalence denotes a sink (removal).

Highest Biomass carbon (1,486.233Gg) is reccorded when the forest land category stays as forestland. There is a very small amout of biomass carbon recorded in forestland conversion to cropland areas, this is attributed to the perennial cropland, otherwise annual croplands and grasslands are usually assumed to have net zero biomass carbon within the year since they are consumed within the same year and do not give the vegetation time to accumulate significant biomass.

All land conversions from forestlands are reduced to zero biomass. This is a loss in sequestration capacity. All land categories contain mineral soil organic carbon except for cases where land has been degraded to otherland, or exists as otherland. Carbon sequestration for each land category is a function of land area occupied as indicated in Equations: 3.3, 3.5, 3.6 and 3.8. This means that if the area occupied reduces then the Soil Organic Carbon and the Biomass Carbon Stock also proportionately reduces.

Consequently, if the current forestland area (2018) of 248,992 hectares is providing a sink capacity of **1,486.233Gg** Biomass Carbon stock, the deforested area of 236,195 hectares is actually losing **1,378.332Gg** Biomass Carbon stock which is equivalent to losing a sequestration capacity of **-5,053.884Gg/yr. ±65.281 Gg/yr.** Refer to table 4.4.

Table 4.4: Carbon Sequestration losses

Value	**Calculations**
Total area (in Ha) Converted=236,195	=157,590 + 77,283 + 501 + 821
Biomass Carbon Stocks Under FF Area (in Ha) =248,992	=1,486.233Gg Carbon stock change
Biomass Lost due to Deforestation=	$= \left(\left(\frac{236{,}195}{248{,}992} \right) * 1{,}486.233 \right) - 31.515$ =1,378.332
CO_2 Equivalent of Sequestration Capacity Lost=	$= 1{,}378.332 * 44/12$ = **-5,053.884 Gg/yr. with Uncertainty ±65.281 Gg/yr.**

The Mineral Soil Orgaic Carbon and Biomass Stock Change results are outlined in table 4.5 for the different land cover categories.

Table 4.5: Soil Organic Carbon and Biomass Stock Change

Mau Forest Complex	Mineral Soil Organic Carbon Stock			Biomass C Stock Change: Gain-Loss Method	
	Inventory (year = 2018)				
Category / Source (1990-2018)	Area (ha)	C Stock (Gg)	95% Uncertainty (%)	C Stock Change (Gg)	95% Uncertainty (%)
Cropland Converted to Forest Land	13,088	999.662	60.233	78.122	24.062
Cropland Converted to Grassland	76,241	5,670.321	52.841	0	0
Cropland Converted to Other Lands	3,134	0	0	0	0
Cropland Converted to Wetlands	649	49.563	52.65	0	0
Cropland Remaining Cropland	319,180	15,054.89	62.745	63.835	30.951
Forest Land Converted to Cropland	157,590	7,433.087	62.746	31.515	30.95
Forest Land Converted to Grassland	77,283	5,747.773	52.841	0	0
Forest Land Converted to Other Lands	501	0	0	0	0
Forest Land Converted to Wetlands	821	62.713	52.65	0	0
Forest Land Remaining Forest Land	248,992	19,018.02	60.234	1,486.233	24.063
Grassland Converted to Cropland	525,836	24,802.31	62.745	105.165	30.951
Grassland Converted to Forest Land	49,624	3,790.28	60.234	296.206	24.063
Grassland Converted to Other Lands	8,508	0	0	0	0
Grassland Converted to Wetlands	2,643	201.869	52.649	0	0
Grassland Remaining Grassland	372,234	26,881.88	53.165	0	0
Other Lands Converted to Cropland	1,506	70.999	62.822	0.295	30.955
Other Lands Converted to Forest Land	59	4.508	60.234	0.352	23.955
Other Lands Converted to Grassland	2,267	168.583	52.84	0	0
Other Lands Converted to Wetlands	539	41.177	52.649	0	0
Other Lands Remaining Other Lands	783	0	0	0	0
Wetlands Converted to Cropland	576	27.166	62.74	0.115	31.107
Wetlands Converted to Forest Land	157	11.995	60.334	0.937	24.147
Wetlands Converted to Grassland	359	26.726	52.836	0	0
Wetlands Converted to Other Lands	20	0	0	0	0
Wetlands Remaining Wetlands	7,360	562.162	52.655	0	0
Total	**1,869,950**	**110,625.7**	**24.129**	**2,062.775**	**17.804**
CO_2 Equivalent of Sequestration Capacity (in Gg per Year)		**405,627,57**	**±88.473**	**-7,563.508**	**±65.281**

4.4.1 Discussion on the findings from Quantification of Carbon Sequestration

The causes of deforestation as determined in objectives one and two are driven by livelihood expansions from agriculture, timber extraction, charcoal trade, and pastoralism. Objective one of this study showed that indeed agriculture was the greatest cause of deforestation. Given that sequestration capacity is a function of area, it's imperative that when these forested areas are converted to other land uses, then sequestration capacity also commensurately decreases. Land conversations of forest area to other land categories leads to loss of carbon sequestration, as both biomass carbon and soil organic carbon get lost. This research found that between 1990 and 2018, a forest area of 236,195 hectares was deforested leading to a Carbon dioxide equivalent sequestration loss of -5,053.884Gg/yr., this means that carbon dioxide that would otherwise have been sequestered from the environment stays in the atmosphere meaning that there shall be a higher concentration of CO_2 leading to increased global warming.

On the other hand, Soil Organic Carbon is significantly lost when forestland is converted to other land cover categories. In our case 157,590 ha forestland converted to was cropland leaving only 7,433.087 Gg of SOC in this land cover category while a conversion of 77,283 ha of forestland converted to Grassland does not have a similar loss in SOC as it records an SOC of 5,747.773Gg. Conversions forestland to grasslands compared croplands leads to a lessor loss in soil organic carbon (De Stefano and Jacobson, 2018). Additionally, Land conversions to otherland completely depletes the SOC to zero. SOC is considered to be one of the most reliable indicator of soil quality and its productivity (Rajan et al., 2010).

This research therefore concluded that land conversions affect soil organic carbon. As we continue to degrade land to otherland, then we completely lose our soil organic carbon. The research also concluded that biomass stocks are highest in forest vegetation compared to other vegetation covers, therefore by deforesting, we are significantly reducing our carbon sequestration capacity due to human related activities that primarily come from expanding livelihoods. Livelihoods such as agriculture and human settlement that led to complete conversion of land cover need to be controlled for sustainability of the land resource.

Chapter 5. Conclusion and Recommendations

5.1 Introduction

This chapter provided a conclusion (Section 5.2) of our research findings and made recommendations (Section 5.3) on what needs to be done particular for the MFC to reduce deforestation activities.

5.2 Conclusion

The main objective of this research was to determine how livelihoods expansion into the MFC had affected carbon sequestration. To this effect, this research determined that land conversions from forestland to croplands significantly reduced the study area's carbon sequestration capacity. In the period of study 1990-2018, 33% of MFC the forest cover was lost and a sequestration capacity loss of -5,053.884Gg/yr experienced. In essence, this means that carbon dioxide that would otherwise be removed stays in the atmosphere hence contributing to global warming. Maintaining status quo on modus operandi means that more deforestation will continue to occur, livelihoods will become threatened and biodiversity lost, we shall suffer the effects of climate change that come with increased frequency and duration of droughts, unpredictable and erratic weather patterns. Stringent action needs to be taken up by the government to protect what is remaining and increase forest cover by reforestation.

The findings within this ecosystem is not only unique to the MFC but other forests ecosystems are facing very similar if not dire challenges. These challenges cumulatively affect all the systems: water recharge, environment, biodiversity, tourism, livelihoods themselves just to mention that depend on the forest ecosystems for their lifeblood. Where all indicators point at increase in demand for food, settlement and livelihood expansion, it's very possible that if nothing is done then the deforestation activities will continue on a downward spiral, we shall continue to lose our carbon sequestration capacity. Sixth Assessment Reports of the IPCC indicated that human induced climate change was responsible for weather and climate extremes being observed in many regions of the world (Zhou, 2021). All forces need to be combined by the government both at national and community level to halt deforestation and ideally restore forests have been lost to the extent that is possible. The community needs to be involved because they like everyone else are affected by the environmental, economic and social impacts of deforestation.

There's a lot of research that has been done on the MFC and this research's findings echoes the need for mitigation action now rather than later. The timing is nigh to have these findings and recommendations translated into action. There's currently support at national, regional and global level to halt deforestation. SDG 15.1 is very clear on this. Africa Agenda 2063 emphasizes the need for sustainable development and Kenya's Vision 2030 embodies measures that support sustainable development and measures that deter increased climate change. Reforestation measures in support on the Bonn challenge need to be at top gear. Kenya's Nationally Determined Contribution (NDC) 2020, submitted to the UNFCCC, aims to reduce national GHG emissions by 30% by 2030, some of the proposed measures for mitigation include increasing our tree cover from the current 6% to 10% and applying measures leading to land degradation neutrality. Further mitigation measures that include Climate Smart Agriculture call for agroforestry and increasing productivity without having to increase the cropland area through agricultural intensification and use of science to optimize productivity of existing agricultural lands.

5.3 Recommendations

Forest conservation and reforestation is key if carbon sequestration capacity is to maintained and even better, to be increased. For this to happen all stakeholders must be involved. Agricultural expansion at the expense of the forestland impacts the forest and later impacts the very agriculture that depends on the benefits of the forest to thrive. Undoubtedly, we agree and this research recommends that:

Objective 1(Land Cover Analyses) Recommendation

1. Earth Observation using technologies like remote sensing and GIS provide a unique capability for monitoring land related activities without bias or prejudice and should be adopted at all levels of government for: monitoring planning, management of all land activities and natural resources;

2. Using existing GIS, GPS and RS technology to establish the boundaries of the forest and even fencing is key for encroachments to be apparent and for enforcement to be clear.

Objective 2 (Drivers of Deforestation and Land Conversions in MFC) Recommendation

1. The community must be empowered to seek alternative livelihoods, be educated to understand the benefits of the forest and be provided with alternative sources of energy;
2. Government needs to facilitate a multi-sectoral, multi-partnership and transdisciplinary approach in combating deforestation and increasing the carbon sequestration capacity particularly in the MFC which is a major water tower and a vital ecosystem in the country with the community at the center of all engagement activities;
3. The community needs to be educated on the value of the forest ecosystem to understand how their livelihoods affect other systems and people that rely on the forest.

Objective 3 (Quantification of Carbon Sequestration) Recommendation

1. Understanding the role of carbon sequestration in an ecosystem is key to prioritization of its management. All stakeholders need to be made aware of this;
2. Engagement of Private sector in efforts to increase carbon sequestration is key.

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Appendices

A 1 Land Cover Definitions

The land cover definitions used were developed an adopted as national definitions by the SLEEK (System of Land based Emissions Estimations in Kenya) program in 2015.

Mapping of forest land in Kenya has been divided into 3 classes based on canopy density. The 'open forest' category includes lands with canopy density from 15% up to 40%. This is a national definition decision.

Crops were divided into two categories: annual crops, and perennial crops. Grasses has also been mapped as two categories: wooded grass (shrubs and grasses) and open grasses.

Wetlands have been sub-divided into water bodies and vegetated wetland.

Finally, all other classes that do not belong into the aforementioned will be included in the category of otherland including: barren land, rocks, soils and beaches.

A 2 Questionnaire for Survey

Introduction done. For the interviewee, the data on introduction included age bracket and gender.

1. How long have you been living in the MFC zone?
2. What do you do to earn a living?
3. What do many people around your community do for a living?
4. In the time you have been around, why do you suppose we are losing forest cover within the Mau Forest?
5. Do you think the land conversions have any impact on the environment? If yes, explain.
6. Do you think land conversions from forests have any impact on climate and water resources?
7. What energy source do you use at home?
8. If fuelwood, why is this preferred?
9. Would you consider other alternatives energy sources?
10. Do you think the government or the political climate has contributed to forests being cut down?

11. Do you see any possibility in future where the existing forest will cease to exist?
12. Have you ever been engaged in a reforestation activity around the MFC at any time since you have been around?

Additional Questions for County Officials to be interviewed

13. What are the country priorities in terms of development?
14. What are the priorities in terms on conservation?
15. Would you say that the county policies in your region conflict with those of the neighbouring counties?
16. If yes, please elaborate?

A 3 Guide for FGDs

Introduction by interviewer and interviewees. Profiling recorded based on age bracket and gender.

1. What are some of the livelihoods around your community?
2. For those who have been around for a long time since the 90s for instance, would you say any of these livelihoods are currently existing in areas previously part of the forests?
3. Do you think the government or the political climate has contributed to forests being cut down?
4. Do you think the land conversions have any impact on the environment? If yes, explain
5. Do you think land conversions from forests have any impact on climate and water resources?
6. What energy source do most people around you neighbourhood use at home?
7. If fuelwood\charcoal, why is this preferred?
8. Would you consider other alternatives energy sources?
9. Have you ever been engaged in a reforestation activity around the MFC at any time since you have been around?
10. Has the government or any NGO supporting forest conservation involved you in any way in the activities they conduct?
11. Do you think your participation would make a difference in behavioural change on how you perceive forest and its conservation?
12. Do you think the government has created sufficient avenues and polices to safeguard forest resources?

A 4 Guide for KII

Introduction by interviewer and interviewees. Profiling recorded based on age bracket and gender and Job function.

1. What is your designation?
2. To the best of your understanding, does you institution conduct any work/ research around or within Mau Forest Complex? If yes, expound on the type of work?
3. Do you have any understanding of the issues surrounding MFC with respect to land conversions?
4. Is your institution involved in any way in addressing the said issues?
5. Do you involve the community in addressing these issues?
6. What challenges do you face in providing optimum solutions for forest conservation?
7. Do you think the government has overtime created an environment to address these issues?
8. What are the working tools you would recommend to ensure that sustainable forest use and management is achieved?