

**EXPLORING POPULATION DENSITY AND FOREST COVER LINKAGES:  
EVIDENCE FROM KENYA**

**BY**

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## **DECLARATION**

### **Declaration by candidate**

This thesis is my original work and has not been presented for a degree in any other University or any other award.

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## LIST OF ACRONYMS AND ABBREVIATIONS

|                 |   |   |
|-----------------|---|---|
| <b>AIC</b>      | - | Akaike's Information Criterion                              |
| <b>ASALs</b>    | - | Arid and Semi-Arid Lands                                    |
| <b>AVHRR</b>    | - | Advanced Very High Resolution Radiometer                    |
| <b>CDM</b>      | - | Clean Development Mechanism                                 |
| <b>DRSRS</b>    | - | Department of Resource Surveys and Remote Sensing           |
| <b>ECABREN</b>  | - | Eastern and Central Africa Bean Research Network            |
| <b>EUBCP</b>    | - | European Union funded Biodiversity Conservation Programme   |
| <b>FAO</b>      | - | Food and Agriculture Organization                           |
| <b>GFC</b>      | - | Global Forest Coalition                                     |
| <b>GIS</b>      | - | Geographical Information System                             |
| <b>ICRAF</b>    | - | International Center for Research in Agroforestry           |
| <b>ICS</b>      | - | Interim Coordinating Secretariat                            |
| <b>ILRI</b>     | - | International Livestock Research Institute                  |
| <b>IPCC</b>     | - | Intergovernmental Panel on Climate Change                   |
| <b>KCC</b>      | - | Kenya Cooperative Creameries                                |
| <b>KFS</b>      | - | Kenya Forest Service  |
| <b>KFWG</b>     | - | Kenya Forests Working Group                                 |
| <b>KMD</b>      | - | Kenya Meteorological Department                             |
| <b>KNBS</b>     | - | Kenya National Bureau of Statistics                         |
| <b>KENAPOFA</b> | - | Kenya National Potato Farmers Association                   |
| <b>NCPD</b>     | - | National Coordination Agency for Population and Development |
| <b>NDVI</b>     | - | Normalized Difference Vegetation Index                      |
| <b>NPCK</b>     | - | National Potato Council of Kenya                            |
| <b>PSRI</b>     | - | Population Studies and Research Institute                   |
| <b>RoK</b>      | - | Republic of Kenya   |
| <b>SPOT</b>     | - | French: Satellite Pour l'Observation de la Terre            |
| <b>UNEP</b>     | - | United Nations Environmental Programme                      |
| <b>USGS</b>     | - | United States Geological Survey                             |
| <b>WRI</b>      | - | World Resource Institute                                    |

## **ABSTRACT**

Forest resources in Kenya are valuable and need to be sustainably managed for present and future generations. Forests are important to our ecological, economic and social wellbeing. They offer a range of benefits and opportunities; they provide wood and non-wood products, recreational opportunities and other non-market goods and services such as water and clean air. But these resources are under serious threat, as a result of the rapidly expanding human population, which is constantly putting pressure on the natural resource base. Kenya continues to face the challenge of managing its natural resources which people use unsustainably. In the face of a rapidly growing population land cover in Kenya has been greatly transformed and in contemporary times, issues of sustainable development, environmental change and related issues of human-environment interaction have been a major concern.

The aim of this study was to empirically establish how changes in population density have affected forest cover. The study provided an opportunity of linking environmental science with social science using Remote Sensing and Geographical Information System (GIS) techniques to integrate vegetation cover data with population data. Remote Sensing data extracted from Advanced Very High Resolution Radiometer (AVHRR) NOAA-series satellites was used as a remotely sensed measure of forest cover to determine NDVI trends for 24 years and also to establish the association between population density and NDVI. Remote Sensing data from Landsat 5 and 7 satellites was used to analyse forest cover changes at detailed scales based on the spatial models built in ArcGIS Software. Multiple regression analysis was conducted to determine the significance of rainfall and population density on NDVI and polynomial regression model was run to establish the relationship between population density and NDVI.

NDVI trends revealed that there was a general increase in forest cover in all study counties but with some years showing forest decline. Narok and Machakos had significant decline from 1998 while in some counties NDVI increased with higher values than in others. The relationship between population density varied within counties with Nyeri, Nyandarua, Baringo and West Pokot showing a positive relationship while Narok and Machakos showed a negative relationship. Spatial analysis show large extent of forest decline in Narok and large extent of forest regeneration in Nyeri county.

It was apparent from the study that population density is a key factor contributing to forest cover change in most counties, (either negatively or positively) depending on the activities that people are engaged in. Nevertheless there are other factors that also influence forest cover and these vary within counties. They vary from changes in rainfall, land ownership, land use policies, market economies, rangeland/grassland restoration, reforestation, deforestation and culture. The main concern in conserving forest therefore, should not necessarily be increase in population density but also, the activities that people engage in and that a detailed understanding of the complex set of factors affecting forest cover change in a given location is required prior to any intervention. The challenge of rapid population growth and natural resource degradation are not isolated from one another; they are intimately related and it is important for strategic planning and development programming to focus on them together taking into account their interrelationship.

## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.1 Background**

It is generally believed that there is an inverse relationship between population growth and vegetation cover (Nath and Mwchahary 2012). Most studies on population and vegetation cover have focused on destructive effects of human activities on vegetation cover (Foster et al. 1992; Shipigina and Rees 2012), but human activities can either increase or reduce vegetation cover. However, some recent studies have reported a positive relationship between population growth and vegetation cover in the past few decades (Mather and Needle 2000; Li et al. 2013; Zhang 2012 and Bhattacharai and Hammig 2001).

Population pressure is frequently pointed out as the main driver of deforestation; this evidence is mixed, because increase in population density does not necessarily mean vegetation destruction. There are cases of increases in population density occurring at the same time as deforestation, increase of population density and no change of forest area or increase in population and increases in forest area. The outcome of increased population appears to depend on economic opportunities available to rural people, agricultural and cropping systems, and access to markets for timber and non-timber products, as well as for other forms of production (Tiffen and Mortimore 1994). Social, political and technological forces also have important indirect impacts and courses of action that can initiate chains of activities leading to deforestation or developments that can actually promote reforestation and improve vegetation cover.

Human activity affects forest cover directly through activities such as harvesting for timber, infrastructure expansion and clearance for agriculture. Conversion of forests to agricultural land takes place as individuals and families open land to feed themselves and their families. It also takes place on a large scale with programs planned and implemented by governments and agricultural industries to resettle populations and to increase agricultural production, often of cash crops for export (Brown and Schreckenberg 1998). In areas such as the Amazon, increased deforestation and population growth happen at almost the same time. But most of the population growth comes from migrants arriving from other areas. In other parts of the world, there are documented examples of increased population leading to more intensive agricultural systems and in increases in the tree cover. The populations of Europe and North America have increased significantly over the last century and as well the area of forest has also increased significantly (Kauppi et al. 2006).

Human population growth and its impacts are one of the most pressing social and economic problems facing many developing countries. Kenya's population is growing rapidly and has more than tripled from 10.9 million people in 1969 to 38.6 million people in 2009. Given the high population growth rate the population in Kenya and especially in the rural areas will continue to increase steadily (KNBS 2010) and continue putting lots of pressure on natural resources. Kenya is currently witnessing a major demographic transition that is creating both opportunities and challenges. Population is a critical factor as it produces direct human actions and occupational activities that cause vegetation change (Contreras-Hermosilla 2000). Population is a driving force of natural-resource base change and the population also bears the consequences (Soneye 2012). Increasing population is associated with need for more food, land

and provision of social amenities in urban areas and demand for energy. These demands lead to over-utilisation and cultivation of ecologically sensitive areas, over-abstraction of water and over exploitation of vegetation including forests. Consequently the environment gets degraded and the cost of extracting these services gets higher, and per capita consumption of these resources diminishes, leading to a fall in human welfare and thus making the society poor (Roba and Mwasi 2006). There has been a debate that some areas are being degraded heavily and as well, there is some evidence of greening in other areas despite high human population growth (Nyangena and Sterner 2009).

This study would like to empirically establish how changes in population density have affected forest cover in selected areas in Kenya for the past 24 years using Normalized Difference Vegetation Index (NDVI) as proxy indicator for forest cover and population density as a proxy indicator for human activities. The study used both high and low resolution remotely sensed data to compile the historical vegetation changes. Models were developed using regression to determine the linkages of population density with forest cover change.

## **1.2 Problem statement**

According to World Bank (1992) as population density increases the supply of people who clear trees increases and the demand for products from forests or forest land grows too. As a result, a larger area is deforested and biodiversity diminishes. Indeed researchers, policymakers, environmentalists realize that greater production in these areas due to population pressure degrades forests, farms, and grazing lands and creates significant, negative off-site environmental impacts (FAO 1994; Repetto 1986; World Bank 1992). Hence improved management of forest in both humid and drylands (arid and semi-arid) is vitally important.

Kenya's population is growing rapidly which can often lead to undesirable ecological and socio-economic implications in the loss biodiversity, forest and also pollution of our marine ecosystems. This also can put lots of pressure on our meagre water resources. Worldwide there has been a concerted effort to reduce the destruction of forest. Also in Kenya we observed some positive trends and this study is to appraise that effort. The World Agroforestry Centre (ICRAF) has mapped some of these changes and observed increase in tree planting and overall tree cover where the density of population is high and where tenure is mostly on private owners (Zomer et al. 2014; Van Noordwijk et al. 2005). Some counties where there has been security of tenure appear to have more tree cover today than they did some thirty to forty years ago (Menzies 2005).

In Kenya the population distribution of the country was dictated mostly by the colonial government. During the colonial period, settlement was controlled by the Colonial government and it was spatially divided into racial blocks, consisting of areas occupied by the Europeans, the Asians and the Africans. In the rural areas, communities still maintained their ethnic regions. After Kenya attained independence in 1963, Kenyans were free to occupy any part of the Country and as a result successive population censuses reveal an interesting dynamics of spatial distribution of Kenya's population (Otuoma 2004). The high rainfall areas had the highest population and population growth rates and these had large impacts on the natural resources especially forest. And this pressure is now building in the Arid and Semi- arid lands (ASALs). The ASALs constitute about 80% of the country's land mass; host about 10 million people (who are mainly pastoralists) and approximately 70% of the national livestock herd (Schilling et al.

2012). The 2009 national census indicates that ASAL citizens make up 36% of the population - 12% in arid counties and 24% in semi-arid (REGLAP 2012). Most of the ASAL counties were under populated for a long-time. However, in the last 20 years the increase in population has been phenomenal because of the influx from the high potential areas to these areas (Shisanya et al, 2011). For instance, the population of North Eastern Province increased six fold between 1989 and 2009 from 371,000 to 2.3 million (Fitzgibbon 2012 p.5).

Thus, over the past few decades, Kenya rangelands have witnessed immigration of agricultural households from high potential agro-ecological zones. This pressure is expected to continue and intensification of farming systems is likely to occur with population growth, sufficient to pose greater potential ecological risks both for local production and for the broader environmental services.

### **1.3 Research Questions**

- i. What are the trends of Normalized Difference Vegetation Index (NDVI) a proxy for forest cover change over the last 24 years?
- ii. How do forest cover changes relate to population density in the study sites?
- iii. To what extent have changes in population density brought about changes in forest cover?

### **1.4 Objectives**

The main objective of this study is to empirically establish how changes in population density have affected forest cover in selected areas in Kenya.

- i. To determine the trends in Normalized Difference Vegetation Index (NDVI) over for the past 24 years

- ii. To establish the association between population density and forest cover (based on NDVI from satellite)
- iii. To establish the extent to which population density have brought about changes in forest cover

### **1.5 Justification of study**

Modern forest management requires that forest resources be efficiently managed, not only for timber production, but also for such purposes as maintaining biodiversity, environmental, climatic and recreational needs (Wang 2004). Quantifying rates of forest cover change is important for improved carbon accounting and climate change modeling, management of forestry and agricultural resources, and biodiversity monitoring as well as for watershed management (Hansen 2010). In Kenya, the continued provision of forest products and services are threatened by forest degradation and accelerated conversion of forestland to alternative land uses. The continued degradation of forest resources requires concerted efforts by policy makers and researchers to slow or stop the loss of forest cover (Langat and Cheboiwo 2010). The results of this study are important in formulating future environmental policies to ensure that people benefit from forest products and as well conserve forest.

The value of forests to the world's human population is becoming increasingly evident. Excessive alterations of the global environment by human activities have led to various changes in the global biogeochemical cycles, transformation of land have increased the mobility of many biota.

Many studies have been undertaken to study the impacts of human population on forest and with availability of long-term monitoring tools such a vegetation indices gathered from satellites it is important to establish some research that can use these tools. This study opens up the possibility

of linking the social and forestry science to that of remote sensing. The study promotes the analysis of human population, vegetation index (Normalized Difference Vegetation Index (NDVI) and rainfall.

The results of this research are important in several aspects: To establish whether policy makers should be apprehensive about forest degradation and other phenomena related to a growing population; it helps establish whether the problems of population density and forest cover linkages are transitional: perhaps an increasing population density can help in solving degradation problems, rather than causing or worsening natural resource base. Hopefully, this study is important in addressing some of the challenges Kenya is having in managing its natural resources and formulating ways of addressing some of these issues.

#### **1.6 Scope and limitations of the study**

The study focused on four semi-arid counties and two humid counties whose rainfall pattern is generally bimodal, has potential for agricultural expansion and has substantial forests. Semi-arid counties that fell within these categories were West Pokot, Baringo and Machakos and Narok while humid counties are Nyeri and Nyandarua.

The study related forest cover (NDVI) data with population density and rainfall (time-dependent) data for long term analysis in order to take into account the lag in vegetation growth. Literature synthesis for time independent variables (land tenure, land use policies, market economies, reforestation, rangeland restoration and culture) was carried out to support the results on forest cover change. Variables such as urbanization and migration could not be used for analysis since the data was available in ten year intervals and data for in-between years cannot be projected.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 Literature Review**

The world population grew to 7.06 billion in mid-2012 after having passed the 7 billion mark in 2011. Sub-Saharan Africa and other developing countries accounted for 97 percent of this growth because of the double effects of high birth rates and young populations. In the developed countries, the annual number of births barely exceeds deaths because of low birth rates and has a much older populations (Haub 2012). The demographic changes are shaped by economic development, employment, income distribution, poverty, social protection and pensions. The dynamic demographics affect and are affected by access to health, education, housing, sanitation, water, food and energy (Meyerson 2006).The ongoing demographic transformation is top of international and national development agendas on how population impact the environment. Rapid population growth leads to environmental destruction, mainly in the form of deforestation caused by slash-and-burn agriculture and therefore implies that the rate of deforestation is going to increase unless the increasing population is controlled (Clark 2012).

Global land cover change, particularly from forest to other land cover types due to increased human activity, is one of the most important issues in global change research. It has been especially remarkable in the last few decades. We have witnessed an increasing rate of deforestation due to pressure caused by the population growth. The focus forests are critical in the sustenance of the ecosystem (provision of ecosystem services such as water, biodiversity) that are important for sustenance of human being (Pahari and Murai 1999).

Deforestation has emerged as one of the major concerns of the world community as significant environmental impacts are attributed to it. Until quite recently, most of the deforestation occurred in Europe, North Africa, and the Middle East. By the beginning of this century, these regions had been mostly converted from the original cover (Gervet 2007). Now, deforestation in these regions has stabilized and regrowth is occurring. In the last few decades, the vast majority of deforestation has occurred in the tropics, and the pace still accelerates (FAO 2012b). The plainly observed association between population increase and deforestation in most of the developing countries has deepened the concern on deforestation. An analysis on forest cover and population of Kokrajhar district of Assam in India over the period 1977-2007 revealed a strong inverse relationship between population increase and deforestation (Nath and Mwchahary 2012). Despite the declining growth rate of population in the forested area, deforestation was taking place at an alarming rate. Nath and Mwchahary (2012) argued that when the population density reaches about 492 person per km<sup>2</sup>, the forest in Kokrajhar district would be almost completely cleared.

Deforestation due to ever-increasing activities of the growing human population has been an issue of major concern for the global environment, but forests are currently expanding in much of the industrialized world, while shrinking in most of the developing world. In the first five years of the 1990s, 65 million hectares of forest were converted to other uses in developing countries (Gardner-Outlaw and Engelman1999). It has been especially serious in the last several decades in the developing countries. A Study on population-deforestation model that was developed to relate population density with cumulative forest loss found out that population is the most significant factor in deforestation and it appeared it was going to be a significant problem especially in developing countries of the tropical region where population growth is still

picking up and is projected to slow down only after the next few decades (Pahari and Murai, 1999).

However, recent studies on population and vegetation cover in countries such as China that has had large increases in population show some recovery and positive trends. Li et al (2013) analyzed population growth and vegetation cover through the panel data of 21 cities in Guangdong Province, China, using an AVHRR NDVI data set and the panel cointegrated regression method. They found that: 1) There can be a positive relationship between population growth and vegetation cover; 2) Unlimited population growth will eventually lead to a significant reduction of vegetation cover; 3) Population urbanization may free up space for vegetation ecological construction at some stage; 4) Population growth and vegetation cover affect each other in the long term. They recommended further study to provide validation using data from more regions since there may be the same relationships in most of the regions where there are frequent human activities, including humid, sub-humid, semiarid and arid climate regions.

Zomer et al. (2014) carried out a study to update and reanalyze agroforestry's global extent and socio-ecological characteristics, using geospatial analysis of remote sensing-derived global datasets conducted in 2009 to investigate the correspondence and relationship of tree cover, population density and climatic conditions within agricultural land at 1 km resolution. They found out that there are mixed relationships between tree cover and population density depending on the region and that specific divergences of tree-canopy cover from climate influence are stronger where population density or human activities are higher like in China and India (Zomer et al. 2014). Van Noordwijk 2005) in his study to find out what a development

mechanism do to enhance trees in the land scape, related population density with tree cover and found out that, overall, there is a clear relationship at island level between the logarithm of population density (number of inhabitants per km<sup>2</sup>) and the fraction of closed forest cover or relative carbon stock (using guesstimates for the various vegetation types). The logarithmic relationship suggested that an even spread of Indonesia's population over all the available land would lead to a substantial decline in forest cover and carbon stocks. He also found out that the relationship between forest cover and population density also holds (and explains 61% of data variability) at district scale for a data set of pre-1990 forest cover (Van Noordwijk et al. 2005).

The pressure on forest cover will be greatest in Africa. By far, the largest regional percentage increase in population by 2050 will be in Africa, whose population can be expected to at least double from 1.1 billion to about 2.3 billion. This paints a grim picture for forests in Africa since maintaining such a huge population in terms of subsistence may cause a strain on the environment (Haub 2012). Evidence shows that rapid population growth, in combination with other factors, contributes to increasing deforestation. Small frontier farmers, living on the edge of forests, drive much of the developing world's deforestation by cutting down forests for settlement and food production (PAI 2011). Deforestation is a widespread problem and has many negative impacts. The biggest threat to forest is human activities. Despite increasing efforts regarding forest management and forest conservation, the deforestation continues at a high rate to give space for other land uses such as agriculture and pasture. Gashaw et al. (2014) in their study on population dynamics and land use/ land cover changes in Dera District, Ethiopia concluded that high population density implies that there is a need for high food production, both

for crop and livestock production, which may lead to land use/land cover change thus continue in putting pressure on land resources (Gashaw et al. 2014).

Over the past century, growing human populations have put increasing pressure on tropical forests, threatening to do irreversible damage to these ecosystems. Long-term studies of tree population dynamics are critical to increase policy makers understanding of the conservation needs of tropical forest ecosystems. Kenya among other countries in East Africa has experienced significant losses in forest cover, particularly over the last two decades and the main reasons include agricultural expansion and a rapidly growing population (Ministry of Forestry and Wildlife 2013). A study in Kakamega on Long-term tree population dynamics and their implications for conservation found out that the high human density in the Kakamega area has led to considerable long-term human influence on the forest. For example, local people have long used the forest as a thoroughfare for herding cattle to grasslands in the forest interior and as a source of charcoal, fuelwood, gold, honey, medicinal plants, and construction materials (Flashing et al. 2004).

Owuor (2013) carried out research to demonstrate the use of Remote Sensing in forest cover change monitoring in Kinale forest Kenya. She employed post classification analysis to identify, describe, and quantify the changes observed in the images and found out that, the annual rate of forest cover change between the year 1988 and 1995 in the dense and moderately dense forest was 0.93% and 0.01% decrease respectively and between 1995 and 2000 the mentioned respective classes were lost at 2.26% and 2.1%. Between the year 2000 and 2010, the dense and moderately dense forest increased at the rate of 2.19% and 0.38%. In Taita hills Kenya, SPOT

XS satellite imagery, aerial photography and digital camera data were applied to monitor environmental change, the results indicated that: SPOT satellite image analysis indicated that erosion areas had increased 33% (10 km<sup>2</sup>) and built-up areas, indicating urban growth, had doubled between 1987 and 2002. The area of coniferous plantation forests had increased 32%, while the area of broad-leaved forest types (indigenous and plantation) had decreased 3% (1.6 km<sup>2</sup>). Based on the results, the gully erosion and land degradation was an on-going process in the area (Pellikka et al. 2005). To analyse the extent of deforestation in Aberdare forest within a period of 13 years between 1987 and 2000. Ochego (2003) used Landsat TM images and the results reflected a significant decline in forest cover within the period of study.

According to Johansson and Svensson (2002), population in the Baringo area is growing at a fast rate today. The fact that over 60 % of the population is under 20 years contributes to the thought that a drastic population growth will be unavoidable in the future, even if the growth rate is declining. Thus exerted pressure on the land is to wait. Therefore better land management is crucial to stop the land degradation and prevent further soil erosion so at least more people do not have less land as well. The fast increasing population must be regarded as one of the main future threats to the area. The land is divided into smaller and smaller pieces, pieces too small to feed a family. That less suitable land is taken under cultivation is unavoidable since the dependency of the land is so large (Johansson and Svensson 2002). A study on land management in Africa by Tanui, 2003 showed that most areas surrounding Mount Kenya are marginal and hence limiting in carrying capacity. Mount Kenya forest- the largest natural forest area in the country is heavily impacted by among other things illegal human activities. Forest was logged and used by human beings to support their productive and living activities (Bussmann 1996).

The case of Laikipia is borne out of by the fact that the larger the population growth by birth and through migration, the more the tendency of the communities to settle and lead sedimentary lives on fragile and marginal lands. This leads to vicious cycle of environmental degradation with more land being demanded to meet an increasing number of households. The marginal and newly settled areas in Laikipia, Embu and Nyeri showed improved tree cover and this was attributed to the habit by the newly settled communities of planting trees on their farms. This phenomenon notwithstanding, the increase in population has also meant reduced farm sizes, which therefore makes it imperative for improved farm productivity per area (Tanui 2003).

Results from a study conducted in Machakos District in Kenya found that contrary to expectations, aerial photos suggest Machakos District has become more, wooded since the 1930s. Small-scale tree planting efforts have been beneficial since farmers plant trees to stabilize soils and supply fruits and timber. Farmers in Machakos also minimize deforestation by using dead wood, farm trash, and hedge clippings for firewood. Through innovation, cultural tradition, access to new markets, and hard work, farmers in Machakos district despite the high population growth have turned once-eroded hillsides into productive, intensively farmed terraces (Tiffen and Mortimore 2002). In Marakwet District Gunlycke and Tuomaala (2011) aimed at detecting forest degradation using remote sensed data and they found out that 14% of forest cover had been cleared during the study period which used data that covered for 23 years. They also concluded that it was not possible in their study to prove statistically the linkage between deforestation and population increase.

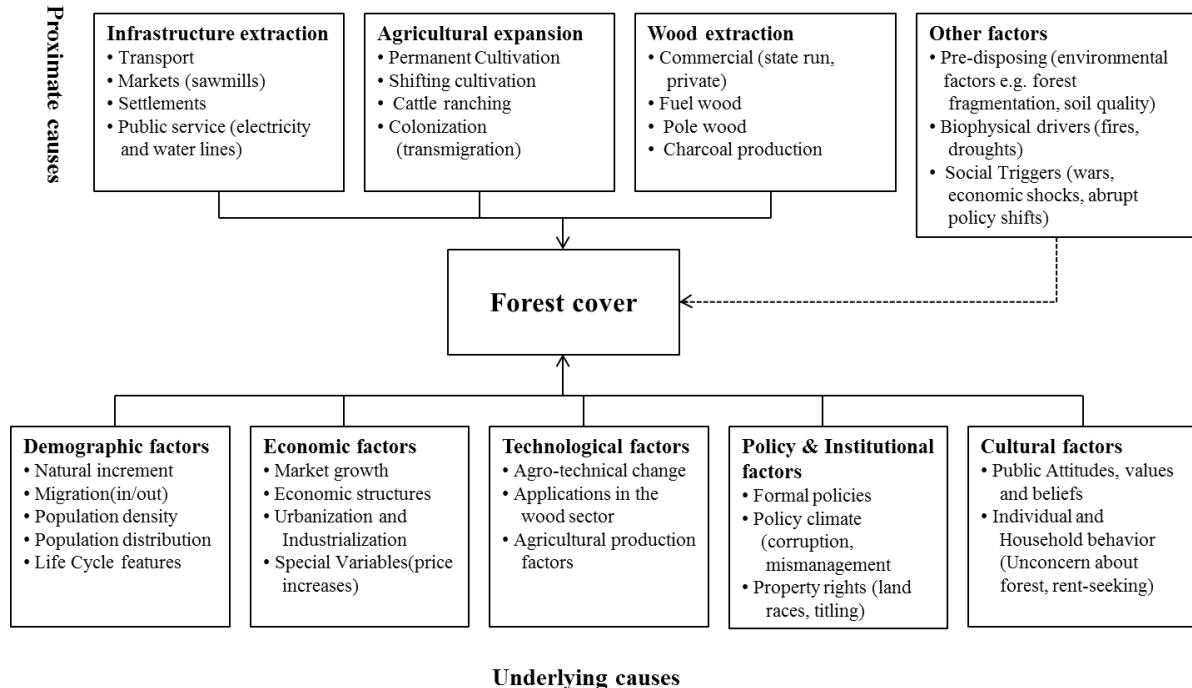
Natural resources constitute Kenya's largest potential, which support community livelihoods and economic development in the country and forests are part of these resources. Different sources define forest in very different ways. Peltorinne (2004) defines forest as a continuous stand of trees at least 10 m tall, their canopy interlocking. According to Pulla et al. (2013) Food and Agriculture Organization of the United Nations (FAO) defines forest as land under natural or planted stands of trees of at least 5 meters in situ, whether productive or not, and excludes tree stands in agricultural production systems (for example, in fruit plantations and agroforestry systems) and trees in urban parks and gardens. Forest in this study is defined based on University of Maryland definition where trees are defined as all vegetation taller than 5m in height and are expressed as a percentage per output grid cell as '2000 Percent Tree Cover'. 'Forest Loss' is defined as a stand-replacement disturbance, or a change from a forest to non-forest state and 'Forest Gain' is defined as the inverse of loss, or a non-forest to forest change entirely within the study period (University of Maryland 2013).

Kenya's tree cover falls under various classes such as forests, woodlands, bushlands and wooded grasslands. Most of Kenya's closed forests, where tree canopy covers a high proportion of land surface, fall under government jurisdiction (i.e., as gazette forest reserves). Extraction of forest products from these reserves is highly regulated or illegal (WRI 2007). Most of these forests are located in high rainfall zones and are surrounded by areas with high population densities and intensive agricultural production. In addition, dry forests are found scattered, mainly as small "islands" at higher altitudes on isolated hills and mountains surrounded by arid or semi-arid bush land. Drylands cover 88 % of the land area in Kenya and contain more than twice as much wood as all close-canopy forests combined. The drylands have to be managed taking into account their prominent role in forest product supplies (Luukkanen 1996). Despite being sparsely populated,

drylands are essential in the national economy in the tourism industry, livestock management and as fuelwood energy sources. Published population growth scenarios by NCPD, 2013 and wood supply and demand trends estimated by Luukkanen, 2003 show that between the years 2010 and 2015 the dryland areas will not be able to even produce enough wood for their own use any more and that the export of fuelwood to urban centres should be restricted in order to maintain an overall positive biomass balance in the dryland areas.

Problems related to population growth and its effects on the economy and environment of the dryland areas include sedentarization, the displacement of pastoralist communities, land conversion to permanent crop cultivation, land-use conflicts, land privatisation, poor land-use practices and the influence of land-use and hydrological changes outside the dry land area (Luukkanen 1996). Natural resources in Kenya are and will continue to be the most vulnerable especially in arid and semi-arid lands (ASAL) areas with the semi-arid regions now being the only areas still available for agricultural expansion, an expansion that is not avoidable due to a constantly growing population (Johasson and Svensson 2002). This study focused on four semi-arid counties and two humid counties which were used as control points. The study adopted Geist and Lambin 2002 framework which is commonly used for studies in forest decline and forest cover change (Klein and Perkins 1987 and Contreras-Hermosilla 2000).

## 2.2 Conceptual framework



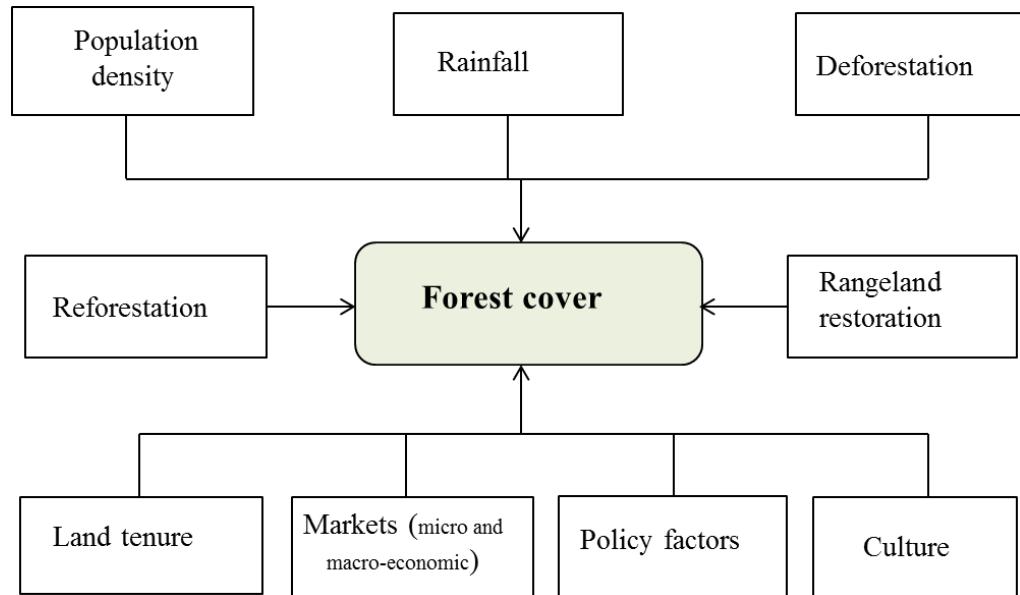
Source: Geist and Lambin (2002)

**Figure 2.2: Causes of forest decline**

Forest decline is best explained by multiple factors rather than single variables. These multiple factors are classified into two major categories: Proximate causes and Underlying causes. Proximate causes are human activities or immediate actions at the local level, such as agricultural expansion, that originate from intended land use and directly impact forest cover. Dominating the broad clusters of proximate causes is the combination of agricultural expansion, wood extraction, and infrastructure expansion.

Underlying driving forces are fundamental social processes, such as human population dynamics or agricultural policies that underpin the proximate causes and either operate at the local level or have an indirect impact from the national or global level. They are best explained by multiple factors and drivers acting synergistically rather than by single-factor causation, with more than one third of the cases being driven by the full interplay of economic, institutional, technological, cultural, and demographic variables (Geist and Lambin 2002). concepts

### 2.3 Operational framework



Source: Modified, Geist and Lambin (2002)

**Figure 2.2:** Causes of forest cover change (-/+ ve)

Forest cover change can either be negative or positive which can be caused by two major factors: Time dependent variables and time-independent variables. Time-variant variables are those whose response on the dependent variable (forest cover) is time dependent, while time-independent variables are those whose response does not depend on time. This study analysed time-dependent (population density and rainfall) in relation to NDVI and time- independent variables (policy factors, land tenure, markets, reforestation, rangeland restoration and culture) to support the results of the analysis.

### **2.3.1 Definition of variables**

Forest cover change results from complex socio-economic processes and in many situations it is impossible to isolate a single cause and the particular mix of causes vary from place to place and therefore, it may be difficult to generalize that one is the most important.

Population density is the number of people living per unit of an area (per square kilometer); the number of people relative to the space they occupy. Population density is associated with (positive/ negative) environmental change (Korr et al. 2014; Woodroffe 2000) including change in forest cover.

The nature of the relationship between population density and forest cover depends on human activities. For instance negative patterns of human activities such as planned deforestation for development needs, and unsustainable forest practices such as illegal logging, charcoal burning and encroachment contribute directly to forest degradation and eventually to decline of local habitats and species (Bistinas et al. 2013; Wachiye et al. 2013). McKee et al. (2003) concurs with Bistinas in a study on forecasting global biodiversity threats associated with human population growth revealed that two predictor variables, human population density and species richness (of

birds and mammals), account for 88% of the variability in log-transformed densities of threatened species across 114 continental nations. Using the regression model with projected population sizes of each nation, they found that the number of threatened species in the average nation is expected to increase 7% by 2020, and 14% by 2050, as forecast by human population growth alone.

Rainfall is the quantity of rain falling within a given area in a given time. It is widely believed that forest clearance may inhibit rainfall but feedbacks between terrestrial ecosystems and the atmosphere mean that vegetation also affects rainfall in that, more rain makes for more plant growth and the reverse is also true that, more plants also make for more rain. Changes in the amount of rainfall in an area results to changes in vegetation cover which includes forest cover.

Forest policy is a principle of action chosen by governments to guide management of forests within their jurisdiction. Forests should often be the subject of government action because they provide a mix of public goods such as ecosystem services and private goods such as fibre and forage. The key drivers of deforestation related to policy include failure to implement policies and legislation governing the use of forest resources, and the inability to monitor and enforce forest rules.

Land tenure defines how property rights to land are to be allocated based on rules invented by societies to regulate behaviour. They define how access is granted to rights to use, control, and transfer land, as well as associated responsibilities and restraints. Secure land tenure significantly influence tree planting practices as renters are less likely to adopt medium or long-term

conservation practices. Where belongs to the community, communities are able to secure collective tenure over resources.

Changing global markets and prices for key commodities are making scaled-up investments increasingly viable and attractive. Market prices can lead to conservation of forest. For instance new markets for forest and tree products are creating incentives for tree and forest planting and management. When Kenya imposed forest logging bans, the result was higher prices and more favorable market opportunities for investment in tree growing and forestry-related enterprises especially by the private sector. With overall forest cover declining and rewards for carbon and other environmental services from forests increasing, forests are likely to be further regulated. Better prices from high value crops gives people an alternative source of income rather than depending on forest products as a source of income. Culture is the sum total of ways of living built up by a group of human beings and transmitted from one generation to another. Culture contributes to forest conservation in that, some communities preserve forest for use as a dry season grazing refuge as well as for fuel wood and building materials, water catchment, traditional medicines, and a range of spiritual and cultural purposes.

In forest cover mapping the use of remotely sensed information has gained recognition. Remote sensing relates to studying the environment from a distance using techniques such as satellite imaging, aerial photography, and radar (Hoang and Caudill 2012). Remote sensing data is acquired through, a range of airborne and space-borne sensors, with the number of sensors and their diversity of capability increasing over time. Today a large number of satellite sensors observe the Earth at wavelengths ranging from visible to microwave, at spatial resolutions

ranging from sub-meter to kilometers and temporal frequencies ranging from 30 minutes to weeks or months. In addition, archives of remotely sensed data are increasing and these data provide a unique chronological data of the Earth during the specified time period (Asano et al. 2008). New sensors are continually being launched and existing sensors are often replaced to ensure continuity in the data record. Given this enormous resource, remote sensing has proven to be an effective tool to monitor forest/vegetation cover.

There are various methods of assessing forest structure. Traditional methods like field inventories and aerial photo interpretation are intrinsically limited in providing spatially continuous information over a large area. Utilizing remote sensing data reduces the amount of field sampling and hence information gathering becomes more cost-effective (Wang 2004). Remote sensing has been a valuable source of information over the course of past few decades in mapping and monitoring forest. Remote Sensing provides a unique opportunity to assess and monitor forest cover for a number of reasons. First, it allows forest cover assessment at multiple scales ranging from few meters to several kilometers. This included detailed study at local level to global forest resources assessment. Second, remotely sensed data can be acquired repeatedly (e.g. daily, monthly) that helps monitor forest resources in a regular basis. Third, remote sensing data has general coverage and information can be acquired in places where accessibility is an issue. Fourth, we could use wavelengths that are not visible to human eye (Tejaswi 2007). Thus, remote sensing is the most effective means of assessing and monitoring forest resources. It is important to understand that remote sensing does not replace field survey but provides complimentary information. Using these data you can map forest changes using change detection techniques.

There are many types of change detection methods of multi-spectral image data and they can be classified as three categories: Characteristic analysis of spectral type, vector analysis of spectral changes and time series analysis. The aim of characteristic analysis of spectral type method is to make sure the distribution and characteristic of changes based on spectral classification and calculation of different phases remote sensing images. The methods are multi-temporal images stacking, algebraic change detection algorithm of image, and change detection of the main components of the image and change detection after classification. The aim of the method of time series analysis is to analyze the process and trend of changes of monitoring ground objects (such as deforestation as in our study) based on remote sensing continual observation data (Shaoqing and Lu 2008).

This study used population density and rainfall to establish the statistical linkage between forest cover and population density through modelling and regression analysis to determine the significance of rainfall and population density on forest cover change. Literature synthesis was conducted to explore how time-independent variables support the results of the regression analysis in contributing to forest cover change in the study counties.

## **CHAPTER THREE**

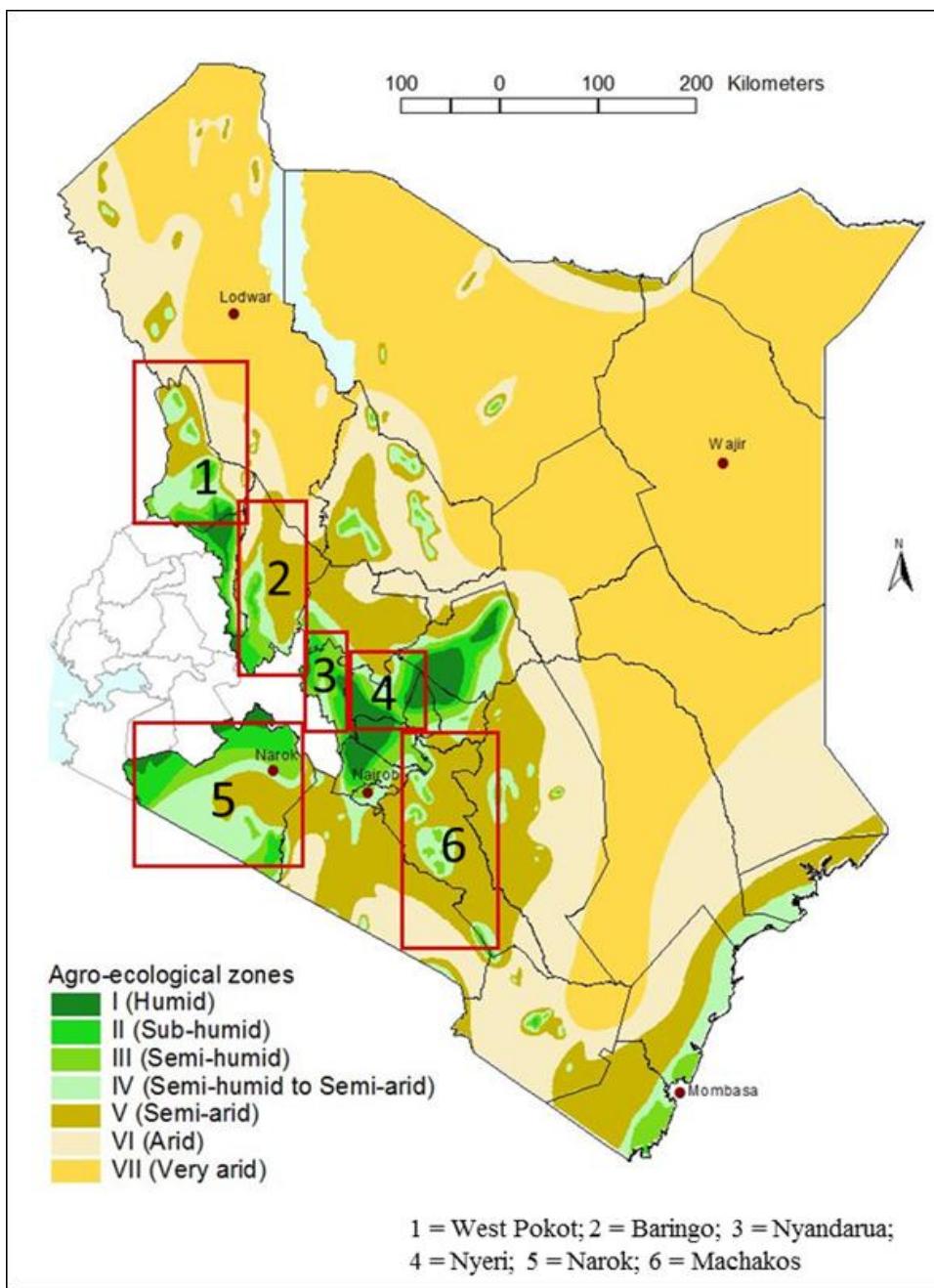
### **DATA AND METHODS**

#### **3.1 Study Area**

The study focused on four semi-arid counties and two humid counties. Figure 3.1 shows the Location and biophysical characteristics of these counties . The two humid counties had least 75% of the total area classified as arable land – Nyandarua (89) and Nyeri (75%). Classification of arable land in semi-arid counties varied per county with highest to lowest potential being Narok (39%), West Pokot (25%), Baringo (9%) and Machakos (5%).

The six counties selected for this study have the potential of forest cover exploitation and conservation of trees. The two counties with high agriculture potential were taken as control sites in that we should expect more exploitation of resources. Summarises of the biophysical and social characteristics of the six counties are given in Figure 3.1 and Table 3.1. In the humid counties the one with highest population growth rate was Nyandarua (3.2%) followed by Nyeri (1.2%). In the ASALs the growth rate ranked high in Narok (4.8%), West Pokot (4.0%), medium in Baringo (3.4%) and lowest in Machakos (2.2% ).

**Figure 3.1:** Location and biophysical characteristics of the study sites



**Source:** Authors design

**Table 3.1:** Biophysical and social-ecological characteristics of the study sites

| No. | District   | Area % |           |            |                         |           |      |           | Population growth rate (%)<br>1979-2009 |     |
|-----|------------|--------|-----------|------------|-------------------------|-----------|------|-----------|---|-----|
|     |            | Humid  | Sub-humid | Semi-humid | Semi-humid to Semi-arid | Semi-arid | Arid | Very arid |   |     |
| 1   | West Pokot | 3      | 8         | 14         | 35                      | 27        | 13   | 0         | 15                                      | 4.0 |
| 2   | Baringo    | 0      | 2         | 7          | 13                      | 60        | 19   | 0         | 8                                       | 3.4 |
| 3   | Nyandarua  | 14     | 33        | 42         | 11                      | 0         | 0    | 0         | 27                                      | 3.2 |
| 4   | Nyeri      | 32     | 20        | 23         | 21                      | 4         | 0    | 0         | 44                                      | 1.2 |
| 5   | Narok      | 5      | 14        | 20         | 38                      | 23        | 0    | 0         | 17                                      | 4.8 |
| 6   | Machakos   | 0      | 0         | 5          | 18                      | 70        | 7    | 0         | 2                                       | 2.2 |

**Source:** Author's design

### 3.2 Population Census data

The calculation of inter-censal population totals was based on the Kenya Population and Housing Census data for the period 1979 -2009 which represent a complete enumeration of all persons in the country at a specified time. The censuses are conducted decennially and we calculated the yearly population growth rates based on exponential growth rate model as expressed as:

$$P_t = P_0(e^{rt}) \quad (1)$$

where

$P_t$  = population at year:  $P_0$  = initial population:  $e$  = base of the natural logarithm:

$r$  = annual rate of growth:  $t$  = number of years over which growth is to be measured

Population density was for each study county and the time period calculated by dividing total population for each county by its total area in square kilometres. Population density was then plotted against time to analyse the population trends across the 6 counties for the period 1979 to 2009 as to match the remotely sensed data. The remote sensing data cover the period 1982 to

2008. Population density data was also used to establish it's association with NDVI. It was also used to run regression analysis in conjunction with rainfall data to determine the significance of population density and rainfall on NDVI.

### **3.3 Rainfall data**

Monthly precipitation data was obtained from the Kenya Metrological Department (KMD) from 1982 to 2008 for the six study sites. One rainfall station with the most complete data was selected for each county and the yearly average totals calculated by adding the monthly totals and dividing by 12 months. Missing data in the record periods were estimated by dividing the yearly rainfall total with the number of months in the year. Rainfall data was used to run regression analysis to determine it's significance to forest cover change.

### **3.4 Normalized Difference Vegetation Index (NDVI) data**

Consistent Normalized Difference Vegetation Index (NDVI) time series is widely applied to monitor forest (Yao et al. 2011; Beck et al. 2006) and therefore we used it in this study as a remotely sensed measure of forest cover. NDVI is related to biophysical variables such as leaf area, canopy coverage, and productivity and chlorophyll density as well as to vegetation phenology (Goward et al. 1985; Justice et al. 1998; Vrieling et al. 2013) and is used to reflect vegetation growth status. Satellite-based NDVI provides long time series data as a powerful tool to understand past events, monitor current conditions and prepare for predicting future change.

Normalized Difference Vegetation Index (NDVI) is a ratio often used to determine the density of vegetation in an area based on visible and near infra-red (NIR) sunlight reflected by plants. The pigment in plant leaves, chlorophyll, strongly absorbs visible light for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light. The more

leaves a plant has, the more these wavelengths of light are affected. NDVI is calculated from remotely sensed data as:

$$\text{NDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{red}}}{\rho_{\text{NIR}} + \rho_{\text{red}}} \quad (2)$$

where  $\rho_{\text{NIR}}$  and  $\rho_{\text{RED}}$  are reflected values in the near-infrared and red spectrum respectively.

NDVI values with higher value indicate more abundance of green vegetation. Vegetated areas give positive values due to their high reflectance in NIR and low reflectance in the visible spectrum. On the other hand, bare areas or areas with very sparse vegetation cover have higher reflectance in the visible spectrum than in NIR, leading to negative and near zero NDVI values. The NDVI data used in this study was sourced from Advanced Very High Resolution Radiometer (AVHRR) NOAA-series satellites with a spatial resolution of  $8 \times 8$  km (Tucker et al. 2005). The data was downloaded from United States Geological Survey (USGS) website accessed through: <http://earthexplorer.usgs.gov/> and covered the period 1982 – 2008 when the satellites were active.

The data was processed in WinDisp 5.1 software and the processed data transferred to Microsoft Excel. To minimize data with cloud cover a 10 day composite NDVI, which takes the maximum NDVI from the 10 daily values for each pixel were used and with further corrections as suggested White et al. (1997). The algorithm is based on the concept that abrupt decreases in NDVI followed by relatively fast (within approximately two to three 10-day periods) recoveries can be safely attributed to the effects of clouds. These decreases were removed, and the data series reconstructed by a three year moving average operation. This data was used to determine NDVI trend analysis and to establish the association between population density and forest cover.

### **3.5 Forest cover change data**

High resolution images of Landsat 5 and 7 satellites were used to analyse forest cover changes at detailed scales. These images map the global forest loss and forest gain between 2000 and 2012 at a resolution of 30 meters. Forest cover and forest cover change raster images were downloaded from Maryland University Global forest change images website accessed through <http://www.earthenginepartners.appspot.com/science-2013-global-forest/download.html>. This data offers a consistent characterization of forest change at a resolution that is high enough to be locally relevant (Hansen et al. 2013).

Forest loss is defined as a stand-replacement disturbance or the complete removal of tree cover canopy at the Landsat pixel scale while forest gain is defined as the inverse of loss, or the establishment of tree canopy from a non-forest state and forest change is the difference between forest gain and forest loss (Hansen et al. 2013). This global dataset is divided into 10x10 degree tiles, consisting of seven files per tile. All files contain unsigned 8-bit values with spatial resolution of approximately 30 meters per pixel at the equator (Hansen et al. 2013). The data was downloaded in individual 10x10 degree granules adjacent to one another covering the study area. A mosaic of several contiguous areas comprising of the total area was put together and processed using ArcGIS (ESRI 10.1) Software. Forest gain and forest loss was extracted for each study site for the period 2001 and 2012. Maps of forest status in 2001 and 2012 were created and statistics generated for the loss and gain based on the spatial models built in ArcGIS. This data was used to establish the extent to which population density have brought about changes in forest cover.

### **3.6 Remote Sensing and Geographic Information Systems (GIS) techniques**

Remote Sensing and Geographical Information Systems techniques have contributed significantly in monitoring vegetation change which affects the ecosystem. Clearing forested land, for example, affects multiple ecosystem services (such as food production, biodiversity, carbon sequestration, and watershed protection), each of which affects human well-being. Assessing environmental condition requires scientifically based analysis to quantify environmental changes. In this study, Remote Sensing data was extracted from Advanced Very High Resolution Radiometer (AVHRR) NOAA-series satellites using Geographical Information Systems techniques. The data was used as a remotely sensed measure of forest cover to determine NDVI trends for 24 years and also to establish the association between population density and NDVI. Remote Sensing data from Landsat 5 and 7 satellites was extracted and used to analyse forest cover changes at detailed scales based on the spatial models built in ArcGIS softwares. This was important to establish the extent to which population density have brought about changes in forest cover.

Scientific advances over the past few decades, particularly in computer modeling, remote sensing, and in analytical tools such as geographic information systems allow data on the physical, biological, and socioeconomic characteristics of ecosystems to be assembled and interpreted in a spatial framework, making it feasible to establish linkages between drivers of change and trends in ecosystem services (Adamowicz et al. 2005).

Operational meteorological satellites, most notably the Advanced Very High Resolution Radiometer, have provided the longest continuous record for NDVI from the 1980s to the

present. Advances in remote sensing technologies over the past few decades now enable repeated observations of Earth's surface. The potential to apply these data for assessing trends in environmental condition has been used over the years. Remote Sensing, broadly defined as the science of obtaining information about an object without being in direct physical contact (Levin 1999), is the primary data source for mapping the extent and condition of ecosystems over large areas. Remote sensing provides measurements that are consistent over the entire area being observed and are not subject to varying data collection methods in different locations, unlike ground-based measurements. Repeated observations using the same remote sensing instrument also provide measurements that are consistent through time as well as through space. Satellite data are generally digital and consequently amenable to computer-based analysis for vegetation change and assessing trends. Analyses of satellite data are a major contribution to assessments of ecosystem conditions and trends, especially over large areas where it is not feasible to perform ground surveys.

Over the last few decades, satellite data have increasingly been used to map land cover at national, regional, continental, and global scales. During the 1980s, pioneering research was conducted to map vegetation at continental scales, primarily with data acquired by the U.S. National Oceanographic and Atmospheric Administration's meteorological satellite, the Advanced Very High Resolution Radiometer. Multitemporal data describing seasonal variations in photosynthetic activity were used to map vegetation types in Africa (Tucker 1985) and South America (Townshend 1987). In the 1990s, AVHRR data were used to map land cover globally at increasingly higher spatial resolution (DeFries and Townshend 1994). Global satellite data also

have enabled mapping of fractional tree cover to further characterize the distributions of forests over Earth's surface (DeFries 2000).

GIS is used in conjunction with remote sensing to identify land cover change. A common approach is to compare recent and historical high-resolution satellite images (such as Landsat Thematic Mapper). For example, Adamowicz et al. (2005) illustrated the changes in forest cover between 1992 and 2001 in Mato Grosso, Brazil. Achard et al. (2002) have used this approach in 100 sample sites located in the humid tropical forests to estimate tropical deforestation. GIS has also been applied in wilderness mapping, also known as "mapping human impact." These exercises estimate human influence through geographic proxies such as human population density (Fritz 2000). GIS is also applicable for depicting critical environmental situations, biodiversity loss (Myers et al. 2000) and rapid land cover change (Lepers et al. 2005). The analytical and display capabilities of GIS can draw attention to priority areas that require further analysis or urgent attention.

Remote Sensing and Geographical Information System (GIS) methodologies have been used at regional scales (Alqurashi and Kumar 2013), as well as on a global scale (for example, UNEP 2001; Sanderson 2002). Sanderson et al. (2002) used the approach to estimate the 10% wildest areas in each biome of the world. The U.N. Environment Programme's Global Biodiversity (GLOBIO) project uses a similar methodology and examines human influence in relation to indicators of biodiversity (UNEP 2001). Remote Sensing and GIS have been widely used for vegetation change analysis and human impact on environment and hence the choice of these techniques for analysis in this study.

### **3.7 Regression Analysis**

Regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables focusing on the relationship between a dependent variable and one or more independent variables. In this study, multiple regression analysis was conducted in order to determine the significance of rainfall and population density on NDVI and polynomial regression model was used to establish the relationship between population density and NDVI.

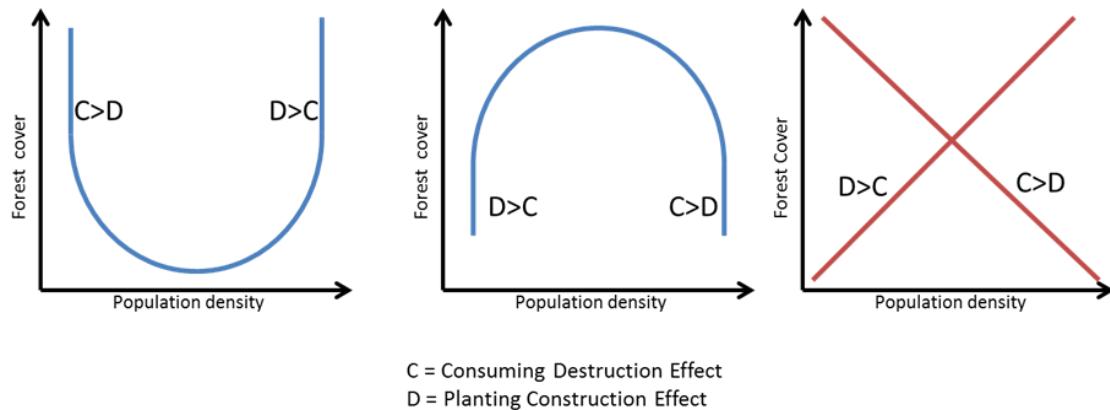
The relationships between forest cover change and its driving factors have been evaluated using different types of regression models. For example ordinal regression analysis (Minetos 2007), linear regression analysis (Miyamoto et al. 2014), multiple regression models (Wright 2008), logistic regression model (Kumar et al. 2014) and polynomial regression models (Abdullah et al. 2007; Bentley et al. 2013; Li et al. 2013). There is relevant application of polynomial regression models in the international literature that has proven useful in understanding certain aspects of land use change processes. Relative applications have been conducted by (Abdullah et al. 2007) to evaluate forest land use changes in Greece. A second application was made by (Bentley et al. 2013). They applied polynomial regression equation after the Environmental Kuznets Curve in the investigation of forest cover Change in the Northeastern U.S. A third application was made by (Li et al. 2013) to establish the long-term relationship between population growth and vegetation cover: an empirical analysis based on the panel data of 21 Cities in Guangdong Province, China. Polynomial regression model was used in this study to show its relevant application in establishing the relationship between population density and NDVI.

The influence of population growth on vegetation can be considered as two effects (Li et al. 2013). One is the consuming destruction effect. Population growth can inevitably result in increasing demands for life necessities. To meet these demands, large areas with good vegetation cover will be exploited and many vegetation resources will be plundered resulting in vegetation cover decrease. Another is the planting construction effect where with increasing population the demands for ecological functions takes precedence with resulting vegetation cover increase through action such as vegetation protection, reforestation and so on.

In this study we explored the relationship between population density and NDVI - a remotely sensed measure of forest cover using population density as independent variable and forest cover as dependent variable. To test the relationship between population density and forest cover, we adopted a simplified cubic polynomial regression equation after the Environmental Kuznets Curve (EKC) as follows:

$$V = c + \beta_1 P + \beta_2 P^2 + \beta_3 P^3 + u \quad (3)$$

where  $V$  is the index reflecting the vegetation,  $P$  is the index reflecting the population,  $c$  is a constant,  $u$  is the random error, the parameters  $\beta_1$ ,  $\beta_2$  and  $\beta_3$  are the coefficients of the first, second and third term of  $P$ , respectively. If  $\beta_3 = \beta_2 = 0$ ,  $\beta_1 \neq 0$ , there is a linear relationship between population density and forest cover. If  $\beta_3 = 0$ ,  $\beta_2 > 0$ ,  $\beta_1 < 0$ , there is an U-shaped curve relationship between population density and forest cover, which means that forest cover tends to decrease first and then increase with the population density. If  $\beta_3 = 0$ ,  $\beta_2 < 0$ ,  $\beta_1 > 0$ , there is an inverted U-shaped curve relationship between population density and forest cover, which means that the forest cover tends to increase first and then decrease with the population density (Li et al. 2013; Mather et al. 1999).



**Figure 3.2:** Influence of population density on forest cover

To select the best model that shows the relationship between population density and forest cover three models were based on linear, second and third order polynomials regression using SAS Software. The best model was based on the lowest values of Akaike's Information Criterion (AIC).

For any statistical model, the AIC value is

$$AIC = 2k - 2\ln(L) \quad (4)$$

where  $k$  is the number of parameters in the model, and  $L$  is the maximized value of the likelihood function for the model.

Given a set of candidate models for the data, the preferred model is the one with the minimum AIC value, hence AIC rewards goodness of fit of the selected model. The advantages of AIC is that it can be used to compare models based on different probability distributions. AIC does not depend directly on sample size like Bayesian Information Criterion (BIC) does. It is able to simultaneously compare multiple nested or nonnested models, assess model selection

uncertainty, and allow for the estimation of model parameters using all available models (model-averaged inference or multimodel inference).

The AIC makes several assumptions. First, there is the assumption of "uniformity of nature" (Posada and Buckley 2004), that is, that all data sets (future and past) are drawn from the same underlying process. Second, the AIC assumes that the sample size is large enough to ensure that the likelihood function will approximate its asymptotic properties. Finally the AIC assumes that the true distribution of parameter estimates, when the number of data  $n$  is sufficiently large, follows a multivariate normal distribution. The best model in a group compared is the one that minimizes the maximum likelihood estimates scores. As data is introduced and the scores are recalculated, at relatively low  $N$  (7 and less) BIC is more tolerant of free parameters than AIC, but less tolerant at higher  $N$  (as the natural log of  $N$  overcomes 2). This limitation did not affect the results of AIC in this study because the values of the parameters (population density and NDVI) were higher than 7. AIC, the Akaike Information Criterion, is generally regarded as the first model selection criterion introduced in 1973. Today, AIC continues to be the most widely known and used model selection tool among practitioners hence the choice of AIC tool as a model selection tool in this study.

## CHAPTER FOUR

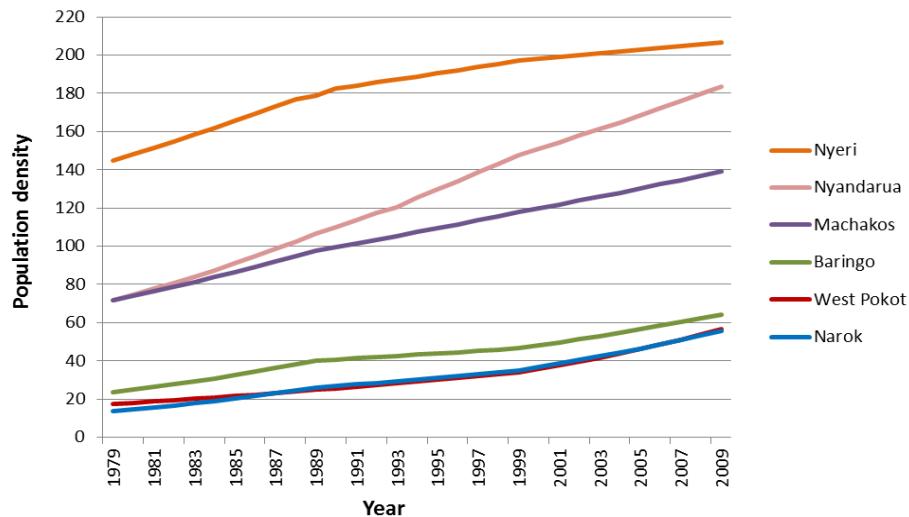
### RESULTS AND INTERPRETATION

#### 4.1 Introduction

Kenya's population is growing rapidly and has more than tripled from 10.9 million people in 1969 to 38.6 million people in 2009. This increase will continue to put pressure on natural resources especially forests which are important for protecting ecological diversity, regulating climate patterns and as a basis of water catchment. Forest destruction in return increases pressure on a population grappling with hunger and water shortage and power shortage. This chapter discusses trends in population density; relationship between population density, NDVI and rainfall; trends in Normalized Difference Vegetation Index (NDVI) and spatial changes in forest cover.

#### 4.2 Trends in population density

The humid counties (Nyeri and Nyandarua) have the highest population density while semi-arid county of Machakos has the highest population density among the semi-arid counties.



**Figure 4.1:** Trends in population density

Source: Author's design

### 4.3 Regression analysis

In multiple linear regression is a statistical process where two or more independent variables are used to predict the value of a dependent variable. The focus is on the relationship between a dependent variable in this case NDVI and independent variables (population density and rainfall). Multiple linear regression analysis was conducted to determine the significance of population density and rainfall on NDVI. Table 4.1 below summarizes the results of the regression analysis.

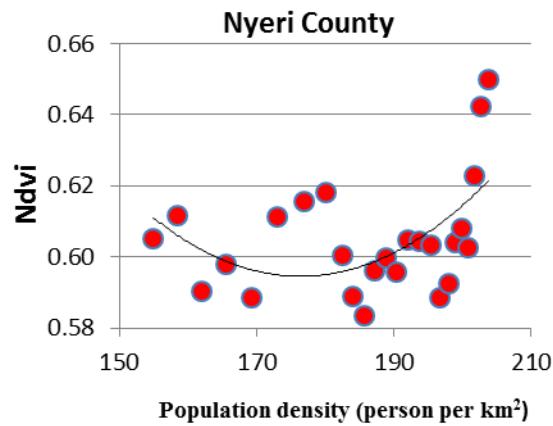
**Table 4.1:** Summary of population density and rainfall regression analysis

|                     | Baringo  |           | West Pokot |           | Machakos |           | Narok    |           | Nyandarua |           | Nyeri    |         |
|---------------------|----------|-----------|------------|-----------|----------|-----------|----------|-----------|-----------|-----------|----------|---------|
| Predictor variables | t- Value | Pr > t    | t- Value   | Pr > t    | t- Value | Pr > t    | t- Value | Pr > t    | t- Value  | Pr > t    | t- Value | Pr > t  |
| Population          | 6.34     | <.0001*** | 7.31       | <.0001*** | -4.34    | 0.0002*** | -4.24    | 0.0003*** | 3.29      | 0.0034*** | 2.7      | 0.013** |
| Rainfall            | 0.6      | 0.5556    | 3.57       | 0.0016**  | 0.95     | 0.3542    | 0.19     | 0.8483    | 2.88      | 0.0085**  | 1.36     | 0.018** |

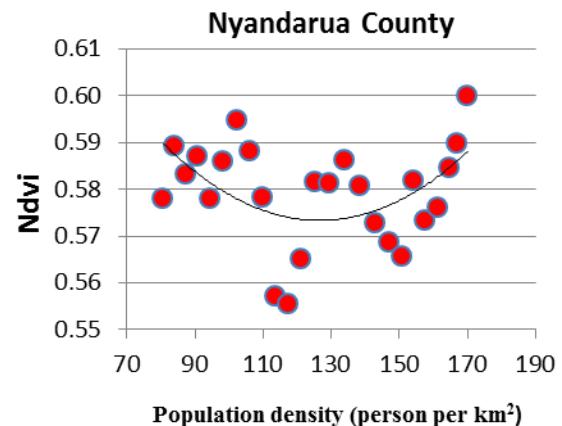
\*p < .05, \*\* p < .01, \*\*\* p < .001  
no asterisk= not statistically significant

Population density has a low p-value and therefore is a meaningful addition to the model thus changes in population density are related to changes in NDVI, while on the other hand rainfall has a larger (insignificant) p-value and as such not as significant as population density in most cases. It is important to note that the insignificance of rainfall for inclusion in further analysis of this model does not mean that it has no contribution to forest cover change. The regression analysis was used to determine the significance and insignificance of independent variables in relation to the dependent variable.

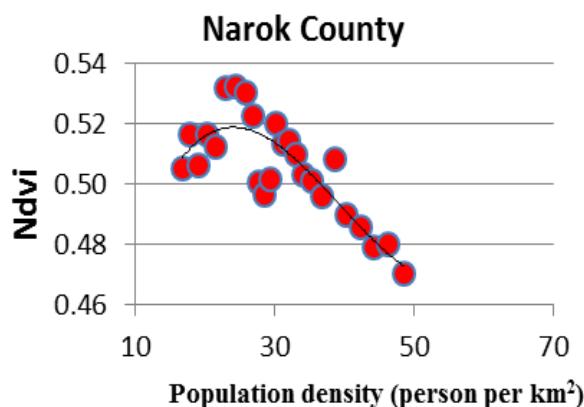
To select the best model that showed the relationship between population density and forest cover, three models for each study county based on linear, second and third order polynomial regressions were run using SAS Software. Akaike's Information Criterion (AIC) was used to select the best model that relates population density and NDVI. The smallest AIC score provided an adequate fit to the data for each county.



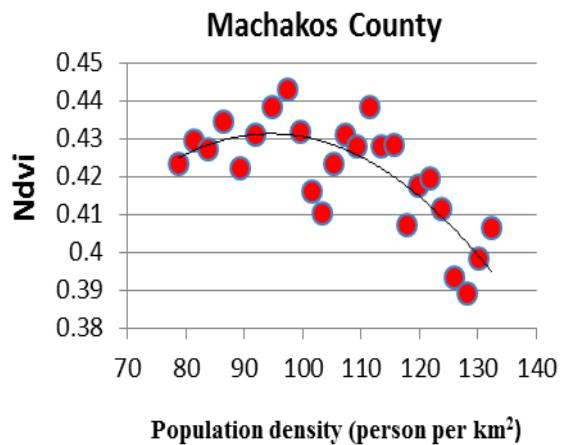
**Figure 4.2** Population density and NDVI in Nyeri



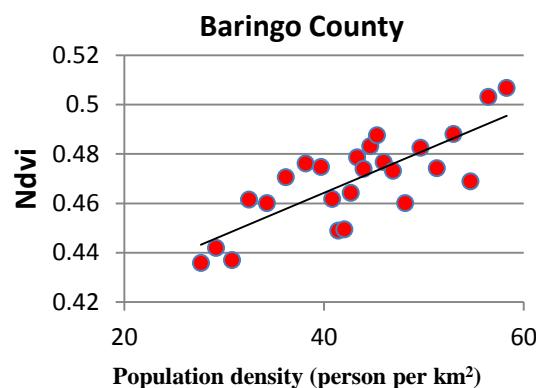
**Figure 4.3** Population density and NDVI in Nyandarua



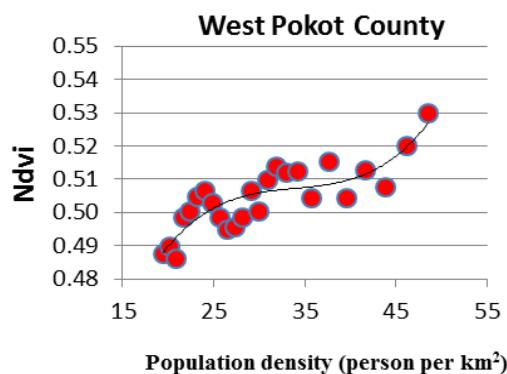
**Figure 4.4** Population density and NDVI in Narok



**Figure 4.5** Population density and NDVI in Machakos



**Figure 4.6** Population density and NDVI in Baringo



**Figure 4.7** Population density and NDVI in West Pokot

From Figure 4.2 and Figure 4.3, Nyeri and Nyandarua indicated a U-shape relationship between population density and NDVI. As the population density increased the NDVI value decreased. This means as population density continued to increase people continued to exploit forest resources leading to forest destruction, later as the population density increased the NDVI values increased which means that it reached a point when people started realizing that forest destruction was affecting them and they started forest management initiatives to conserve forest resources. Narok and Machakos counties show an inverted U-shaped curve relationship between population density and forest cover, which means that forest cover tended to increase first and then decrease with population density (Figure 4.4 and Figure 4.5). For Narok and Machakos as population density increased people were not over exploiting forest resource and therefore forest cover was also increasing but it reached a point when population density in Narok was about 30Sq.Kms and 100 sq. Kms, in Machakos people started over exploiting forest with less conservation initiatives hence forest cover started decreasing as population density increased.

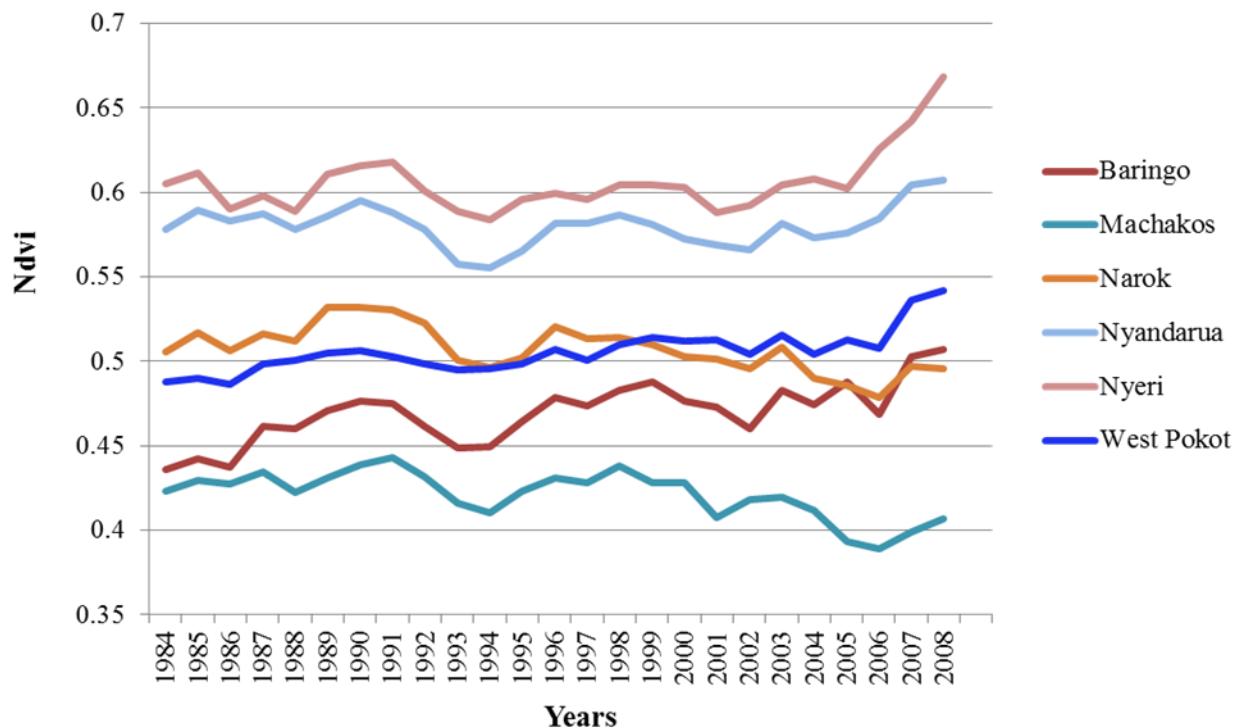
There is a linear relationship between NDVI and population density in Baringo (Figure 4.6), while in West Pokot the relationship is generally linear which shows that NDVI increased first as the population density increased, then decreases slightly and rose again with population density increase (Figure 4.7). In both Baringo and West Pokot there is a balance in forest exploitation and conservation as population density increases.

#### **4.4 Trends in Normalized Difference Vegetation Index (NDVI)**

The trends of NDVI in the six counties indicates three major ecological regions: Nyeri and Nyandarua have high NDVI values above 0.55 indication of areas with high rainfall and also dense vegetation. Both counties have high forest cover (Table 4.2 ). The second group of counties

Narok, West Pokot and Baringo fall more on the semi-arid ecoregions with NDVI values between 0.45 and 0.55, with forest cover between 8 – 17%. Machakos was the driest area with NDVI less than 0.45 and had the least forest cover (2%).

In terms of the NDVI trends the analysis indicates all the counties registering increases of forest cover between 1987 and 1991, decline between 1991 and 1994, another period of increase between 1994 and 1998 (Figure 4.8). However, the major shifts in the trends occurred between 2002 and 2008. Nyeri, Nyandarua, West Pokot and Baringo showed an upsurge of the NDVI. However, we observed declines in counties of Narok and Machakos. Both Narok and Machakos show a slight increase in NDVI between 2006 and 2008. The NDVI values in 2008 were still lower than those in 1984 showing deterioration of the environmental conditions in these Counties. The increase in NDVI in the Nyeri, Nyandarua and West Pokot indicate positive change in forest condition over the period 2002 and 2008 (Figure 4.8)



**Figure 4.8:** Trend in Normalized Difference Vegetation Index (NDVI) for the six counties between 1984 and 2008

**Source:** Author's design

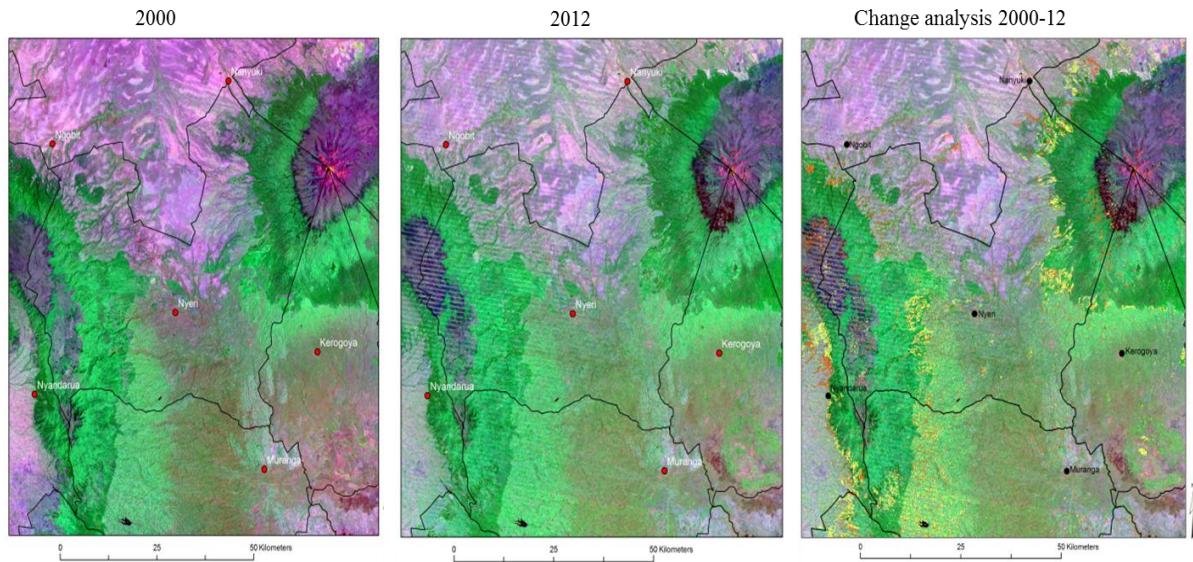
**Table 4.2:** Summary statistics on forest cover

| District   | Area<br>(km <sup>2</sup> ) | Forest Area<br>(km <sup>2</sup> ) | Forest cover<br>(%) |
|------------|----------------------------|-----------------------------------|---------------------|
| Nyeri      | 3356                       | 1470                              | 44                  |
| Nyandarua  | 3245                       | 883                               | 27                  |
| Narok      | 15263                      | 2520                              | 17                  |
| West Pokot | 9064                       | 1389                              | 15                  |
| Baringo    | 8655                       | 652                               | 8                   |
| Machakos   | 14243                      | 213                               | 2                   |

**Source:** Author's design

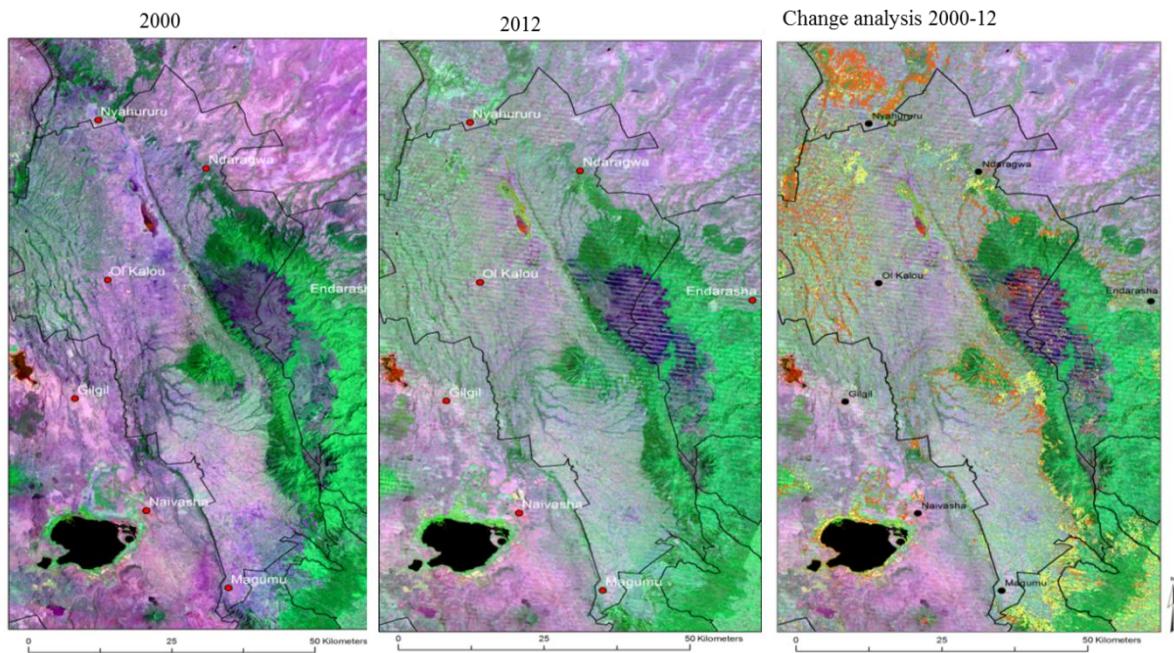
#### **4.5 Changes in forest cover**

The detection of changes in forest cover involved comparison of satellite images taken in different years. In this case, the situation in 2000 was compared with the situation in 2012. Image differencing was performed by subtracting the NDVI pixels values of 2000 images from the NDVI pixel values of the corresponding 2012 images. A positive change (increase in forest cover) was assigned yellow color whilst a negative change (decrease in forest density) was assigned orange color. The green color represents vegetation cover and areas with heavy tinge color shows areas of denser forest cover.



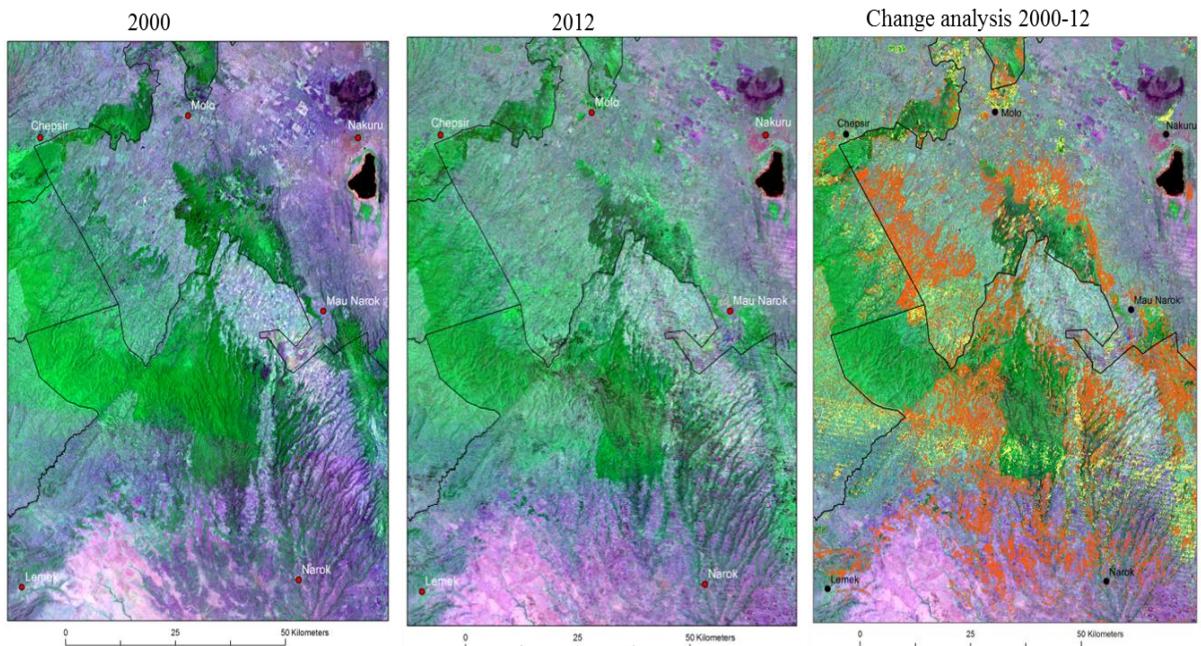
**Figure 4.9:** Changes in forest cover in Nyeri County between 2000 and 2012

**Source:** Author's design



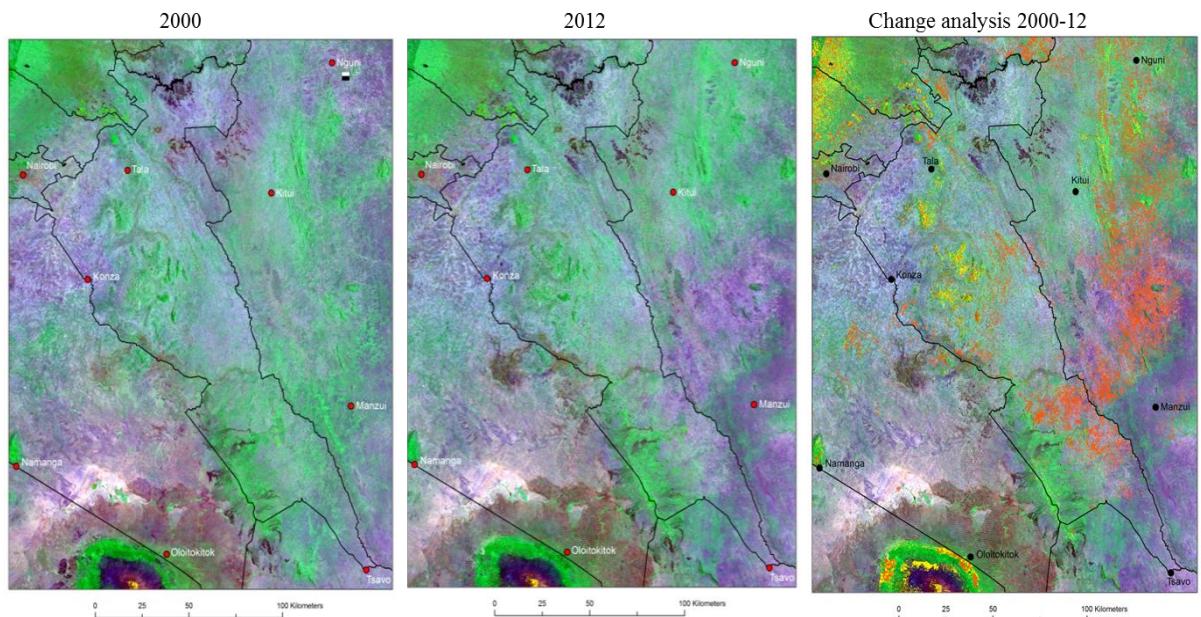
**Figure 4.10:** Changes in forest cover in Nyandarua County between 2000 and 2012

**Source:** Author's design



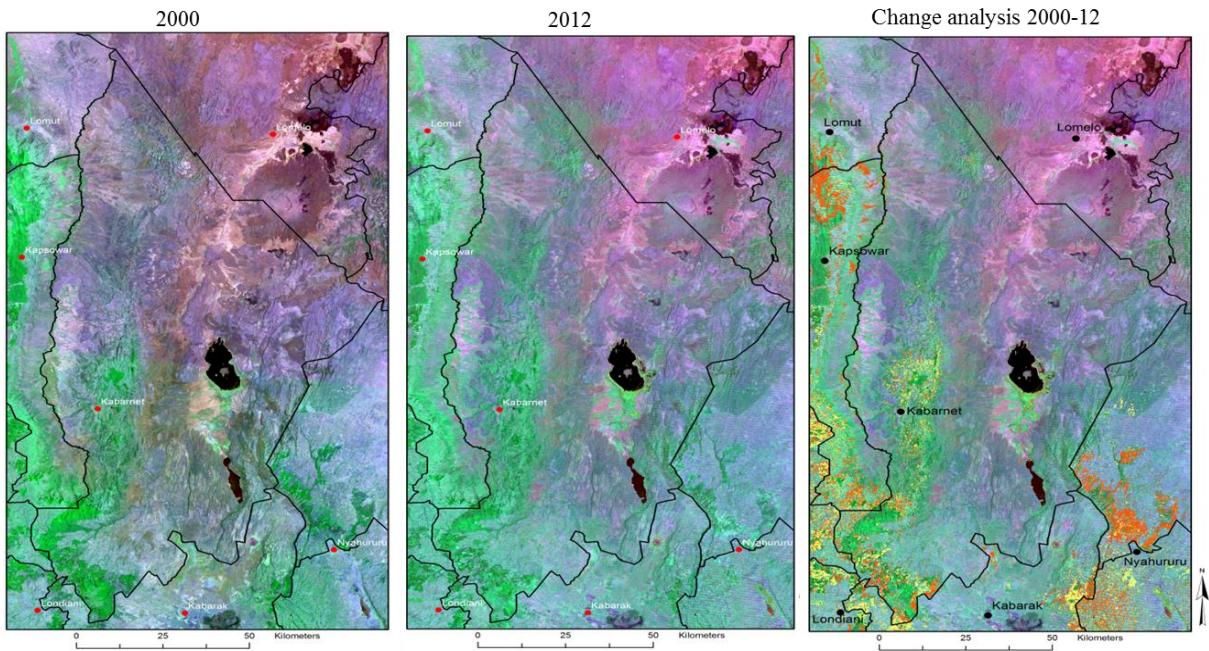
**Figure 4.11:** Changes in forest cover in Narok County between 2000 and 2012

**Source:** Author's design



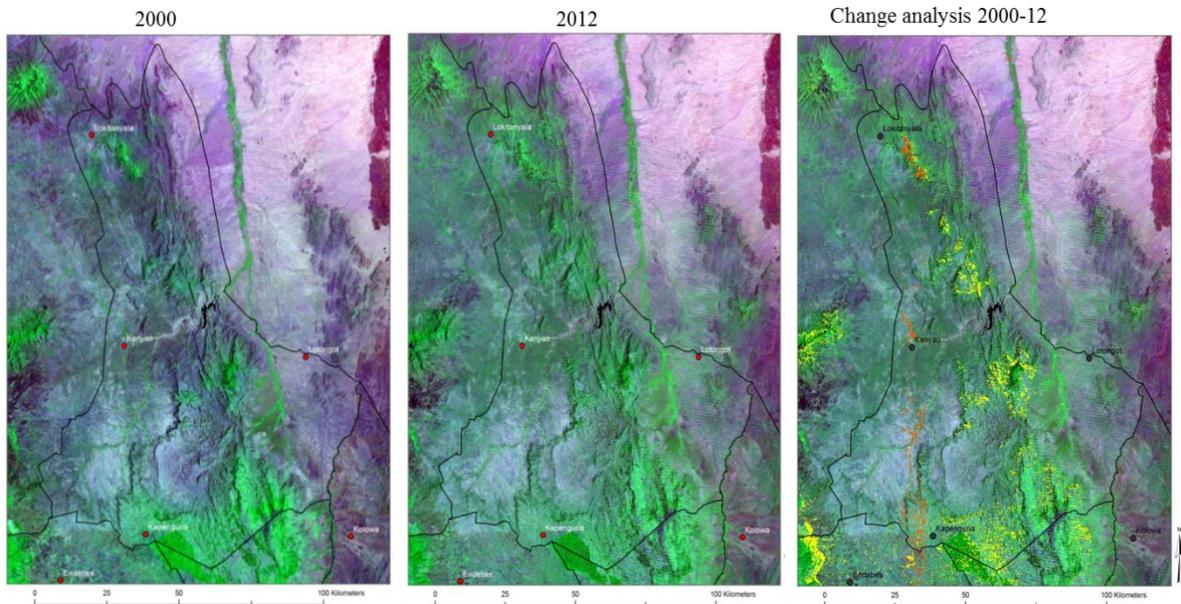
**Figure 4.12:** Changes in forest cover in Machakos County between 2000 and 2012

**Source:** Author's design



**Figure 4.13:** Changes in forest cover in Baringo County between 2000 and 2012

**Source:** Author's design



**Figure 3:** Changes in forest cover in Narok County between 2000 and 2012

**Source:** Author's design

The major destruction of forest cover between 2000 and 2012 took place in the Mau forest followed by forests in Machakos. The forests of Mount Kenya are further improving, with some 2,240 hectares of forests regenerating, consistent with the findings of a study conducted by DRSRS and KFWG in 2006 which showed that between 2000 and 2005 Mount Kenya forest was improving, with some 2,147 hectares of forests regenerating (Akotsi et al. 2006). Analysis of change in the Aberdare Range forests between 2000 and 2012 showed that forest cover was more stable with slight changes during that ten year period.

**Table 4.3:** Summary of forest loss and gain in the 6 counties between 2000 and 2012

| County     | Forest loss<br>Area (Ha) | Forest gain<br>Area (Ha) | Forest<br>gain/loss<br>Area (Ha) |
|------------|--------------------------|--------------------------|----------------------------------|
| Nyeri      | 2121                     | 4361                     | 2240                             |
| Nyandarua  | 4407                     | 3954                     | -453                             |
| Narok      | 46577                    | 12404                    | -34173                           |
| Machakos   | 9166                     | 1779                     | -7386                            |
| Baringo    | 5010                     | 2140                     | -2869                            |
| West Pokot | 10085                    | 946                      | -9139                            |

**Source:** Author's design

Table summarizes forest change in the 6 counties. Nyeri was the only county that showed forest gain from the year 2000 to 2012 and the other counties showed variable losses. Nyandarua loss was minimal of about 453 hectares. Forest loss in descending order for the remaining counties was Narok, West Pokot, Machakos, and Baringo.

## **CHAPTER FIVE**

### **DISCUSSION**

#### **5.1 Introduction**

Population density and rainfall are some of the key factors contributing to forest cover change. However causes of forest cover change may vary within counties and they can be determined by different combinations of factors. This combination of factors challenges single-factor explanations that put most of the blame of forest cover change especially deforestation upon population density increase. These factors are discussed in this chapter and they include: forest and rangeland restoration programs, land management, tenure, markets (micro and macro economy), local and national policies and culture.

#### **5.2 Forest and rangeland restoration**

In the rangelands the efforts of improving the landscape are different from those in high rainfall areas. The rangelands of Kenya are unique in nature and require special attention to strengthen the economic base of the inhabitants and the national economy. Although frequently stressed by drought, they are rich in biodiversity and have the potential to supply marketable commodities on a sustainable basis such as gums and resins, aloe, charcoal, essential oils, silk, edible oil, fruits, honey and timber. Woody vegetation in the rangelands provides useful cover to the fragile and highly erodible soils, shelter for people and livestock in the harsh environment and habitats for wildlife (Muga, 2009). The establishment of enclosures, denoting areas closed off from grazing for a specific period, is a well-known management strategy for restoring degraded semi-arid rangeland ecosystems. Range enclosure has profound ecological (biophysical) effects and a

number of socio-economic implications that vary significantly, depending on local conditions (Mureithi et al, 2010).

In West Pokot and Baringo the positive trends are related to positive land management interventions. It has taken a lot of education and efforts in developing and working with communities to come with programs that restore land but also generate livelihoods to the communities. The community in West Pokot practices mixed land-use system, combining pure pastoralism in the drier zones with cultivated agriculture in the better watered key production areas (Jama and Zeila 2005). The West Pokot county has been experiencing the effects of severe land degradation and desertification before the inception of Vi Agroforestry project in the mid 1980s by international non-governmental organization which introduced the concept of agroforestry in the district. The organization targets small-scale farmers, and focuses on increased food security, energy security and wealth creation. Because of the widespread loss of tree biodiversity, Vi Agroforestry began re-vegetation of bare, denuded landscapes with trees. Land rehabilitation was seen as a method of land management through soil conservation and tree planting (Jama and Zeila 2005).

According to Nyberg (2007) West Pokot county Vi Agroforestry Project has been able together with the community to rehabilitate land since the mid-1980s. In one of their project in early 1980s and early 1990s, they used land mostly known for common use but designated for a special purpose (school compounds or church compounds) to demonstrate to local farmers/pastoralists how they could rehabilitate their land. They used strategies such as (i) enclosure of grazers where fencing to keep grazing animals out during an establishing phase is

done with an aim of controlling grazing. When grass has regenerated naturally, limited numbers of animals are allowed to graze within specified time (ii) water harvesting which was done during rain events. A structure for holding water was often filled up with water, making it available for the seedlings for extended period of time. The seedlings were taken care of until they were fully established and were planted/ sowed to control erosion. The plantations started on communal lands like school and church compounds. A few years after the government of Kenya started to demarcate private land in the area. Farmers got private ownership with clear boundaries between neighbors. Very many farmers took up the example set by the project with fencing of their (or part of their) private land. Many also established water harvesting structures and planted/sowed trees.

Vi Agroforestry has adopted a concept called ‘Area of Concentration Approach’ (AoCA). An extension agent is stationed in an area where the agent works with 200-350 farmers/pastoralists for up to five years, depending on the community enthusiasm. The result of this is that the community’s capacity for sustaining agroforestry technologies and practices is enhanced. Some spin-off benefits from enclosure areas include the evolution of individualization of land tenure, reduced nomadism and improved animal health as well as higher livestock production (Kitalyi et al, 2002). Traditional grazing areas on rangelands in northern Kenya, were supported by additional incentives generated through partnerships with private tourist interests who would ensure that recovery and conservation is being effective. Similar efforts in Baringo to rehabilitate the degraded areas have had positive impacts on the vegetation. Thousands of hectares of degraded areas in Baringo are now planted with forage that is commercially used to feed

livestock. It is evident that farmers are keen in multiplying grass seed for improvement of livestock productivity and also selling the surplus seed (Coughenour et al. 1990).

In Baringo the county has also made great efforts in restoring the rangelands. During the period 1964 to 1994, the rangelands of Baringo District are thought to have undergone major changes. Overgrazing and cultivation over much of Baringo District have been considered responsible for serious environmental degradation and reduction in rangeland productivity (Jacobs and Coppock, 1999). In the late 1970s and 1980s projects concerned with conservation and rehabilitation of rangelands were initiated mainly by World Bank and FAO. On the highland, where people mainly live off agriculture, some projects to promote terracing were conducted during the late 1980's and beginning of the 1990's and were quite successful (Johansson and Svensson , 2002).

Herlocker, 1994 (as cited by Jacobs and Coppock, 1999, p.9) pointed out the major reason of environmental changes in the 1980s was the change of tenure from communal land in the southern portion of the district switching to private small-holder ownership and group ranches. Consequently, pastoralists in this area became increasingly sedentary,whereas in the northern part of the District, cattle is moved to lowlands during the wet season and highlands for the dry season. The increase in green vegetation was strongly captured by satellite data although there was reduction of actual forest cover but there was increase in vegetation in other landscapes.

In addition the European Union funded Biodiversity Conservation Programme (EUBCP) has over the last five years provided a demand-driven funding mechanism for grassroots community-based groups to access grants for biodiversity related development activities. EUBCP's had three

primary objectives: 1) Promoting activities that create awareness of the need to conserve biodiversity, 2) Enhancing enterprises that promote sustainable use of biodiversity resources and lastly 3) Supporting interventions that reduce conflicts between people and biodiversity conservation.

This project undertook to support bio-prospecting activities in Kenya. In the Kenya's Arid and Semi-Arid Lands (ASALs). Pastoralist communities in Baringo county are now able to exploit the naturally growing aloe for the export market. In order to propagate and eventually domesticate aloe in their own farms, local communities have established over 10 nurseries with support from the programme. A partnership was established between the government, private sector and local community to develop the bio-enterprise and a market outlet was secured in China for the product. Key outputs from the EUBCP support include; the development of certification procedures and mechanisms and aloe resource mapping to facilitate the exploitation of aloes in Kenya (EUBCP 2006). Although pastoralism is the main income source in the lowlands. The lands limited carrying capacity for livestock and the low price of animals has led to an increasing number of households starting to enlarge their activities with some farming hence diversifying their income sources. Further, the programme has effectively participated in the forestry donor forums with an aim of offering advice on resources mobilization and allocation of the funds in biodiversity conservation and capacity development (EUBCP, 2006).

This study has indicated that with increasing calls of intensification agriculture there are vital lessons that can be learnt from proper land management. The increasing population and more focus on sustainable land management (SLM) practices, which combine soil conservation, tree and grass planting, and assurance of land rights can accelerate the greening up of landscapes.

### **5.3 Reforestation, diversification and markets**

The changes in forest cover in both Nyeri and Nyandarua has been heavily impacted by reforestation. Reforestation activities are supported by the Kenya forest policy through a national strategy to increase and maintain forest and tree cover to at least 10% of the total land area through rehabilitation and restoration of degraded forest ecosystems, and the establishment of a national forest resource monitoring system (RoK 2014). This is helping many counties in forest restoration. The policy also recognizes the importance of community participation in natural resource management through devolution of community forest conservation and management. According to Matiru (2002), Forest Landscape Restoration (FLR) is a planned process that aims to regain ecological integrity and enhance human wellbeing in deforested or degraded forest landscapes. FLR focuses on restoring forest functions as opposed to simply increasing tree cover with a particular emphasis on the relationship between various functions within different areas of the landscape. The approach can also involve the use of a wide range of restoration options that may include active promotion of natural regeneration as well as different types of tree planting, urban forestry and the management of indigenous vegetation for tourism, aesthetics and cultural purposes as well as agricultural and sustainable land management strategies (Deweese et al. 2011).

The two counties of Nyeri and Nyandarua have initiated many programs that support reforestation (CDM 2013; RoK 2011; ICS 2009) and thus the positive increase in vegetation index with increasing population. Reforestation measures for degraded lands, strategies for the sustainable management of forest resources, and agroforestry practices that incorporate trees into farming systems are increasingly becoming an alternative source of income by producing commercialized tree products (Githomi and Oduor 2012). Smallholder farmers in Kenya

recognize the importance of trees on farms and are investing in saplings and nurturing trees from existing roots are getting immediate and tangible benefits such as: increased crop yields, diversified income sources, and reduced vulnerability to climate extremes (Deweese et al. 2011). Trees on farms also support animal life, control erosion, and protect watersheds. For example, a combination of napier grass and leguminous shrubs in contour hedgerows reduced erosion by up to 70% on slopes above 10% inclination without affecting maize yield in central Kenya (Neufeldt et al. 2009).

According to FAO, investors in trees and landscape restoration fall into multiple categories. At the household level, individual farmers make carefully considered decisions about the use of their land, labor, and capital; in some areas, these decisions have resulted in the very extensive use of agricultural land for planting trees. FAO foresees tree growing on agricultural land as the major bright spot in forestry for Africa (FAO 2012b), especially the expansion of private woodlots, increased planting in home gardens, and increased use of out grower schemes.

Changing global markets and prices for key commodities are making scaled-up investments increasingly viable and attractive especially in the two counties of Nyeri and Nyandarua. New markets for forest and tree products are creating incentives for tree and forest planting and management (FAO, 1996). The growth in local and national urban markets for tree products has been the driver of landscape restoration in the central Kenyan highlands. For example a long-settled farming region, Embu District was substantially deforested by the mid-20th century, with land use dominated by annual crops and a tradition of farm agroforestry practice.

Market conditions changed sharply with the development of commercial coffee, expanding markets in the nearby capital of Nairobi, and local population growth. Demand for tree products grew quickly, especially for building poles, farm-grown tree fodder for the mushrooming smallholder dairy industry, tree fruits for local consumption, and other products (Mutsotso et al. 2011). Improved agroforestry species and technologies were introduced in the 1990s and 2000s that increased the productivity of trees that grew compatibly with crops. As higher value trees were grown, Embu began to import lower value products such as fuelwood from places like Mbeere. Over the past 25 years, the landscape has been transformed to a high level of tree density, although little natural forest cover (Program on Forests 2011). This change has been associated with significant increases in crop productivity and whole farm income. Important examples were tea and coffee factories, and the Kenya Cooperative Creameries (KCC) and other milk producers. Prices in fruits also play a part in income sources. Prices of avocados, mangoes, and passion fruit increased about 50 percent from 2007 through 2009, significantly faster than the inflation rate (Kenya Horticulture Development Programme 2010).

Crops diversification in Kenya which aims at producing high value crops has become important in increasing income sources for people. This means they have other source of income other than income from forest products. In Nyeri and Nyandarua there have been deliberate efforts to maximize use of land by growing high value crops that will fetch high price per unit thus reducing the pressure of opening more natural vegetation such as forest patches (Owondo et al. 2011).

For instance, in Nyandarua potato tuber is attracting great interest as one possible answer to the multiple challenges the country faces, including hunger, poverty and climate change. The potato tuber is an ideal candidate for crop diversification programmes in Kenya because of its great adaptability to almost any altitude and to a wide variety of climates, including arid and semi-arid lands (FAO 2013). It is already cultivated as both a primary and off-season crop in different parts of Kenya. Production of this tuber helps in boosting food security, raising incomes, generating employment and improving nutrition. According to Obare et al (2010) recent initiatives undertaken by the Kenyan\_Government, stakeholders and development partners include: introduction of rapid seed multiplication technologies; training in alternative seed production methods; private sector involvement in basic seed production; and the formation of the National Potato Council of Kenya (NPCK), a multi-stakeholder and public-private partnership (PPP) platform. A growers' association- Kenya National Potato Farmers Association (KENAPOFA) has also been formed to help address the need of farmers.

Another initiative in crops diversification is promoting climbing beans in central and eastern highlands of Kenya. Introduced into Kenya in the mid-1970s, climbing beans are gaining popularity among farmers in the central and eastern highlands of the country. Initial efforts to introduce the beans did not achieve much success because research then was in favour of bush beans. Through the Eastern and Central Africa Bean Research Network (ECABREN), climbing beans have been promoted, adopted and disseminated over the years using participatory on-farm trials, education institutions, local farmer groups, and involving other collaborators. There are several factors that have led to the widespread acceptance of these beans. These include high grain yields (upto 5 t/ha), availability of inputs locally, the shrinking farm sizes which have made climbing beans more attractive than bush beans, relatively low cost of production, the ability of

the beans to contribute to soil fertility in the region and the good environmental conditions available for its cultivation. Yields of climbing beans have gone up by 50% over a 10-year period in comparison to a 60% reduction in the yields of bush beans (Kimenye and Bombom, 2009). The varieties are currently cultivated by smallholder farmers, students within school garden projects, and by scientists as experimental crops. Uptake of the climbing beans is still spreading and, in areas where the technology has been promoted, adoption rates of about 30% amongst farm families have been reported. In Kenya, the climbers are currently being grown in Embu, Thika, Meru South, Murang'a, Meru Central, Nyeri, Kirinyaga, Nyandarua, Kakamega and Kisii districts.

#### **5.4 Deforestation and rainfall**

Changes in forest cover in Machakos are mainly climate driven. Machakos has suffered cumulative poor crop harvest because the community depends on the short rain (between October to November) which is unreliable. This causes serious food shortage, diminishing pasture for livestock and land management. Water sources are also drying up resulting into livestock deaths as reported in divisions like Kalama and Mwala in 2005 (Ochieng et al. 2006). There is food insecurity due to low agriculture production thus, majority of households are net buyers of staple foods (maize and sorghum grains and cassava chips) which are expensive to buy and food relief is common in the area (JEL 2012).The great majority of the poor households are found in the drier regions of the district where frequent droughts have affected their livelihoods. Divisions like Masinga and Yatta have experienced perennial droughts that have made the people dependent on relief food. Traditional coping mechanisms like sheep, goats and poultry rearing are no longer viable, leaving most of the families destitute. The prices of livestock have

gone down and food prices have sharply risen in the district (RoK 2009). These factors have made the communities more vulnerable to food insecurity which has resulted in the community engaging in charcoal burning as one of the coping mechanisms but in return destroying the natural vegetation and conservation efforts that had taken long to develop.

The other major driver of forest change is logging and clearance of forest for farming. These drivers have been the main cause of heavy decline of forest in the Narok and especially the Mau Forest. The need for timber for construction from people in Elburgon and Molo towns are exerting pressure on the East Mau and Molo forests through extensive logging for economical ends (Ministry of Forestry and Wildlife 2013). The biggest logging companies in Kenya, Timsales and Comply, are based in the towns of Elburgon and Nakuru respectively, on the edges of the forest. Logging is the main economic activity in Elburgon and employs about 30,000 people (Kipkoech et al., 2011). The big companies collect timber for export, while hundreds of small-scale loggers supply the local market in Nakuru, Molo, Elburgon and other neighboring towns (Spruyt, 2011). Timber for construction from the Narok area thus finds its way into homes in Nairobi, Kisii, and Kisumu. There is a high demand for indigenous *Podocarpus* and Red Cedar trees, which are considered reliable and durable (GFC, 2010). Lack of infrastructure can also pose barriers. In Kenya, for example, it was noted that there is virtually no road network in areas bordering Mau, especially in Narok South. And where a road is present, they are impassable during the rainy seasons. This makes monitoring and enforcement of forest laws against logging and the charcoal trade virtually impossible. Local loggers use donkeys to ferry illegal logs to the markets. In addition, it seems that morale among the Kenyan forest staff and

district administration officials is extremely low due to underpayment. They are therefore prone to receiving bribes, which allows the illegal logging and charcoal trade to flourish (GFC, 2010).

Kenya is one of the countries which have already imposed forest logging bans, which have resulted in higher prices and more favorable market opportunities for investment in tree growing and forestry-related enterprises by the private sector (Cheboiwo et al. 2010). Much can be learned from examples of large-scale landscape restoration in Kenya and the variable roles of the private sector, farmers, government, and civil society in supporting and undertaking investment (Cheboiwo et al. 2010). With overall forest cover declining and rewards for carbon and other environmental services from forests increasing, forests are likely to be further regulated. Biomass, specifically wood, is by far the most widely used renewable fuel in Kenya especially in the rural areas. Currently, the wood-fuel deficit exceeds 5,000 metric tons and is expected to grow. This excessive demand for wood fuel continues to lead to deforestation, forest fragmentation, and land degradation, and threatens water catchments. Moreover, the national demand for energy is projected to greatly increase by 2030 (UNEP 2009). The increase in wood fuel prices, provides greater incentives for wood production for energy. In response to this increase, the government must devise creative means to develop more energy sources to deal with some of this pressure. This can be dealt by having alternatives such as growing high value crops that will reduce the pressure of opening the fragile lands such as forest.

## **5.5 Land tenure**

The Mau forests complex is immensely important, as it serves as a catchment for rivers west of the Great Rift Valley. These rivers in turn feed major lakes in the region, including Lake Nakuru and the trans-boundary lakes of Lake Victoria in the Nile River Basin, Lake Turkana in Kenya and Ethiopia, and Lake Natron in Tanzania and Kenya. Thus, the Mau forest provides critical ecosystem services, not only for Kenya, but also for the entire region (Jacqueline and Sang 2011). The ecosystem has also been experiencing deteriorating conditions over the years and the NDVI and forest trends in Narok confirm the deteriorating conditions and are driven much by policies that are conflicting. The key drivers of deforestation include failure to implement policies and legislation governing the use of forest resources, and the inability to monitor and enforce forest rules due to the prevalence of corruption and political interference (Banana et al. 2010). For instance, the Ogiek hunter-gatherers of the Mau forest in Narok District who benefit from the forest and at the same time conserve it, have seen their land rights and access to the forest resources they depend on extinguished following gazetttement of the area as a reserve (Sang 2001).

In Kenya community institutions are complex mixtures of local interest, traditional structures and a strong influence of central government representatives. While conservation policy and legislation is important, it is this overall local governance and land tenure institutional environment that is most critical to the status of community conserved areas (Oeba et al. 2012). Community Conserved Area” (CCA) are rarely considered in national policy or legal frameworks, few legal mechanisms exist for communities to defend their resources against external forces or conversion to alternative land uses and in some cases, communities are being

dispossessed of resources traditionally under their control as they are converted to other land uses or absorbed into the national protected area system (Blomley et al. 2007). Most pastoralist areas in southern Kenya are in an advanced stage of individualizing their rangelands among the Group Ranch memberships, which is seen as necessary to secure members' rights but renders livestock pasture as well as wildlife habitat fragmented and destroys traditional landscape-scale pastoralist management practices (Roba, 2012). The creation of local land trusts has been one of the main ways of setting aside land as conservancies in pastoral rangelands, but many of these areas face the challenge of being swept away by broader trends towards individualization and conversion of rangelands.

According to Oeba et al (2012) secure land tenure significantly influence tree planting practices as renters are less likely to adopt medium or long-term conservation practices. Tenure rights have driven much changes in the rangelands with many counties now encouraging its people to take more care of its land (ICRAF 2009, Mwangi 2005).

## **5.6 Policy**

Policy and institutional frameworks can affect forest cover negatively or positively. For instance in Narok lack of cohesive policy, legal and institutional framework supporting customary land ownership has contributed to decline in forest cover while conservation initiatives in Nyeri and Nyandarua through development and implementation of District strategic plans and Forest conservation plans have contributed positively to forest cover change.

Kenya's social and economic policies since the colonial era have emphasized either state reservation of land or individualization and spreading of freehold titles (Kabugi 2009).The

dominance of the state as the legal custodian of natural resources and the emphasis on exclusion of local communities from forest and wildlife resources continued through policy and legal statutes long after independence, despite the fact that much of these resources are found outside officially recognised protected areas such as forest reserves and national parks (Ongugo et al. 2011). Large areas of forest reserves were de-gazetted and passed onto political allies and supporters (Blomley 2007; FAO 2010). This went relatively unchallenged until civil society organisations such as Green Belt movement and more recently the Kenya Forest Working Group began to demand greater accountability and benefit sharing at the local level (Geller et al. 2007).

Land in Kenya falls into three basic categories: government land (13%), trust land (74%), and private lands (13%) (Wily and Mbaya, 2001). Importantly, none of these categories provides an effective institutional framework for collective local conservation and resource management efforts. Trust lands are managed by district (county) councils on behalf of the district's residents, although in practice the 'trust' doctrine holds little legal security for an area's residents. The Kenya Land Alliance (KLA) states that, rather than securing land in trust for local communities, "there appears to be an unwritten policy on the part of government that sees community land as land that is not owned but rather is available for County Councils and government to appropriate" (KLA/RECONCILE 2007). Thus there has been no cohesive policy, legal and institutional framework supportive of customary land tenure. Some of the most notable CCAs in Kenya that have been considered successful in conservation are Loita and Loima forests, which fall on trust lands, and although communities have retained control over these areas their statutory jurisdiction over them is fundamentally weak (Ongugo et al. 2011). In response to such problems as well as long-standing distributional problems emanating from Kenya's history as a

settler colony, land policies and conservation plans need to be more emphasized. Agriculture is one of the sectors that is directly exposed to destruction in the Mau and the Government has been working on a conservation policy that will compel farmers to plant at least 10 per cent of their farms with trees in a campaign to grow the country's 1.7 per cent forest cover towards the 10 per cent threshold that the United Nations Environmental Programme (UNEP) recommends (Nabutola 2010).

Development of forest conservation plans in some counties has played a big role in conserving forest. For instance, Aberdare Forest Reserve Management Plan for the year 2010-2019 developed by the Kenya Forest Service. The plan covers the Aberdare Forest Reserve, Kipipiri Escarpment, Kikuyu Escarpment, South Laikipia, Ol-Bollosat, Kirima-Muruai, Nyamweru, Nyeri Hill, Nyeri forest, Kijabe hill, Mugumo South, Mugumo North and Kingatua forest all referred to as Aberdare Forest Reserve (AFR). The purpose of this management plan is to enhance conservation and management of biodiversity, water catchment and economic values of Aberdare Forest Reserve (KFS 2009).

This was to be achieved through implementation of twelve development programmes addressing priority thematic areas. The development programmes include natural forest management, forest plantation development, bamboo development, watershed management, tourism development, farm forestry development, community participation, protection and security, infrastructure development, research and monitoring, human resource development and Aberdare fence management programme.

In addition an implementation programme was included to provide the means of resource mobilization and plan implementation organization structure (KFS, 2009). As part of Kenya Government forest conservation initiatives, the Aberdare National Park was created in 1950 to protect the forested slopes and moors of the Aberdare Mountains. Encompassing some 767 square km of uninhabited forest and moor-land, the Aberdare Mountain Range is the largest complete and natural eco-system left in Kenya today and is a perfect rhino habitat (Njuki et al. 2004). The goal of establishing the Aberdare National Park electric fence was for mitigating human-wildlife conflict and reducing illegal exploitation of forest resources (UNEP 2011). These broad initiatives have also expanded into other counties. To integrate population and environment issues into development, Nyeri county through its District Strategic Plan of 2005 identified and is practicing activities such as: sensitize the community on planting of trees, teaching community on the use of energy saving jikos, establish tree nurseries, sensitizing and mobilize community on afforestation programmes, mobilize and promote Community-Based Organizations's (CBO's) on development of tree- nurseries in the community, reinforce legal-actions on deforestation, sensitize the community (leaders) through barazas (seminars) on the need to conserve the environment (NCPD 2005). These initiatives have contributed immensely to conservation hence observed increase in forest cover, more environmental protection and also community benefiting from the resources. Vital lessons can be learnt from these initiatives and could be expanded and tried in other water catchments across the country.

## **5.7 Culture**

Culture is the sum total of ways of living built up by a group of human beings and transmitted from one generation to another. Certain national laws, for example the National Museums and Heritage Act 2006, Forests Act 2005, the Forests (Participation in Sustainable Forest Management) Rules 2009, the Environmental Management and Coordination Act 1999 and Environmental Management and Co-ordination (CBD) Regulations 2006 recognize and encourage community participation in protecting ecosystems and natural and cultural heritage, including sacred natural sites. However, they do not go as far as recognizing and supporting the rights and responsibilities of communities to govern and protect their sacred natural sites and territories on their own terms, according to their customary governance systems (Adam 2012).

The rights and responsibilities of communities to self-governance of their sacred natural sites and territories is very important and contribute to forest conservation in one way or another. For instance, some communities preserve forest for use as a dry season grazing refuge as well as for fuel wood and building materials, water catchment, traditional medicines, and a range of spiritual and cultural purposes to mention a few (Nelson, 2012). But these institutions are being progressively eroded away by external pressures such as land privatization found in Nyeri, Nyandarua and now extending to semi-arid and arid areas of Kenya. Many community forests in Kenya appear to have disappeared because there are few avenues for locals to secure collective rights over local forests. Some of the most notable community conservancy area in Narok is Loita forest which falls on trust lands where local tenure is statutorily weak, but communities have been able to retain control over forest resources (Ongugo et al. 2011, Maundu et al. 2001) making the impact on forest losses lower than that of Mau forest. The Maasai Mau Forest is part

of the Mau Complex, the largest forest of Kenya. The Ogiek community rely on Maasai Mau forest for honey and hunting (Ogiek literally means “*the caretaker of all plants and wild animals*”), while the Maasai depend on it as a source of water and grazing for their livestock during the dry season. Yet the forest is receding drastically, as part of a complex scenario involving indigenous communities pitched into competition with each other because of colonially instigated land laws, and with non-indigenous communities because of demand for fertile farmland. The situation has been further complicated by the illegal issuing of land tenure rights (Sang 2001).

## **CHAPTER SIX**

### **SUMMARY, CONCLUSION AND RECOMMENDATIONS**

#### **6.1 Summary**

The results of this study, show that we can use remotely sensed data NDVI and human population to investigate forest changes and impacts of population on forest. The importance of remote sensing is that now we have continuous data for the last 30 years and we can match this temporal data with many of social economic data such as human population which is now regularly updated in a country like Kenya every 10 years. The results of this study has shown major shifts in the trends of forest in six case study counties. Between 2002 and 2008 Nyeri, Nyandarua, West Pokot and Baringo showed an increase in forest and as indicated in the analysis of NDVI and also supported by other associated information such as reforestation and land restoration programs in these districts. However, we observed declines in counties of Narok and Machakos.

The association of population density and forest cover based on NDVI from Satellite revealed that in humid counties (Nyeri and Nyandarua) forest cover decreased initially with increase in population density and then reached a turning point where forest cover started increasing with population density, showing that forest cover has improved. This phenomena has also been reported in Europe and latest publications have shown countries like China and other south east Asia are going through similar changes. In our analysis we attributed these changes to the various conservation initiatives (reforestation) as well as market economies through production of high value crops to reduce the pressure of destroying more forest. Even in the arid districts where we had observed a surge in population there are cases of positive build of its green

vegetation, Baringo and West Pokot show consistency in forest cover increase with increase in population density. This consistency is mainly accredited to rangeland/grassland restoration initiatives that have been going on for more than 20 years. Land tenure changes in these regions have also contributed highly to these positive changes.

In Narok and Machakos the results demonstrate a negative relationship between forest cover and population density - as population density increase there is decline in forest cover. It is also revealed that population density has more negative effects on forest cover while rainfall has a slight positive effect in both counties. The population factor outweighed the rainfall factor. The negative change in forest cover in Narok is attributed to the incursion of people to the forest, illegal logging and protected legal battles on the use of Mau Forest by various stakeholders. In Machakos, remote sensing data revealed that forest cover has been decreasing with population density and rainfall as the main contributing factor in its decline. Machakos in the earlier year had put much in conservation of its landscape. However, the vulgaris of climate has made it difficult for the county to still maintain its green fields. The short rains are no longer reliable which has forced many communities to engage in activities such as charcoal burning as an alternative source of income which has a ready expanding market in the nearby city of Nairobi.

## **6.2 Conclusion**

The study aimed at exploring the linkages of population density and forest cover. Kenya has one of fastest growing population in Africa thus the impacts on forest are very high. Forest cover in 1980s was approximately 3% and this has reduced to less than 2% (Roba, 2006). The study has shown that in a number of counties the destruction of forest is very high. In the six counties that we studied the largest declines in forest cover was reported in Narok. There was a negative

relation between population density and NDVI. Also from the analysis of high resolution satellite data, the area under forest declined heavily. While in Nyeri and Nyandarua there is positive signs of recovery and increase in forest cover. In West Pokot and Baringo the relationship between NDVI and population density showed a positive correlation. These trends (positive or negative) in forest or range cover can be attributed to a number of factors including population density, rainfall, forest and rangeland restoration programs, tenure, markets (micro and macro economy) deforestation and local and national policies. It will be important to extend this study to other counties in Kenya. This will help in monitor the success of many programs that have been put in place and also in refocusing on areas that have problems. The results of this study help with vital lessons of combatting loss of forest and what programs need to be put in place in the various counties in different ecological settings. The choice of counties in this study has revealed that we can learn vital lessons from both biophysical and social factors.

It is apparent from the results that population density is a key factor in contributing to forest cover change in most counties. However, there are other factors that also influence forest cover and these vary within counties. By including other factors such as rainfall it was possible to discern the impact of rainfall and it is significant in West pokot, Nyandarua and Nyeri counties. However, other factors that contributed positively to forest cover change in humid counties (Nyeri and Nyandarua) are reforestation and markets, While in Baringo and West Pokot the relationship is supported by influences of rangeland restoration activities and culture. In Narok, land tenure and land policies are strong factors contributing to forest cover decline and in Machakos the decline in forest cover is driven by rainfall and markets.

Remote sensing has been identified as a useful tool to aid the process of understanding human-environment interaction. It gives rise to the advent of more precise and geographically referenced and near real time data on land cover and use of land, which in turn create opportunities for improved assessments and analysis. Satellite remote sensing data have been proven to be one of the best techniques for monitoring forest cover change and land use conversion patterns. It was linked with population density in this study to bring out a better understanding of the linkages of population density and forest cover change. This advancement has brought out an opportunity of linking environmental science with social science. However, challenges of having both the dataset in the same temporal and same scale still needs to be advanced.

### **6.3 Recommendations**

More studies using remotely sensed data at various scales and linking it to the social economic variables to be further strengthened. More statistical approaches should be investigated and linkages between remote sensing and social economic data further developed. Both mechanistic and stochastic models should be developed further to give much more insights on the process of deforestation, what drives it and what are main drivers and their contribution to these changes.

It is apparent from the results of this study that the main concern in conserving forest is not increase in population density but the activities that people engage in and that a detailed understanding of the complex set of factors affecting forest cover change in a given location is required prior to any intervention. The results of this study have demonstrated strong linkages between population density, environment and development. For instance, in counties where people are engaged in conservation activities, environment is less degraded and development is enhanced. Therefore the challenge of rapid population growth and natural resource degradation

are not isolated from one another; they are intimately related and it is important for strategic planning and development programming to focus on them together taking into account their interrelationship.

This study has shown that forest cover changes can be evaluated, even though there are still some data gaps, with additional good social economic and climatic variables collected at reasonable temporal and spatial scales the models used can be improved further. Further improvements of these methods will help a lot in monitoring of programs, review of policy and help the government to come up with better programs and strong policies governing forests and land management.

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