**Kenya's Water Towers Protection and Climate Change Mitigation and Adaptation (WaTER) Programme**

# Historical Land Use Land Cover Change analysis, Current Land Use Map generation, Forest Degradation and Hot-Spot Mapping for Mt. Elgon and Cherangany ecosystems

**Component 4: Science to Inform Design of Community-Level Actions and Policy Decisions**

**Project Report of February 2017**

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**Kenya Forestry Research Institute (KEFRI)**

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# 1.0 EXECUTIVE SUMMARY

## 1.1 Background of the study

Forests cover only about seven per cent of Kenya's land area, yet they provide crucial direct and indirect goods and services to its people and make a significant contribution to the national economy. About 70 per cent of Kenya's domestic energy comes from wood, for example, and out of the 20 million of fuelwood consumed annually, 95 per cent is collected from forests and rangelands. Kenya's forested landscapes, including Kenya's water towers, store rainwater, regulate river flows and prevent runoff. Despite their indispensable role in supporting life on earth, forests are facing myriad threats mainly from land use changes. Deforestation has reduced Kenya's forest coverage from 12% in the 1960s to currently 6.9%. Deforestation costs the Kenyan economy an estimated KES 5.8 billion per year. An estimated 50,000 ha lost between 2000 and 2010, has resulted in cumulative negative effects amounting to KES 3,652 million/year, more than 2.8 times the cash revenue of deforestation.

Following this challenge, several organisations (both government and non-governmental) have come up with various projects to contribute to the effort of reversing this trend. KEFRI under the funding of the European Development Fund came up with programme on Kenya's Water Tower Protection and Climate Change Mitigation and Adaptation (WaTER). This programme aims at contributing to poverty reduction and sustainable livelihoods by applying scientific principles to inform design of community level actions and national policy decisions on rehabilitation and conservation in Cherangany and Mt. Elgon water towers.

One of the components of this programme is to carry out a baseline assessment of the biophysical and socio-economic status of the 2 Ecosystems undertaken to inform rehabilitation and conservation actions. The scope of this component is to provide information and knowledge on the current status of the two ecosystems in terms of land use, land tenure to facilitate the identification of hotspots and associated drivers for land use and land cover change.

## 1.2 General Approach

Mapping land use Land cover, even for only a limited number of classes, is a large undertaking with many challenges that are unique to each of the ecosystem. For a given class, many different forest types and physiognomy within Mt. Elgon and Cherangany ecosystems give rise to great variations in their spectral or seasonal properties. This will therefore require adequate baseline information regarding the current and past status of Land use, forest distribution and the use of flexible stratification in the mapping of Mt. Elgon and Cherangany ecosystems. This project employs supervised classification for image classification so as to classify the various land uses within the two ecosystems.

The dominant causative factors of the different types of land degradation within Mt. Elgon and Cherangany ecosystem were identified in the field during socio-economic survey, ground trothing activity and also collected from the available technical reports. The fieldwork was carried for 30 days visiting both ecosystems for data validation. Classified image acquired at different periods covering Mt. Elgon and Cherangany ecosystems were compared using cross-tabulation in order to determine qualitative and quantitative aspects of the changes in terms of Land use land cover and degradation for the periods from 1985 to 2000. In assessing and mapping of forest degradation in Mt. Elgon and Cherangany ecosystem, direct method of visual interpretation using very high-resolution satellite image data to detect canopy damage in some cases (Saatchi et al., 2007) and image classification method were applied.

## 1.3 Degradation in the two ecosystems

In Mt. Elgon and Cherangany ecosystems, the impact of degradation varies from fine-scale structural changes in canopy cover and height, or subtle disruptions to ecosystem services, to broad-scale loss of biomass. These changes can occur over a range of spatial and temporal scales. Degraded forest may assume a similar canopy cover to intact forest, but have lower biomass, as was noticed in Mt. Elgon and Cherangany forest ecosystem during ground trothing activity. It important to note within the ecosystems, different types of forests was noticed to respond differently to disturbance and change, with variable recovery rate, depending on the species composition, age, location and type, intensity and extent of degradation (Anthea L. et al 2017).

The approach of the study in Mt. Elgon and Cherangany ecosystem to asses and monitor forest degradation and disturbance using high resolution satellite image was a success as the resultant hot spot areas mapped, with ground validation shows tree cutting remains an ongoing problem in these major water towers, especially cutting of the larger, mature trees with the severity along the forest edges. From the result, more of degradation in Cherangany was experienced on the southern part of the ecosystem with patches spreading throughout the ecosystem.

During the fieldwork and interactions with the adjacent communities within Mt. Elgon and Cherangany water towers, there was some indication that forest management in these areas is poor. Participatory appraisal research with the adjacent local communities revealed that the current forest governance approach were inadequate, and follow-up by local line agencies on community-based forest management approach. From the discussion with the locals, it appeared that timber was being "leaked" out of Mt. Elgon and Cherangany ecosystem, both legally and illegally. Remoteness in terms of accessibility, inadequate forest governance, and authorized and unauthorized overuse of local forests in Mt. Elgon and Cherangany have resulted in continuing deforestation and forest degradation

## 1.4 Land use and cover in the two ecosystems

Both ecosystems showed a significant change in land use and cover, in terms of land conversion and modification. However, the Cherangany ecosystem showed more changes in land use and cover change as compared to Mt. Elgon ecosystem. The ground trothing and validation process of both areas showed that there were less land conversion activities around Mt. Elgon forest. This could be attributed to the fact that this ecosystem is more protected due to the presence of wild animals and their management by KWS. Also, the Cherangany ecosystem was observed to be entirely surrounded by community members which increases its accessibility and subsequently the chances of encroachment.

The decrease in closed forest and subsequent increase in open forest and grassland was also observed in the two ecosystems. The slight increase in open forest observed in 2000 could be attributed to the decrease in closed forest cover or the natural succession in plant communities with changes from either grassland or shrubland to forest. Further, both ecosystems showed a decrease in riparian vegetation and bare surfaces. This was seen mainly to result from encroachment by community members for the purpose of farming relying on constant water.

The effort to understanding land use and cover change in the two ecosystems will not only lead to sustainable forest management, but also result to systematic approach of conserving natural resources in the country. The systematic approach (also referred to as ecosystem approach) was first described by the Convention on Biological Diversity (CBD) as the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. This is a science based approach that treats conservation of forests in relation to all ecosystem components such as land, water and living resources including humans their culture and diversity.

The need for an effective conservation strategy for the two ecosystems will additionally have a global significance. For instance, it will contribute towards the attainment of the Sustainable Development Goals (SDGs) that are relevant to forest conservation. Specifically, it will support SDG15 which involves the reduction of deforestation and the protection and restoration water catchment areas. This will also help in meeting specific targets of SDG15 which include; By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests, and increase afforestation and reforestation: By 2020, protect and restore water-related ecosystems including mountains, forests, wetlands, rivers, aquifers and lakes (SDG6.6). By this study informing effective strategies to conserve the Mt. Elgon and Cherangany ecosystems, it is directly contributing towards the achievement of this targets and thus sustainable development on earth.

## 1.5 Summary of Recommendations

After considering the results of the study, the following recommendations were suggested;

- **Encouraging substitutes like Bamboo farming**

Within Mt. Elgon and Cherangany ecosystem, the adjacent community fully relies on forest for wood, fodder, timber etc. this encouraged forest degradation and hence alternative sources like Bamboo farming should be encouraged and supported to relieve off the pressure. For all purposes where tropical or other timber is used, other woods or materials could be substituted.

Policy, legislative and regulatory measures-enforcement and compliance

In Kenya, wide variety of policy statements and legislative and regulatory measures have been established to protect forests and major water towers but need to be effectively enforced. New modifications/adjustments are of course needed for site specific conditions due to difference in cultural, political and perception of the adjacent communities.

- **Encourage Participatory forest management and rights**

In Kenya, most of the forests are state owned including Mt. Elgon and Cherangany ecosystem, but the reach of government and the rule of law are weak. In order for forest management to succeed in Kenya, all parties with an interest in the fate of the forest should be communally involved in planning, management and sharing of the accrued benefits. But forest ownership and management rights are almost always restricted and restrictions on ownership and use define alternative tenure systems.

Land reform is essential in order to address the problem deforestation within Mt. Elgon and Cherangany ecosystem. However, an enduring shift in favour of the peasants is also needed for such reforms to endure (Colchester and Lohmann, 1993). Moreover, the rights of indigenous forest dwellers and others who depend on intact forests must be upheld. Therefore, the recognition of traditional laws of the indigenous peoples as indigenous rights will address the conflicts between customary and statutory laws and regulations related to forest ownership and natural resource use while ensuring conservation of forest resources by the indigenous communities within these Water towers.

- **Increase investment in research, education and extension**

Training and education of stakeholder's helps people understand how to prevent and reduce adverse environmental effects associated with deforestation and forestry activities and take appropriate action when possible to conserve and protect these water towers. Research substantiates it and helps to understand the problem, its cause, mitigation and challenges. There is a lack of knowledge and information in the general community about forests and forestry.

- **Improve the information base and forest monitoring**

Information on the forest distribution and coverage, biodiversity and forest poverty is inadequate for forest management within the Kenyan water towers. Current and accurate knowledge of how much forest, where it is and what it is composed of seems to be straightforward but surprisingly this most basic information is not always available within these Kenyan water towers. Within these ecosystems, it is not possible to properly manage a forest ecosystem without first understanding it. New remote sensing technologies make it feasible and affordable to identify hotspots of deforestation. The local and adjacent communities are very important in forest monitoring, the approach like citizen science that could help in forest monitoring efforts that would have immediate payoffs.

# 2.0 INTRODUCTION

## 2.1 General overview

The importance of forests in supporting life on earth cannot be overstated. The ecological and socio-economic role played by forests support up to 80% of the earth's terrestrial biodiversity and the livelihood of 1.6 billion people around the world (FAO, 2010.). Distinctively, forests are important as water catchments, soil erosion barriers, source of timber and non-timber materials. Forests also provide some very important services in the new and growing leisure industry, which involves the 'none' consumptive use of biological diversity for example eco-tourism.

Forests also deliver very important ecosystem services. These constitute the direct and indirect contribution of forest ecosystems to human wellbeing. Such essential services include nutrient cycling, soil formation, oxygen production, carbon sequestration and climate regulation. Forest biodiversity also has a 'hidden' value locked up in the genetic stock whose potential value is not yet known.

Despite their indispensable role in supporting life on earth, forests are facing myriad threats mainly from land use changes. Land cover modification and conversion are driven by the interaction in space and time between biophysical and human dimension (Lambin et al., 2001). Social and economic forces often dictate how land is used. Human use is the important factor in land cover modification and conversion than natural change. Consequently, change of population is often investigated as one of the driving forces of global land use change. Demographic effects can be aggravated or dampened by the effect of other forces driving global land use change, such as technological innovation, change of lifestyle or political decisions (Lambin et al., 2001). The competing forms of land use; forests and other agricultural land, are often linked directly to population growth.

Following its direct impact on forest degradation, it is of paramount importance for stakeholders to understand the dynamics and extent of land cover change in order to come up with effective sustainable forest management options and forest related policies. This study set out to assess the land use and land cover change in Mt. Elgon and Cherangany hills forest ecosystem so as to inform the design of community level actions and policy decisions.

Forests cover only about three per cent of Kenya's land area, yet they provide crucial direct and indirect goods and services to its people and make a significant contribution to the national economy. About 70 per cent of Kenya's domestic energy comes from wood, for example, and out of the 20 million of fuelwood consumed annually, 95 per cent is collected from forests and rangelands (GoK, 2007).

Many forests in Kenya serve as essential wildlife habitats, and are traditionally important for cultural ceremonies and as sacred sites to local communities. It is estimated that 530 000 forest-adjacent households derive direct benefits from indigenous closed-canopy forests. This amounts to about eight per cent of Kenya's population (FAO, 2015a). Forests not only benefit communities living adjacent to the forest, but also those living miles away from the forest. This is through the critical role played by forests in climate regulation and water catchment. For this function, the major forest blocks in Kenya are termed as 'water towers.' These include Mount Kenya, the Aberdare Range, the Mau Forest Complex, Mount Elgon, and the Cherangany Hills. The "water towers" are sources of water for irrigation, agriculture, industrial processes, as well as to all installed hydro-power plants, which produce about 60 per cent of Kenya's electricity output (GoK, 2007). This report will focus on the two forest ecosystem located in the western region of Kenya (Cherangany Hills and Mt. Elgon).

The density of the vegetation and the species diversity of the Mt. Elgon forest are about normal for this ecological zone. However, the commercial and the subsistence values of the forest is regarded as below normal (Hitimana et al., 2004). Over the past 5 years, the density of trees have decreased due to clearing and over-exploitation of some species. Forest fires have also destroyed some trees, causing overgrowth of non-palatable species. The destruction caused on trees by medicine harvesters, and big animals have also contributed to decrease in tree species and density.

The western block of the Cherangany forest, which totals approximately 20,000 Ha comprises of Kapkanyar, Kapolet and Kiptaberr Forest Reserves. The eastern block, which comprises of Lelan, Embotut, Kerrer, Kaisungor,Toropket, Chemurokoi, Kupkunurr, Cheboit,Sogotio and Kapchemutwa Forest Reserves are less well connected. Apart from a large south-eastern block along the escarpment, these forests are fragmented and separated by extensive natural grasslands, scrub and farmlands especially in the central part of the ecosystem. This close proximity of the people to the forest reserves over an extensive distance along the boundaries poses a major challenge to the institution of proper management of the forest areas.

The Cherangany hills forest ecosystem is important as a water catchment as it is situated between Lakes Victoria and Turkana basins. The streams from the watershed flowing to the west feed the Nzoia River and into Lake Victoria while those to the east flow into Kerio River and eventually Lake Turkana.

Mapping land use Land cover, even for only a limited number of classes, is a large undertaking with many challenges that are unique to each of the ecosystem. For a given class, many different forest types and physiognomy within Mt. Elgon and Cherangany ecosystems give rise to great variations in their spectral or seasonal properties. This will therefore require adequate baseline information regarding the current and past status of Land use, forest distribution and the use of flexible stratification in the mapping of Mt. Elgon and Cherangany ecosystems. This project employs supervised classification for image classification so as to classify the various land uses within the two ecosystems.

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This project aims to carry out a baseline survey to inform on what has been done and what remains to be done in classifying the various land uses and land cover change in the two ecosystems. The results will also facilitate identification of degradation hotspots and their associated drivers for land use land cover change. The findings of the report aim to avail recommendations to inform design and approach for the rehabilitation and conservation of the two ecosystems.

# 3.0 LITERATURE REVIEW

## 3.1 Introduction

Forests cover 30% of the Earth's land area, or nearly 4 billion hectares, and are essential to human wellbeing, sustainable development and the health of the planet. An estimated 1.6 billion people (25% of the global population) depend on forests for subsistence, livelihood, employment and income generation. Forests provide essential ecosystem services, such as timber, food, fuel, fodder, non-wood products and shelter, as well as soil and water conservation and clean air. Forests prevent land degradation and desertification and reduce the risk of floods, landslides and avalanches, droughts, dust and sand storms and other disasters. Forests are home to an estimated 80% of all terrestrial species. Also, forests contribute substantially to climate change mitigation and adaptation and in conservation of biodiversity.

Africa's forests and woodlands can be classified into nine general categories including tropical rain forests, tropical moist forests, tropical dry forests, tropical shrub lands, tropical mountain forests, subtropical humid forests, subtropical dry forests, subtropical mountain forests and plantations. Only 32.5 million ha of forests and woodlands, or 5 percent of the total forest area, are formally protected. The forest sector in Africa plays an important role in the livelihoods of many communities and in the economic development of many countries. This is particularly so in Western, Central and Eastern Africa where there is considerable forest cover (UNEP 2006).

Africa has a high per capita forest cover of 0.8 ha per person compared to 0.6 ha globally. On average, forests account for 6 percent of GDP in Africa, which is the highest in the world. In Uganda, for example, forests and woodlands are now recognized as an important component of the nation’s stock of economic assets and contribute in excess of US$ 546.6 million to the economy through forestry, tourism, agriculture and energy (NEMA 2008). The state of Rwanda’s forests and woodlands and their importance to the national economy is also well documented. Forests are designated as protected areas which host game parks and forest reserves and make contributions to the national economy by supplying renewable sources of energy in the form of wood fuel and charcoal. They also make an indirect contribution to sustainable agriculture and are sources of medicines, fodder, honey, essential oils, as well as handicraft and construction materials. However, they are also threatened with mining, fires and poaching (REMA, 2009).

Forests are central to the long-term social and economic development goals of New Partnership for Africa's Development (NEPAD) and will play an important role in meeting the Sustainable Development Goals. They provide energy, food, timber and non-timber forest products and are important contributors to wealth and health at the household, community, national, sub-regional, regional and even global levels. Forests and woodlands still remain key components of the environment that provide essential services to African countries where they play a critical role in combating land degradation and climate change as well as conserving wetlands, coastal areas and freshwater systems.

## 3.2 Forest Policy Issues

In the East African region, policy issues in management of montane forests are deliberated upon under the umbrella of the East Africa Community which oversees the East African Treaty of 1999 (Better Globe, 2009). The rivers flowing from the Mau Forest Complex in Kenya drain into five lakes, three of which are international water bodies: Lake Victoria (shared by Kenya, Uganda and Tanzania), Lake Natron (shared by Kenya and Tanzania) and Lake Turkana (shared by Kenya and Ethiopia). All the five rivers, which flow into Lake Victoria, form part of the Nile Basin. Increased sediment influx from these five rivers and from the Kagera River annually costs farmers in excess of US$ 40 million worth of lost soil. Such a high sediment or nutrient load into the lake is a major contributor to the expansion of the areas covered by the water hyacinth, an invasive plant with a negative impact on fisheries and associated economic activities.

The sediment load is particularly high during flash floods and can be mitigated by maintaining a good forest cover in the upper catchment areas (Better Globe, 2009). In this regard, regional programmes such as the Nile Basin Initiative and others which focus on safeguarding common resources such as Lake Victoria should be facilitated to fulfil their mandates (UNEP 2007). On a broader level, the NEPAD programme on forests and woodlands is critical to the success of the other NEPAD programmes, including those on combating land degradation and climate change and on conserving wetlands, and coastal and freshwater resources.

Even though there is growing public recognition of the benefits of these ecosystems, they are increasingly under threat from deforestation and nearly 13 million ha are lost every year. Deforestation rates are particularly high in the tropical countries. It is estimated that some 1.8 billion of wood are harvested annually for wood fuel (GEF 2009). Protected areas are considered one of the most efficient and cost-effective options for conserving forests. The world's forests are estimated to contain about 80 percent of above-ground and 40 percent of below ground terrestrial carbon. At present, there is more carbon stored in forests than in the earth's atmosphere.

International agreements which touch on the conservation and management of forest resources include the CBD and the United Nations Framework Convention on Climate Change (UNFCCC), both of which have been in force since 1992. Kenya is a signatory to these and a number of other multilateral environmental agreements (MEAs), including the 1971 Ramsar Convention.

## 3.3 Global Development Goals relevant to Forest Conservation

The development of an international forest policy has been going on since the 1980s and especially so after the Rio Summit, the United Nations Conference on Environment and Development (UNCED) in 1992. Despite these efforts, the global natural forest cover was lost at a rate of about 13 million hectares per year between 1980 and 2010 (FAO, 2010). Currently, forest degradation and deforestation are major contributors to the total global greenhouse gas emissions.

Deforestation is thus a major contributor to climate change and with it the increased frequency of natural disasters experienced globally. Some countries like Rwanda, Costa Rica, China and Vietnam have reversed the trend of national deforestation. The loss of forests is also a major problem in many African countries including Kenya. The African Union has fully recognised this: In this regard, during the last decade Kenya has been active in taking definite steps to reduce forest degradation and deforestation. The country has increasingly participated in international forest dialogues and has embraced international approaches to enhance sustainable forest management at national and local levels.

A series of international events have led to a new international forest agenda. Forest development is now considered an integral part of sustainable development. The need to integrate sustainable development with forest development became a central element in the United Nations Conference on Environment and Development, also known as the Earth Summit. An outcome of the conference was a recognition declared worldwide that sustainable development and forests are inter-twined dynamics. Forestry was specifically referred to in chapter 11 of Agenda 21 under "Combating Deforestation". A subsequent outcome was the Forest Principles, a set of guiding principles for Sustainable Forest Management.

Between 1995 and 1997, dialogue on forests took place in the Intergovernmental Panel on Forests, which was transformed into the Intergovernmental Forum on Forests 1997–2000, and again in 2002 into the UN Forum on Forests (UNFF). In 2000, the United Nations General

Assembly adopted the Millennium Development Goals. Forestry development was specifically related to most of the Millennium Development Goals. At the World Summit on Sustainable Development held in South Africa in 2002, sustainable development was recognised as the overarching goal. The MDGs were presented for implementation. In the same year, the UNFF developed the landmark Non-Legally Binding Instrument on all types of forests, commonly known as the Forest Instrument, entailing four Global Forest Objectives (FAO, 2013b). The four Global Forest Objectives include; Reverse the loss of forest; Enhance forest-based economic, social and environmental benefits; Increase significantly the area of sustainably managed forests, including protected forests, and increase the proportion of forest products derived from sustainably managed forests; Reverse the decline in official development assistance for sustainable forest management (UNFF Secretariat, 2014).

The Sustainable Development Goals succeeded the Millennium Development Goals as the international development agenda from 2015. Forests have received remarkable attention from the SDGs dialogue on multiple aspects. In the SDGs, forests are addressed directly under three SDGs: 13,14,15; SDG13: Take urgent action to combat climate change and its impacts; SDG14: Conserve and sustainably use the oceans, seas, marine resources for sustainable development; SDG15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss.

Recognising multiple functions of forests, the SDGs set out strong forest-based targets: By 2020, ensure conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems with their services, in particular forests, wetlands, mountains and dry lands, in line with obligations under international agreements (SDG15.1). By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests, and increase afforestation and reforestation (SDG15.2). Significantly mobilise resources from all sources and at all levels to finance sustainable forest management, and provide adequate incentives to developing countries to advance sustainable forest management including conservation and reforestation (SDG15.b). By 2020, protect and restore water-related ecosystems including mountains, forests, wetlands, rivers, aquifers and lakes (SDG6.6). By 2030, achieve the sustainable management and efficient use of natural resources (SDG12.2).

However, the SDGs do not capture the true value of forests nor tackle drivers of deforestation nor ensure more focus on social balances in the use of and benefit from forests. Such priorities must instead be refined and adopted through a national strategic forest framework, notably, national forest programmes (adapted from IIED 2014a; IIED2014b; IIED 2014c).

## 3.4 Approaches to Forest Conservation

### 3.4.1 Sustainable Forest Management

Developments in forest management over the past decade have focused on progress towards Sustainable Forest Management (SFM), an approach that balances environmental, sociocultural and economic objectives of management in line with the "Forest Principles" adopted at the United Nations Conference on Environment and Development (UNCED) in 1992.

Parallel efforts in biodiversity conservation, particularly within the framework of the Convention on Biological Diversity, have led to the development of the Ecosystem Approach (EA) as a framework and holistic approach for the conservation and sustainable use of biological diversity and its components in all types of ecosystems.

The guiding objective of the Forest Principles is to contribute to the management, conservation and sustainable development of all types of forests and to provide for their multiple and complementary functions and uses. Principle 2b specifically states that: "Forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations." It goes on to specify that: "These needs are for forest products and services, such as wood and wood products, water, food, fodder, medicine, fuel, shelter, employment, recreation, habitats for wildlife, landscape diversity, carbon sinks and reservoirs, and for other forest products." And that: "Appropriate measures should be taken to protect forests against harmful effects of pollution, including air-borne pollution, fires, pests and diseases, in order to maintain their full multiple value."

### 3.4.2 The Ecosystem Approach

The Ecosystem Approach, as developed under the CBD, builds on previous, similar approaches such as the so-called "systemic approach" applied to the management of natural resources by the Man and Biosphere (MAB) programme of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in the 1970, the ecosystem management approach, developed in the US forestry sector in the 1980s, similar developments in Canada and other countries as well as work undertaken by the Commission on Ecosystem Management of the World Conservation Union (IUCN), the World Wide Fund for Nature (WWF) and other environmental non-governmental organizations.

The Convention on Biological Diversity (CBD) describes the Ecosystem Approach as follows (CBD 2000): The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. And further: An ecosystem approach is based on the application of appropriate scientific methodologies focused on levels of biological organization, which encompass the essential structure, processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of many ecosystems.

As concerns the term "ecosystem": it can refer to any functioning unit at any scale. Indeed, the scale of analysis and action should be determined by the problem being addressed. It could, for example, be a grain of soil, a pond, a forest, a biome or the entire biosphere.

## 3.5 Characteristics of Kenya's Forests and Water Towers

According to the last inventory undertaken in 2010 (KFS, 2013a), forests in Kenya occupy 6.99% of the land area. These forests are categorised as Montane, Western rainforest, Bamboo, Afro-montane undifferentiated forest, Coastal and Dryland forests. The montane forest and the coastal forest regions are the most forested with 18% and 10% forest cover, respectively.

Natural forests in Kenya are made up of montane forests, which occupy about 2% of the total land area (1.14 million hectares). A considerable area of 2.13 million hectares consists of bushland and mangroves. Public and private plantations constitute 220, 000 hectares (FAO, 2015d).

Analysis of change in forest cover over the last 25 years revealed improved afforestation activities. Forest land has decreased by 311,000 ha while crop land increased by 1,018,000 ha between 1990 and 2015. Between 1990 and 2000, Kenya lost approximately 1.2 million ha of forestland, equivalent to 25% of forest cover.

However, there is a remarkable increase in forest cover from 6.01% in 2000 to the predicted 7.46% in 2015. This is equivalent to an annual increase of 0.1%.

Most (77%) of the forest land in Kenya is under community and private ownership while 23% is public. Private plantations cover 47% of the total forest plantation area, which is almost equal to the area of stocked plantations under public management (53%).

The five “water towers” of Kenya — Mount Kenya, the Aberdare Range, the Mau Forest Complex, Mount Elgon, and the Cherangany Hills — are montane forests and the five largest forest blocks in the country. They form the upper catchments of all the main rivers in Kenya (except the Tsavo River originating from Mt. Kilimanjaro). The “water towers” are sources of water for irrigation, agriculture, industrial processes, as well as to all installed hydro-power plants, which produce about 60 per cent of Kenya’s electricity output.

These montane forests are also surrounded by the most densely populated areas of Kenya, because they provide enough water for intensive agriculture and urban settlements (DRSRS and KFWG 2006). Their importance in the supply of timber and non-timber products to the communities living within their surroundings cannot be over emphasized. As such these forests are important and support livelihoods for all Kenyans in one way or another. At the same time, however, they are being lost or degraded by extensive illegal, irregular, and ill planned settlements and illegal forest resource extraction.

Such extensive and on-going destruction of the country’s natural assets and their economic value is a matter of national concern. This section presents each of the two “water towers” of interest and describes their changing physical conditions over time. Assessing changes in these two regions is important not only for ensuring the livelihoods of millions of Kenyans, but also for preserving their intrinsic beauty and richness.

### 3.5.1 Mt. Elgon Forest

Mt. Elgon lies north of Lake Victoria on the Kenya-Uganda border. Its Kenyan side is protected by Mt. Elgon National Park, Chepkitale National Reserve, and Mt. Elgon Forest Reserve; the latter covers 73 706 ha. Mt. Elgon forms the upper catchment area for two major rivers, the Nzoia and Turkwel. The forest contains globally threatened species, including some endemic to the Afro-montane region and others endemic to Mt. Elgon alone, making the area a priority for species conservation and a major attraction for tourists. A rapidly growing population of around two million people in the area around the mountain puts very high pressure on this unique ecosystem. Authorized logging has been practiced in Mt. Elgon since at least the 1930s. In the 1970s, land was excised from the Mt. Elgon Forest around Chebyuk where 600 families were settled to make way for a national game reserve. While a 1986 Presidential Decree banned all logging in Kenya's natural forests, it excluded Mt. Elgon where legal logging continues. Agricultural encroachment and charcoal production are degrading the forest in many areas as well. In many cases forest has been cleared for crops on slopes that are not suitable, making them susceptible to erosion and landslides. Continued degradation and forest loss on Mt. Elgon threatens to undermine the area's crucial role as a water catchment for the surrounding region and will reduce the viability of the ecosystem itself.

### 3.5.2 Cherangany Hills Forest

The Cherangany Hills, an ancient fault-block formation of non-volcanic origin, are a series of gently rolling hills that form an undulating upland plateau on the western edge of Kenya's Rift Valley. They lie between the Elgeyo Escarpment to the east and Mt. Elgon to the west, rising to 3,365 m above sea level at Cheptoket Peak in the north-central section. Located on the Cherangany escarpment, the hills are largely covered by a series of gazette indigenous Forest Reserves. River Nzoia has its source in these Hills. Over the last 20 years, local inhabitants have encroached on the forest land converting it to farmlands.

Because the Cherangany Hills are one of the five most important water catchment areas in Kenya, a joint project of UNEP and the Department of Resource Survey and Remote Sensing monitored the change in forested area between 2000 and 2003.

It found that the Cherangani Hills were the least affected of the five forested water towers, with 174.3 ha deforested. Since this forest cover is indigenous, however, it was recommended that the area be closely watched to prevent further destruction. The forests of the Cherangany Hills bear scenic features suitable for ecotourism and are home to the rare De Brazza's Monkey. The Hills are also classified as an Important Bird Area (IBA) with over 73 forest-dependent species recorded of which four species are regionally threatened.

## 3.6 Underlying Principles of Land use land cover change studies

It is estimated that undisturbed (or wilderness) areas represent 46% of the earth's land surface. Forests covered about 50% of the earth's land area

8000 years ago, as opposed to 30% today. Agriculture has expanded into forests, savannas, and steppes in all parts of the world to meet the demand for food and fiber (Lambin et al., 2003). Land use in East Africa has changed swiftly over the last half-century: expansion of mixed crop-livestock systems into former grazing land and other natural areas and intensification of agriculture are the two largest changes that have been detected (Olson and Maitima, 2006).

According to Lambin (2005) sustainable resource use refers to the use of environmental resources to produce goods and services in such a way that, over the long term, the natural resource base is not damaged so that future human needs can be met. One of the most significant global challenges in this century relates to management of the transformation of the earth's surface occurring through changes in land use and land cover (Mustard et al., 2004). Land use and land cover changes may be grouped into two broad categories as conversion and modification. Conversion refers to changes from one cover or use type to another, while modification involves maintenance of the broad cover or use type in the face of changes in its attributes (Daniels et al., 2008).

Accordingly, land cover classification has recently been a hot research topic for a variety of applications (Liang et al., 2002). A great deal of research has been conducted throughout the world in an attempt to understand major shifts in land use and land cover and to relate them to changing environmental conditions. According to Daniels et al. (2008), during the next decades, land-use dynamics will play a major role in driving the changes of the global environment. Hence, global mapping of irrigated and dry land agriculture, semi-natural areas and forest cover, reflecting their dynamics, can contribute to the assessment of the biophysical implications of land use and land cover change within the Earth's system. Generally, agriculture is found tobe the major driver of land cover change in tropical regions (Daniels et al., 2008). Over the past 50 years in East Africa, there has been expansion of agriculture at the expense of grazing land (Olson and Maitima, 2006). Before 1950, semi-arid and sub-humid areas were predominantly pastoral with scattered settlement and cultivation but from then onwards, there has been significant transformation of grazing land to mixed crop-livestock agriculture. Understanding the mechanisms leading to land use and land cover changes in the past is crucial to understand the current changes and predict future ones. These changes occurred at different time periods, paces, and degrees of magnitude and with diverse biophysical implications (Liang et al., 2002).

Therefore, Land use and land cover change (LUCC) research needs to deal with the identification, qualitative description and parameterization of factors which drive changes in land use and land cover, as well as the integration of their consequences and feedbacks (Baulies and Szejwach, 1998). However, one of the major challenges in LUCC analysis is to link behavior of people to biophysical information in the appropriate spatial and temporal scales (Codjoe, 2007). But, it is argued that land use and land cover change trends can be easily assessed and linked to population data, if the unit of analysis is the national, regional, district or municipal level.

Land use and land cover changes result from various natural and human factors within social, economic and political contexts. Hence, the local human activities expressing the drivers can be determined by measuring the rates and types of changes and analyzing other relevant sources of data like demographic profiles, household characteristics and policies related to land resources administration.

To achieve this, it is crucially important to consider multiple sources of information and to acquire temporal, spatial and other non-spatial forms of data. This is due to the fact that land use attributes are complex and the boundaries between different types of data are quite diffuse (Baulies and Szejwach, 1998). LUCC studies have been designed to improve understanding of the human and biophysical forces that shape land use and land cover change. Thus, linking human behavior and social structures to biophysical attributes of the land is a fundamental aspect of LUCC research (Baulies and Szejwach, 1998). Land use and land cover plays an important role in global environmental change and sustainability, including response to climate change, effects on ecosystem structure and function, species and genetic diversity, water and energy balance, and agro-ecological potential (Codjoe, 2007).

Land use and land cover mapping is one of the most important and typical applications of remote sensing data (Chrysoulakis et al., 2004). Remotely sensed data are a useful tool and have scientific value for the study of human environment interactions, especially land use and land cover changes (Codjoe, 2007).

## 3.7 Application of Remote Sensing for Land Use and Land cover Change

There is significant variation between various sensor instruments' capability and wealth of information captured and also the applicability depends on the objective of the intended study. There is also clear variation in the spatial and spectral properties of satellite images acquired by different versions of a particular sensor instrument. Landsat instruments can be taken as a good example of showing continuous improvement in radiometric and spectral property of images enabling better understanding of land resources.

Since 1972, the Landsat satellites have provided repetitive, synoptic, global coverage of high-resolution multispectral imagery. Their long history and reliability have made them a popular source for documenting changes in landcover and use over time (Turner et al., 2003) and their evolution is further marked by the launch of Landsat 7 by the US government in 1999. Multispectral Scanner (MSS) data from the U.S. Geological Survey's (USGS) EROS Data Center (EDC) has provided a historical record of the Earth's land surface from the early 1970s to the early 1990s. The MSS and TM sensors primarily detected reflected radiation from the Earth's surface in the visible and IR wavelengths, but the TM sensor provides more radiometric information than the MSS sensor (http://edc.usgs.gov/guides/landsat_mss.html#mss4).

The wavelength range for the TM sensor is from the visible (blue), through the mid-IR, into the thermal-IR portion of the electromagnetic spectrum and it has a spatial resolution of 30 meters for the visible, near-

IR, and mid-IR wavelengths and a spatial resolution of 120 meters for the thermal-IR band. Each pixel of Landsat TM images contains a wealth of information about the surface materials that reflect light from that pixel to the satellite sensors. Each band in a TM image represents a separate piece of data whose value ranges from 0 to 255 enabling the whole image to contain 2565 (approximately 1.1billion) different possible spectral combinations. However, it does not mean that each one of these combinations represents a different type of land cover and most of these variations represent very small and, to us, "unseeable" differences in surface reflectance. ETM+ instrument measures upwelling radiance in the same seven bands as the TM, and has an additional 15 m resolution panchromatic band (Mather, 2004). The spatial resolution of the thermal infrared channel is 60 m rather than the 120 m of the TM thermal bandand this instrument has substantially the same operational characteristics asLandsat-4 and Landsat-5. All the Landsat image archives used for this study were acquired from ILIR's information database.

The characteristics of the MSS and TM bands 4,3,2 and 1 were selected to maximize each band's capabilities for detecting and monitoring different types of land surface cover characteristics. For example, MSS band 1 can be used to detect green reflectance from healthy vegetation, while MSS band 2 is designed for detecting chlorophyll absorption in vegetation. MSS bands 3 and4 are ideal for recording near-IR reflectance peaks in healthy green vegetation and for detecting water land interfaces. MSS Bands 4, 2, and 1 can be combined to make false-color composite images, where band 4 controls the amount of red, band 2 the amount of green, and band 1 the amount of blue in the composite. This band combination makes vegetation appear as shades of red with brighter reds indicating more vigorously growing vegetation. Soils with sparse or no vegetation will range from white (sand) to green or brown, depending on moisture and organic matter content. Water appears dark blue to black in color, while sediment-laden or shallow waters appear lighter in color. Urban areas appear blue-gray in color.

## 3.8 Approaches in image classification

Remote sensing change detection techniques can be broadly classified as either pre- or post-classification change methods. A pre-classification process refers to operations carried out to bring satellite images to the desirable geometric and spectral standard by correcting errors, and it is performed prior to image classification. Whereas, post-classification methods refers to activities done after classification of images like computation of class statistics, accuracy assessment, and map preparation. Pre-classification methods can further be characterized as being spectral or phenology based. Originally, the post-classification approach was considered to be the most reliable approach and was used to evaluate emerging methods (EPA, 1999). Factors that limit the application of post-classification change detection techniques include cost, consistency, and error propagation (EPA, 1999). Numerous pre-classification change detection approaches have been developed and refined to provide optimal performance over the greatest possible range of ecosystem conditions (Lunetta et al., 2006).

The satellite instruments employed some decades ago provided images with coarse resolution. With advancement in remote sensing science, various sensor instruments with improved radiometric, temporal and spatial resolution were being developed. Hence, this allowed the integration of satellite images acquired by various sensor types in order to better understand land resources dynamics. The use of data from different sensors poses a serious challenge to many change analyses, which can be addressed through use of post classification comparisons (EPA, 1999).

## 3.9 Approaches in Land Use and Land Cover Change Detection

Research evaluating the comparative performance of various land cover change detection methods has indicated that no uniform combination of data types and methods can be applied with equal success across different ecosystems (Lunetta et al., 2006). Despite this, the two general approaches to change detection are comparative analysis of independently produced classifications, and simultaneous analysis of multi-temporal data. Examples of the simultaneous analysis techniques include image differencing, ratioing, principal component analysis (PCA), and change vector analysis (EPA, 1999). The first approach is straight forward and employs independently classified images being converted to same projections and it has the advantage that it allows compensating for variations in atmospheric and phenological conditions. The method has been criticized as it tends to compound errors that may have occurred in the two initial classifications (EPA,1999). On the other hand, simple image differencing is a widely used technique that involves taking the mathematical difference between geo-registered images from two dates (EPA, 1999). Even if the method has often been reported to produce excellent results, it has been suggested that image differencing alone may be too simple a procedure to adequately describe many surface changes (EPA, 1999).

A major attribute of the landscape is its spatial pattern and structure. It is shown that the detection of land-cover change processes by remote sensing is improved when both spectral and spatial indicators of surface condition like slope and topography are used (EPA, 1999). It is further suggested by this author that spectral indicators are more sensitive to fluctuations in primary productivity associated with the inter-annual variability in climatic conditions. Temporal aspects of natural phenomena are important for image interpretation because such factors as vegetation growth and soil moisture vary during the year, and hence, more positive results can be achieved by obtaining images at several times during the annual growing cycle (Lillesand and Kieffer, 2004). Furthermore, changes in landscape spatial pattern are more likely to reveal long term and long-lasting land cover changes.

Following image classification as part of the change detection process, accuracy needs to be assessed to evaluate the degree of acceptability of the classification process. A standard accuracy assessment procedure for baseline land cover products involves the use of the error matrix (EPA, 1999) and the standard procedure for one-point-in-time land cover products can be extremely difficult to apply to multi-temporal change analysis products (EPA,1999). The methods are well established for small areas and single time periods. However, the assessment of accuracies for large areas, past time periods, and change databases can become problematic (EPA, 1999) as it will be difficult to acquire an adequate data base of historical reference materials. Accordingly, accuracy assessments are usually limited to the very recent image that serves as a reference using ground control points (GCPs) collected as part of the data required for the change analysis.

## 3.10Drivers of Land Use Change

The many ways that people have used and managed land throughout history have emerged as a primary cause of land cover change around the world. Thus, land use and land management increasingly represent a fundamental change in the Global environment (Dale et al., 2000). Land use change is driven by a combination of socio-economic (e.g. income levels, infrastructure, demographic structure), political (e.g. land tenure, subsidies, nature protection) and biophysical (e.g. soil and climate characteristics) factors, the so called land use drivers. Dale et al., (2000) explained that the major determinants of land use and land cover change are physical, climatic and demographic factors, level of poverty, and economic and institutional structure of the resource use. It wasa also pointed out that human economic and social conditions influence pattern of land use, and that technological innovation affect how land is managed. These all are changing facets of human societies that the way land is used for the benefit of individual owners or for the members of the society.

In comparing the influence of man versus nature, Steffen et al. (2001) reported that human use is a more significant factor in land cover modification and conversion than natural change. Change of population is often investigated as one of the major driving forces of global land use change. It is positively associated with two other variables: technological capacity and levels of consumption (Steffen et al., 2001). In developing countries population growth, the major barrier to development is found to be the major driving force on land use change. Population increases always demand more food and this results in demand to bring more land under cultivation. As a country gradually advances towards technology and development, consumption per capita also increases thereby increasing the need for more production that ultimately results in more agricultural land and enhanced land use changes.

Inversely, many land use changes and their outcome are directly responsible for population growth (Dale et al., 2000). Demographic effects can also be aggravated or dampened by the effect of other forces driving global land use change, such as technological innovation, change of lifestyle or political decisions (Dale et al., 2000;). The competing forms of land use; forests and other agricultural land, are often linked directly to population growth.

The densely populated regions of Southeast Asia can be described as areas of land deficit. This deficit normally comes with negative repercussions ecological and climatic. Given these repercussions, it is very desirable that land is correctly allocated between the various types of land use. Growth of population leads to increasing demand for more agricultural land to produce more food encouraging the conversion of forests to agriculture. Population growth also increases the demand for wood, both for timber and for fuelwood, leading to wood scarcity. This in turn leads to deforestation on one hand and deterioration of agricultural land on the other hand as more and more agricultural residues, needed to maintain the nutrient contents of agricultural land, are being used as fuel in the rural areas due to wood scarcity. Steffen et al. (2001) also showed the agricultural sector as one of the main driver of deforestation. If this situation happens to exist for a long, forest cover will significantly reduce in most parts of the globe. Other driving forces of agricultural expansion are the degradation of biophysical environment, increased demand for land to grow cash crops and technological change (Stephenne and Lambin, 2001). Having shown this, it is important to note that there is no other way to conserve forests except careful planning of the land resources among different competing land uses for sound economic and environmental development of a country.

## 3.11Effects of Land Use Change

Changes in land use reflect the history of mankind. Economic development, population growth, technology and environmental change are directly linked with land use change. Rate of land use changes are often parallel rates of population growth (Houghton, 1994). During the past several thousand years, humans have taken an increasingly large role in the modification of the global environment (Chen et al., 2001).

In last few decades, the effects of land use change have become global, not only in the sense that changes in land use and their effects are present almost everywhere on the earth, but in the sense that they contribute to global changes in climate through increasing emission of greenhouse gases (Houghton, 1994). Land use activities are calculated to contribute from 20-75% of all atmospheric emissions of greenhouse gases (Chen et al., 2001). If the present growth trends in the world population, industrialization, pollution, food production and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next hundred years. Global climatic systems, biodiversity, soil and water quality are greatly influenced by the changes in land use and land cover (Chen et al., 2001).

Land use change also affects soil properties either in a positive or negative way. Deforestation, for example, negatively affects soil properties and enhances land degradation by reducing land productivity (Fischer and Sun, 2001). The conversion of forest to grasslands and permanent crops usually leads to less degradation. But conversion from forest or grassland to arable lands can have strong negative impact in terms of soil productivity.

# 4.0 METHODOLOGY

## 4.1 Data collection

The data used in this research were divided into satellite data and ancillary data. Ancillary data included ground truth data for the land cover/use classes and topographic maps for Mt. Elgon and Cherangany. The ground truth data were in the form of reference data points collected using Geographical Positioning System (GPS) from 25$^{th}$ May to 8$^{th}$ June

2016. Though, it was estimated that a total of about 648 points were to be collected from the formula, but this was not achieved due to inaccessible of some areas because of the terrain characteristics and insecurity reasons. Only a total of 415 ground reference points were collected during the exercise as shown in the table for image classification and overall accuracy assessment of the classification results.

**Table 1: Ground control points as the per the land use**

| S. No. | **Land cover type** | **No. of Points** |
|---|---|---|
| 1 | Build up area | 32 |
| 2 | Grassland | 33 |
| 3 | Farmland | 90 |
| 4 | Forest | 144 |
| 5 | Water body | 46 |
| 6 | Shrub land | 32 |
| 7 | Riparian vegetation | 16 |
| 8 | Wetland | 18 |
| **Total** | | 411 |

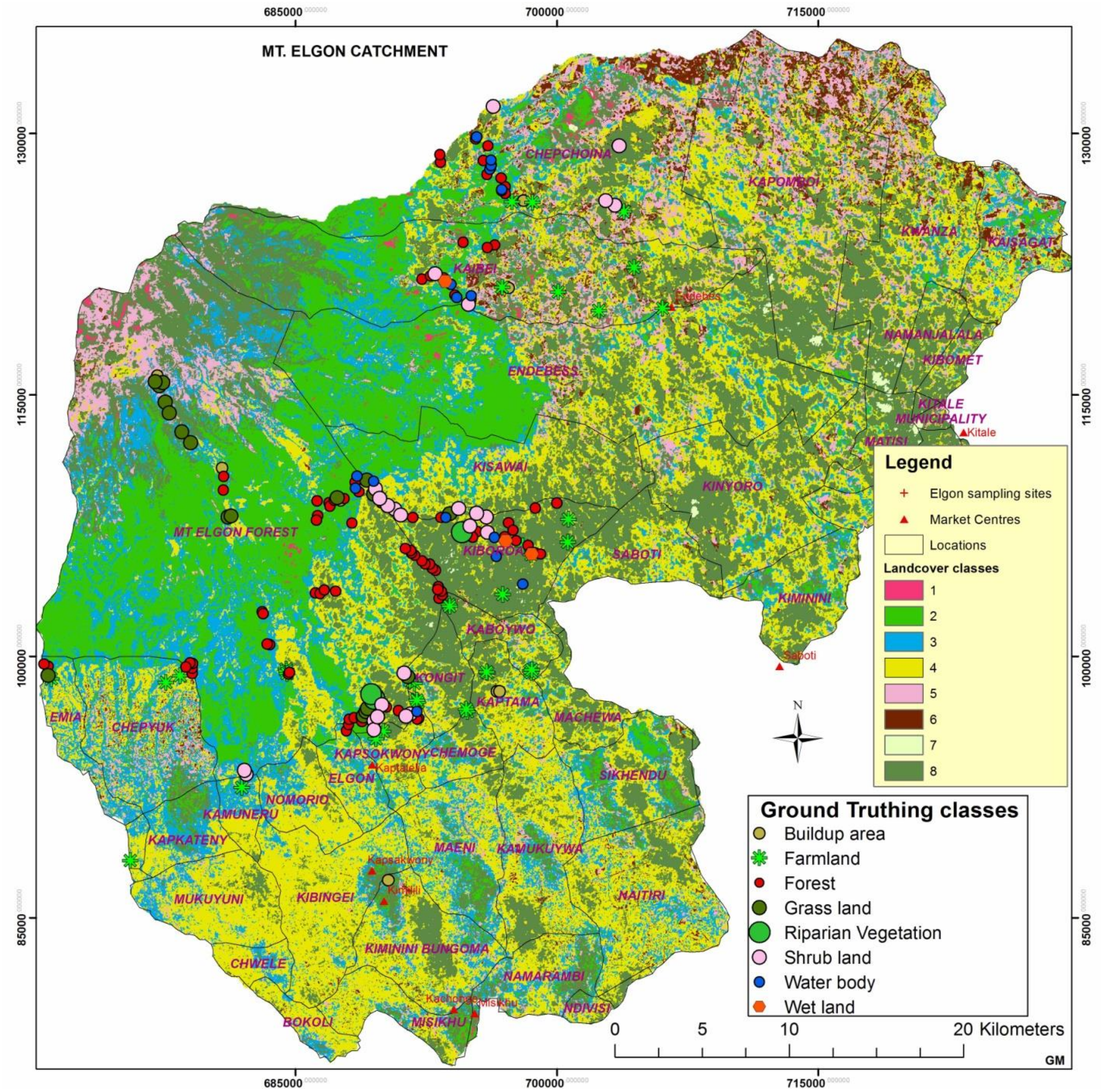



**Figure 1: Map showing distribution of ground control points in Mt. Elgon**

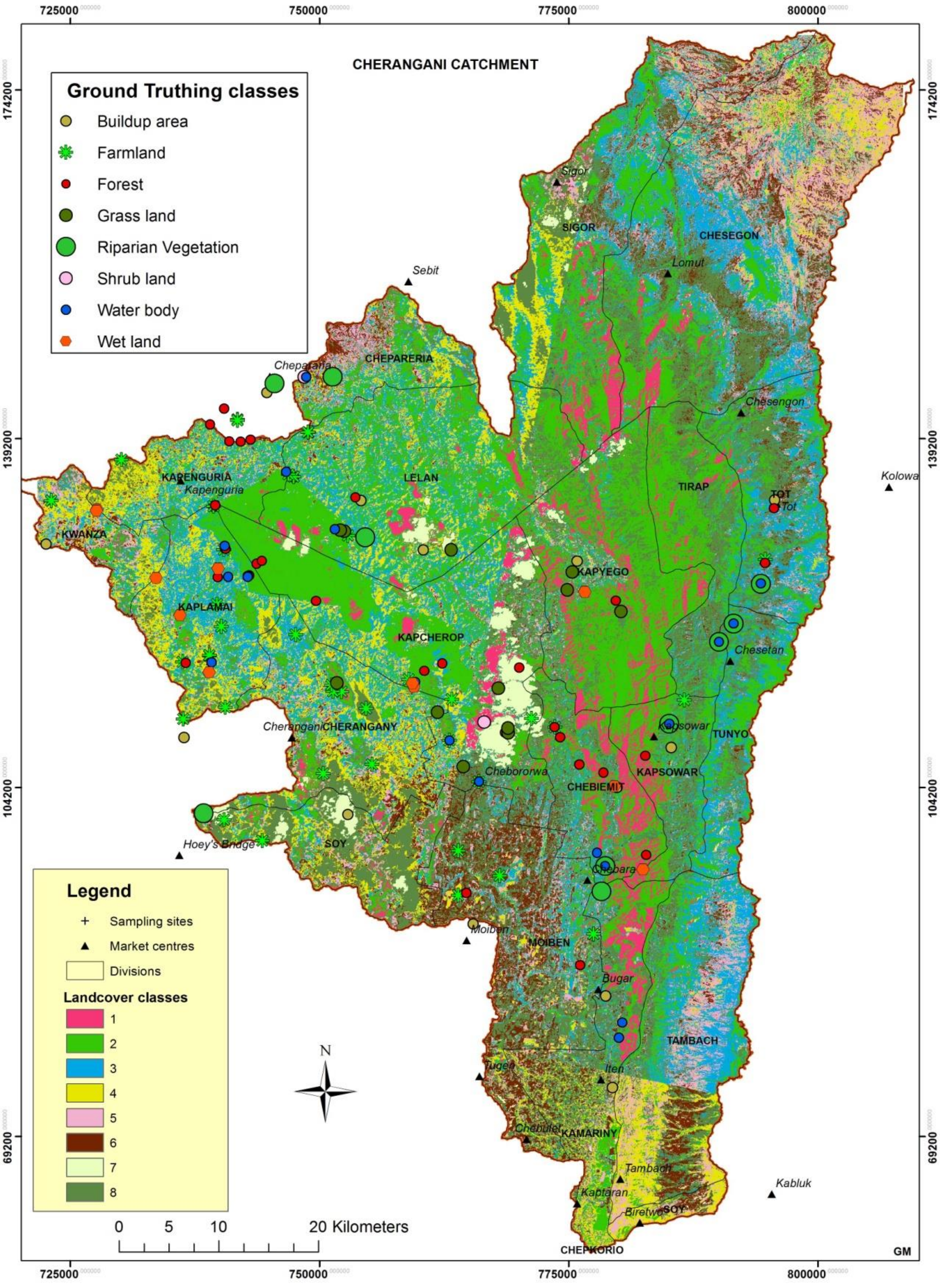



**Figure 2: Map showing distribution of ground control points in Cherangany**

## 4.2 Satellite image data

In conducting land cover land use change analysis, Landsat series images acquired from 1985 and 2000 was used for Mt. Elgon and Cherangany ecosystem. The initial year of 1985 was informed by the availability of the past images. It should be noted that Cherangany ecosystem is larger in coverage and require multiple scenes of the same time for change analysis. This led to discontinuity in time intervals as it was impossible to have complete coverage of all the scenes for the whole ecosystems of the same time acquisition. Landsat satellite images of the year 1985, 1995 and 2000 for Mt. Elgon were used while images of 1985, 1995 and 2003 were used for Cherangany ecosystem. Six land use classes were identified namely; Farm land, open forest, closed forest, Grassland, Water bodies and others (bare surface, riparian vegetation, etc.)

## 4.3 Image Preprocessing

### 4.3.1 Geometric correction and orthocorrection

In temporal change detection, the thematic accuracy of the output is directly proportional to the product of the categorical accuracies and relative spatial accuracy of the input classified images. In turn, classification often depends on absolutely accurate image datasets in, for example, the combining of the imagery with ancillary large-scale maps to refine the classifications and/or in accuracy assessment. Such absolute accuracy is also important when relating the image data to ground-collected biophysical measurements. All of the intended outputs of the current project within Mt. Elgon and Cherangany (land cover classifications and their change over time, degradation assessment and mapping as determined from ground measurements collected with a Global Positioning System [GPS] during ground trothing activity) therefore rely on images that are geometrically as accurate as possible in both a relative and absolute sense.

Therefore, to produce accurate result from the images geometric correction was undertaken on all the images following the required procedure followed by an orthocorrection using ASTER Digital Elevation Model to further enhance the image geometry by accounting for the significant spatial distortion caused by relief displacement

### 4.3.2 Image Correction for Noise

The brightness value measured for any given object is influenced by factors such as changes in scene illumination, atmospheric conditions, instrument response characteristics and viewing geometry. In the current project, considerably more of these influences needed to be considered rather than if, for example, a single-image, broad classification was carried out. This was not just due to the outcomes of the activity (classification, change detection and biophysical models), but also to the fact that a multitemporal, multispatial dataset was being used. Correcting radiometry between adjacent scenes and across time was also considered when deciding which corrections to apply.

The radiometric error considered and possible corrected, was image noise produced by sensor irregularities. Noise correction partly involves calibrating the radiometry between each of the detectors, for each band, in each era. This procedure reduces much of the scan line striping inherent in imagery, produced by irregularities between the many different detectors within scanning systems.

### 4.3.3 Conversion to Top of Atmosphere reflectance

The next process in radiometric correction involved conversion of the measured multispectral brightness values to top of atmosphere (TOA) reflectance units. This normalization procedure is crucial when creating multitemporal and/or multispatial mosaics as it largely removes variations between these images due to sensor differences, Earth-sun distance and solar zenith angle (caused by different scene dates, overpass time and latitude differences). The process involved two steps. The first step involved conversion of measured DN to radiance using inflight sensor calibration parameters. These parameters are supplied with the imagery and are determined from comparison of inflight calibration sources with pre-flight absolute radiance values. The exact radiometric response function for each band could therefore be determined and applied to normalise temporal radiometric differences between sensors.

The second step involved calculating top of atmosphere (TOA) reflectance for each band, which corrected for illumination variations (sun angle and Earth-sun distance) within and between scenes. The correction was applied on a pixel by pixel basis for each scene in each era.

## 4.4 Image classification

**Image classification** is the process of assigning land cover classes to pixels. There are two major types of classification which include unsupervised and supervised classification. For this project, supervised classification was applied. The first attempt was made to classify the various land uses in ENVI and results exported to ArcGIS, image processing software using supervised classification techniques. In supervised classification, spectral signatures were developed from training sites collected during ground trothing activity in Mt. Elgon and Cherangany ecosystem in the image. These specified locations are given the generic name 'training sites' and are defined by the user. The training sites directed the image analysis softwares develop spectral signatures for the outlined areas. The land use categories of interest in this example are water, agriculture, grassland, and forest.

## 4.5 Change detection and analysis

The dominant causative factors of the different types of land degradation within Mt. Elgon and Cherangany ecosystem were identified in the field during socio-economic survey, ground trothing activity and also collected from the available technical reports. The main type of human induced land degradation in the investigated areas is farming, illegal logging for timber and charcoal burning within the ecosystem. Classified image images acquired at different periods covering Mt. Elgon and Cherangany ecosystem were compared using cross-tabulation in order to determine qualitative and quantitative aspects of the changes in terms of Land use land cover and degradation for the periods from 1985 to 2000.

As reported by Weng, (2001), a change matrix is generated from this process. Quantitative areal data of the overall land use/cover changes as well as gains and losses in each category between 1985 and 2000 are then compiled.

These degradation variables were assessed showing the changes that occurred during the period of 1985 and 2000 for human induced land degradation using multi-dates satellite images.

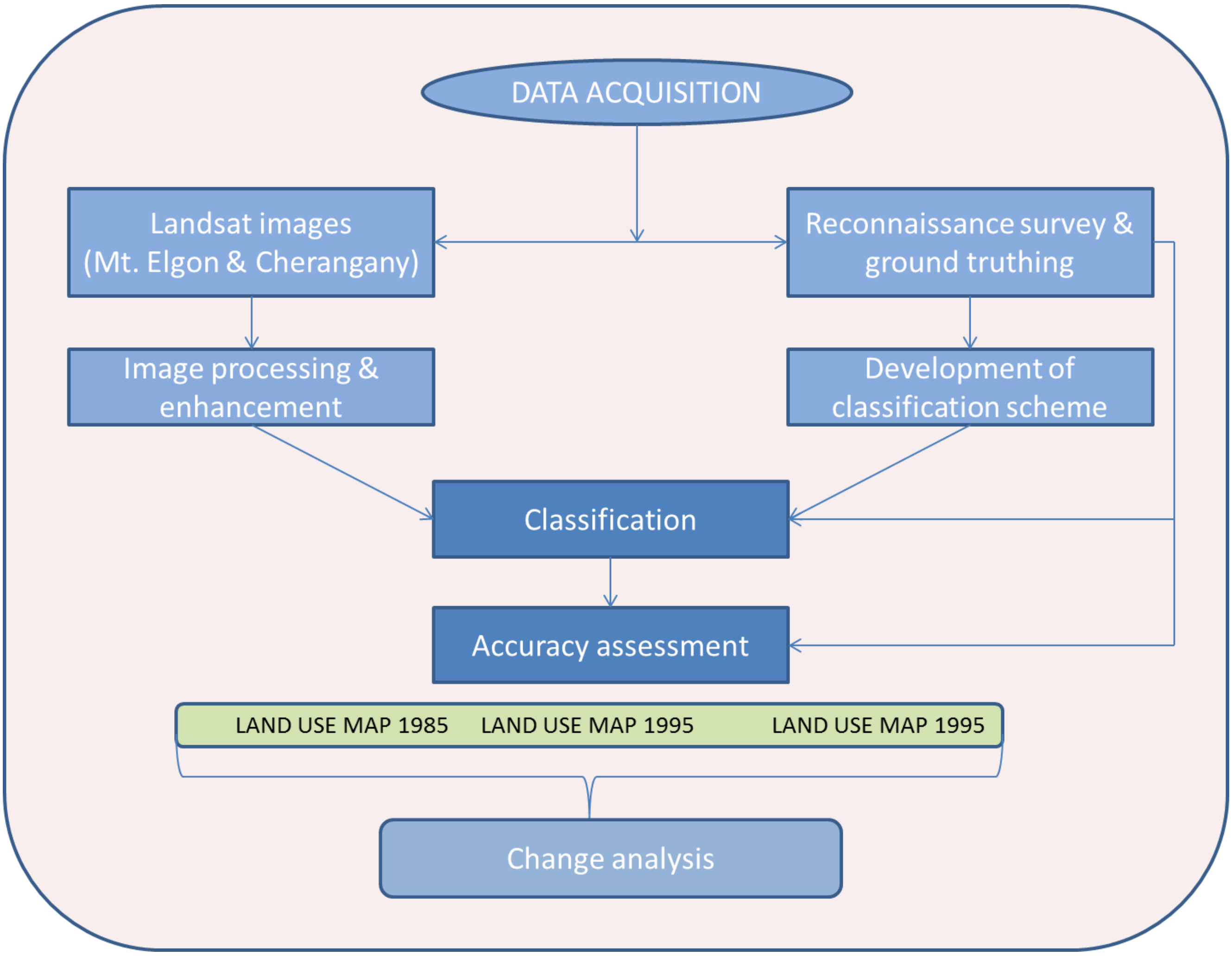



**Figure 3: Summary of Methodology used in Change analysis**

## 4.6 Current Land Use Land Cover Maps for the ecosystem

Mapping land use Land cover, even for only a limited number of classes, is a large undertaking with many challenges that are unique to each of the ecosystem. For a given class, many different forest types and physiognomy within Mt. Elgon and Cherangany ecosystems give rise to great variations in their spectral or seasonal properties. This requires adequate baseline information regarding the current and past status of Land use, forest distribution and the use of flexible stratification in the mapping of Mt. Elgon and Cherangany ecosystems. There are problems with persistent clouds, atmospheric contamination, sensor viewing angle, and solar illumination, leading to varied data quality in within these two ecosystems data sets. Under these circumstances, which are inherent and unique to the scale and pixel sizes of large-area mapping, many large-area land cover mapping efforts have relied on the use of temporal composite data, stratification, unsupervised classification, and interpreter skills to compensate for these scale-dependent factors.

In developing accurate and precise current land use maps for the ecosystems, it was clearly suggested that there was a need for a flexible methodology that allowed certain interactive flexibility in deriving and assigning of classes derived through segmentation. It is at this stage that the team adopted Mapping Device for Change Analysis Tool (MAD-CAT), QGIS and Land Cover Classification System (LCCS) for developing the legend due to their compatibility and flexibility.

### 4.6.1 Data set used

Source data used for developing current land use land cover map for Mt. Elgon and Cherangany ecosystem were drawn from USGS Landsat images composites acquired between late December, 2015 to early January 2016. Data set inputs included scenes p170 r59 2016, p169 r59 2015 and p169 r60 2015, all acquired in dry seasons ranging to reduce the effects of cloud within these ecosystems.

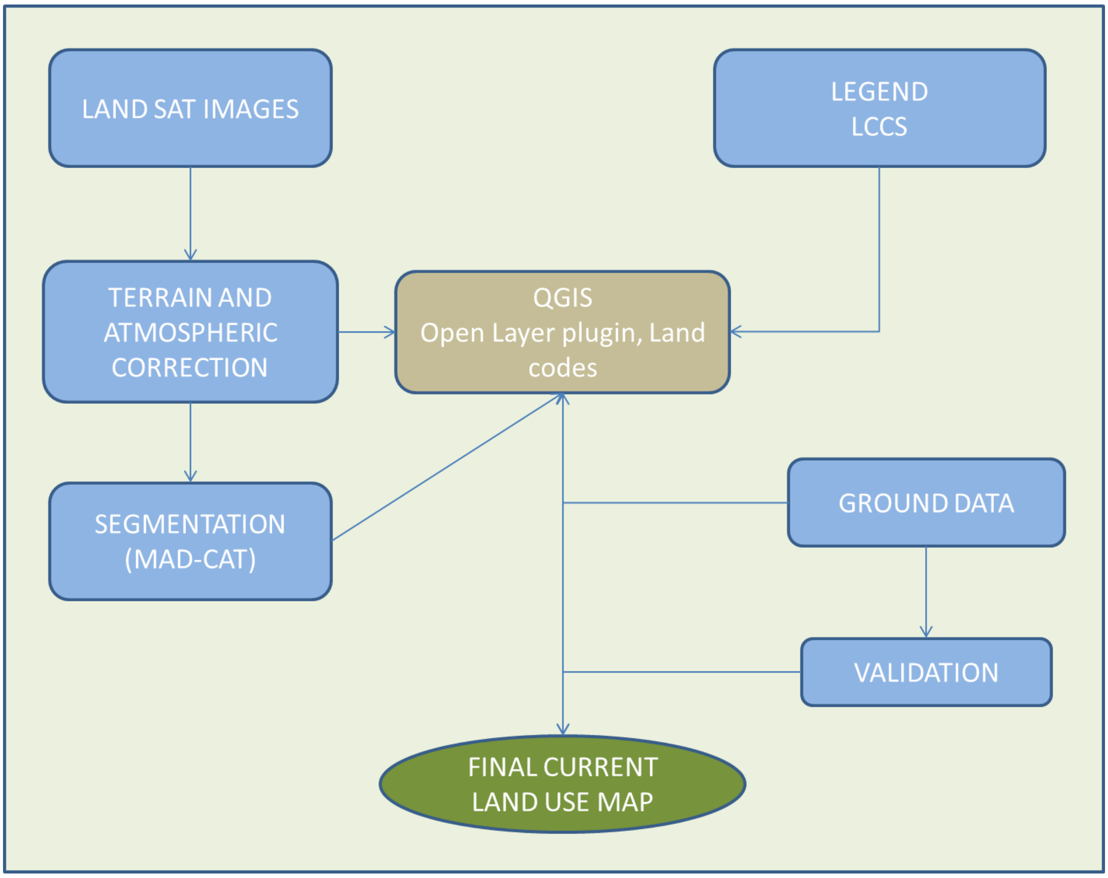



**Figure 4: Summary of the Methodology for Current Land use**

### 4.6.2 Validation – a pragmatic plan

Assessing accuracy for results of Mt. Elgon and Cherangany ecosystem current land cover mapping was necessary undertakings as it provide the baseline information to inform rehabilitation of the ecosystems. However, undertaking this activity was met with some challenges of time resource and accessibility issue of the ecosystems.

## 4.7 Forest degradation in Mt. Elgon and Cherangany

Forest degradation is a serious problem, environmentally, socially and economically particularly in developing countries. According to ITTO (2002), it is estimated that as much as 850 million hectares of forests and forest lands are degraded. Yet it is difficult to quantify the scale of the problem since at national and sub-national levels forest degradation is perceived differently by the various stakeholders who have different objectives within these Kenyan major water towers.

Forest degradation in Mt. Elgon and Cherangany ecosystem has adverse impacts on forest ecosystems and on the goods and services they provide. Many of these goods and services are linked to human well-being and some to the global carbon cycle and thus to life on Earth. Therefore, Policy makers and forest managers need information on forest degradation within these two major water towers. They need to be able to monitor changes happening in forests. They need to know where forest degradation is taking place, what causes it and how serious the impacts are in order to prioritize the allocation of scarce human and financial resources to the prevention of degradation and to the restoration and rehabilitation of degraded forests.

## 4.8 Forest degradation assessment Method

In assessing and mapping of forest degradation in Mt. Elgon and Cherangany ecosystem, direct method of visual interpretation using very high resolution satellite image data to detect canopy damage in some cases (Saatchi et al., 2007) and image classification method was applied.

### 4.8.1 Image Acquisition/Selection

Selection or acquisition of the appropriate remotely sensed imagery is foremost determined by the application or objective of the analysis and the budget. Upon considering these factors, a very spatial resolution satellite image covering Mt. Elgon and Cherangany ecosystem acquired in January, 2017 was used.

The acquired was then pre-processed using most important techniques which include: geometric registration and radiometric/ atmospheric correction

# 5.0 RESULTS AND DISCUSSIONS

## 5.1 Historical Land use land cover Maps for Mt. Elgon

### 5.1.1 Mount Elgon water tower ecosystem

Closed forest observed to be decreasing over the three years having lost to steady increase in grasslands and farmlands. Open forest declined in 1995 and appears to have recovered/regenerated slightly in 2000 (Table 2). The class categorized as others (riparian vegetation, bare areas and rock surfaces) appears to be decreasing, probably conquered by farmlands and grasslands). The decline in closed forest cover agrees with a study conducted by Nield et al, 1999, pinpointing loss in vegetation diversity and density, attributed primarily to a combination of encroachment by local communities and large illegally allocated logging concessions (Nield et al, 1999). This generally agrees with study carried out by Hitimana et al., (2004), who reported that the density of trees had decreased due to clearing and over-exploitation of some species in the past five years. This reduction was attributed to Forest fires have also destroyed some trees, causing overgrowth of non-palatable species. The destruction caused on trees by medicine harvesters, and big animals have also contributed to decrease in tree species and density. Similarly, according to a study carried out by GEF (2009), it was reported that deforestation which is being carried out for various reasons claims nearly 13 million ha of forest every year. Although these were global estimates, most of this was observed in tropical countries like Kenya.

**Picture 1: Land Cover transformation in Mt. Elgon ecosystem**

Biophysical analysis of forest condition in Mount Elgon-ADapTEA project suggested that between the periods 1984, 1995 and 2008, significant areas in Mount Elgon forest ecosystem transitioned from high canopy cover to low/no canopy cover. Figures 6, 7 and 8 of this analysis represent land uses in the year 1984, 1995 and 2000 with change results summarized in table 1 or figure 9. Change detected during AdapTEA study with decline in canopy cover is reflected in this analysis. This transition is further corroborated by IFRI plot-level forest vegetation sampling data from both Chorlim and Kimothon IFRI sites in Mount Elgon, showing trending decline in tree cover since 1997-2013. According to the IFRI article, forest vegetation cover declined by approximately 20.4% given 1997 & 2013 tree mean density. Aerial photography and Land cover mapping of Mt. Elgon 1999 and 1960s cited in IFRI site report 2001, further confirms this depreciation by a marked decline in the area covering the indigenous forest. Forest cover declined from 49% to 35% while the shamba systems rose from non-existence to 9%. Linked to this analysis, farmlands have remained on the ascent indicating the forest ecosystem encroached for agricultural motives among others.

Farmlands and grasslands have conquered forested areas according to the historical trend analysis. Most clearing are a function of subsistence agriculture, though logging and infrastructure development has also contributed to forest loss (Russel, 2012). Mount Elgon forest holds a high percentage of forest resources, crucial to local community' livelihoods (van Heist, 1994). Major products contributing to socio-economy are firewood, poles or timber, vines, water and fodder (Scott, 1994). The value of the resource to proximate communities and those further apart designated as indirect users puts pressure on the resource capacity.

### Table 2: Land use coverage (Km2) for Mt. Elgon Ecosystem

| Class Type | 1984(AreaSq Km) | 1995(AreaSqkm) | 2000(AreaSqkm) |
|---|---|---|---|
| Closed Forest | 469.21 | 388.06 | 262.20 |
| Open Forest | 121.40 | 185.63 | 131.97 |
| Grasslands | 536.98 | 559.13 | 618.00 |
| Farmland | 691.32 | 727.76 | 872.13 |
| Water body | 0.51 | 0.31 | 0.76 |
| Others | 318.71 | 277.84 | 253.07 |
| Total | 2138.13 | 2138.13 | 2138.13 |

**Picture 2: Forest disturbance in Mt. Elgon ecosystem**

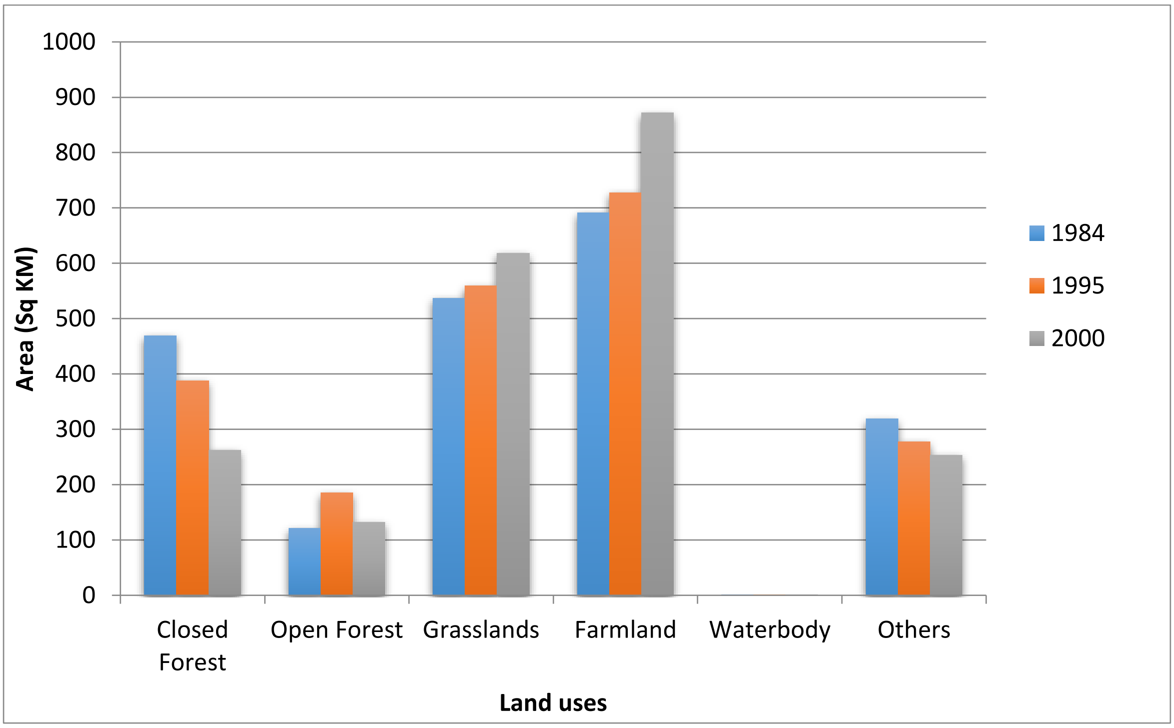
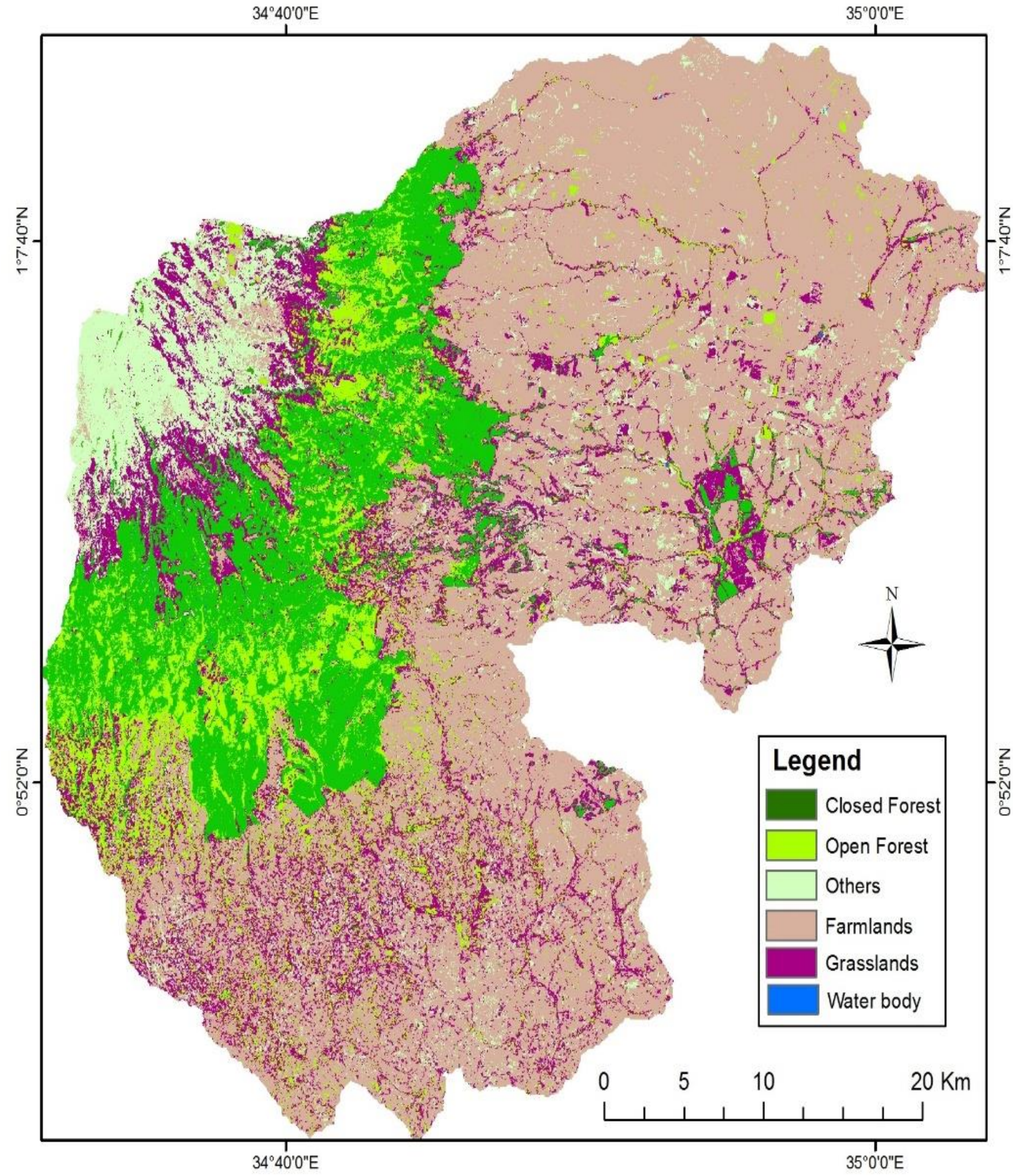
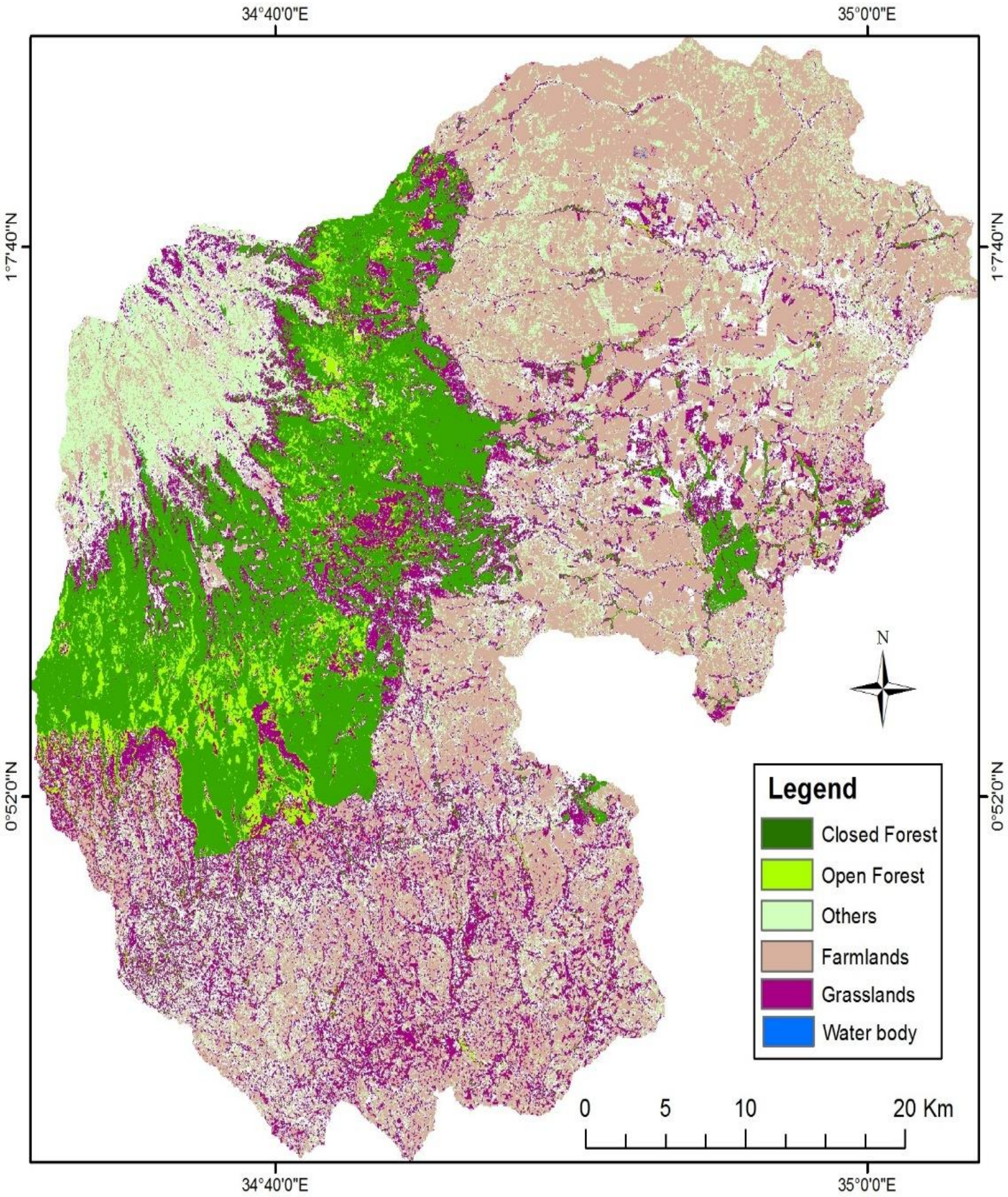



**Figure 5: Summarized historical trend for Mt. Elgon forest ecosystem**

**Picture 3: Forest disturbances assessment in Mt. Elgon ecosystem**




## Figure 6: 1984 Land Use Map for Mt. Elgon Ecosystem




## Figure 7: 1995 Land Use Map for Mt. Elgon Ecosystem

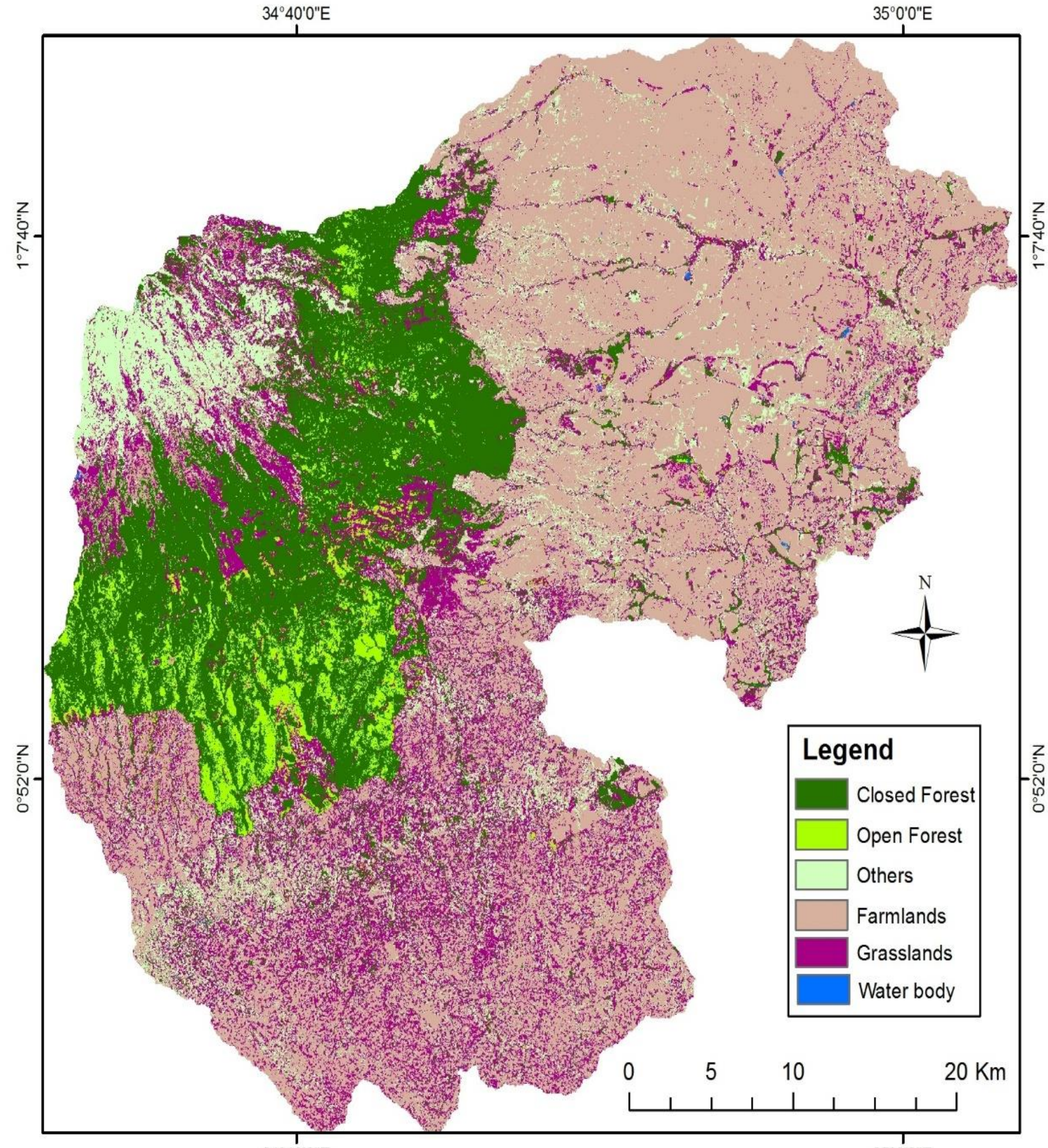



**Figure 8: 2000 Land Use Map for Mt. Elgon Ecosystem**

## 5.2 Historical Land use land cover Maps for Cherangany

### 5.2.1 Cherangany Water tower forest ecosystem

Closed forest has steadily decreased in a span of the three years with open forest, farmlands and grasslands on the ascent according to this historical analysis output. Others (riparian vegetation, bare areas and rock surfaces) category shows decline as well. This decline in closed forest cover is a function of competing land uses and unsustainable extraction of forest products to supplement the resource proximate livelihoods (KFWG and DRSRS, 2000-2003). Cherangany forest ecosystem is reported to have competing land uses according to a report on a project: "Strengthening the protected area network within the Eastern Montane forest hotspots of Kenya, 2009", in Cherangany Hills Forest ecosystem, pointing the land uses as settlements, farming and grazing. With population said to be on the ascent, forest encroachment is pinned to streaming needs of communities to establish settlements, practice farming to sustain their livelihoods and still secure grazing areas for livestock and or use the forest itself as grazing areas.

**Picture 4: Land Cover transformation in Cherangany ecosystem**

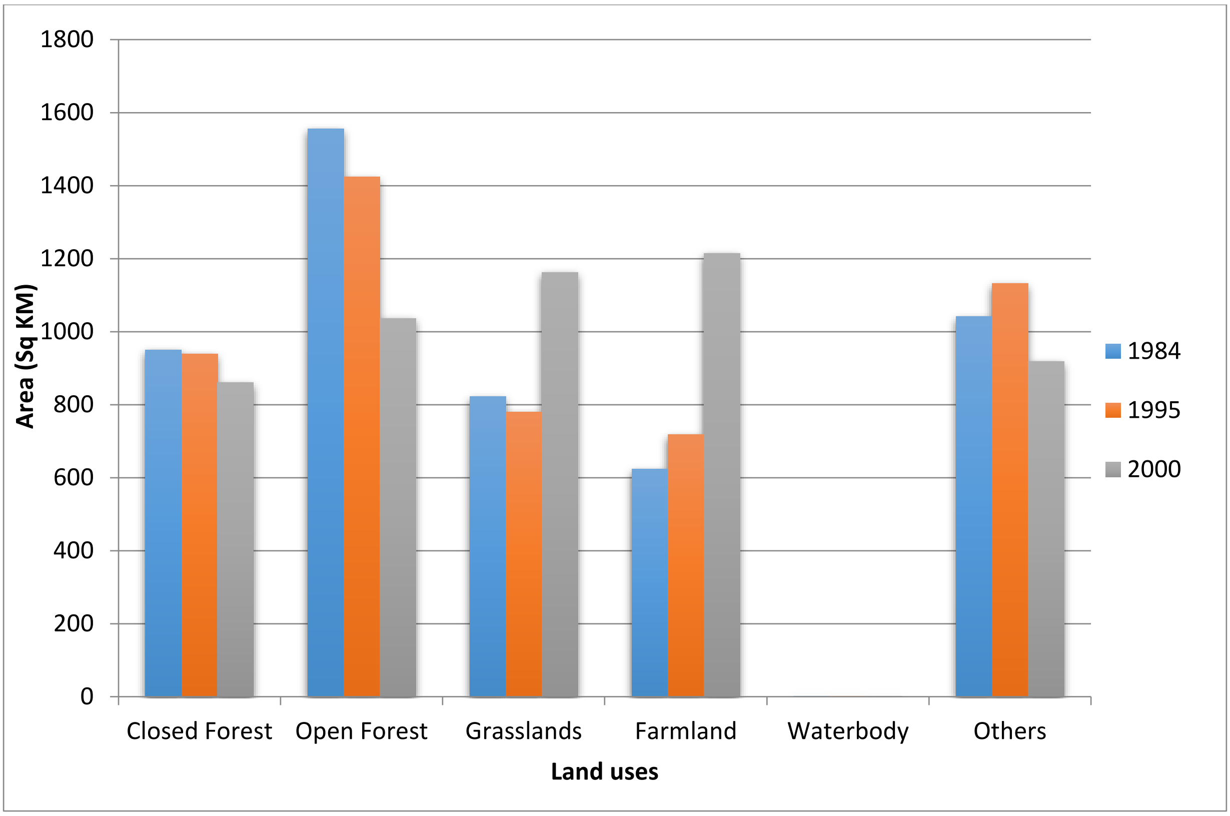
Encroachment on the forest dates back to colonial times when local people were given permits to graze livestock in forest glades. Since then, people have been encroaching onto the forest from the glades (Lambretchs et al 2002). The forest also provides refuge to people running away from frequent cattle raids between the Marakwet and West Pokot communities (UNEP 2001). Diversifying practices among pastoralists has been seen as a coping strategy and increasingly, livestock keepers have established farms, replacing forested lands. The project further reports conflict in water resource use between upstream and downstream communities, as watershed degradation reported to originate upstream, compromising downstream activities.

High rise in grasslands and farmlands noticed in the analysis output indicates a higher contribution of anthropogenic drivers towards degradation. This change analysis output is further corroborated by forest catchment report on the five Kenyan water towers by KFWG and DRSRS, 2000-2003, which revealed significant changes in forest cover, pointing out degraded hotspots within each ecosystem.

Regeneration was noticed to occur in few spots, though outweighed by degradation levels. In addition, forest fires have been reported to be frequent in the area, suppressing and destroying forest growth and regeneration. The analysis results of land uses in 1984, 1995 and 2002 are as presented in figures 10, 11 and 12 with result summary in table 2 and figure 16.

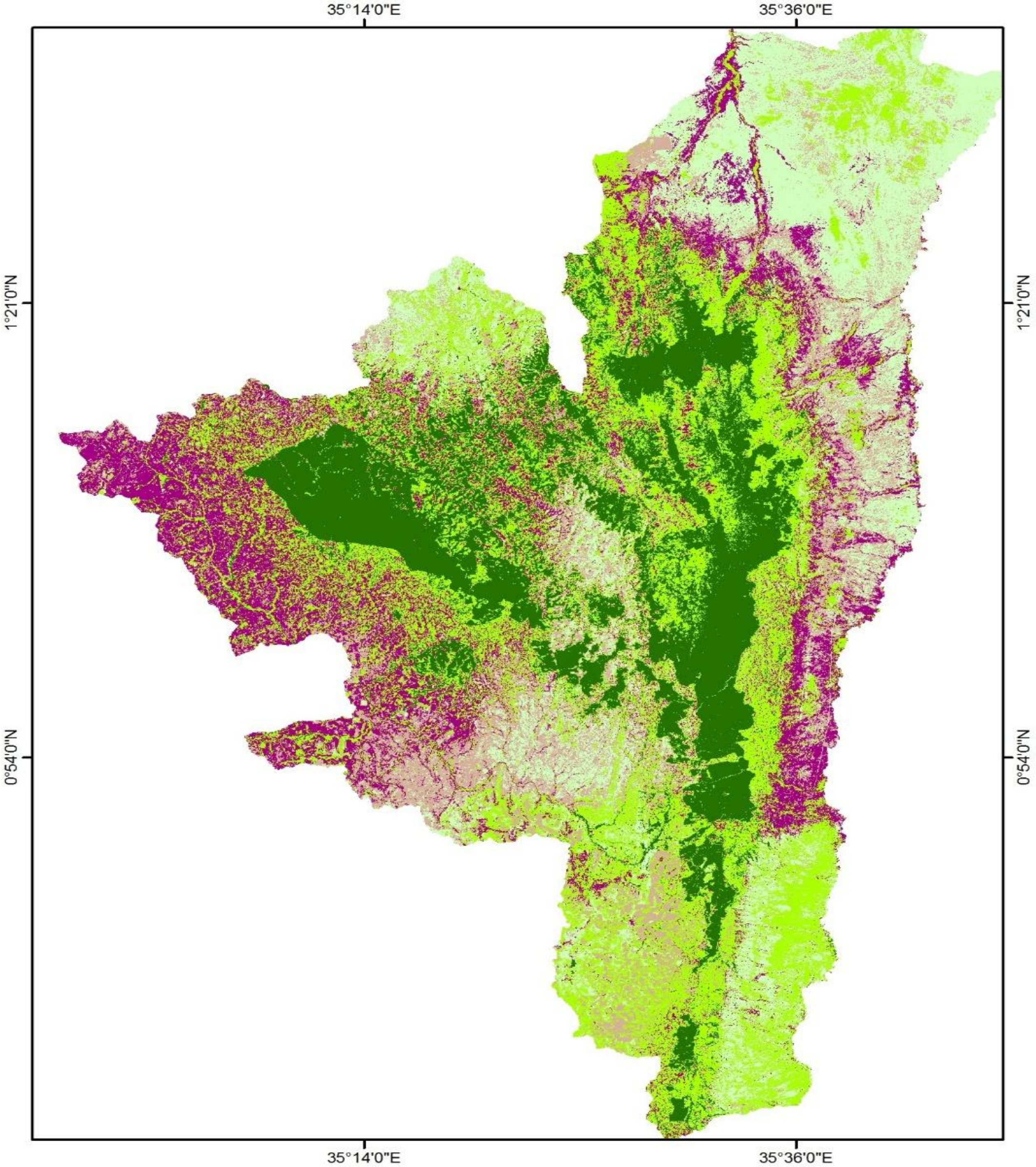
### Table 3: Land use coverage (Km2) for Cherangany Ecosystem

| Class Type | 1984(AreaSq Km) | 1995(AreaSqkm) | 2000(AreaSqkm) |
|---|---|---|---|
| Closed Forest | 949.66 | 938.80 | 860.55 |
| Open Forest | 1555.57 | 1424.58 | 1036.85 |
| Grasslands | 822.54 | 779.33 | 1162.90 |
| Farmland | 623.59 | 718.27 | 1214.50 |
| Water body | 0.94 | 1.44 | 1.21 |
| Others | 1042.22 | 1131.60 | 918.01 |
| Total | 4994.02 | 4994.02 | 4994.02 |

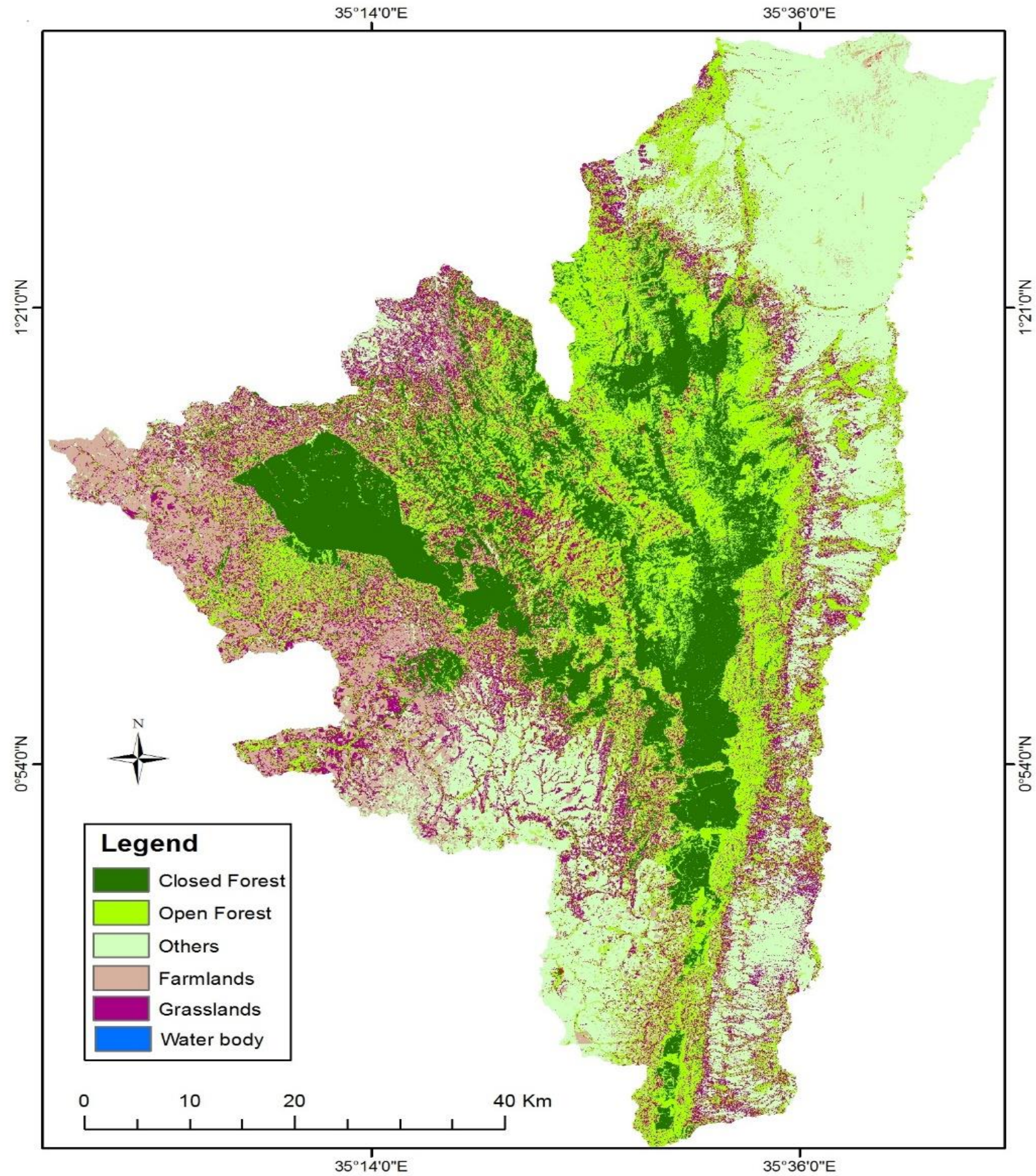



# Figure 9: Summarized historical trend for Cherangany forest ecosystem

# Picture 5: Animals grazing in Cherangany Forest ecosystem




# Figure 10: 1984 Land Use Map for Cherangany Ecosystem




## Figure 11: 1995 Land Use Map for Cherangany Ecosystem

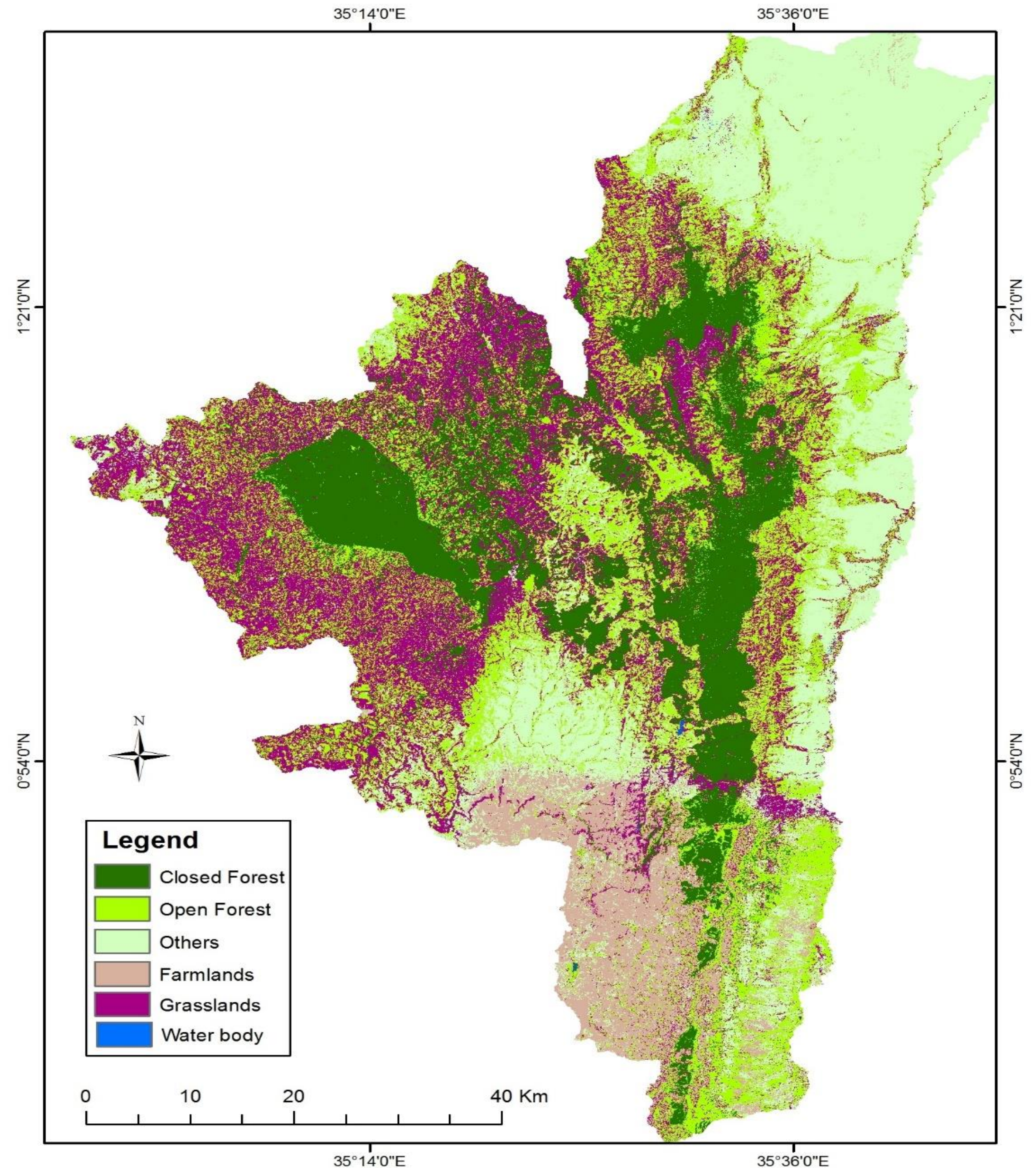



**Figure 12: 2000 Land Use Map for Cherangany Ecosystem**

## Recent Land Use Maps

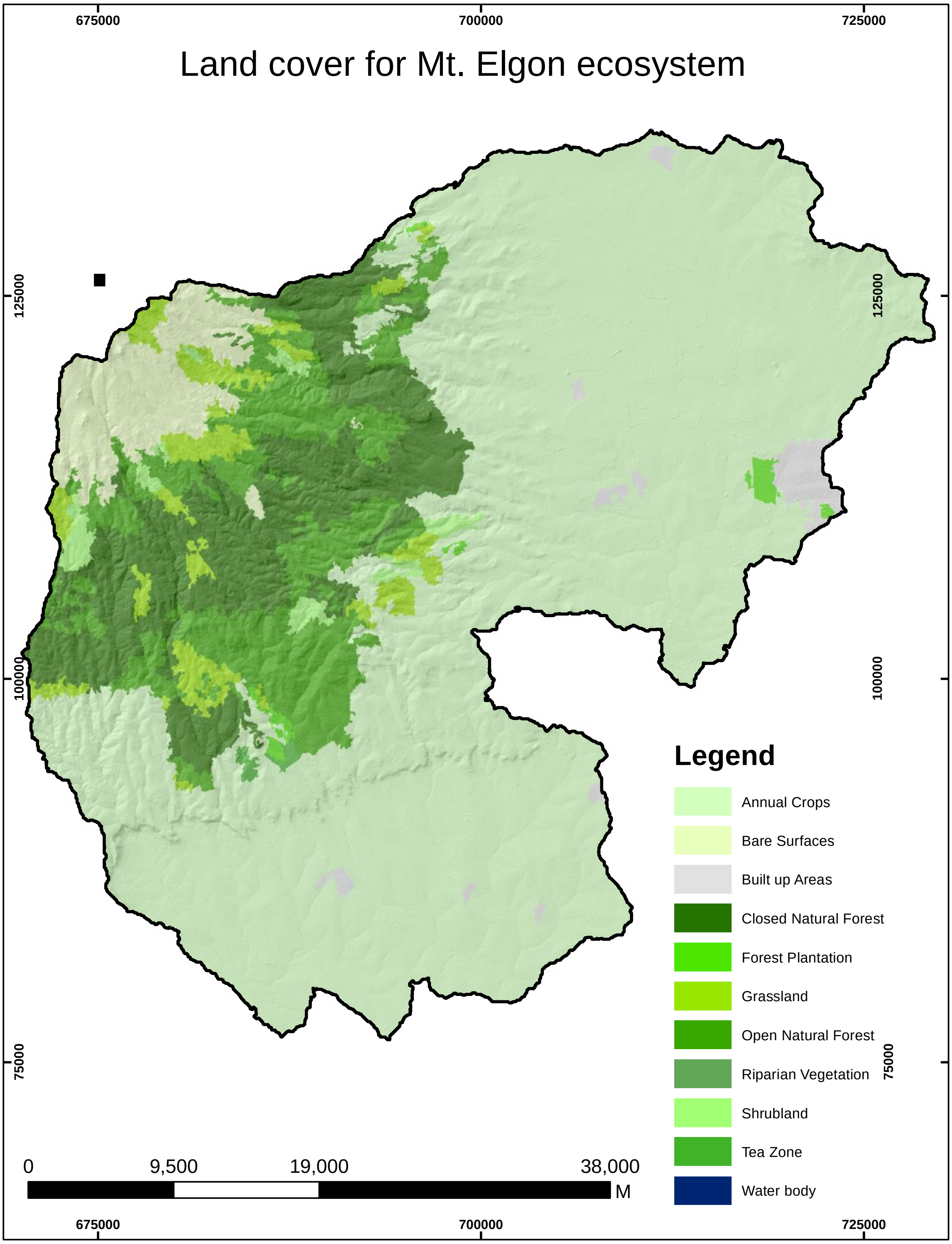



**Figure 13: 2016 Land use land cover for Mount Elgon Ecosystem**

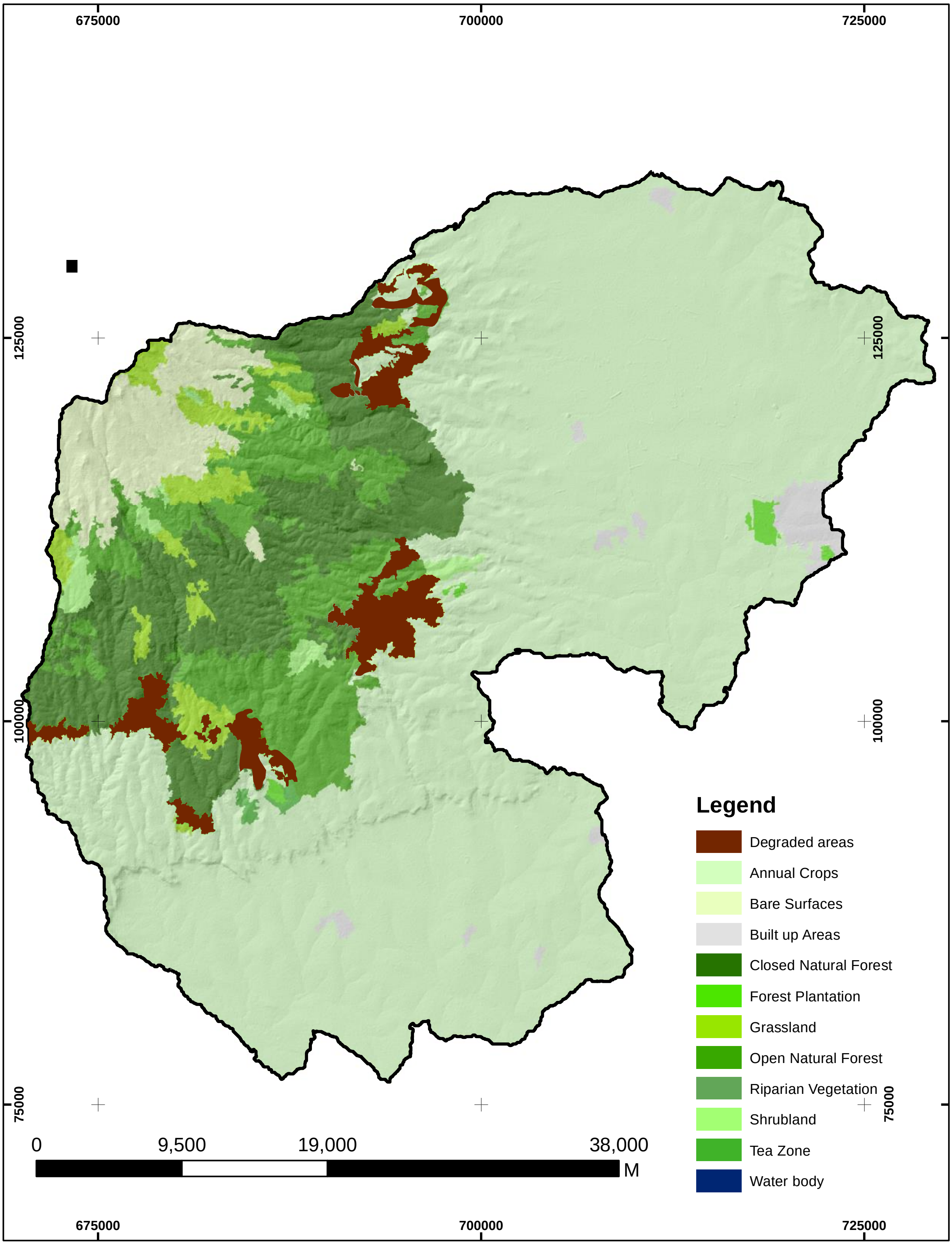



**Figure 14: Degraded areas generated using 2017 High resolutioin satellite image Elgon Ecosystem**

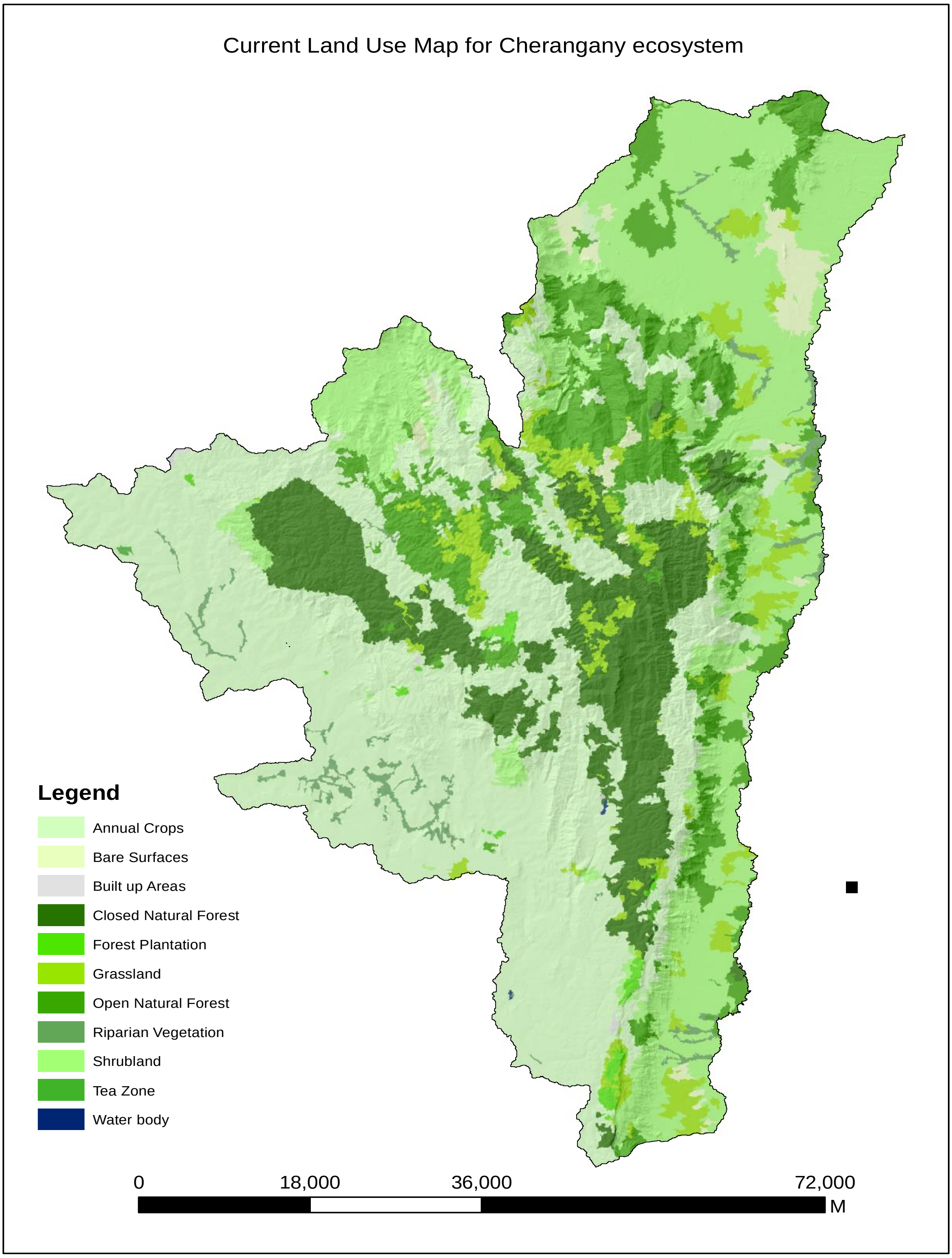



**Figure 15: 2016 Land use land cover for Cherangany Ecosystem**

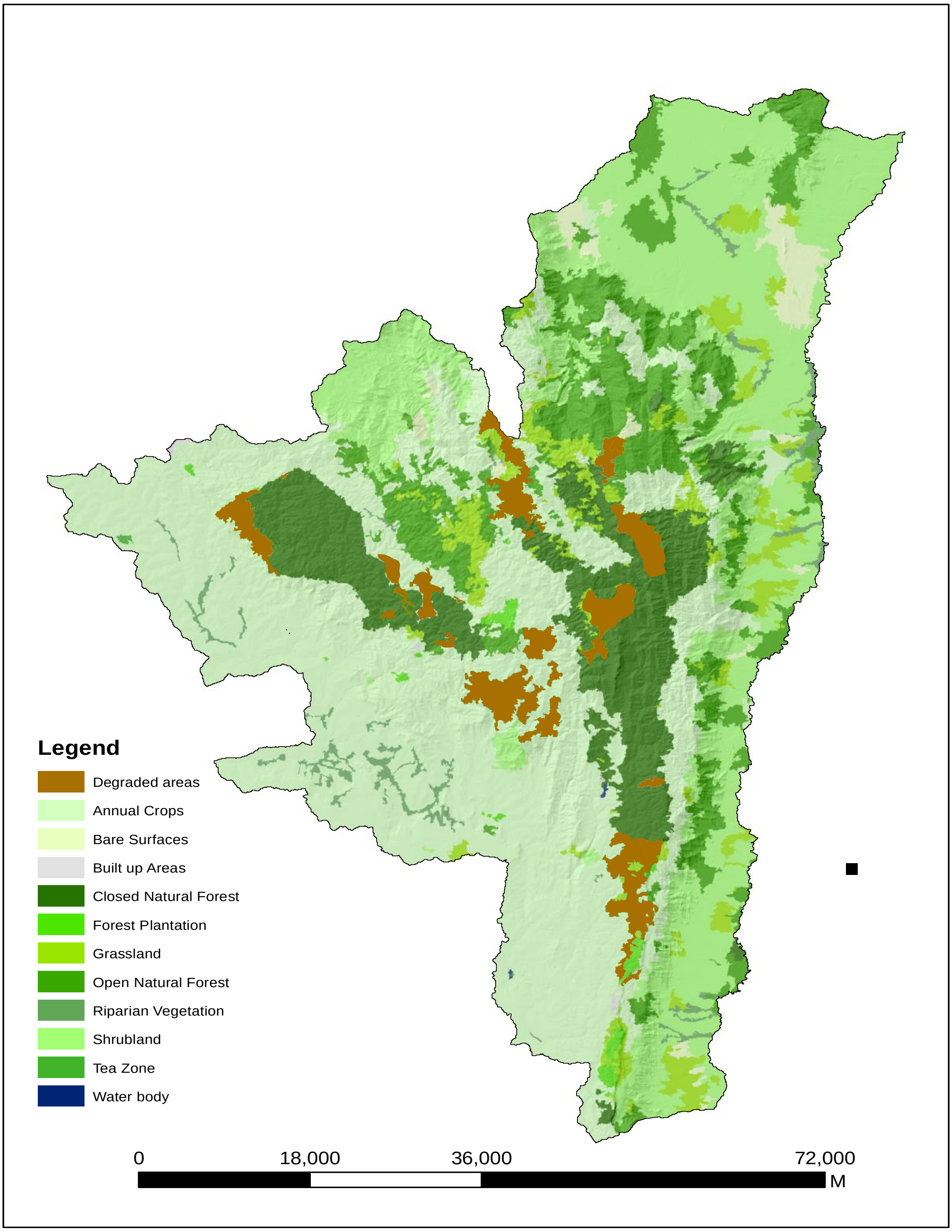



**Figure 16: Degraded areas generated using 2017 High resolution image for Cherangany Ecosystem**

## 5.3 Degradation and Hot spot mapping discussion

Forest degradation mapping is a challenging undertaking than deforestation (Herold et al, 2011), as was experienced in Mt. Elgon and Cherangany ecosystem during this project implementation. Forest degradation (as well as enhancements of carbon stocks) is typically manifested through a change in forest composition and structure, often subtle, and carbon losses (and gains) are smaller and more difficult to detect and quantify than deforestation using remote sensing where often significant reductions in canopy cover are observed (Anthea L. et. al., 217).

Picture 6: Forest Degradation in Mt. Elgon through Charcol burning

During this study, there were some forest disturbance and degradation processes in Mt. Elgon and Cherangany ecosystems that defy detection by remote sensing altogether, including, for example, fuel wood extraction and understorey grazing (Skutsch MM. et al 2011), while others which changes the canopy structure and spectral response like logging, insect or disease infestations burning, could be detected using high resolution remotely sensed satellite image. While there is a loss of AGB associated with these activities, the forest canopy remains untouched. As reported by FAO. (2011), estimates of above ground biomass loss in these cases are best collected by forest inventory or consumption/production surveys.

**Picture 7: Illegal logging in Cherangany ecosystem**

In Mt. Elgon and Cherangany ecosystems, the impact of degradation varies from fine-scale structural changes in canopy cover and height, or subtle disruptions to ecosystem services, to broad-scale loss of biomass. These changes can occur over a range of spatial and temporal scales. Degraded forest may assume a similar canopy cover to intact forest, but have lower biomass, as was noticed in Mt. Elgon and Cherangany forest ecosystem during ground trothing activity. It important to note within the ecosystems, different types of forests was noticed to respond differently to disturbance and change, with variable recovery rate, depending on the species composition, age, location and type, intensity and extent of degradation (Anthea L. et al 2017).

**Picture 8: Clearing of Forest through burning in Cherangany ecosystem**

The approached of the study in Mt. Elgon and Cherangany ecosystem to asses and monitor forest degradation and disturbance using high resolution satellite image was a success as the resultant hot spot areas mapped, with ground validation shows tree cutting remains an ongoing problem in these major water towers, especially cutting of the larger, mature trees with the severity along the forest edges. From the result, more of degradation in Cherangany was experienced on the southern part of the ecosystem with patches spreading throughout the ecosystem.

During the fieldwork and interactions with the adjacent communities within Mt. Elgon and Cherangany water towers, there was some indication that forest management in these areas is poor. Participatory appraisal research with the adjacent local communities revealed that the current forest governance approach were inadequate, and follow-up by local line agencies on community-based forest management approach. From the discussion with the locals, it appeared that timber was being “leaked” out of Mt. Elgon and Cherangany ecosystem, both legally and illegally. Remoteness in terms of accessibility, inadequate forest governance, and authorized and unauthorized overuse of local forests in Mt. Elgon and Cherangany have resulted in continuing deforestation and forest degradation. The outcome of one of the objective which was to conduct land use land cover change provide important information derived from historical Landsat satellite images included in this report can help increase awareness and understanding of the problems, support the development of appropriate management plans, and provide a low-cost means for detailed monitoring of forest status within Mt. Elgon and Cherangany ecosystems.

**Picture 9: Forest Degradation in Cherangany ecosystem through Charcol burning**

However, during forest degradation assessment using high resolution satellite images in Mt. Elgon and Cherangany ecosystems, there are a number of challenges in the interpretation of satellite images and detection and delineation of degraded areas. These include the intermingling of tree crowns, the effects of shadow from surrounding hills and mountains, topography, and GPS readings from the field (Dare 2005). In this study, some of these were addressed through geometric correction, followed by manual scanning of high resolution satellite images covering the two ecosystems. In an effort to solves some of these challenges arising from optical satellite, active remote sensing data are also becoming available to improve detection and delineation of individual tree crowns as an indicator of forest disturbance and degradation. Integration of passive satellite data and active (LiDAR, radar) has been shown to produce more effective and efficient tree crown identification (Leckie et al 2003; Ke and Quackenbush 2011). Previously one of the major limitations of very high resolution satellite data was the limited number of spectral bands (Herold et al 2003), but this has now been overcome with WorldView-2 and similar products. In the future, species, monitoring, forest degradation and disturbance assessment will be able to provide an effective means of support for improved forest management, monitoring and associated local decision-making (Immitzer et al 2012).

**Picture 10: Forest disturbance through grazing**

## 6.0 Conclusion

Land use and land cover changes may be grouped into two broad categories as conversion and modification. Conversion refers to changes from one cover or use type to another, while modification involves maintenance of the broad cover or use type in the face of changes in its attributes (Daniels et al., 2008). Both ecosystems showed a significant change in land use and cover, in terms of land conversion and modification. However, the Cherangany ecosystem showed more changes in land use and cover change as compared to Mt. Elgon ecosystem. The ground trothing and validation process of both areas showed that there were less land conversion activities around Mt. Elgon forest. This could be attributed to the fact that this ecosystem is more protected due to the presence of wild animals and their management by KWS. Also, the Cherangany ecosystem was observed to be entirely surrounded by community members which increases its accessibility and subsequently the chances of encroachment.

The decrease in closed forest and subsequent increase in open forest and grassland was also observed in the two ecosystems. The slight increase in open forest observed in 2000 could be attributed to the decrease in closed forest cover or the natural succession in plant communities with changes from either grassland or shrubland to forest. Further, both ecosystems showed a decrease in riparian vegetation and bare surfaces. This was seen mainly to result from encroachment by community members for the purpose of farming relying on constant water.

In Kenya, land use and cover change not only affects the two ecosystems under study but also has been shown to be a concern in the five major "water towers." Globally, land use and cover change is significant not only because it affects the global ecosystems, but also because they contribute to global changes in climate through increasing emission of greenhouse gases (Houghton, 1994). Land use activities are calculated to contribute from 20-75% of all atmospheric emissions of greenhouse gases (Chen et al., 2001). Therefore, an effort to apprehend the change in land cover for the purpose of enhancing conservation is necessary for both local and global sustainable development.

The effort to understanding land use and cover change in the two ecosystems will not only lead to sustainable forest management, but also result to systematic approach of natural resources in the country. The systematic approach (also referred to as ecosystem approach) was first described by the Convention on Biological Diversity (CBD) as the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. This is a science based approach that treats conservation of forests in relation to all ecosystem components such as land, water and living resources including humans their culture and diversity.

The need for an effective conservation strategy for the two ecosystems will additionally have a global significance. For instance, it will contribute towards the attainment of the Sustainable Development Goals (SDGs) that are relevant to forest conservation. Specifically, it will support SDG15 which involves the reduction of deforestation and the protection and restoration water catchment areas. This will also help in meeting specific targets of SDG15 which include; By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests, and increase afforestation and reforestation: By 2020, protect and restore water-related ecosystems including mountains, forests, wetlands, rivers, aquifers and lakes (SDG6.6). By this study informing effective strategies to conserve the Mt. Elgon and Cherangany ecosystems, it is directly contributing towards the achievement of this targets and thus sustainable development on earth.

# 7.0 Recommendations

## 7.1 Encouraging substitutes like Bamboo farming

Within Mt. Elgon and Cherangany ecosystem, the adjacent community fully relies on forest for wood, fodder, timber etc. this encouraged forest degradation and hence alternative sources like Bamboo farming should be encouraged and supported to relieve off the pressure. For all purposes where tropical or other timber is used, other woods or materials could be substituted.

## 7.2 Policy, legislative and regulatory measures-enforcement and compliance

In Kenya, wide variety of policy statements and legislative and regulatory measures have been established to protect forests and major water towers but need to be effectively enforced. New modifications/adjustments are of course needed for site specific conditions due to difference in cultural, political and perception of the adjacent communities. Laws, policy and legislation should be such that they encourages local people and institutional participation in forestry management and conservation along with safeguarding indigenous people's traditional rights and tenure with rightful sharing of benefits from these Water towers. Many formal and informal enforcement/compliance mechanisms are used to prevent deforestation and environmental problems from within Mt. Elgon and Cherangany as was reported by some of the community members. These approaches include negotiation, warnings, cancelling work orders, notices of violation, fines, arrests and court action.

## 7.3 Encourage Participatory forest management and rights

In Kenya, most of the forests are state owned including Mt. Elgon and Cherangany ecosystem, but the reach of government and the rule of law are weak. In order for forest management to succeed in Kenya, all parties with an interest in the fate of the forest should be communally involved in planning, management and sharing of the accrued benefits. But forest ownership and management rights are almost always restricted and restrictions on ownership and use define alternative tenure systems. The balance of rights can be tilted strongly toward society in the form of publicly owned strictly protected areas. State ownership and management can be retained but with informed approach in including the local communities. Land reform is essential in order to address the problem deforestation within Mt. Elgon and Cherangany ecosystem. However an enduring shift in favour of the peasants is also needed for such reforms to endure (Colchester and Lohmann, 1993). Moreover the rights of indigenous forest dwellers and others who depend on intact forests must be upheld. Therefore, the recognition of traditional laws of the indigenous peoples as indigenous rights will address the conflicts between customary and statutory laws and regulations related to forest ownership and natural resource use while ensuring conservation of forest resources by the indigenous communities within these Water towers. A means must be found to reconcile conservation and development by involving local/indigenous populations within Mt. Elgon and Cherangany more closely in the decision-making process and by taking the interactions between 'societies' and forest resource more fully into account

## 7.4 Increase investment in research, education and extension

Training and education of stakeholder's helps people understand how to prevent and reduce adverse environmental effects associated with deforestation and forestry activities and take appropriate action when possible to conserve and protect these water towers. Research substantiates it and helps to understand the problem, its cause, mitigation and challenges. There is a lack of knowledge and information in the general community about forests and forestry. Forest managers and those developing forest policies need to be comprehensively educated and need to appreciate the complexity of the interacting ecological, economical, social, cultural and political factors involved and how these factors contribute to forest degradation

## 7.5 Improve the information base and forest monitoring

Information on the forest distribution and coverage, biodiversity and forest poverty is inadequate for forest management within the Kenyan water towers. Current and accurate knowledge of how much forest, where it is and what it is composed of seems to be straightforward but surprisingly this most basic information is not always available within these Kenyan water towers. Within these ecosystems, it is not possible to properly manage a forest ecosystem without first understanding it. New remote sensing technologies make it feasible and affordable to identify hotspots of deforestation. The local and adjacent communities are very important in forest monitoring, the approach like citizen science that could help in forest monitoring efforts that would have immediate payoffs.

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