ASSESSMENT OF THE EFFECTS OF CLIMATE CHANGE AND LAND USE CHANGES ON KIPKUNURR FOREST AND ITS SURROUNDINGS, ELGEYO MARAKWET COUNTY, KENYA

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A THESIS SUBMITTED TO THE SCHOOL OF ENVIRONMENTAL SCIENCES AND NATURAL RESOURCE MANAGEMENT, DEPARTMENT OF ENVIRONMENTAL PLANNING, SUSTAINABILITY AND GEOINFORMATICS, IN PARTIAL FULFILMENT OF A MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL INFORMATION SYSTEMS

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DECLARATION

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DEDICATION

I dedicate this thesis to my parents for educating me to be the best version of myself, my siblings and relatives for supporting and encouraging me during the whole research process.

ABSTRACT

Globally, the combined impacts of climate change and land use alterations have accelerated forest degradation, disrupting ecological balance and contributing to biodiversity loss.The Kipkunurr Forest region and its surroundings in Elgeyo Marakwet County are undergoing significant environmental transformation brought about by climate fluctuations and landscape modifications of land use/land cover (LULC). The reduction of forest cover caused by these changes transforms ecosystem operations and negatively impacts biodiversity, water resources, and local livelihoods. The goal of the study was to assess the effects of climate change and land use/land cover changes on Kipkunurr Forest and its surroundings. The study specifically sought to analyze the spatio-temporal changes in LULC from 1995 to 2024; to evaluate forest health using the Normalized Difference Vegetation Index (NDVI) over the same period; to assess temperature and rainfall variability between 1994 and 2024; and to establish the relationships between climate change, LULC changes, and forest health. This research adopted a descriptive research design, integrating remote sensing and GIS analysis, climate data assessment, household surveys, and Key Informant Interviews (KIIs) to comprehensively examine land use changes, climatic trends, and their implications on forest conservation. Landsat images were used for land use and land cover analysis and NDVI calculation and meteorological station climate data for analysis of temperature and rainfall. The study relied on data from 382 households selected for interviews, five key informant interviews, including a Forester, four forest rangers, and a NEMA official along with local communities to examine LULC change factors and climate change. The analysis reveals significant changes in land use and land cover (LULC), with forest cover declining from 57.45% in 1995 to 35.06% in 2004, before slightly increasing to 36.98% by 2024. Climate data analysis for the period 1994 to 2024 reveals a gradual increase in mean annual temperature from approximately 20.2 °C to 20.8 °C. Although annual rainfall exhibited notable interannual variability, an overall increasing trend was observed, rising from around 1,100 mm to over 1,350 mm by 2024. The major drivers of land use and land cover transformation consisted of agricultural growth, population growth, logging and resource extraction with climate change acting as a moderate force against forest health conditions. Satellite-derived NDVI data pointed to a little vegetation density increase under ongoing land use stress which amounted to a value range of -0.48 to 0.77 in 1995 then decreased to 0.58 in 2004 and 0.57 in 2014 and rose to 0.61 by 2024. According to research findings, Kipkunurr Forest is under a lot of environmental stress due to factors like climate fluctuation, unclear boundaries, high reliance on forest resources, and agricultural growth. Due to human and climatic stresses, persistent forest degradation continues, especially close to forest boundaries, despite modest advances in recent years in forest cover and vegetation health. The study recommends that reforestation, defined boundaries, controlled grazing, and less dependence on forest-based fuel be implemented by the Kenya Forest Service in collaboration with the County Government and local communities as components of integrated solutions necessary for effective forest conservation.

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LIST OF ACRONYMS AND ABBREVIATIONS

CFAs: Community Forest Associations

EVI: Enhanced Vegetation Index

EMC: Elgeyo Marakwet County

FCMA: Forest Conservation and Management Act

GIS: Geographic Information System

GPS: Global Positioning System

IPCC: Intergovernmental Panel on Climate Change

KFS: Kenya Forest Service

KNCHR**:** Kenya National Commission on Human Rights

LULC: Land Use Land Cover

MODIS: Moderate Resolution Imaging Spectroradiometer

NASA: National Aeronautics and Space Administration

NBR: Normalized Burn Ratio

NDVI: Normalized Difference Vegetation Index

PELIS-Plantation Establishment Livelihood Improvement Scheme (Shamba System)

RCMs: Regional Climate Models

ROK: Republic of Kenya

SDGs: Sustainable Development Goals

UNFCCC: United Nations Framework Convention on Climate Change

USGS: United States Geological Survey

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Forests are not just a collection of trees but are intricate ecosystems characterized by an abundance growth of trees, plants, and other types of vegetation (Perry et al., 2008; Oldeman, 2012). The various types of forests include montane, temperate, mangrove, boreal, and equatorial. These types are classified according to climate, vegetation, and location (Xu et al., 2022; Thakur et al., 2021).

Forests are essential to the continuation of life on Earth providing numerous ecological, social, and economic advantages (Chazdon et al., 2020). Forests cover approximately 31% of the Earth's total land area, which is equivalent to about 4.06 billion hectares (FAO, 2020). Forests act as a home for many plant and animal species offering them food, shelter, and places to breed. Forests are also integral to climate regulation due to their ability to store vast amounts of carbon and mitigate the effects of human activities that emit greenhouse gases into the atmosphere (Mackey et al., 2020). Furthermore, they are essential for watershed protection and water regulation because they assist in maintaining water quality, controlling water flow, lowering the risk of flooding, and lessening soil erosion (Kastridis et al., 2021). Additionally, forests promote tourism and provide leisure and recreational activities, which boost the regional economy.

The importance of forests was also emphasized by Wangari Maathai in her environmental campaign centered on restoration activities and forest conservation (Maathai, 2004). In addition, global initiatives such as the United Nations' REDD+ (Reducing Emissions from Deforestation and Forest Degradation) emphasize the critical role of forests in combating climate change and preserving biodiversity. Ecologist Aldo Leopold also talked of forests as a ‘’community to which we all belong," emphasizing their crucial role in maintaining both natural ecosystems and human lives (Sacco, 2022).

However, forests are being threatened by different factors including climate change and land use changes. According to Kissinger et al., (2012), there are two types of forces that cause forest degradation: direct and indirect causes. The direct causes are human activities, such as mining, logging, agriculture, urbanization, grazing animals, and forest fires. On the other hand, the indirect factors are an interplay between political, socio-economic, cultural, and technical processes. Some include increase in population, poor leadership and corruption. Additionally, forest ecosystems are more vulnerable to the effects of climate change because of their complex interactions with climate variables such as temperature, rainfall, and extreme weather events (De Frenne et al., 2021). The health and viability of forested areas are endangered by fluctuations in temperature, rainfall patterns, and the occurrence of extreme weather events (Gebeyehu & Hirpo, 2019).

The world’s population is increasing from time to time. For instance, in 2020 the world population was about 7.8 billion, and expected to reach 8.6 billion by 2030 and 9.8 billion by 2050. (UN, 2020). To accommodate the demands of an expanding population, people are turning forests and other types of land cover into agricultural areas. It is anticipated that forests will continue to be converted into agricultural land in the future due to the growing population (Pellikkaa et al., 2018).

The net forest loss in Africa has increased in three decades since 1990, with the highest annual net forest loss occurring between 2010 and 2020, at 3.9 million ha (FAO, 2020). However, over the past ten years, Africa's efforts to manage its forests sustainably have shown progress; with some nations having seen increases in their forest cover, whereas others continue to experience decreases (Hove et al., 2013).

Demands on land use are reflected in changes in forest area over time. Assessing land use and climate trends is useful for sustainable forest conservation and management. Decision-making processes benefit greatly from an understanding of the features, scope, and pattern of land use land cover change (LULCC) (Armenteras et al., 2019). The use of remote sensing and GIS technologies in mapping and monitoring land use and land cover change is essential because it offers relevant data for locating environmental hotspots to assist in the development of restoration plans, conservation-related policies and decision-making, and the overall long-term conservation of forest ecosystems (Zafar et al., 2021).

Therefore, against this background, this study seeks to assess the effects of climate change and land use/ land cover changes on Kipkunurr forest and its surroundings, Elgeyo Marakwet County, Kenya.

1.2 Statement of the Problem

Kipkunurr Forest remains one of the most important ecological zones that is part of the Cherangani water tower and livelihood-supporting resources in Elgeyo Marakwet County.

The forest covers an area of approximately 15,175.7 hectares and directly sustains more than 77,000 people through key ecosystem services like water catchment, local climate regulation, and biodiversity support (Mackey et al., 2020). However, this critical forest is increasingly under threat due to shifts in land use patterns and unpredictable climate conditions.

In the past 20 years, Elgeyo Marakwet has witnessed a worrying drop in overall forest cover from 37.6% to 29.95% reflecting a broader trend of environmental degradation (EMC CIDP 2023–2027). Kipkunurr Forest, in particular, is experiencing the impact of expanding agricultural activities, increased logging, growing settlements, and shifts in rainfall and temperature patterns. These pressures are contributing to a decline in forest health, especially through visible loss of vegetation cover and thinning canopies death (Funatsu et al., 2019). Even with efforts from government agencies like the Kenya Forest Service (KFS) and Kenya Wildlife Service (KWS), there remains a shortage of spatially explicit and data-driven studies that examine how these factors interact and contribute to forest degradation. This lack of detailed research makes it difficult for planners and conservation actors to act effectively.

This study aims to fill the existing gap by assessing the effects of climate change and land use/land cover (LULC) changes in Kipkunurr forest and its surroundings. The study will help in the formulation of well-informed conservation policies and promote sustainable use of land and forest resources in the region by employing geospatial analysis and forest health metrics like Normalized Difference Vegetation Index (NDVI).

1.3 Study Objectives

The main objective of this study was to assess the effects of climate change and land use/land cover changes using geospatial techniques on Kipkunurr forest and its surroundings, Elgeyo Marakwet County, Kenya

1.3.1 Specific Objectives

1. To assess spatio-temporal changes in land use and land cover in Kipkunurr forest and its surroundings between 1995 and 2024.
2. To evaluate the changes in forest health in Kipkunurr forest and its surroundings between 1995 and 2024 using NDVI.
3. To analyze trends in temperature and rainfall of Kipkunurr forest between 1994 and 2024.
4. To establish the relationships between climate change, LULC change, and the health status of Kipkunurr forest.

1.3.2 Research Questions

i. What spatio-temporal changes in land use and land cover in Kipkunurr forest and its surroundings have taken place between 1995 and 2024?

ii. What are the drivers of LULC change in Kipkunurr Forest in Elgeyo Marakwet County?

iii. How has forest health changed in Kipkunurr forest and its surroundings between 1995 and 2024?

iv. How have temperatures and rainfall patterns influenced Kipkunurr Forest between 1994 and 2024?

v. Are there any significant relationships between climate change, LULC change, and the health status of Kipkunurr forest?

1.4 Justification of the study

Forests are essential to the continuation of life on earth providing numerous ecological, social, and economic benefits (Chazdon et al., 2020). Forests act as a home for many plant and animal species offering them food, shelter, and places to breed. Forests are also integral to climate regulation due to their ability to store vast amounts of carbon and mitigate the effects of human activities that emit greenhouse gases into the atmosphere (Mackey et al., 2020). Furthermore, they are essential for watershed protection and water regulation because they assist in maintaining water quality, controlling water flow, lowering the risk of flooding, and lessening soil erosion (Kastridis et al., 2021). Tourism and leisure activities are also offered by forests, enhancing the region’s economy.

Kipkunurr Forest falls within the Cherangani water tower, a recognized water catchment area in Kenya located in Elgeyo Marakwet County. Cherangani water tower is a significant water resource for the nation as it supplies water to different regions (Rouillé-Kielo, 2021). Kipkunurr forest is also a source of Chebara river, which distributes water to various areas such as Eldoret city and its environs, Kapsowar market centre and other surrounding areas. This demonstrates the importance of the forest to the communities residing within the region as well as the water security of the entire nation.

Kipkunurr forest is being encroached by various factors, posing a threat to Elgeyo Marakwet Countys' status as one of the leading Counties with the highest percentage of forest cover in Kenya. Therefore, this study is important as it comprehensively investigates spatio-temporal changes in land use and land cover in Kipkunurr forest and its surroundings with the aim of supporting its conservation and management initiatives. It also examined the key drivers of forest depletion, aiding in the development of effective interventions to mitigate forest degradation. The Kenyan constitution of 2010 provides that environmental protection and sustainable management of natural resources must be upheld through Articles 42, 69, and 70 which guarantee the right to a clean, healthy environment and the conservation of natural resources (GOK, 2010). The findings of this study will help achieve Kenya's Vision 2030, which emphasizes environmental sustainability and green economy, placing a high priority on effective forest conservation and climate resilience measures (Vision 2030). In addition, this study supports the efforts of the Kenyan government, which aims to plant 15 billion trees by 2032 to resolve the issues of deforestation and combat climate change (Cassina & Gachara, 2023).

In addition, Elgeyo Marakwet County lies within a fragile ecosystem that has Arid and semi-arid lands (ASALs) nature like Kerio Valley, where communities often engage in social conflicts, especially cattle rustling. This decline in forest cover could increase water and pasture shortages, hence the possibility of continuous conflicts over limited resources among communities. This study is also informed by the Sustainable Development Goals (SDGs), which emphasize the need to manage forests in a sustainable way and addressing climate change , particularly SDG 13 (Climate Action) and SDG 15 (Life on Land) (UN, 2015).

1.5 Scope and Limitation of the Study

The study aimed to determine the effects of climate change and continued modification of land use and land cover on Kipkunurr forest and its surroundings. Trends in temperature and rainfall were analyzed for the period 1994-2024, while land use/land cover and forest health trends were assessed from 1995-2024. The study also considered a 5 km radius around the forest to capture the immediate area interacting directly with the forest ecosystem. The rationale for selecting the 5 km radius is that past research studies have shown that spillover impacts of land use are prominent within this distance (Xia et al., 2023). The study aimed to provide insights about land use and land cover changes, forest health, and climate variability (temperature and rainfall) and how these factors affect the sustainability of Kipkunurr forest and its important function in water catchment and the regional environment.

The significant limitation of the study was the high percentage of cloud cover in the 1994 Landsat satellite images, which interfered with the quality and made the analysis of the images difficult. As a result, the study period was adjusted to start from 1995 to enable accurate classification of land use and land cover.

1.6 Thesis Structure

The report contains six chapters. Chapter One sets the context of the study, providing an overview of the research problem, objectives, justification and the scope. Chapter Two presents the literature review, offering a detailed discussion of previous studies, theoretical and conceptual framework related to the research study. Chapter Three describes the study's methodology, which includes research design, the study area, nature of data, source and type of data, data collection methods, data analysis techniques, and data presentation. Chapter Four presents the findings of the study, while Chapter Five provides a discussion of these findings. Chapter Six concludes and provides recommendations based on the study findings, and gives direction for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The chapter reviews literature on the effects of climate change and land use/cover (LULC) changes at both regional and global scales, focusing on their effects on forest ecosystems. The 21st century has been marked by challenges of climate change and LULC dynamics, which affect biodiversity, ecosystem services, water resources, and the well-being of humans. These processes are highly interdependent since the impacts of climate change may be affected by changes in land cover and vice versa. Also, changes in climatic patterns influence land use decisions and affect the general health of the ecosystem.

Temperature changes, shifts in precipitation patterns, and an increasing frequency of extreme weather conditions occurring globally have significant effects on natural systems (Valipour et al., 2021). Locally, these impacts vary according to ecological zones, socio-economic pressures, and systems of governance. Forests and neighboring landscapes in most developing nations, including Kenya, are facing an increase in degradation due to climate variability and land use changes such as expanding agriculture, new infrastructural development, and extraction of resources.

The review provides an overall picture of how climate change and LULC changes affect the conservation of forests by synthesizing findings from studies done under similar ecological conditions. It identifies a knowledge gap, outlines a methodological approach used in previous studies, and creates a foundational understanding for defining the scope and focus of the current study.

2.2 Understanding land use and land cover change (LULCC)

Land use refers to activities that occur on land or how people are using the land such as agriculture, residential and commercial. Land cover, on the other hand, refers to the natural and human-made characteristics visible on Earth's surface such as forests, water, built areas, and grasslands (Wulder et al., 2018). Land use and land cover are classification methods that explain what is on the Earth's surface at a certain location (Zhang et al., 2019). Therefore, land cover change refers to a modification in some continuous features of the land, such as vegetation type, soil conditions and water bodies, whereas land-use change refers to a change in how humans utilize or manage a specific area of land such as for agriculture and commercial purposes (Patel et al., 2019. According to Chen et al. (2025) LULC classification includes sorting land in to classes or groups depending on what is on it or how it is being used for by individuals and examples include; forests, wetlands, homes and farms. LULC classification helps us to understand how these uses change overtime, for instance, when forests are cleared to plant crops or build homes due to population growth. Therefore, this process is continually shifting and dynamic because the changes take place over time and space. The process in which the land changes seem to follow a specific pattern depending on how humans use the land or even basing on natural conditions. LULC classification aids in measuring and comprehending these changes by examining how human activities like construction in urban areas and natural factors such as climate interact to modify the land (Chen et al., 2025). Modelling of LULC change is made possible by machine learning which then helps in observing trends through satellite images and forecasting potential changes to the land over time (Wang et al., 2022). Therefore, machine learning approaches are well appropriate for LULC classification as it entails the analysis of dense complex image data. Some of the examples of frequently employed approaches of machine learning include Artificial Neural Networks (ANN) which function similarly like the human brain.

The primary source of data for LULC classification is now remote sensing imagery because of its benefits, which include extensive coverage and ongoing monitoring to collect time series data. Outstanding outcomes in image processing have been attained since deep learning was introduced, making LULC classification an attractive field of study (Zhao et al., 2023). Information on land use and land cover (LULC) is essential for disaster management, environmental preservation, urban planning, environmental preservation, and agricultural output. It is also a major area of study for Earth observation, which sheds light on how people and the land interact. For instance, knowing LULC aids in disaster management by identifying regions susceptible to landslides, floods, and droughts. In order to prioritize relief efforts, it also helps in planning evacuation routes, determining safe areas for makeshift shelters, and evaluating damage (Khan, 2023). Also, in terms of safeguarding the environment, LULC maps are essential for managing natural resources including forests, soil and water conservation, monitoring ecosystems, preserving biodiversity, and reducing deforestation. LULC data is crucial for achieving sustainable growth in urban planning since it ensures effective resource management and reduces environmental impact. In order to ensure that residential, commercial, and industrial activity are distributed appropriately, it supports land use zoning (Zhao et al., 2023). Furthermore, LULC data aids in tracking urban growth and its consequences on nearby ecosystems and natural resources.

2.3 Methods of assessing land use and land cover changes

Assessing land use and land cover (LULC) changes is critical to understanding the patterns of environmental change, conserving natural resources, and planning for long-term development. To study these changes, many methodologies have been created that take advantage of technological improvements such as remote sensing and Geographic Information Systems (GIS).

2.3.1 Remote sensing

Remote sensing refers to the art and science of obtaining information about the Earth's surface without being in direct physical contact with it (Chuvieco, 2020). It is a method that gathers data without coming into direct touch with the region of interest by using aerial photography and satellite imagery (Thenkabail, 2018). It is a valuable instrument because it allows measurements, visualizations, and analyses of significant biophysical features and human activity on the surface of the earth. It uses sensors that are mounted to airplanes, drones, satellites, or other platforms to gather information from various electromagnetic spectrum regions (Chuvieco, 2020).

The sensors record different electromagnetic radiation wavelengths that are emitted or ref lected by different features on the earth's surface such as vegetation, buildings, and water (Richards & Richards, 2022). The data the sensors acquire from the different features is then processed, analyzed, and used for different objectives such as agricultural studies, forest studies, weather forecasting, and infrastructure monitoring (Reddy, 2018). The sources of these remote sensing data include satellite sensors like Landsat, Sentinel, and MODIS (Moderate Resolution Imaging Spectroradiometer). To detect changes in land use and land cover over time, remote sensing data is interpreted using different techniques such as image classification and the Normalized Difference Vegetation Index (NDVI) (Gao et al., 2020). Therefore, remote sensing is useful for monitoring land use and land cover across large areas and for long periods.

The use of remote sensing technology in forestry has increased significantly. There exists data on the amount of forest cover worldwide and the results of disturbance to forests that span many continents and periods (Fassnacht et al., 2024. Additionally, time series of publicly available passive optical imagery from satellites are being used to create maps and data products that depict forest types or tree species information for regions of different sizes (Fassnacht et al., 2024) Digital Aerial Photogrammetry (DAP) and Airborne Light Detection and Ranging (LiDAR) are innovative methods used to produce precise maps of forests. They provide precise data on tree height, density, and general structure to scientists and forest managers (Guimarães et al., 2020).LiDAR measures the time it takes for laser pulses to return to the ground after being sent there from an airplane. By displaying tree heights and canopy structures, this aids in the creation of 3D representations of forests. DAP, on the other hand, makes use of high-resolution aerial photos captured by aircraft or drones. It generates 3D models of forests using ordinary photographs, much to LiDAR, by examining several photos taken from various perspectives (Guimarães et al., 2020).

2.3.2 Geographic Information System (GIS)

According to Ali (2020), Geographic Information System (GIS) refers to a computer-assisted method for gathering, managing, storing, analyzing, and displaying georeferenced data to aid in decision-making (Ali, 2020). GIS is important in land use/land cover analysis as it offers the tools required for managing, analyzing, and visualizing spatial data. It makes it easier to integrate a variety of datasets, such as aerial and satellite photos, allowing for thorough analysis. Monitoring changes in land use/ land cover over time is made possible by GIS and its spatial analysis tools, which include classification and change detection techniques. To determine the geospatial components that makeup land features, geographic information systems (GIS) and remote sensing techniques become crucial instruments. According to Khodaie and Zandi (2024), remote sensing provides spatial information about land features while GIS gathers, stores, manipulates, displays, analyzes, and presents the remotely sensed data.

Unsupervised and supervised classification are the two categories of classification employed in GIS to achieve land use/ land cover classes ((Fassnacht et al., 2024). Unsupervised classification uses no training data and groups pixels in an image according to their inherent similarities. Clusters are automatically identified by the algorithm and subsequently given labels by the users (Berry et al., 2020). In contrast, users must choose known land cover types to supply training data for supervised classification. Based on these predetermined categories, the system subsequently classifies the remaining portion of the image. Although supervised categorization takes more time and skill, it typically yields more accurate results (Hiran et al., 2021). K-means and Expectation Maximization are two examples of unsupervised classification techniques that automatically classify data into distinct groups without the requirement for prior labeling. However because these techniques don't know what each category means, the findings could be ambiguous and need to be interpreted by humans. Conversely, supervised classification classifies new data more precisely by using training data (Sur et al., 2023). Typical supervised classification techniques include Maximum Likelihood Classification, which predicts categories based on probability; Decision Trees, which divide data according to rules; and Support Vector Machines (SVM), which determine the optimal boundary between various categories. Since these techniques learn from labeled data, they are typically more accurate (Sur et al., 2023).

Kanda (2024) conducted a study on land use and land cover (LULC) changes and their impact on land degradation in the Elgeyo Escarpment, Kenya**,** using Geographic Information Systems (GIS) and remote sensing. The study analyzed Landsat satellite images from 1995, 2014, and 2020 to map and quantify LULC changes over time. GIS techniques were applied to assess the extent of deforestation, expansion of agriculture and settlements, and their effects on soil erosion. Additionally, GIS was employed to analyze spatial variations in soil properties such as pH, organic carbon, nitrogen, and moisture content, revealing significant differences between forests and agricultural land. This study highlights the importance of GIS in monitoring land cover changes, assessing environmental impacts, and informing sustainable land management practices**.**

2.4 Drivers of land use and land cover changes

Land use and land cover change (LULCC) is influenced by numerous factors at global, regional, and local scales. Anthropogenic activities are the main contributory factor of these drivers (Hassen & Assen, 2018; Bekele & Yirsaw, 2019). However natural forces like earthquakes, landslides, volcanic eruptions, and climatological events can also have a significant impact. The main drivers in Africa include population growth, agricultural expansion, urbanization, and development of infrastructure (Arfasa et al., 2023). Apart from these human-induced factors, recent research suggests that climate change is also another contributing factor to land use and land cover changes (Schönhart et al., 2018). The mentioned factors are among the primary ones, although they are not the only ones that contribute to LULC changes**.** Other contributing factors include insecure land tenure, limited enforcement of forest conservation laws, and widespread poverty that drives dependence on forest resources for livelihoods (Kouassi et al., 2021; Amsalu & Kefale, 2023).

2.4.1 Population growth and urbanization

Land use and land cover change is mainly attributed to population growth and urbanization which in turn have substantial effects to earth's natural resources, farming and even urban settings (Naikoo et al., 2020). As the world's population grows, the demand for land and resources increases. This demand often drives the conversion of forests, marshes, and other natural ecosystems into land for agriculture, housing developments, and industrial areas (Hassen et al., 2018). This pattern is common and has been observed in various places such as Egypt, India, Sudan and Oman. Rapid population growth in developing countries raises the need for food, pushing agricultural expansion into forested regions. This expansion not only reduces forest cover but also disrupts habitats, threatening biodiversity and disturbing biological processes (Hasan et al., 2020). A study by Kamran et al. (2023) highlighted that population increase is a major factor influencing LULC changes since the increasing need for social services, housing, infrastructure, and transportation keeps putting strain on the amount of land that is available. Urban ecosystems are deteriorated and environmentally sensitive regions are frequently converted as a result of this demographic strain.

Another major factor contributing to land use and land cover change is urbanization, which involves transforming rural areas into urban spaces (Sang et al., 2022). Urbanization replaces arable and natural lands with urban infrastructure like buildings, roads, and other impermeable surfaces. This shift significantly impacts local and regional environments (Ren et al., 2022). Urban areas tend to expand both horizontally and vertically, encroaching on nearby rural and natural environments. This development often leads to habitat destruction, increased pollution levels, and changes in local climate conditions. The replacement of permeable surfaces with impervious ones disrupts hydrological cycles, increases surface runoff, and diminishes groundwater recharge (Briassoulis, 2020). Population growth and urbanization are intertwined in that as population rises, rural-urban migration increases leading to the alteration of rural land use patterns. The migration in turn results to the demand of more physical and social infrastructure such as housing, schools, and roads which insert pressure on the environment like clearing forests for construction. A study by Naikoo et al. (2020) employed satellite imagery from remote sensing platforms to study LULC change in the suburbs of Delhi in India. They discovered from the analysis of the images that built up areas increased sharply at the expense of farm lands. In the 28 year study period, the built up areas increased by 326 percent and the drivers of this change included population growth and migration. This study recommended that unless there is appropriate land-use planning, the natural settings will continue to be converted in to urban settings to accommodate the growing population.

2.4.2 Agricultural expansion

It is estimated that around 80% of deforestation globally is directly caused by agriculture. It is one of the main causes of forest degradation in Africa (Chirwa & Adeyemi, 2020).

The conversion of wooded lands into agricultural fields, especially for cash crops and cattle grazing, is driven by the need for food security and rapid population increase. Both large-scale commercial agriculture and small-scale subsistence farming contribute to deforestation (Chirwa & Adeyemi, 2020). About two-thirds of the deforested area in Latin America is caused by commercial agriculture, making it the main cause of deforestation in the region. About one-third of deforestation occurs in Africa and (sub) tropical Asia, where it is equally important to subsistence farming (Southgate, 2023). The need to produce more food as populations rise, particularly in Africa, forces farmers and agricultural companies to clear natural habitats and replace them with grasslands and croplands (Assede et al., 2023). Land use patterns are changed by this process, which leads to an increase in cultivated areas and a decrease in natural vegetation. Mechanized farming and better irrigation systems are two examples of technological developments that have further accelerated agricultural growth by allowing large-scale farming operations in traditionally inappropriate areas (Assede et al., 2023).

An empirical study, carried out by Akanga et al. (2022) investigated the dynamics of land use and land cover (LULC) in Kenya's Greater Mau Forest Complex (GMFC), emphasizing the part played by agricultural growth. Utilizing land cover classification methods and satellite remote sensing, the study measured the rate of forest cover loss over time and determined that the main cause of LULC change in the area is agricultural growth. According to the study, forested regions have suffered greatly from the substantial growth in agricultural land, especially near forest margins and in densely inhabited areas. Key contributory factors were highlighted by the study, including the dependence on agriculture for economic survival and subsistence, resettlement, and population pressure. These results highlight how human activities farming in particular have an impact on the changing landscape. The study also pointed out that the forest's ecological stability is threatened by the increasing rate of agricultural encroachment, which includes increased carbon emissions, altered watershed functions, and biodiversity loss. In order to prevent environmental deterioration, the authors suggested strengthening land governance structures, improving forest protection measures, and encouraging sustainable agriculture practices.

2.4.3 Infrastructure development

Most scholars acknowledge the development of infrastructure plays a significant role in transforming LULC change especially in areas that are growing in developing countries. This growth impacts most natural settings such as the wetlands or forests since they are cleared to give space for construction of infrastructure such as railway and road construction as illustrated in **Figure 2.1**. Transportation routes, dams, and towns are examples of infrastructure development that disrupts forests and produce edge effects that lower the quality of forests (Fischer et al., 2021; Sang et al., 2022). The term "edge effects" describes alterations in the structure of communities that take place when two ecosystems meet (Miranda et al., 2022). The forest interior can deteriorate as a result of these consequences, which lead to other negative effects such as increased wind exposure, light penetration, and the likelihood of fires and invasive species. Expanding infrastructure developments in Kenya have resulted in the destruction of habitat and deforestation, which has an impact on forests. The construction of roads disturbs animal corridors and modifies hydrological cycles in addition to making illicit logging and agricultural encroachment easier to access (Albertazzi et al., 2018).

An example is the construction of the proposed Mau Mau road to pass through the Aberdare forest in Kenya. The project faced a lot of opposition from conservationists who were worried about its environmental impact, even though it is anticipated to improve regional transportation. The conservationists argue that the development could lead to deforestation, habitat destruction, and threats to endangered species such as the mountain bongo and elephants (Tyrell & Allan, 2020). In addition, the Aberdare environment plays a crucial role in water catchment, delivering water to millions of people and supporting hydropower generation. Environmentalists warn that the road could disturb these ecological services, resulting in detrimental environmental and socio-economic repercussions. Environmental agencies have given the project conditional approval despite these reservations, and talks are in progress to put mitigation measures in place that will lessen ecological harm (Tyrell & Allan, 2020). Therefore this case highlights the effects of infrastructure development on natural ecosystems like forests.

Another example is the biggest railway project in India, a 760km Konkan railway which happened after independence. According to Navalkar et al. (2023), who conducted a study on the Konkan railway, such infrastructure projects have impacts to the environment. The construction of such railways requires several changes to the terrain such as removal of vegetation, passing into natural terrains and blasting through hills and mountains. All these construction and activities result in disturbance of different environments including biological and the physical landscapes. The study examined the effects of this project on LULC as it is constructed in areas rich in biodiversity and ecologically sensitive places. The researchers found a decline in water bodies, decrease in vegetation cover including reduction in forest cover. In addition, the railway has improved transportation in the area has individuals can access inaccessible places but the disadvantage is that it has resulted in environmental damage, and unplanned urban growth.

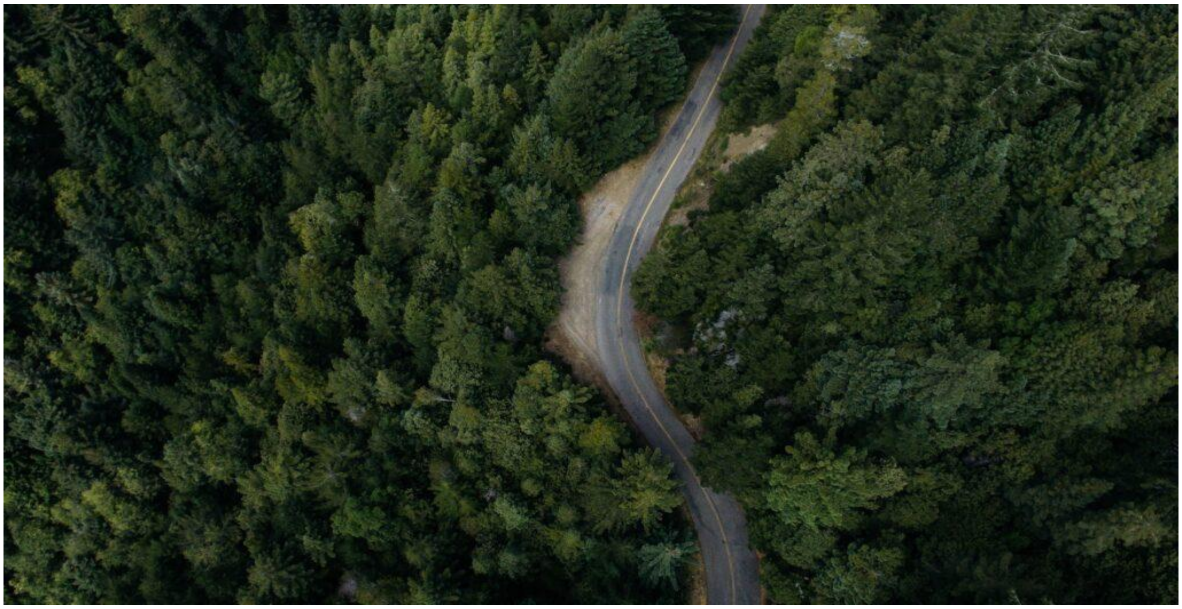

Figure 2.1: Road passing through the forest

Source: (John, 2021)

2.4.4 Climate change

Climate change is a major driver of land use and land cover changes, influencing forest ecosystems by altering temperature, precipitation patterns, and the frequency of extreme weather events. Africa's forest ecosystems are facing serious problems due to climate change and related extreme weather events such as floods, wildfires, and droughts (IPCC, 2019). Rising temperatures may result in shifts in the distribution of species, phenology changes, and greater vulnerability to pests and diseases (Hartmann et al. 2022). On precipitation patterns, climate change alters the patterns such that droughts become frequent which affects forest ecosystems as they slow growth and increase death (Funatsu et al., 2019). **Figure 2.2**, which depicts the global increase in temperature anomalies over the 20th century, demonstrates the rising trend of global warming, which directly affects the distribution and health of forests. Annual mean temperature anomalies and smoothed trends, which indicate a sharp increase in world temperatures, particularly after the 1970s, when anthropogenic activity intensified (Valipour et al., 2021; Lindsey & Dahlman, 2020).

In addition, Climate change increases other drivers of land use change, including agricultural growth and construction of infrastructure as communities adjust to new circumstances. The long-term effects of climate change on forest ecosystems highlight the necessity for responsive management practices that improve forest resilience while mitigating the effects of these changes.

According to a thorough review study by Assede et al. (2023) titled "Understanding Drivers of Land Use and Land Cover Change in Africa," the various and interrelated factors affecting land use and land cover (LULC) dynamics throughout the African continent were investigated. Out of all the drivers found, the study focused especially on climate change as a major factor in LULC transformation. Particularly in dry and semi-arid areas, the authors emphasized how climatic variability which can be seen by long periods of drought, unpredictable rainfall patterns, and rising temperatures has directly decreased land production. Because of these climate stressors, societies have responded by extending agricultural practices into previously uncultivated areas, frequently at the expense of ecosystems that depend on forests and grasslands.

Furthermore, the study pointed out that ecological deterioration brought on by climate change increases a landscape's vulnerability to wildfires, soil erosion, and overgrazing, hastening the change in land cover (Assede et al., 2023). The indirect effects of climate change, especially through migration brought on by it, were also highlighted in the review.

Communities are forced to relocate as a result of water scarcity and failing crops, which raises the demand for land for farming, housing, and services and further changes the land cover. The authors noted that socioeconomic issues like poverty, insecure land tenure, and weak land governance institutions frequently exacerbate the effects of climate change (Assede et al., 2023).

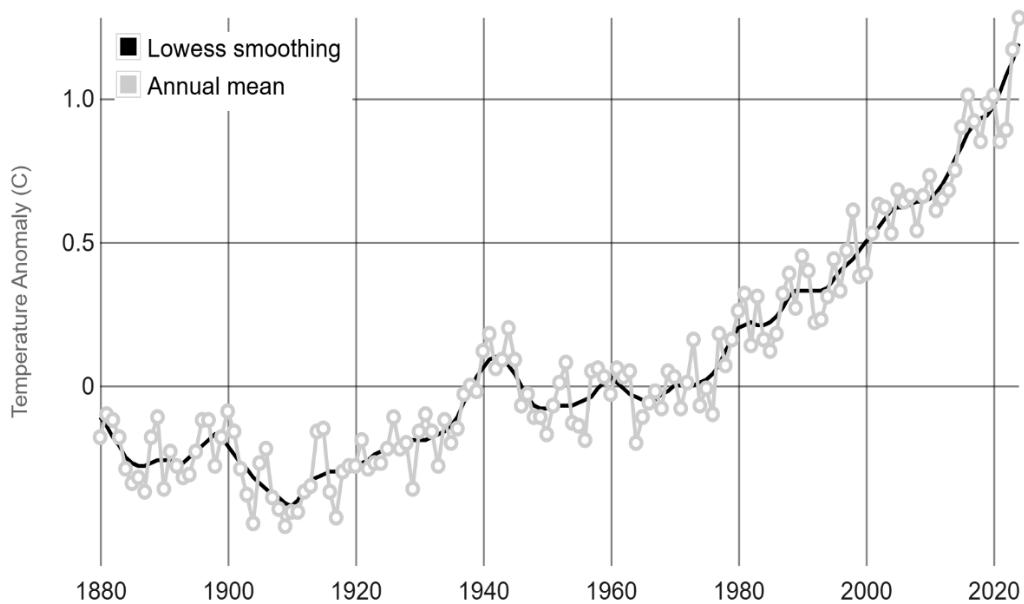

Figure 2.2: Global surface temperature change

Source: National Aeronautics and Space Administration (NASA), 2024

2.4.5 Insecure land tenure

Insecure land tenure is a critical driver of land use and land cover (LULC) changes, particularly in regions where land governance systems are weak or poorly defined. When individuals or communities lack legal ownership or clear, enforceable rights to land, they are less likely to invest in long-term sustainable land management practices and more prone to engage in activities that lead to rapid land degradation, such as deforestation, overgrazing, or unsustainable agriculture (Chigbu et al., 2019). In such contexts, land users often exploit forested areas without regard for conservation, fearing future eviction or competing claims (Chigbu et al., 2019). Moreover, insecure tenure can fuel land conflicts and discourage reforestation or restoration efforts, as people may not benefit directly from the long-term outcomes of these initiatives. Without formal recognition of tenure, communal lands are especially vulnerable to encroachment, illegal logging, and conversion to farmland (Chigbu et al., 2019). The lack of land rights also makes it difficult to enforce environmental regulations, as land users may operate outside formal governance structures. Addressing land tenure insecurity is therefore essential for promoting responsible land stewardship and mitigating harmful LULC changes.

As study by Alemie and Amsalu (2020) looked in to how changes in forest cover in Ethiopia's Gerejeda State Forest was contributed by insecure land tenure. The study sought to determine how forest degradation is influenced by local opinions and views of land ownership and the absence of secure tenure. From the study, using various ways of data collection such as interviews and household questionnaires, the researchers discovered that regions with insecure land tenure had noticeably greater rates of forest area loss. This study confirmed that, when communities are unsure about their long-term land rights, they are less willing or unwilling to practice the sustainable techniques of forest management. According to the study findings, insecure land tenure promotes the short-term use of forest resources and discourages conservation initiatives, which all lead to forest degradation. Therefore, this study offers a crucial proof of the close relationship between institutional factors in focus on land tenure security and forest conservation outcomes. Similarly, a study carried out specifically in Kenya by Schürmann et al. (2020) examined how changes in land cover in Arabuko Sokoke Foest in the coast are influenced by land tenure systems. This study also found a strong relationship between insecure land tenure and forest degradation. It proved that agricultural expansion that led to encroachment in to the forest areas by communities living near the forest was due to land insecurity. The absence of recognized property rights put the forest under more stress.

2.4.6 Weak enforcement of forest conservation laws

Analysis shows that the lack of effective forest law enforcement acts as a major factor behind land use and land cover (LULC) transitions especially within forests found in developing nations. Successful implementation of forest protection laws remains limited by weak institutions, insufficient funds, limited staff as well as corruption (Mwangi & Dooley, 2016; Nkonya et al., 2016). The combination of operational challenges enables illegal logging activities as well as charcoal production and unregulated grazing and agricultural encroachment to operate without effective restraint. Degraded forest regions continue to be exploited repeatedly which jeopardizes both tree planting initiatives and natural conservation goals because of lack of enforcement and penalties (Chenje & Johnson, 2009). Additionally, absence of robust enforcement creates distrust about forest governance systems among the public which discourages community involvement particularly when violators profit without facing consequences (FAO, 2018). The problem continues to worsen because of political interference and insufficient transparency which both hide perpetrators while diminishing institutional performance (Barrow et al., 2020). The persistent degradation of forest ecosystems combined with biodiversity decline and land-use changes demonstrate the critical necessity of enhanced policy enforcement within comprehensive forest sustainability plans.

According to Kweyu et al. (2020) the Eastern Mau Forest Complex land cover changes and forest loss were caused by political interference and disputed land allocations. The study emphasizes how conservation efforts are hindered by unclear land administration and also disputes. The results point to a larger challenge of weak enforcement of laws pertaining forest protection, where key institutions such as the government allow illegal distribution of land and settlement inside the forest which should be a protected area. Lack of legal enforcement accelerates LULC change by encouraging conflicts and forest degradation.

2.4.7 Poverty

The practices of managing land in an unsustainable manner result largely from poverty levels. Many forest-adjacent communities increasingly depend on forests to obtain their basic resources including fuelwood, building materials, food and income from timber harvesting and charcoal production (Razafindratsima et al., 2020). Faced without suitable alternative survival options these communities exhaust their forest resources excessively to provide for basic requirements which results in forest loss. Kipkunurr Forest shows widespread changes from forested areas to agricultural land by people who want to either expand their food production abilities or raise their income levels. The situation becomes critical because population growth increases the demand for already limited forest resources. When poverty interact with land degradation it forms a vicious cycle. Decreasing forest cover leads to community poverty which then accelerates the depletion of existing forest resources (Xu et al., 2020). When communities lack alternative ways to earn money they must persist in using practices that are harmful to their environment.

A recent study by Mutenyi et al. (2024) looked in to the factors influencing changes in land use and land cover changes (LULC) in Khwisero Sub County, Kakamega County, Kenya. The study found poverty as the key driver to changes in land use and land cover. Due to lack of other options of earning a living apart from farming, many people in the community turned to clearing forests to expand their farms and also burning charcoal using timber from the forest. The authors stress that poverty increases dependency on forest resources which also limits the community members from engaging in sustainable land management.

2.5 Forest health assessment

Forest health refers to the general condition of forest ecosystems that maintains their complexity while meeting human demands (Sharma & Raj, 2024). A healthy forest can provide ecosystem services like water management, habitat for animals and birds, and carbon sequestration. Forest health indicators comprise tree vitality, biodiversity, soil quality, regeneration capability, disturbance resistance, and water quality and quantity (Hartmann et al., 2018; Albrich et al., 2020). There are different methods of assessing forest health, including monitoring forest indicators such as tree vitality. In addition, remote sensing techniques are particularly useful in forest health assessment in large areas. The commonly used remote sensing indices used for assessment include Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and Normalized Burn Ratio (NBR).

2.5.1 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is an important tool for measuring forest health because it provides a consistent and efficient method of monitoring vegetation status and changes over time. It is a widely used vegetation index that is produced from data from remote sensing, especially satellite imaging. It measures the difference between red light reflectance and near-infrared (NIR) light reflectance to quantify the existence and health of vegetation (Pettorelli, 2013).

NDVI is calculated using the following formula;

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

Where NIR denotes the reflectance of near-infrared light and Red denotes the reflectance of red light. Red and NIR are commonly expressed as digital values or numbers between 0 and 1 (Pettorelli, 2013).

The range of NDVI values is -1 to 1, with greater positive values denoting healthier and denser vegetation and lower or negative values denoting areas that are less or non-vegetated (Huang et al., 2021). The detailed interpretation of NDVI values is that values close to -1 represent water bodies, clouds, or other non-vegetated features. Values near 0 correspond to bare soil, rocks, or sparsely vegetated urban areas. Lastly, values between 0 and 1 indicate varying degrees of vegetation cover, with higher values indicating denser and healthier vegetation (Pettorelli, 2013). When evaluating the quantity and quality of vegetation in forested areas, NDVI is a useful tool. In order to monitor and manage forest ecosystems, it is helpful to quantify the amount and density of vegetation cover (Huang et al., 2021). Therefore, the Normalized Difference Vegetation Index (NDVI) is an important tool for measuring forest health because it provides a consistent and efficient method of monitoring vegetation status and changes over time.

Ahmad et al. (2020) assessed the condition of forest ecosystems in Sholayar Reserve Forest, Kerala, using the Normalized Difference Vegetation Index (NDVI) and AVIRIS-NG hyperspectral data. The study found that NDVI, when combined with hyperspectral imaging, provides a more nuanced picture of vegetation health by identifying minor differences in plant stress and canopy density. The study's findings highlighted NDVI's usefulness in identifying regions of forest degradation, reinforcing its importance as a tool in forest health monitoring and management, especially when paired with advanced remote sensing technologies.

Wilson and Norman (2018) investigated the effectiveness of utilizing the Normalized Difference Vegetation Index (NDVI) to monitor vegetation regrowth surrounding a restored wetland. NDVI, which assesses vegetation health and density by examining the reflectance of near-infrared and red light, demonstrated considerable improvements in vegetation health following restoration. The study's temporal analysis of NDVI values revealed that vegetation had been successfully reestablished, emphasizing the index's usefulness in measuring ecosystem recovery. This highlights NDVI's broader applicability in forest health research, as it provides a dependable tool for tracking vegetation cycles and directing conservation activities.

Several scholars have explored the use of the Normalized Difference Vegetation Index (NDVI) in forest management, showing both its strengths and weaknesses. Its capacity to deliver consistent, large-scale, time-series data for tracking forest changes is one of its main advantages. According to studies, NDVI can accurately identify seasonal changes in plant cover, deforestation, and degradation (Zhu & Woodcock, 2014). Furthermore, because NDVI uses publicly available satellite data from sources like Landsat, MODIS, and

Sentinel images, it is affordable and suitable for long-term forest monitoring (Zhao et al., 2024).

Nevertheless, NDVI has significant drawbacks despite its benefits. One drawback is that it tends to saturate in deep forests, which makes it unable to distinguish between moderate and high biomass vegetation cover (Smeenk, 2023). In densely forested locations, this reduces its ability to distinguish between primary forests and secondary regrowth. Furthermore, NDVI can cause problems in interpretation due to its sensitivity to weather conditions and soil background reflectance (Nagol et al., 2014). For example, NDVI measurements may be impacted by aerosols, cloud cover, and changes in soil moisture, which could result in an incorrect assessment of the health of the vegetation ((Smeenk, 2023). Additionally, the NDVI by itself does not offer thorough insights into forest structural characteristics like canopy height, biomass, and species composition; therefore, other indices or remote sensing methods include LiDAR data.

2.5.2 Enhanced Vegetation Index (EVI)

Enhanced Vegetation Index (EVI) is an enhanced remote sensing metric that is used to measure the health and density of vegetation. This EVI metric functions similarly as the NDVI tool but offers improved performance by overcoming some of the NDVI limitations especially in regions with denser vegetation where NDVI mostly saturates (Mizen et al., 2024). Some of the NDVI limitations it is able to correct include background noise from the canopy and atmospheric interference (Macdonald et al., 2025). With its comprehensive and useful insights in areas of plants such as health and biomass, EVI has emerged as a useful tool in forest conservation and management, agriculture, and environmental monitoring in general. Just like NDVI, EVI also uses data from two parts of the spectrum; Visible and Near-infrared. However, to correct the limitations of NDVI, EVI includes the blue band part of the spectrum. Therefore EVI is calculated using the formula;

$$EVI = G \times (NIR - Red) / (NIR + C1 \times Red - C2 \times Blue + L)$$

Where NIR, Red and Blue are the spectral reflectance values in the near-infrared, red and blue bands respectively. The G, C1, C2, and L coefficients are constants usually set to 2.5, 6, 7.5 and 1 saturates (Mizen et al., 2024).

Although meaningful values lie between 0 and 1, EVI values normally range from -1 to +1 just as the NDVI values. Bare or degraded regions are usually indicated by values below 0.1 whereas sparse or stressed vegetation is indicated by values between 0.1 and 0.3. On the other hand, moderate vegetation is indicated by values between 0.3 and 0.6 where as dense and healthy vegetation is indicated by values above 0.6. Therefore, in forest health assessment, the EVI tool is able to tell the condition of the forest from its ability to reflect light. Higher NIR reflectance and low blue and red reflectance means high EVI values that represent healthy forests with dense vegetation canopy and high contents of chlorophyll saturates (Mizen et al., 2024). On the other hand, high reflectance in blue and red bands give low EVI values that depict stressed vegetation vulnerable to diseases and forest fires. By using these thresholds, researchers can measure the health of forests overtime and identify stresses and changes that the human eye cannot tell using various indicators.

The use EVI in forest health assessment has been validated by several empirical studies. For instance, a study by Vijith and Dodge-Wan (2020) investigated how well the Enhanced Vegetation Index (EVI) together with land cover data from MODIS monitor changes in vegetation vigor in Borneo tropical rainforest. For EVI effectiveness in assessing forest condition, the study demonstrated the metric capability in detecting the changes in vegetation health overtime due to its sensitivity in densely vegetated areas. Therefore, in general the study showed that EVI is a useful tool for large scale forest monitoring and especially dense forest ecosystems such as the tropical rainforest. Similarly, a study by Rodriguez et al. (2024) also examined the use of temporal variations in the EVI tool to track and monitor forest conditions overtime and help guide management choices. The findings showed that the EVI tool is useful and effective in identifying vegetation stress and disturbances thus its continuous monitoring can help forest managers in restoring degraded areas. In summary, EVI as a remote sensing tool is more reliable and accurate in assessing forest health than NDVI.

2.5.3 Normalized Burn Ratio (NBR)

The Normalized Burn Ratio refers to a spectral indicator that is mostly used to detect burned regions and measure the intensity of fires but it has also been proven to assess the health of forests (Alcaras et al., 2022). This tool becomes useful especially when detecting vegetation stress and forest deterioration caused by droughts, pest and diseases and forest fires. It is computed using the following formula;

NBR = (NIR- SWIR)/(NIR+SWIR)

Where, NIR denotes the reflectance of the near-infrared light whereas SWIR denotes the reflectance of the short-wave infrared light. Higher reflectance of the NIR light and low reflectance of the SWIR light result in high NBR values. The lower values on the other hand, are produced when there is low reflectance of NIR light and high reflectance of SWIR light. Therefore, higher NBR values denote healthy, dense vegetation whereas stressed, damaged and burned vegetation are implied by low NBR values. The NBR values or thresholds used to assess forest health range from -1 to +1 but in most times they fall between -0.1 and 0.9 (Alcaras et al., 2022). The delta NBR is frequently calculated by comparing the images taken before and after the burn in order to evaluate the condition of forest overtime. Thus values below 0.1 are used to denote unburned or slightly impacted regions while delta NBR values more than 0.6 indicate substantial burn severity.

Several empirical studies have shown how useful NBR is in assessing forest health. For instance, in a study by Delcourt et al. (2021) carried out in Asia investigated the efficacy of determining fire severity in Northeast Siberian Larch Forests using Normalized Burn Ratio (NBR), which is generated from Sentinel-2 satellite imagery. The study calculated the dNBR values using images from satellites taken before and after the fire, also to verify the information from the satellite images field-based measurements from Composite Burned Index (CBI) was used. From the results, a strong correlation between dNBR and CBI was found showing that the index can accurately capture different severity levels of fire, particularly in zones with high-severity burns. The images from the Sentinel-2 enabled for fine scale burn mapping because of the high spatial resolution. The study also pointed out some of its limitations, for instance the decreased sensitivity of dNBR in places where the fire took place but without significant loss of vegetation. Despite this limitation, the study found dNBR as a reliable and effective tool for post-fire evaluation in boreal forest ecosystems.

Another study carried out in Kenya by Henry and Maingi (2024) also assessed how well burn indices taken from Sentinel-2 and landsat images mapped fire scars in Kenyan's Chyulu hills. The purpose of the study was to evaluate how well different spectral indices performed in identifying and mapping areas affected by fire, with a focus on Normalized Burn Ratio and its differenced form dNBR. The researchers employed field data to validate the analysis of how well these particular indices could identify the severity and extent of fires using the images taken before and after the fire. From the images, the ones from Sentinel-2 were clearer than the Landsat ones because of its high resolution of 10 by 10 Meters. Based on the indices, the study found out that the differenced form dNBR was capable of identifying the various classifications of burn severity. Therefore the study concluded that dNBR does well and is effective in fire monitoring

2.6 Factors influencing forest health

Forest health is impacted by an intricate combination of natural and manmade causes. Understanding these variables is critical for successful forest management and conservation efforts, particularly in light of climate change. Some of the factors influencing forest health are forest fires, pests and diseases, climatic factors, soil conditions, and anthropogenic activities (Canelles et al., 2021).

2.6.1 Forest fires

Fire is a significant disruption factor that has both positive and negative consequences. Certain forest ecosystems have adapted to fire and rely on it to maintain their vitality and potential for reproduction. In California, for instance, a tree known as Ponderosa Pine (*Pinus Ponderosa*) and other pine species contain thick bark and self-pruning branches that enable them withstand fires of low intensity. In addition, the Giant Sequoia (*Sequoiadendron giganteum*) has cones that need heat in order to release seeds (Kolden et al., 2025). Nevertheless, fire frequently goes beyond control and burns forest plants and biomass, resulting in significant soil erosion by wind and water (Peñuelas & Sardans, 2021). The devastation spreads to adjacent environments and livelihoods, causing atmospheric pollution and accumulated contaminants. Forest fires endanger people's lives and undermine the environmentally friendly utilization of natural resources. Unregulated agricultural land expansion, as well as the growing usage of forests for tourism and leisure activities, all enhance the likelihood of forest fires (Zhao et al., 2019). Both natural and man-made sources can start forest fires. Lightning strikes and the random burning of dry plants are examples of natural causes. Fire risks are greatly exacerbated by human activities such as deforestation, agricultural growth, charcoal burning, and increased recreational usage of forests (Sadowska et al., 2021). Forest fires have far-reaching effects on the stability of soil, biodiversity, water cycles, and the state of the atmosphere. Fires contribute to air pollution and global warming by releasing large amounts of carbon dioxide (CO_2), methane (CH_4), and other pollutants (Agbeshie et al., , 2022).

Over the past 20 years, the number of forest fires in the United States has increased. Since the year 2000, this nation has seen an average of 72, 600 wildfires annually and destroying seven million of land annually most which are forest or vegetated areas (Franklin & MacDonald, 2024). Compared to the wildfires in the 1990s, the 2000 one are more than twice meaning the trend is increasing. From the US National Interagecy Fire, more than 4.5 million acres have been destroyed by 43, 438 wildfires as per the year 2024 alone affecting the western zones such as California (Franklin & MacDonald, 2024). The Silker Creek Fire **(Figure 2.3**, one of the California's most destructive wildfires in 2024, burned over 1,200 buildings and 180,000 acres in Nothern California thus causing people to evacuate (Kolden et al., 2025).Even historically less affected regions such as the

Southeastern parts and North Carolina are expected to experience more regular and destructive wildfire occurences as climate change accelerates.

Based on their severity and rate of spread, forest fires can be divided into three primary categories, ground, surface, and crown fires (Xu et al., 2021). Layers of organic debris, including humus, peat, and dried plants, are burned by ground fires that start beneath the forest ground. These fires burn slowly and emit very little smoke. Conversely, fuels from the forest floor, such as fallen leaves, branches, and tiny plants, are consumed by surface fires (Xu et al., 2021). They can occasionally burn or harm the lower parts of trees, but their primary effect is on ground vegetation. Crown fires, the most severe kind, quickly engulf branches, tall bushes, and both dead and living vegetation as they advanced through the forest canopy. Crown fires, which are frequently started by surface fires, spread quickly from treetop to treetop and pose serious threats to neighboring towns and forest ecosystems (Loboda et al., 2022).

Figure 2.3: Forest Fire in California Forest

Source: (Annie, 2024)

2.6.2 Pests and diseases

Pests are described as any plant, animal, or disease agent that causes harm to plants. Pest infestations can result in either immediate or unforeseen economic and ecological effects (Canelles et al., 2021). Although insects and diseases are essential elements of forests and serve critical purposes, occasional outbreaks can have a negative impact on tree development and survival, production and quality of timber and non-wood forest products, habitat for animals, and the recreational, attractive, and cultural significance of forests (Canelles et al., 2021). Insects like bark beetles and defoliators can destroy wide regions of forest, damaging trees thus rendering them more vulnerable to other stresses (Burdon & Zhan, 2020). Furthermore, fungal diseases, such as those that cause decay of roots and leaf blight, can spread quickly under ideal conditions, resulting in extensive tree loss. Climate change aggravates these difficulties by modifying the distribution and lifecycle of pests and pathogens, leading to more frequent and serious outbreaks (Canelles et al., 2021).

Both native and non-native insect pests and diseases pose a threat to Africa's forests (Graziosi et al., 2020). About 100 kinds of dangerous insects and microorganisms impact trees in both natural and planted forests in different parts of Africa, such as Ghana, Kenya, Malawi, Mauritius, Morocco, South Africa, and Sudan (FAO, 2015). More than one-third of these species are invasive, 15% are of unknown origin, and almost half are native. Most forest-damaging illnesses are either introduced or of unknown origin, and a large percentage of tree-damaging insects are non-native species (Graziosi et al., 2020). **Table 2.1** shows categories of primary insect pests and their corresponding impacts on trees.

Table 2.1: Categorization of insect pests and their impact on trees

Classification	**Description**	**Examples**
Defoliators	Insects that feed on leaves, causing defoliation and weakening trees.	Gypsy moths, Pine sawflies
Bark Beetles	Insects that burrow into tree bark, disrupting nutrient flow and leading to tree death.	Mountain pine beetle
Borers	Insects that bore into tree trunks and branches, weakening or damaging trees.	Ambrosia beetles
Sap-Sucking Insects	Insects that feed on tree sap, weakening trees and potentially spreading diseases.	Aphids, Scale insects

Source: Burdon & Zhan, 2020

2.6.3 Climatic factors

Climatic factors such as temperature, precipitation, and extreme weather events all have a substantial impact on forest health (Gebeyehu & Hirpo, 2019). Temperature impacts tree metabolic processes, which influence development and reproduction. For example, increased temperatures can lengthen the growth season while also increasing stress from heat waves and droughts, resulting to greater death rates (Gebeyehu & Hirpo, 2019). Precipitation patterns impact the supply of water, which is critical for tree survival. Variations in precipitation may lead to droughts or floods, both of which are detrimental to forest health. For instance, extended droughts can cause water shortages, lowering tree tolerance thus rendering them more vulnerable to deaths (Yi et al., 2022). Heavy rainfall and flooding, on the other hand, can cause soil erosion and loss of nutrients, negatively damaging forest health. Lastly, Extreme weather conditions such as storms and hurricanes can cause rapid harm by toppling trees and changing forest structure, resulting in permanent ecological alterations (Gebeyehu & Hirpo, 2019).

2.6.4 Soil conditions

Soil health is critical to forest ecosystems because it directly affects the development of trees, biodiversity, and general forest health (Cherubini et al., 2021). Nutrient-rich soils with critical components such as nitrogen, phosphate, and potassium promote healthy tree development and resistance to pests and diseases (Maaroufi &De Long, 2020). On the contrary, soils lacking in nutrients can result in poor tree health, slowed development, and greater sensitivity to environmental pressures. Soil pH is also important as ideal pH levels guarantee efficient nutrient uptake. Soil serves as a storage for water, which is required for physiological activities in trees such as nutrient intake and photosynthesis (Maaroufi &De Long, 2020). Extended periods of drought can decrease soil moisture, causing water shortages in trees and making them more vulnerable to pests and diseases (Lloret & Batllori, 2021). Another component is the biological activity, soils that are healthy contain the following things in plenty; enzyme activity, micro flora and soil fauna which are essential for certain processes in the forest ecosystem such as nutrient cycling. Therefore, the health of the forest is determined by the soil conditions which is why it is crucial to monitor or study the different components of the soil to ensure long-term forest health. The continuous monitoring ensures soil quality as degraded soils take long to recover since even in 30years full recovery may not be achieved (Shao et al., 2020).

2.6.5 Anthropogenic activities

Human actions create the dominant factors that result in worldwide forest health deterioration. Forest ecosystems experience lasting ecological harm when humans initiate various modifications including deforestation, agricultural development, logging activities, urban development, and mining projects (Assede et al., 2023). Forests throughout Africa face destruction because local communities cut them down to expand their land for farming, settlements and towns because of increasing population numbers and economic demands. The transition of forest land causes both tree-cover loss and breaks down natural habitats and leaves the remaining forests exposed to diseases and extreme weather events (Assede et al., 2023). The process of logging both authorized and unauthorized operations causes severe damage to forests because it destroys established trees as well as alters the natural arrangement of the forest. The implementation of poor logging approaches inflicts damage to adjacent vegetation and creates conditions that boost the entry of harmful invasive species and diseases. Cities expanding towards forested regions along with construction of roads as well as settlements have created additional barriers between ecosystems and limited wildlife connectivity (Kariuki et al., 2022).

The practice of mining and quarrying results in severe damage to forest health through destructive changes to land quality and environmental contamination as well as eliminated vegetation. Artisanal and small-scale mining which persists throughout many regions of Africa frequently happens without required environmental precautions thus resulting in tree removal and pollution related damage to both soil and surface water (Kumar et al., 2022). Industrial emission pollution and agricultural chemical contamination modifies soil chemistry while simultaneously damaging plants that grow in forests. However, forest soil and tree health suffer damage from two major pollutants: acid rain and pesticide runoff which degrade necessary forest-recovery. The harvesting of fuel wood and charcoal removal affects forests extensively since Sub-Saharan Africa heavily relies on these energy sources for domestic use. Unsustainable wood extraction causes forest trees to decrease while destroying biodiversity and promoting soil degradation (FAO, 2022). Generally, human pressures continue to damage forest health even though they stem mainly from socio-economic needs while requiring better forest management practices and strengthened governance and involved local commu nities in conservation work (Baddianaah et al., 2023).

2.7 Climatic trend analysis

Temperature and rainfall are key climatic variables that have a significant impact on forest ecosystems. These variables influence the distribution, development, and overall condition of forests by influencing biological processes such as respiration, photosynthesis, and water intake (Ammer, 2019). Temperature impacts tree's rate of metabolism, diversity of species, and phenological processes such as blooming and leafing out. Patterns of precipitation influence the availability of water, which is critical for tree survival, particularly in water scarce areas (Cherubini et al., 2021). Variations in these climatic variables can cause modifications to forest structure, and function, hence analyzing temperature and rainfall data is critical for understanding how forests function under changing climate circumstances (Kijowska et al., 2020). Assessing climate trends is critical for comprehending how climatic variables like temperature and rainfall have changed over time and how these changes affect ecosystems. This analysis has important implications for forest management, conservation initiatives, and anticipating future climate scenarios. Climate trends are analyzed using a variety of methodologies like descriptive statistics, regression analysis, time series analysis, and climate models.

2.7.1 Descriptive statistics and regression analysis

Descriptive statistics entail summarizing climate data using measurements like mean, median, and standard deviation. These statistics provide a preliminary knowledge of the central tendency, variability, and overall trends in climate data throughout time. Descriptive statistics are frequently employed as a first step before employing more advanced analytical approaches (Islam, 2018). Regression analysis is used to measure the relationship between climate variables across time, which enables trend estimates. Linear regression models forecast future climate conditions by fitting a straight line over historical data sets. Non-linear regression models are employed when there is no linear relationship between variables. Multiple regression analysis can incorporate additional factors impacting climatic variables, resulting in a more complete knowledge of trends (Gunst & Mason, 2018).

2.7.2 Time series analysis and climate models

Time series analysis is a statistical tool for analyzing climate trends that examines data points collected at regularly spaced intervals over time. This strategy aids in the identification of patterns, trends, seasonal fluctuations, and other relevant properties in climate data (Mills, 2019). For example, by using time series analysis to historical temperature and rainfall data, researchers can identify trends over time suggesting warming or cooling periods, shifts in precipitation patterns, and potential anomalies that could indicate uncommon climate events. Climatic models such as General Circulation Models (GCMs) and Regional Climate Models (RCMs), simulate climatic processes to forecast future climate conditions (Chokkavarapu & Mandla, 2019). GCMs simulate the global climate system using different greenhouse gas emission scenarios, whereas RCMs give more comprehensive simulations at the regional level.

2.8 Impact of climate change on forests ecosystems

Climate change, caused by increased greenhouse gas emissions, alters temperature, precipitation patterns, and the frequency of severe weather events that affect forests. Average global temperature are predicted to rise by two to four degrees Celsius by 2100 which will continue to influence the composition, function and health of forests .As a result, forests may be directly impacted by climatic changes for instance, temperature and precipitation. These effects differ depending on the type and region where the forest is located and they might be positive or negative effects. Positive and negative in the instance that some trees may experience tree growth while others decline in growth in increased temperatures. Some of the effects of climate change that are discussed below include decreased carbon sequestration, diminishing forest health and altered hydrological cycles.

2.8.1 Decreased carbon sequestration

Over half of carbon stored in terrestrial environments comes from forest ecosystems, which have been found to be the greatest carbon sinks on earth (Hui et al., 2022). However carbon cycling may be impacted by how climate change affects forest environments. Through photosynthesis, forests absorb and store carbon dioxide from the atmosphere hence important sinks that assist in mitigating the impacts of climate change. Nevertheless, the same climate change is hinders the trees capacity to perform its faction of carbon sequestration as the climate continues to change progressively. Climate change has emerged as one of the world's most critical environmental challenges, owing principally to the massive quantity of carbon emissions pumped into the atmosphere by human activity (Masson-Delmotte et al., 2021). Forest ecosystems are the largest terrestrial carbon store and can absorb almost one-third of global carbon emissions (Friedlingstein et al., 2022; Jenkins & Schaap, 2018). Forests contribute significantly to global climate change mitigation by capturing carbon from the atmosphere (Jenkins & Schaap, 2018). However, carbon sequestration in forest ecosystems is heavily impacted by climate conditions. For instance, trees experience stress due to frequent droughts and higher evapotranspiration caused by erratic rainfall patters and increased temperatures (Masson-Delmotte et al., 2021). These conditions cause trees to grow more slowly and increases the risk of dying which limits the quantity of carbon that forests can take in and store. Furthermore, disruptions which include pest and diseases, forest fires most of which are made worse by climate change contribute to carbon loss as the lead to destruction in vegetation thus release of carbon in the atmosphere. Moreover, availability of water and nutrients like phosphorus and nitrogen hinder the success rate of carbon dioxide fertilization. Due to these ecological limitations, even if higher levels of carbon dioxide increases photosynthesis, the amount of carbon stored may not rise proportionately (Hui et al., 2022).

2.8.2 Diminishing forest health

Pests and diseases that affect forest ecosystems are expected to rise either directly as a result of climate change or indirectly as a result of higher levels of water stress making trees more vulnerable to attacks (Hartmann et al., 2022). In addition to promoting the emergence and spread of foreign species, climate change modifies the disturbance patterns of native pests and diseases. Therefore, the health and survival of trees may be impacted by pathogen's ability to exploit the changing climate. Forest diseases can be either fungal or bacterial and their manner of spreading appear to change depending on forests area moisture content and temperature (Hartmann et al., 2022). For example, throughout a broad temperature range, diseases such as fungi can endure and continue to spread. Nevertheless, many fungal diseases can only thrive epidemically in environments that are within just a few degrees Celsius.

Climate change pose a growing hazard to forest health. Temperature increases and shifting precipitation patterns cause physiological stress in trees, leaving them more vulnerable to diseases, insects, and invasive species (Yi et al., 2022). Higher temperatures for example, increases the vapor-pressure deficit which leads to more water evaporating from the soils and trees in a forest. The increased evaporation then leads to other stresses like increased drought, tree mortality and low growth. In addition, increased temperatures lead to frequent wildfires happening which affects forest health species (Yi et al., 2022). On the other hand, shifting precipitation patterns lead to prolonged drought which cause air bubbles to develop in transport systems preventing water from reaching the tree leaves hence diminished health. In terms of insects that affect trees in forests, bark battles are said to have caused more disturbance causing tree mortality. The damage to trees caused by insects and pathogens have significant economic repercussions. This is because trees have short generation rates, are physiologically sensitive to climate and have explosive reproductive capacity. Conditions that are warmer, wetter or have more carbon dioxide will cause many pests and diseases to multiply more quickly, spread their ranges and invade new areas (Hartmann et al., 2022).

2.8.3 Altered hydrological cycles

Climate change has an impact on hydrological cycles by changing precipitation patterns, increasing temperatures, and altering both the severity and frequency of severe weather events (Dai et al., 2018). As temperatures around the globe rise, so do evapotranspiration rates, resulting in drier conditions and lower water content in the soil in some locations (Douville et al., 2021). These changes have the potential to cause extended droughts, putting forest ecosystems that rely on continuous water availability at risk. Furthermore, climate change can influence the time and pattern of precipitation. In some regions, rain events can intensify, resulting in more runoff with decreased infiltration, reducing the recharge of groundwater (Allan et al., 2020). Reduce recharge of groundwater means lack of enough for tree growth. On the other hand, land use and land cover changes alter hydrological cycles. For example, deforestation affects tree absorption and evapotranspiration, increasing surface runoff and reducing groundwater recharge (Ellison, 2018). This change can create alterations in stream flow patterns, raising the danger of both floods and droughts. Therefore, altered hydrological cycles have far-reaching consequences for forest health and productivity. Water stress can cause decreased tree growth, increased susceptibility to insects and diseases, and higher rates of death (Aguirre-Gutiérrez et al., 2022; Ellison, 2018).

2.8.4 Biodiversity loss

Climate change alters temperature and precipitation trends, potentially shifting species' geographical distributions (Hisano et al., 2018; Shivanna, 2022). Several species are used to certain environmental conditions, and even slight modifications can make habitats uninhabitable. For example, species sensitive to temperature can be driven to move to colder places in pursuit of more favorable conditions. Nevertheless, not all species can migrate at the required rate or locate suitable habitats, resulting in their decreases and extinctions (Nic Lughadha et al., 2020). At the same time, land use and land cover changes including urbanization, deforestation, and agricultural expansion divide forests and limit the availability of habitat (Foley et al. 2005). Fragmentation of habitat separates populations, limiting the transfer of genes thus rendering it hard for species to adjust to shifting conditions. This fragmentation can also result in the edge effect, in which changed circumstances at the forest's edge generate unfavorable settings for several species, which further reduce biodiversity (Bodo et al., 2021). Additionally, climate change and land use and land cover changes can work together to accelerate biodiversity loss.

2.9 Impacts of land use and land cover changes on forest ecosystems

Land use and cover changes (LULC) such as deforestation, agricultural expansion, urbanization, and infrastructure development transform and split forest landscapes. These changes impact forest environments leading to deforestation, disruption of ecosystem services and habitat loss and fragmentation. These effects frequently caused by human activities have the potential of impacting both the health and functionality of forests affecting a range of ecosystem services they provide like climate regulation. Understanding these implications is critical for creating effective conservation and management strategies to preserve forest ecosystem resilience in the face of global problems.

2.9.1 Deforestation

One of the most widespread and damaging effects of land use and land cover changes is deforestation especially in developing countries where the forest ecosystems are progressively used for farming, infrastructure development , settlements and above all extraction of resources (Amoakwah et al., 2022). Deforestation entails the permanent loss of forest area which has detrimental environmental and ecological effects and reduces the area under forest area (FAO, 2020). Population increase, poverty, settlements, agricultural expansion and construction of infrastructure all contribute to increased deforestation in tropical and subtropical regions especially in highland forests of Africa. As a result of this process, species that depend on forests as a home lose their habitats, therefore reducing biodiversity. Additionally, it degrades the soil interfering with nitrogen cycling and the general soil structure (Amoakwah et al., 2022). Because of deforestation there is reduced canopy cover making the soils vulnerable to erosion thus causing water sources to become sedimented. When water sources are sedimented, they affect water supply and even hydroelectric power generation. Another effect of deforestation is that it alters the carbon balance. Forests area known to be major carbon sinks and their destruction means the release of carbon dioxide back in to the atmosphere increasing the global climate change. Deforestation accounts for around 10% of global greenhouse gas emissions according to IPCC (2021). In Kenya for example reduced water supply, more flooding and altered rainfall patterns have all been linked to the destruction of the Mau and Cherangany forest ecosystems which are among the main water towers.

Numerous studies using remote sensing and GIS have shown that LULC alterations have resulted in significant forest loss especially in Africa. For instance, the patterns and drivers of forest cover change in Cherangany hills forest environments of western Kenya, were investigated by Rotich and Ojwang (2021). The study which analyzed satellite imagery specifically the Landsat images from 1990 to 2018 using remote sensing and GIS, discovered a decrease in the 28 year period. They identified several factors leading to this change which included agricultural expansion, population growth, expansion of settlements and charcoal burning which are all connected to changes in land use and land cover. From the study, the strain on land resources due to population increase has resulted in the conversion of forest environments in to residential plots and crop lands. Moreover, illegal logging and encroachment were mainly due to weak forest enforcement laws. These land use practices led to various effects on the forest ecosystems such as biodiversity loss, disruption of ecosystem services and forest being fragmented.

2.9.2 Disruption of ecosystem services

Numerous ecosystem services that forest offers are important for both human well-being and environmental sustainability. They consist of provisioning services (medicinal plants, wood fuel, and food), supporting services (nutrient cycling), regulating services (climate regulation, carbon sequestration) and cultural services (such as recreation) (Balvanera et al., 2017). These services are disrupted by changes in land use and land cover, especially when forested areas are turned in to crop land and settlements due to population growth. For example, when a forest is cleared its ability to control climate and water flows is greatly hindered with, thus resulting in frequent floods or droughts and low ground water recharge. In addition, due to the damage on the roots that hold the soil together, sol erosion becomes more common especially in steep terrains. Changes in land use and land cover also affect the ability of the forest to perform its supporting services such as nutrient cycling. This happens when forests are cleared for agriculture or settlements leading to removal of important nutrients such as phosphorus, nitrogen and carbon usually stored in leaves, stems and roots (Fang et al., 2022). This leads to loss of important organic matter and increased soil erosion. Furthermore, the regulatory functions like air purification and water regulation are jeopardized. Decrease in canopy cover lead to extreme local climate conditions by reducing absorption of pollutants and regulation of climate. All these result socioeconomic repercussions particularly for the local communities who depend on the forest resources to sustain their livelihoods (Fang et al., 2022).

2.9.3 Habitat loss and fragmentation

Land conversion from forested to non-forested uses results in habitat loss whereas fragmentation happens when large, intact forest areas are divided into smaller patches usually by roads, dams, railways, and farms thus decreasing the total area of habitat available for wildlife and therefore changes the structure and function of ecosystems (Scanes, 2018). There are several ecological repercussions of habitat fragmentation. The first one is that it separates population of species which results in inbreeding and local extinctions by making it harder for them to migrate and find mates. Another repercussion of fragmentation is that it increases edge effects which include variations in temperature, humidity light penetrations at the margins of forest. These changes therefore increase the susceptibility of these areas to disturbances such as pests and diseases, fires and even encroachment. Mostly loss of endangered species and change in their composition result from the shrinking interior forest areas that are important for the survival of specific species when the forest is fragmented (Sharma et al., 2019). Some of the common drivers that have caused forest fragmentation throughout Africa and particularly Kenya include agricultural expansion, illegal logging, infrastructure development and settlements. Apart from endangering the elephants, forest fragmentation threatens species that rely on intact forest environments such as the African crowned eagle and tree hyrax (Zhyvko, 2024). This therefore, decreases ecological connectedness between forest areas and jeopardizes ecosystem services like pollination. Additionally, as wildlife moves in to agricultural regions, habitat fragmentation increases the likelihood of human-wildlife conflict, which then lowers biodiversity by causing crop devastation. Also, because of diminished size and even changed structure, fragmented forests are less able to withstand the effects of climate change and other stressors (Zhyvko, 2024).

2.10 Policy, legal and institutional framework of forest conservation in Kenya

The conservation and sustainable management of forest ecosystems, like Kipkunurr Forest in Elgeyo Marakwet County, necessitate a strong legislative and institutional framework. This framework guarantees that policies and activities are in place to reduce the effects of land use and land cover changes, as well as climate change, on forest health. In Kenya, numerous essential legal instruments and policies establish the standards and enforcement mechanisms required for sustainable forest management and climate change mitigation.

2.10.1 Kenya vision 2030

Kenya Vision 2030 is Kenya's long-term development roadmap, to change the country into a newly becoming industrialized, middle-income country with a good standard of living for all of its residents by 2030 (Kenya Vision 2030). Environmental management is a vital component of this vision. Vision 2030 stresses the responsible utilization of natural resources, particularly forests, to promote economic growth and enhance livelihoods. It intends to enhance forest cover to at least 10% of Kenya's land area, which is directly in line with Kipkunurr Forest conservation initiatives (Kenya Vision 2030). The goal of increasing forest cover to at least 10% of Kenya's land area aligns with the Social Pillar of Kenya Vision 2030, which aims to ensure environmental sustainability. Additionally, the vision encourages the use of effective methods in forest management practices, reforestation, and afforestation, which are all essential for mitigating the impacts of land use and land cover changes, as well as climate change on forest health.

2.10.2 National tree growing and restoration Campaign (15 Billion trees by 2032)

The Kenyan government started the National tree growing and restoration campaign in 2022 with the goal of planting 15 billion trees by 2032 in an attempt to combat the growing impacts of climate change, deforestation and environmental degradation (Ministry of Environment, Climate Change and Forestry, 2022). By 2032, this effort hopes to raise the country's tree cover from about 8.3% to at least 30%. This campaign supports Kenya's adherence and commitment to national framework including Kenya Vision 2030 and the

Climate Change Act (2016), as well as international environmental accords like the Paris Agreement. The programs main objectives include better watershed management, biodiversity conservation, increased carbon sequestration and ecosystem restoration. Some of its implementation techniques include community mobilization, incorporating tree growing into county development plans, using climate-resilient and native tree species and using digitals tools like the Jaza Miti app to track planting efforts and tree survival rates (Kameri-Mbote et al., 2021). In contrast with traditional tree planting initiatives, the focus of this campaign is on tree growth in order to guarantee ecological functionality and long-term survival. It is anticipated that the project will make a substantial contribution to the restoration of degraded forest landscapes, particularly important water towers like Mau Forest and other highland forests.

2.10.3 Water towers policy

According to the Water Towers Policy of Kenya, forests are important water catchment areas that need to be taken care of ecologically and in terms of national water security (Odawa & Seo, 2019). In such water towers, rainfall is captured and stored in forests in a gradual process that maintain ground and surface water sources. The policy emphasizes sustainable management, conservation and restoration of forest ecosystem, such as the Kipkunurr forest. The policy is also embracent of afforestation and restoration policies, aiming at reclaiming the degraded lands and optimizing the intended forest cover improvement (Odawa & Seo, 2019). Community engagement is also a crucial component of this strategy, since it acknowledges that engaging local communities in protecting the forests to develop a sense of ownership, thus improving the longevity of the conservation.

Also, the plan considers such aspects of the population and land cover dynamics since they may affect the effectiveness of water towers (Odawa & Seo, 2019). For instance, the changes in the land use and climate impact the water production in situations when the East African water towers are forested (Wamucii et al., 2020). Thus, the policy aimed at reducing the impacts and ensure the sustained delivery of ecosystem services by implementing sustainable land management practices and methods into reality.

2.10.4 Agenda 21

In 1992, at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, a general global action plan known as Agenda 21 was adopted. To ensure responsible management of natural resources, particularly forests, it provides a framework for sustainable development that integrates social, economic, and environmental aspects. The plan emphasizes the need to incorporate environmental protection as part of the local, regional, and national development plans (UNCED, 1992). Since forests play a critical role in the conservation of biodiversity, climate regulation, and sustaining livelihoods, the sustainable management of forests forms one of the core elements of Agenda 21 (Chapter 11). To curb deforestation and degradation of forests, it plan promotes reforestation, afforestation, agroforestry, and participatory forest management (United Nations, 1992). These approaches aid the conservation activities in Kipkunurr Forest, where the two vital requirements needed to keep the forest healthy and thriving in its services are climate adaptation measures, and sustainable land management activities. Furthermore, in an attempt to emphasize the need to incorporate a coordinated global effort in protecting forests and climate resilience, Agenda 21 echoes with initiatives of international environmental treaties like Sustainable Development Goals (SDGs) and The Convention on Biological Diversity (CBD) (Sitarz, 1993). Kenya has been undertaking the implementation of Agenda 21, which has impacted on environmental governance, the plan concerning climate adaptation strategies and the policy choices to manage the natural resources. Such decisions have helped in conservation of forests like Kipkunurr.

2.10.5 Sustainable Development Goals (SDGs)

One of the 2030 Agenda, adopted in 2015 are the Sustainable Development Goals (SDGs), which provide a global framework on how to shift the world to resolving social, economic, and environmental challenges. The United Nations (2015), described that forest conservation, including the conservation of Kipkunurr Forest, supports several SDGs, one of which is to conserve the biodiversity, fighting climate change, sustaining the provision of water, and making land use sustainable. One of the forest's role is they help with a reduction of greenhouse gas emissions, and therefore, is mentioned in SDG 13 (Climate Action) (IPCC, 2019). Climate Change Act (2016) based on Kenya, entails strategies on climate change adaptation and climate change mitigation in Kipkunurr Forest, one of the forests that constitute Cherangani Hills Water Tower.

SDG 15 (Life on Land) is important in determining the role of forests with the view to maintaining biodiversity, desertification control, and restoration of the damaged or degraded ecosystems. Kipkunurr Forest contributes to preserving wildlife and ecological balance as per the Forest Conservation and Management Act (2016) and the Water Towers Policy that encourage afforestation, reforestation, and sustainable management of the forests in Kenya (Ministry of Environment and Forestry, 2018). Moreover, (SDG 6), Clean Water and Sanitation explains that there exists a strong connection between water security and forests ecosystems, considering that forests such as Kipkunurr play a great role in ensuring clean and available water sources.

Kipkunurr Forest is an important water catchment area of Chebara Dam, which supplies water to Eldoret, Kapsowar, and the surrounding regions. Its conservation highlights the recognition of forests as significant elements of national water security, reflected in policies formulated towards its conservation. Moreover, SDG 12 (Responsible Consumption and Production) supports the responsible utilization of forest resources in line with Kenya's vision 2030, which is committed to agroforestry and conservation-based economic activities. Soil erosion and water pollution are all consequences of forest degradation, and they have a potential to impact on SDG 14 (Life Below Water) as it increase the sediments in rivers and dams. Kenya Environmental Management and Coordination Act (EMCA, 1999) provides a legislative basis for mitigating such environmental impacts by the integrated management of land and water resources.

Socioeconomic development is closely linked to environmental sustainability through forest conservation. Another way in which the forests promote local livelihood is by provision of non-timber forest products, such as honey, fruits, and medicinal plants, as stated in SDG 1 (No Poverty) and SDG 2 (Zero Hunger). Since the introduction of sustainable forest management, communities reliant on forests have been empowered, hence higher level of food security and economic resilience (FAO, 2020). Moreover, to enhance air quality, reduce urban heat levels and climate resilience in rapidly growing cities, SDG 11 (Sustainable Cities and Communities) promotes the protection of green areas and forests to improve the quality of air and reduce urban heat (UN-Habitat, 2019). Furthermore, SDG 17 (Partnerships for the Goals) underpins the importance of multi-stakeholder collaboration in achieving conservation goals. The compliance to global agreements like Agenda 21 and Convention on Biological Diversity (CBD), shows Kenya's commitment to protect its forest ecosystems.

2.10.6 The Constitution of Kenya 2010

Environmental protection and sustainable development is given a legal foundation in the Kenya Constitution (2010), and should be understood in the same context of Kipkunurr Forest. Constitutional Article 42 establishes the right of every individual to a clean and healthy environment, including the right of everybody to protect the environment on behalf of the present and the future generations with the help of legislation and other required measures (RoK, 2010). This constitutional provision favors the implementation of sustainable management practices, which are crucial in forest and biodiversity health maintenance. Also, Article 69 describes the mandate of the State concerning environmental issues, one of them being the promotion of sustainable receipt, use, management and conservation of natural resources (RoK, 2010). It also demands the state to promote its public to play a role in environmental governance, which is fundamental in ensuring that the locals join in efforts to preserve Kipkunurr Forest. Also, under Article 69 (1) (b) the state is mandated to strive to achieve, maintain and promote reforestation and afforestation measures that will contribute to the ecological balance of forest resource lands like Kipkunurr to at least 10 percent tree cover of the land volume of Kenya.

2.10.7 Forest Conservation and Management Act 2016

Through the Forest Conservation and Management Act of 2016, Kenya as a detailed legal framework for the safeguarding and sustainable use of its forest resources. According to the Act, the Kenya Forest Service (KFS) is made the overall body responsible for the management of forests (FCMA, 2016).

It necessitates the adoption of management strategies for all the publicly owned forests, where the local people, and the stakeholders are involved. Such participatory nature is essential for the successful conservation of Kipkunurr Forest. It calls for the formulation and implementation of policies to manage all the protected forests, ensuring active engagement of both locals and stakeholders. Effective protection of Kipkunurr forest is necessary through such an approach. The act also emphasizes the importance of forests ecosystems, restoration, afforestation, and combating deforestation. Such provisions correlates with the objectives of this research, as they define sustainable land use and forest management as a legal framework of forest health preservation and minimizing the effects of land use alterations and climate change (FCMA, 2016). Sections 48 and 49 of this Forest Conservation and Management Act 2016, further underlie the Plantation Establishment and Livelihood Improvement Scheme (PELIS), which is a government project to restore the lost forests as well as improve the living standards of the locals in surrounding areas (FCMA, 2016). In this PELIS program, communities residing around the forest are given pieces of land in the forest, particularly in degraded land to cultivate their different farm products. As they cultivate these crops, they also nurture tree seedlings until they grow to maturity. They grow the crops between the lines of trees and once the trees become big enough, they stop cultivating. The program is useful in restoring the forest as well as improving livelihoods. The local people also play a role in management of forests by participating through associations referred to as Community Forest Associations (CFAs) (Mwaura et al., 2024). The CFAs, constituted under the Legal Notice 165 of 2009 is a community-based organization to which communities agree with Kenya Forest Service with an objective of ensuring that the forests are conserved and protected (Mwaura et al., 2024).

2.10.8 Climate Change Act 2016

The Act of 2016, Climate Change Act, is the legislation laying down legal instruments to reinforce the fight against climate change in Kenya. The act is in compliance with international agreements that Kenya is signatory to like the Paris Agreement. It establishes the National Climate Change Council that coordinates and plans the action and policy implementation in the area of climate change (Wambua, 2019). This may be applicable to Kipkunurr forest because it will help curb and adjust to the effects of climate change. The Act requires planning of development processes to take into consideration the issue of climate change and promotes the practice of sustainable land use activities, which are significant in conservation of forests (Wambua, 2019). It also emphasizes the need of afforestation, re-forestation and forest maintenance with the view of conserving carbon pools in forests. The provisions are linked to the aims of the study, especially in tracking and promoting a healthy state of forests in the climate change era.

2.10.9 Wildlife Conservation and Management Act 2013

The Act is geared to protect, conserve, and manage sustainably the species, and their habitats, including forests. The Act centres on the conservation and sustainable management of forests, which are essential ecosystems that harbor significant diversity of wildlife (Krausman & Cain, 2022). Among its main provisions, is the creation of Kenya Wildlife Service (KWS) a government department tasked with achieving the management and regulation of national parks, reserves and sanctuaries as part of wildlife resources in Kenya.The Act also encourages community involvement in conservation processes through their empowerment to manage the natural resources in a sustainable way, as well as instilling feelings of ownership and care regarding forests and creatures (Krausman & Cain, 2022). Moreover, by adopting policies that prohibit destruction of habitats and cutting of trees, the Act emphasizes on the need to preserve habitats as well as the survival of wild animals in their various forms. It also propagates the sustainable exploitation of wildlife resources through regulating the actions of ecotourism, research, and wildlife marketing, to make sure that it benefits the conservation cause (Krausman & Cain, 2022). The Act promotes biodiversity conservation and protection of the ecosystems by ensuring that forest conservation is included in the management of wildlife. Water catchment areas, which are forests like Kipkunurr and the wild animal habitat have the legislative protection under the Act.

2.10.10 Environmental Management and Coordination Act (EMCA) 1999

In Kenya, as in many other countries, the known environmental management law is the Environmental Management and Coordination Act (EMCA, 1999), which gives a framework for environmental conservation and sustainable development (Muigua, 2023). The Act was later amended by the Environment Management and Coordination (Amendment) Act No. 5 of 2015 to reflect the Constitution of Kenya 2010, promote decentralization through county environmental committees, and strengthening enforcement measures. The Act ensures that environmental considerations are incorporated in the national and local decision-making processes by developing standards for prevention of pollution, protection of the environment, and the management of natural resources (Muigua, 2023). One of its fundamental concepts is the fact that projects have the potential of causing a significant impact on the environment, particularly those endangering forests such as Kipkunurr, are supposed to be subjected to Environmental Impact Assessments (EIA) and Environmental Audits (EA) (RoK, 1999). Another institution created under EMCA is the National Environment Management Authority (NEMA), which oversees implementation of environmental policies and enforces the environmental laws. Under the Act, the environmentally sensitive areas such as forest, wetlands, and water catchments must be preserved since they are crucial in biodiversity conservation, and climate regulation (Muigua, 2023).

2.11 Empirical studies in the study area

Several studies have been carried out within the broader Cherangani Hills ecosystem, with a few focusing specifically on or including Kipkunurr Forest. For example, Rotich et al. (2021) conducted a land cover change assessment in parts of the western Cherangani Water Tower and found significant forest loss due to human activities such as farming and logging. While this study provides useful insights into general trends in forest degradation, its geographic focus was not directly on Kipkunurr Forest, which is located in the eastern section of the Cherangani Hills.

More directly, Misoi et al. (2019) conducted a study titled 'Benefits flow and utilization of Kipkunurr forest products by Upstream and Downstream Users,' which examined how communities living in Elgeyo Marakwet County depend on Kipkunurr forest for various products such as firewood, medicinal plants, timber, and water. The analysis shows that there is a significant socio-economic dependence on the forest by upstream and downstream population groups, with unsustainable harvesting practices and rising demand posing major threats to conservation.

The study by Rotich et al. (2022) on the impacts of the LULC changes on ecosystem service value in Cherangani Hills water tower and zones adjacent to Kipkunurr forest, highlights the pressure on natural resources due to land cover conversion overtime. Despite it being carried out specifically on Kipkunurr, the study underscores the need for conservation measures as a result of increasing land use and land cover transformation.

Although these research studies provided useful information on human-forest relationships and land use trends, there is a gap due to the lack of an empirical study that determines the direct effect of LULC changes and climatic variations on forest health within Kipkunurr Forest.

2.12 Research gaps

As indicated in the reviewed literature and empirical studies carried out in and around the Cherangani Hills, some studies have focused on aspects like community reliance on forest resources (Misoi et al., 2019) and the effects of land use change on ecosystem services (Rotich et al., 2022). However, there remains a need to have research work that specifically incorporates spatial-temporal data to analyze forest cover, forest health, and conservation outcomes in Kipkunurr Forest.

Most studies have mainly focused either on socio-economic factors or the general changes of land cover of the entire Cherangani ecosystem, with greater emphasis on the western forest blocks. In contrast, little research has been conducted in Kipkunurr Forest in the eastern part. Moreover, most existing studies rarely combine climate trends and LULC change analysis to comprehend the effect they collectively have on forest cover and the state of health of forests.

The study seeks to fill this knowledge gap by undertaking a spatio-temporal analysis of the changes of Kipkunurr Forest using geospatial technologies (e.g., NDVI, GIS) and long-term climate data to determine the changing status of Kipkunurr Forest between 1994 and 2024. It also contributes by evaluating the interrelationship between climate variability, land use changes, and forest health, and integrated approach that is currently underexplored in the existing body of research on this critical part of the Cherangani Water Tower.

2.13 Theoretical framework

An accurate understanding of well-established theoretical frameworks aids in determining the causes of forest degradation and their impact on forest cover and health. The two theories that provide insights into the complex nature of things happening in forest ecosystems include, Land Use Transition Theory and Socio-Ecological Resilience Theory.

2.13.1 Land use transition theory

Land use transition theory was proposed by Eric F. Lambin and Patrick Meyfroidt in 2010 to explain landscape changes happening in phases as a result of environmental and socio-economic factors.

Land Use Transition Theory describes how landscapes undergo transitions over the years caused by factors such as natural influences, population pressures, and socio-economic changes. Land use changes occur in phases, such as forest to cropland or even agricultural land to settlements, and possibly revert to forest as a result of conservation initiatives (Lambin & Meyfroidt, 2010). According to this theory, the occurrence of changes in land use do not occur randomly but are a result of land management methods, population increase, and patterns of development.

The theory is relevant to this study as it provides an angle through which to understand how human activities such as farming, growth of settlements, and infrastructure growth are influencing Kipkunurr forest's cover and health. The reliance of local inhabitants on forest resources for grazing land and firewood puts pressure on the area, leading to continuous landscape change, including the degradation of dense forests and increased land fragmentation.

The Land Use Transition Theory aligns with the first objective of the study, which assessed the spatiotemporal changes in land use and land cover between 1995 and 2024. Furthermore, objective 4, which seeked to establish the relationship of climate change, land use/land cover changes, and forest health is supported by this theory. Hence, this theory guides this study since it enables the changes in Kipkunurr forest over time and impacts on forest management and conservation to be assessed.

2.13.2 Socio-ecological resilience theory

According to the Socio-Ecological Resilience Theory, human systems and ecosystems are interrelated, and their ability to survive is determined by their capacity to adjust to shocks like land degradation or climate change (Bronfenbrenner,1979). In this sense, resilience refers to the forests' and the local inhabitants' ability to adapt to changes whether brought on by population pressure, temperature fluctuations, or unpredictable rainfall while preserving vital ecosystem services.

Since the forest environment does not exist in a vacuum, Kipkunurr Forest is subject to change. A broader social-ecological system encompasses the surrounding communities that rely on the forest for their livelihoods. Forest health is also impacted by local climate variability, such as extended dry spells or altered rainfall patterns. The system may deteriorate or fail if these stresses are greater than the forest's ability to respond.

The second objective, which utilizes NDVI to assess forest health, and Objective three, which examines trends in temperature and precipitation, are both supported by socio-ecological resilience theory. By using this approach, the study acknowledges how crucial it is to preserve community resilience as well as ecological integrity in order to guarantee Kipkunurr Forest's long-term conservation.

2.14 Conceptual framework

Research studies require conceptual frameworks to demonstrate variable relationships and explain why specific investigations should be performed. The framework serves crucial purposes because it provides a structured format to understand research context alongside its significance (Varpio et al., 2020). The conceptual framework as shown in **Figur**e **2.4** demonstrates how climate change and land use/land cover (LULC) modifications affect forest cover and health, which in turn shapes sustainable forest conservation and management effectiveness. Temperature increase and changing rainfall patterns as the climate change factors function together with human activities such as agricultural expansion, illegal logging, illegal grazing, charcoal burning, resource extraction and deforestation as primary drivers of LULC changes as the independent variables. All these independent variables directly impact forest health by changing how the ecosystem functions and generally its structure. Conservation policies and management practices, community engagement, planning initiatives, boundary demarcation, and alternative sources of energy act as intermediate factors between forest health and cover and its relationship with climate change and LULC changes. These mediating variables can either lessen or exacerbate the effects of climate factors and LULC changes on the dependent variables, forest cover, and health. Eventually, the current condition of forests shapes future approaches to management and sustainability achievements. This framework guides the analysis of forest degradation and conservation, providing a structured approach to evaluate the complex interplay between environmental and human factors in forest ecosystems.

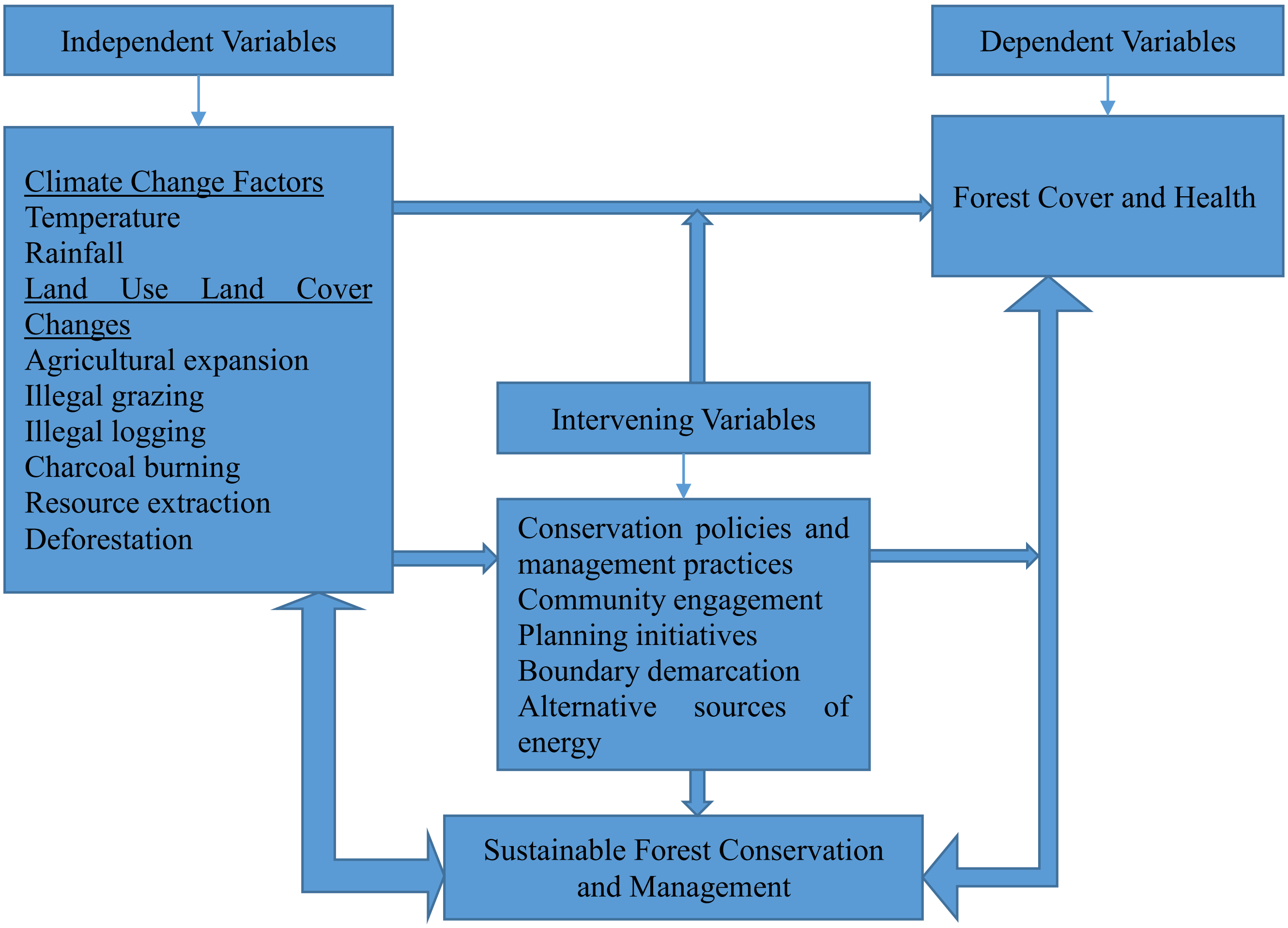

Figure 2.4 Conceptual Framework

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter describes the research methods used for the assessment of the impacts of climate change and land use/land cover changes on Kipkunurr forest and its surroundings in Elgeyo Marakwet County, Kenya**.** The chapter describes the study area, biophysical characteristics, population dynamics, research design, sampling procedures, data collection techniques, data collection tools, and data analysis methods.

3.2 Study area

3.2.1 Location

Kipkunurr Forest exists as a subtropical moist forest located within the Kenyan region of Elgeyo Marakwet County as depicted in **Fig. 3.1**. It is part of the Cherangani Hills which forms one of the five water towers in Kenya. It is bordered by the Cherangany Hills to the East, Trans Nzoia County to the West, and West Pokot County to the North. The forest spans approximately 1,250 square kilometers and extends between Latitude 1° 15' to 1° 45' North as well as Longitude 35° 15' to 35° 35' East according to KFS (2015). The altitude of this area ranges between 1,500 meters and 3,350 meters above sea level. On May 10th 1962, Kipkunurr forest became a protected area under Proclamation Order No. 15 according to official notice (KNCHR Report, 2018).

A 5-kilometer radius around Kipkunurr forest was included in this study to represent its surroundings. This buffer zone was selected based on evidence from previous studies, which have shown that land use spillover effects influencing forest dynamics usually occur within this distance (Xia et al., 2023). For instance, Osano (2021) discovered that activities including agricultural expansion, firewood harvesting, and livestock grazing significantly lead to degradation of forest within 5 kilometers radius of the forest edge in Kenya's Mau forest.

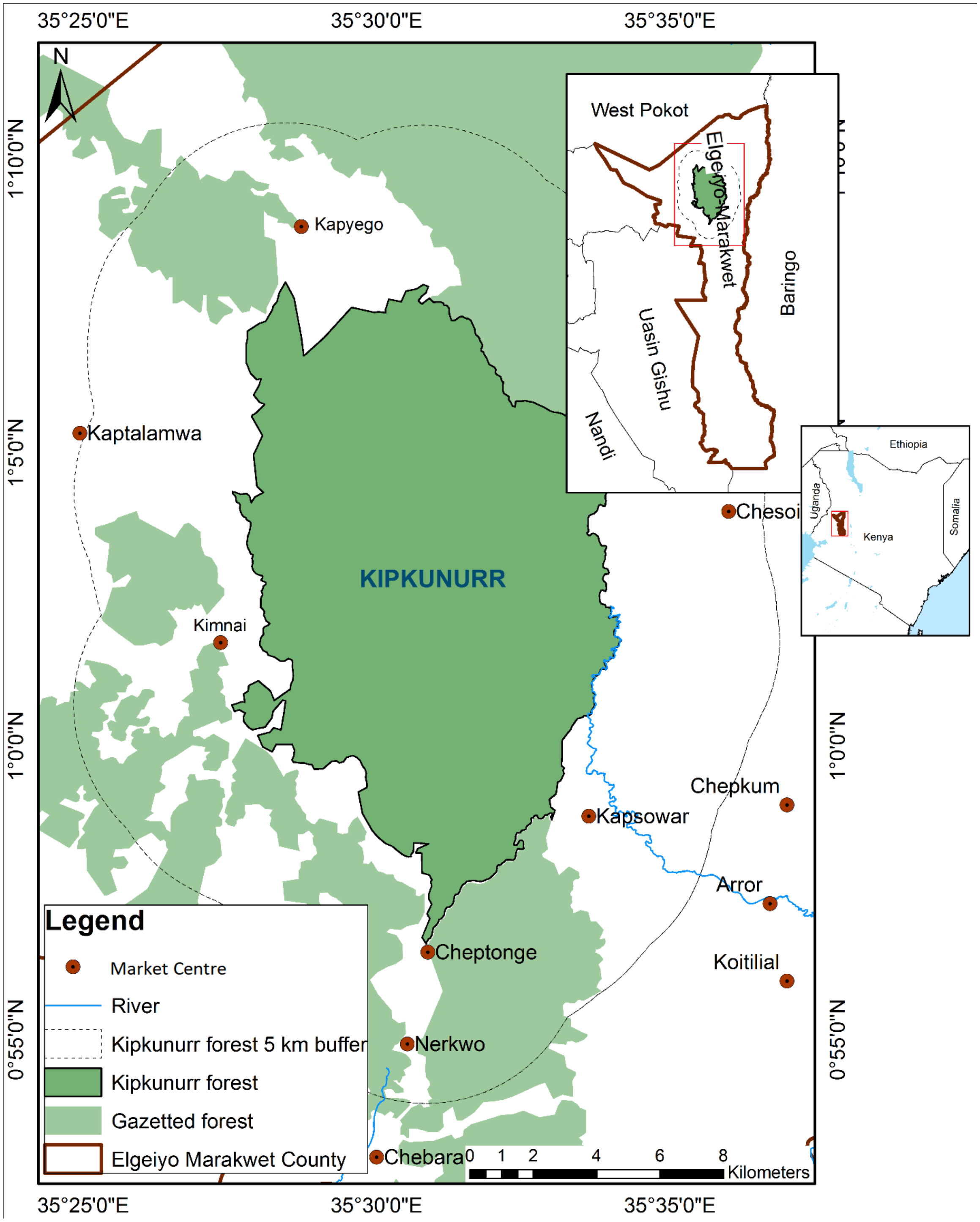

Figure 3.1: Location of the Study Area

3.2.2 Climate

Kipkunurr forest's climate is classified as montane (wet and humid) and the area receives rainfall, usually between 1,200mm and 1,500 mm annually. There are two rainy seasons in the area that follow different patterns, long rains from March to May and short rains from October to December. In addition, the forest's temperatures are moderate because it exists at high altitude between 10°C and 20°C (Kenya Meteorological Department, 2020). The high humidity levels throughout the area is also because of the combination of dense vegetation and frequent cloud cover in the region.

3.2.3 Drainage patterns

Kipkunurr forest is the source of Moiben and Chepkaitit rivers which drain to Lake Victoria through Nzoia River and finally to the river Nile.It is also a source of Chebara dam which supplies water in the region and to other regions such as Eldoret and its environs. Therefore, as an essential water catchment, the forest regulates water movement and maintains the hydrological balance to ensure a consistent water availability and supply all year long. Additionally, the forest contains numerous little ponds and natural springs which both provide essential water resources for wildlife preservation and stable water access to nearby settlements. The modification of drainage patterns indicates forest degradation together with the environmental effects it produces (Rotich, 2019).

3.2.4 Geology and topography

The forest is underlain by volcanic rocks, primarily basalt and andesite, which have weathered to form fertile soils (Murkomen, 2019). The proximity to the Great Rift Valley shapes the geological features which produce diverse soil patterns as well as topographical variations (Rotich, 2019). Kipkunurr Forest exists at the Cherangany Hills slopes where it showcases a heavily rocky terrain. This geographical area presents steep slopes from approximately 2,000 meters to about 3,300 meters above sea level.

3.2.5 Soils

Kipkunurr forest contains fertile soil which derives its rich nutrients from volcanic parent rock. The geographic regions of the forest influence soil texture variation between sandy loam and clay loam classifications (Misoi et al., 2019). The environmental conditions of the soils maintain healthy tree growth along with various plant species found in the region. Such soils eradicate the issue of flooding caused by soil erosion.

3.2.6 Vegetation

The forest is characterized by both hardwood and softwood species that enable multiple wildlife species to inhabit the area. East African Yellow Wood *(Podocarpus gracilior*) together with Pencil Cedar *(Juniperus procera*), Olea europaea, Rosewood *(Hygienia abyssinica)* along with Australian Blackwood *(Acacia melanoxilum*) form the tree species base in the forest. Additionally, under the forest canopy various types of ferns and herbs and shrubs can be found along with other vegetation (Rotich, 2019).

3.2.7 Socio-economic activities

Local communities inhabiting the surrounding Kipkunurr forest, depend on the diverse social and economic activities focused on the forest to keep up their lifestyle. Agriculture is the most common activity in this region, as the fertile soils allow the community members to plant crops such as maize, beans, and potatoes, among others. Livestock farming is another economic practice that is common, with the most kept livestock being sheep, goats, and cattle. The forest is the place where local people can find vital resources like firewood, medicinal plants, water, and wild fruits (Misoi et al., 2019).

Tourism is another great economic activity that exists due to the wide biodiversity of the land, the occurrence of unique wildlife species, and other beauties of the forest. In addition, bird watching and hiking, which are attractions of tourists contributes to economic growth. In the forests, beekeepers get a household income source through honey production.

The forest is also an important water catchment area, guaranteeing a steady supply of water to the residents for domestic use as well as farming activities. This water source is vital for sustainable agriculture and livestock production. Generally, Kipkunurr forest plays a crucial role in the socio-economic wellbeing through the provision of resources and income-generating activities of the communities surrounding it, improving their living standards (Misoi et al., 2019).

3.3 Research Design

Descriptive research design was used in this study to analyze and present the spatial and temporal dynamics of land use and land cover, trends of forest health, and climate variability in Kipkunurr forest and its surroundings. The design enables the detailed recording of any current and historical changes without variable manipulation (Archer, 2023). One core reason for integrating both quantitative (e.g, satellite image analysis, climate data trends) and qualitative (e.g, questionnaires with local stakeholders and the Key Informant interviews) methods is that neither approach alone may be sufficient to fully capture the complexity and patterns of the subject of research. The combination of both methods strengthens the analysis, as each method fills the gaps of the other offering more comprehensive findings. The two methods complement each other, and hence strengthen the analysis, as each method fills the gaps left by the other and enhances the overall findings (Fàbregues et al., 2023).

3.4 Buffer zone creation process

The 5-kilometer buffer zone was created in ArcGIS software version 10.8. The Kipkunurr Forest boundary shapefile served as the base layer. Using the Buffer tool in the Analysis → Proximity menu, a zone extending 5 kilometers outward from the forest edge was generated.

Next, to identify which administrative areas fell within this zone, the buffer was overlaid with ward boundary shapefiles. The Intersect tool in Analysis → Overlay was then used to extract only the wards and sub-locations located inside the buffer area.

3.5 Study population

The study population involved residents of five wards in Marakwet East and West sub-counties, which border the Kipkunurr forest area. The five wards and their populations were Kapyego (20,650), Sambirir (7,163), Arror (5,811), Kapsowar (28,402), and Moiben/Kuserwo (15,811). Thus, the total number of people in the five wards was 77,837 people.

3.6 Sample size determination

This study used Cochran's formula of 1977 to determine the sample population size. The formula is used for research involving infinite populations in order to determine the appropriate sample size for the required degree of precision. The formula is as follows;

$n_0 = Z^{2} \times p \times (1-P) \div e^{2}$

Where n_0 is sample size

Z is the z-value corresponding to the desired confidence level.

p is the estimated proportion of the population with the attribute of interest.

e is the desired level of precision or margin of error.

Z=1.96 at 95% confidence level

p=.50

q=1-.50=.50

e=0.05

Therefore, $n_0 = (1.96)^2 .0.5. (1- 0.5) / (0.05)^2$

$n_0 = 384.16$

3.6.1 Proportional allocation by ward

This research focused on households as the main units of analysis. . Based on the Kenya National Bureau of Statistics (KNBS, 2019) data, the number of households in the five wards is 15,567. The numbers of the households per ward were used and the resultant proportional allocation was employed to give a representative and equal sample distribution to the five wards. In calculating sample size of each ward the formula was:

Sample size per ward = (Households in the ward / Total households in the study area) × Total sample size

Where:

- Total households = 15, 567
- Total sample size = 384

Table 3.1: Proportionate distribution of the sample across five wards

Ward	Population	Household	Proportional sample
Kapyego	20,650	4,130	4,130/15,567×384=102
Sambirir	7,163	1,433	35
Arror	5,811	1,162	29
Kapsowar	28,402	5,680	140
Moiben/Kuserwo	15,811	3,162	78
Total	77,837	15,567	384

3.7 Sampling Procedures

3.7.1 Simple random sampling

Simple random sampling was employed to ensure that every household in the study area had an equal chance of being selected, thereby reducing bias. The total number of households in each ward was first established, after which the required sample size for each ward was determined. Using ArcGIS software version 10.8, random points with known coordinates were generated across the study area, proportionally allocated to each ward's sample size. The assigned coordinates were then used to locate households nearest to those points. From these identified households, one respondent was selected, and a structured questionnaire was administered.

3.7.2 Purposive sampling

Purposive sampling was used to conduct interviews with key informants who possessed information about forest management and conservation alongside its socio-economic factors. Key informants included a forester, forest rangers, and NEMA representative. The forester was representing Kipkunurr forest block and the forest rangers were 3 representing the 3 forest bits in Kipkunurr which are Yemit, Kapsigoria, and Kapsowar.

3.7.3 Map of Sampled Households

The study focused on five wards located within the 5 km buffer zone around the forest, as shown in Fig. 3.2, which also illustrates the proportion of sampled households in each ward.

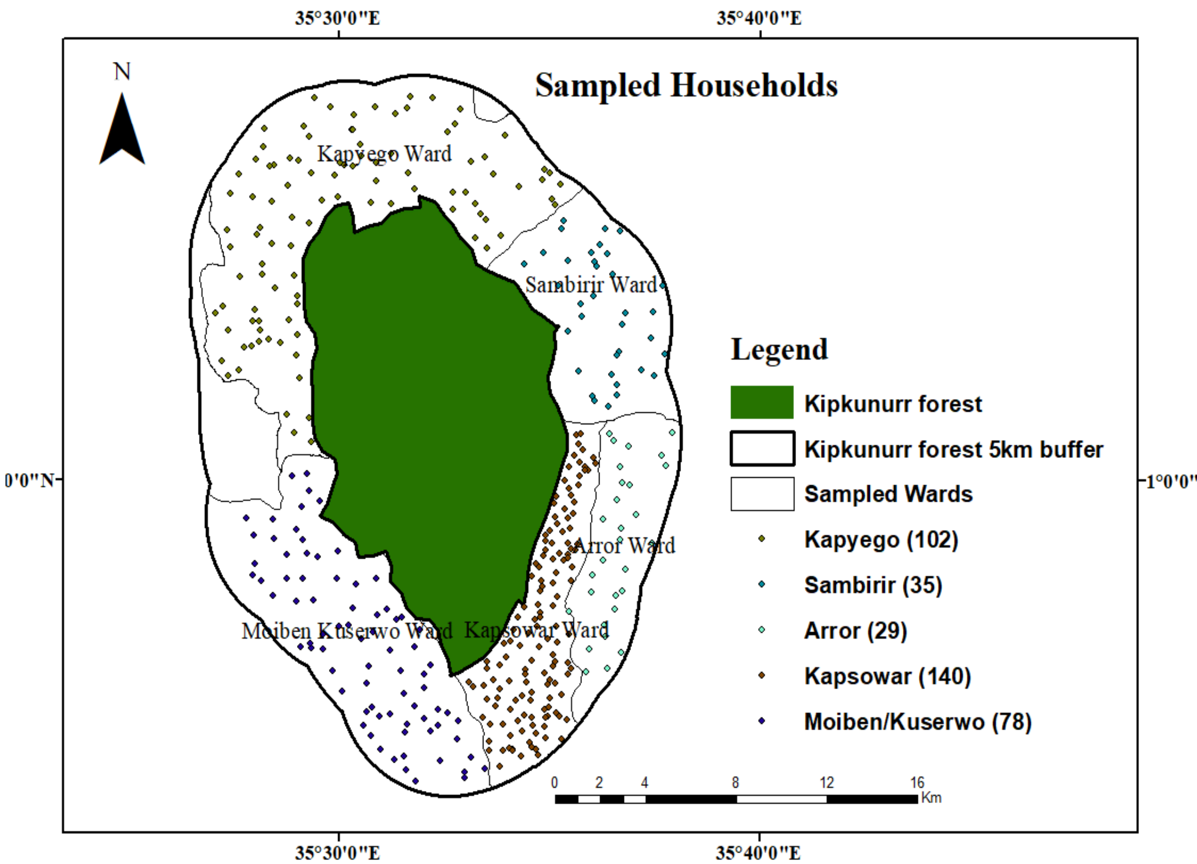

Figure 3.2: Map showing sampled households

3.8 Data collection tools and techniques

This study employed a combination of data collection tools and techniques to provide secure and comprehensive information for all aspects being investigated including land use/land cover changes, forest health, and local community perceptions on the impacts of climate change and land use/land cover changes on Kipkunurr forest and adjacent landscapes. The tools and techniques used are described below:

3.8.1 Remote sensing

Satellite imagery from Landsat for the years 1995, 2004, 2014, and 2024 were obtained to assess the spatiotemporal changes in land use and land cover (LULC) within Kipkunurr Forest and adjacent landscapes.

3.8.2 Field surveys

In-depth field surveys were used for ground truthing in order to verify the land use and land cover classifications obtained from satellite data. During this approach, pre-selected sample locations inside the Kipkunurr Forest and its environs were visited; these locations were chosen based on accessibility and classified satellite imagery. The georeferenced coordinates of the main land cover types such as forest, agriculture, grassland, built-up areas, and bare land were gathered at each location using a handheld GPS device. The gathered data was then utilized to validate the confusion matrix and conduct an accuracy assessment for the land use classification outcomes in the GIS program (ArcGIS 10.8).

3.8.3 Household surveys

Questionnaires were employed to collect quantitative data from the local community in different households. The data gathered included socio-demographic characteristics, perceptions of land use, climate change, and practices related to forest use and conservation. Using this technique, standardized data was collected and statistically examined to identify patterns and relationships.

3.8.4 Key informant interviews

The key informant interviews were used to collect data from stakeholders. Key informants were identified and selected in this study using purposive sampling ; they were the forest rangers, forester, and NEMA representatives.

3.8.5 Secondary data

A review of relevant literature, including scientific papers, government reports, and policy documents related to land use and land cover (LULC) modifications, climate trends, and forest health, was conducted. Specifically, the study reviewed government reports and policy documents from the Kenya Forest Service, Kenya National Bureau of Statistics, and also from departments including Environment, Agriculture, and Water.

3.9 Data collection and analysis

To achieve the objectives of this study, a combination of data collection and analysis techniques was employed. Each method was carefully selected to align with the specific requirements of the research objectives. Data analysis was carried out through systematic steps corresponding to each objective, using various software tools and geospatial techniques. This was done per objective below;

3.9.1 Assessment of spatio-temporal changes in land use and land cover in Kipkunurr forest between 1995 and 2024.

a) Data acquisition

For Objective 1, satellite images of Kipkunurr Forest and its surroundings were obtained for the years 1995, 2004, 2014, and 2024. The images were sourced from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/) and acquired from the Landsat satellite program, specifically Landsat 5 TM for 1995 and 2004, Landsat 7 ETM+ for 2014, and Landsat 8 OLI for 2024. To ensure comparability, the images were selected during the dry season (January–February) when vegetation conditions are more stable, and cloud interference is minimal. A cloud cover threshold of less than 5% was applied to ensure clear visibility of land features. Each image was downloaded at a 30m spatial resolution

Ground truthing was also done in order to verify the remote sensing data. To confirm the observed changes in land use and land cover, field surveys were carried out. The field survey included mapping and recording of different changes in land use/land cover using GPS coordinates.

b) Image pre-processing

The collected satellite images were pre-processed through a number of steps to prepare them for analysis. First, radiometric correction was applied to correct atmospheric interference, sensor-related errors Geometric correction was performed so that all images were registered to the same coordinate system, enabling geographic referencing of the results of spatial analysis to be accurate. Finally, the images were clipped to the boundary of Kipkunurr forest and the five-kilometer buffer zone, focusing the analysis on the study area. These processes were performed in ArcGIS 10.8 version.

c) Land use and land cover classification

In ArcGIS software version 10.8, a supervised classification technique was applied to classify land use and land cover using training data obtained from identified land cover types in Kipkunurr forest and its surroundings. Representative training samples were chosen in terms of land cover category which included cropland, bare land, grassland, shrubland, surface water, forest and built-up areas respectively. The maximum likelihood algorithm was then used to assign each pixel in the satellite images to one of these groups.

The accuracy of the classification findings was evaluated using ground truth data in order to verify their validity. The finished product showed the spatial distribution of different land cover categories and included comprehensive land use and land cover maps for each of the chosen years.

d) Accuracy assessment

An accuracy assessment was done to evaluate the reliability of the classified land use/land cover maps. In ArcGIS 10.8, this involved generating a confusion matrix (error matrix**)** by comparing the classified map outputs with reference data (ground truth points) collected from field observations. Random points were created across the classified image and each point was cross-checked against the actual land cover class on the ground or from reference data. The Kappa coefficient and overall accuracy were computed using the "Accuracy Assessment" tool in ArcGIS to quantify how well the classification matched real-world conditions. Overall accuracy measured the proportion of correctly classified pixels, while the Kappa statistic indicated the agreement between the classification and reference data, adjusting for chance agreement. This step ensured the classification results were statistically valid and could be reliably used for change detection analysis.

e) **Change detection analysis**

To measure and depict the spatiotemporal changes in land use and land cover within Kipkunurr Forest and its surroundings between 1995 and 2024, change detection analysis was used. Using this method, regions with altered land cover were found by comparing categorized images taken in several years. Change matrix analysis and post-classification comparison approaches were used to ascertain the changes. The software used here was ArcGIS version 10.8.

f) Reporting and visualization

To properly convey the findings, reporting and visualization were incorporated into the analysis's last stage. To visually depict changes in land use and land cover over time the findings were presented by creating maps and tables.

3.9.2 Evaluation of the changes in forest health in Kipkunurr forest between 1995 and 2024 using NDVI

a) Data acquisition

In objective 2, the satellite imagery used was the same as the one explained in objective 1. These images had the requisite spectral bands, red (0.63-0.69 µm) and near-infrared (0.76-0.90 µm) used in the calculation of Normalized Difference Vegetation Index (NDVI), a measure of forest health.

b) Image pre-processing

ArcGIS 10.8 was used to pre-process the images downloaded to prepare them for analysis using several steps. Radiometric correction was the first thing that was done to minimize interference from the atmosphere, malfunctioning of the sensors, and to ensure adequate ground conditions are depicted in the images. Furthermore, geometric correction was done to overlay the images to the same coordinate system, to make the spatial analyses accurate and consistent. The final process was to crop the images to the boundary of the forest and the five-kilometer radius to focus the analysis in the study area.

c) NDVI calculation and Trend analysis

NDVI values were calculated for the years 1995, 2004, 2014, and 2024 to evaluate the health of Kipkunurr forest and its surroundings over the 29 years. The formula used for all the images was NDVI = (NIR − Red) / (NIR + Red). To determine how forest health changed over the study period, a trend analysis of the NDVI was done. Trend analysis was undertaken in SPSS software to indicate the significance of any changes and to determine whether the health of forests improved or deteriorated or remained the same. Lastly, the analysis was presented and illustrated using maps and tables to depict changes in NDVI and forest health over the study period.

3.9.3 Analysis of the trends in temperature and rainfall of the Kipkunurr forest between 1994 and 2024.

a) Data acquisition

Temperature and rainfall data were collected from Kenya's meteorological station specifically Cheptongei meteorological station which is near Kipkunurr forest for the period between 1994 and 2024. This information was gathered on a monthly and annually basis, to enable comprehensive trend analysis. Since the data from the meteorological station was not complete, the missing data was collected from climate sources online specifically the Climate Research Unit (CRU) accessed through the link (https://climexp.knmi.nl/start.cgi). ERA5 datasets, with a spatial resolution of 0.25°, were used for missing temperature data, while CHIRPS datasets, with a spatial resolution of 0.05°, were used for rainfall data. ERA5 data were obtained from the Copernicus Climate

Data Store, and CHIRPS data from the Climate Hazards Center Data Portal. Both temperature and rainfall data were downloaded in CSV format. This data was validated by comparing them against observed station data obtained from the Kenya Meteorological Department (KMD) for the Kipkunurr area.

b) Data preprocessing

To improve reliability, preprocessing was done on the acquired data before analysis. Data cleaning was done to correct inconsistencies. To make temporal trend analysis easier, the data was standardized into monthly and annual averages as there were no missing values.

c) Time series analysis

Time series analysis was used to analyze trends and variations in rainfall and temperature over time. The aim was to identify any recurrent cycles, trends, and seasonal influences in the data (Mudelse, 2019). Line graphs and time plots were used to visually analyze the temporal changes, providing an overview of the climatic trends. Microsoft Excel was first used to create temperature and rainfall line graphs, while R and Python were employed to conduct further analyses of dependent fluctuations in climate data in a more detailed way

d) Trend detection with the Mann-Kendall Test

The Mann-Kendall test was employed to find out the significant areas of trends in the time series. Its popularity in hydrology and climatology has made this non-parametric test one of the most used by scientists due to its strength and absence of any assumptions regarding data distribution (Gocic & Trajkovic, 2013). It has several applications, especially where monotonic trends in long-term-datasets could be identified.

In Mann-Kendall test, the null hypothesis (H_0) of no trend is tested against the alternative hypothesis (H_1), which indicates the presence of a trend in the data. The value of the Kendall's Tau (τ) was used to show the strength and direction of the trend, where positive τ values indicates rising trends, whereas negative values indicate decreasing trends, and values near 0 indicate no discernible trend (Sharma et al., 2019). A significance level of 0.05 was used to assess the statistical significance of the trend and the test was done in Kendall and trend packages in R for accuracy and consistency.

e) Visualization and reporting

Further to facilitate interpretation, graphical illustrations of time series on the trends were plotted to show the severity and magnitudes. On the other hand, a table was used to summarize the findings of the trend analysis, which contained the Kendall and the p-value to determine the rate of change overtime time.

3.9.4 Examination of the relationships between climate change, LULC change, and health status of Kipkunurr forest.

a) Data Acquisition

Various sources of data included field surveys, remote sensing, and meteorological records were used to examine the relationships between climate change, change in LULC, and the health status of Kipkunur forest. The data collected under the first, second, and third objective was used.

b) Preparing and integrating data

The first step involved compiling the dataset by combining NDVI, LULC, and climate data for the selected years of the study, which are 1995 to 2024 for NDVI and LULC and 1994 to 2024 for climate variables, temperature and rainfall. Each variable was categorized as either dependent or independent, where forest health in form of the NDVI values was represented as dependent variable (Y). The independent variables (X) included mean annual temperature, total rainfall, forest cover, agricultural land, and bare land percentages. Data was organized in a tabular form, with every year being expressed by an observation, with data structured into a tabular format. The dataset was checked for multicollinearity, outliers and missing values using correlation analysis.

c) Correlation analysis

To determine the direction and the strength of the relationship between each of the independent variables and NDVI, correlation test was done using Pearson. With this test, multicollinearity, which may compromise on the validity of the regression model, was identified. The correlation matrix guided the process of selecting the variables ensuring all the independent variables had diverse explanatory effects.

d) Multiple linear regression analysis

Multiple linear regression was done in SPSS to determine the combined predictive potential of climatic variables (temperature and rainfall), and LULC variables on forest health. $NDVI = \beta_0 + \beta_1 (Temperature) + \beta_2 (Rainfall) + \beta_3 (Forest Cover) + \beta_4 (Agricultural Land) + \beta_5 (Bare Land) + \varepsilon$ was the formulation of the regression model. Where ε is the error term, NDVI represents forest health, β_0 is the constant, and β_1 to β_5 are coefficients for the predictor variables. F-test was used to assess the overall significance of the model, while each predictor's standardized beta coefficient and p-value were examined independently. The amount of NDVI fluctuation that could be explained by the combination of LULC and climate factors was determined using the adjusted R^2.

e) Reporting and visualization

Tables were created in SPSS to present correlation and multiple linear regression, which included p-values, regression coefficients, and odd ratios. These tables helped to interpret the influence of temperature and rainfall, and LULC changes variables on forest health.

3.10 Validity and reliability of data

Multiple methods were used to ensure the validity of this study. Based on existing literature and expert review, content validity was used in writing household surveys, and key informant interviews, ensuring that all aspects of the study were captured. Triangulation was applied by integrating multiple data sources, including remote sensing data, field surveys, climate records, and community perceptions, allowing cross-validation of findings and reducing bias. Ground truthing was conducted to validate LULC classifications derived from satellite images by comparing them with actual land cover conditions in the field. Additionally, standardized data sources, such as Landsat satellite images from USGS Earth Explorer, climatic data from relevant climate data sources such as CHIRPS, and official government reports, were used to enhance credibility and accuracy.

Reliability was ensured through several approaches. Pre-testing of questionnaires was conducted with a small sample to refine questions, eliminate ambiguities, and ensure consistency in responses before full-scale data collection. Remote sensing approaches like NDVI calculations were uniformly applied in all the chosen years (1995, 2004, 2014, and 2024) using same spectral bands from the dry season to reduce variations in the assessment of vegetation health. Statistical reliability test for temperature and rainfall data analysis was done in SPSS, which ensured that observed trends were statistically significant and not due to random fluctuations. Moreover, for qualitative data analysis, an inter-coder method was used, involving standardization of themes and cross-checking of interview transcripts to prevent subjective bias. Through these steps, the study ensured that the information collected was accurate, reflecting climate change and land use changes of Kipkunurr forest and its surroundings, and the need for conservation efforts.

3.11 Ethical issues in research

In this study, the major ethical considerations included data protection, obtaining consent, and confidentiality from participants. The first ethical step involved securing approval for the research through a letter from the University of Eldoret Board of Postgraduate Studies, which was also used to apply for the NACOSTI research permit.

The study also recognized the contributions of previous researchers on land use/land cover, Forest health, and climate change by appropriately acknowledging their work through references and citations. This ensured academic integrity and provided a foundation for the study.

Additionally, verbal consent was sought from all participants, including local community members and key informants from forest conservation organizations, to ensure their voluntary participation. Confidentiality measures were strictly upheld, ensuring that the collected data were solely used for research purposes. To maintain anonymity, participants' identities were not disclosed, and responses were coded to protect their personal information.

Table 3.2: Research Matrix

OBJECTIVE	NATURE OF DATA	SOURCES OF DATA	METHODS OF DATA COLLECTION	VARIABLES	METHODS OF DATA ANALYSIS
1. Assess spatiotemporal changes in LULC in Kipkunurr Forest (1995–2024)	Satellite images from the Landsat platform	Landsat satellite images (USGS Earth Explorer), Secondary reports	Remote sensing, Questionnaire, Key informant interviews	LULC classes (forest, agriculture, bare land, etc.)	Supervised classification and accuracy assessment in ArcGIS 10.8
2. Evaluate changes in forest health using NDVI (1995–2024)	Satellite images from the Landsat platform	Landsat images (USGS)	Remote sensing	NDVI values as an indicator of forest health	NDVI calculation, Time-series analysis in ArcGIS 10.8

3. Analyze temperature and rainfall trends (1995–2024)	Climate data (temperature, rainfall)	ERA5 temperature data, CHIRPS rainfall data and from meteorological station	Downloaded rainfall & temperate data from Climate Explorer, complemented with data from meteorological station	Temperature (°C), Rainfall (mm)	Descriptive statistics, Time-series trend analysis in SPSS and Excel, Mann-Kendall trend test
4. Establish interrelations between climate change, LULC change, and forest health	Integrated dataset (LULC, NDVI, Climate data)	Combined from objectives 1, 2, and 3	Data integration of objectives 1, 2 &3	NDVI values, Temperature, Rainfall, LULC classes	Correlation analysis Multiple Linear Regression (MLR) in SPSS

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter reports the findings of the analyses done on land use and land cover change, forest health, and climate patterns (temperature and precipitation) in Kipkunurr forest and its surroundings. The results are presented according to the key objectives of the study. First, the chapter reports the changes in land use and land cover between 1995 and 2024. It also presents on forest health over the same period using the Normalized Difference Vegetation Index (NDVI). Furthermore, trends in temperature and rainfall were analyzed within the 1994 and 2024 to show patterns associated with climate variability. The chapter further presents the relationship between climate change, land use and land cover changes, and the health of the forest, providing insights on the interaction between these factors.

4.2: Socio-demographic characteristics of the Respondents

The study's sample was three hundred and eighty-four (384) interviewed respondents. Out of the total questionnaires, two had not been duly filled and in that way, were not included in the analysis. The response rate was, therefore, 99.5%, which was adequate and far beyond the threshold of 75% (Mugenda & Mugenda, 2003). Understanding the socio-demographic characteristics of the local community helps in explaining the land use, land cover, and climate change effects on Kipkunurr Forest and its surroundings. Human activities such as farming, settlement expansion, and resource extraction are largely shaped by demographic factors, including occupation, education levels, household size, and proximity to the forest. These characteristics also influence the community's vulnerability and adaptive capacity to climate variability and environmental change. Therefore, profiling the respondents provides a critical background for analyzing the subsequent findings of the study.

The socio-demographic characteristics of the respondents are summarized in Table 4.1**.** A total of 382 individuals participated in the study, with the majority drawn from Kapsowar (36.6%) and Kapyego (26.7%) wards, jointly accounting for over 60% of the sample. Slightly more than half of the respondents (53.9%) were female. The age distribution was fairly balanced across age groups, though the majority (57.3%) were aged between 41 and 60 years. In terms of education, most respondents had attained either secondary (39.3%) or primary education (37.7%), with only a small fraction having tertiary or university-level education. Marital status data showed that nearly all respondents (91.4%) were married. Farming was the dominant occupation, reported by (79.1%) of the participants. Regarding income, a large proportion (75.7%) earned less than Ksh 20,000 per month. Most respondents (41.9%) had lived in the area for between 31 and 40 years, and household sizes were generally large, with (88.7%) of households having between 4 and 10 members. In terms of proximity to Kipkunurr forest, the majority (99.5%) lived within a distance of 1-5 Kilometers.

Table 4.1: Socio-demographic characteristics of the respondents

Demographic character	**Attribute**	**Frequency**	**Percentage frequency**
Ward	Kapsowar	140	36.6
	Kapyego	102	26.7
	Moiben/ Kuserwo	78	20.4
	Sambirir	34	8.9
	Arror	28	7.3
	Total	**382**	**100.0**
Gender	Female	206	53.9
	Male	176	46.1
	Total	**382**	**100.0**
Age (Years)	31-40	64	16.8
	41-50	105	27.5
	51-60	114	29.8
	61-70	64	16.8
	71-80	30	7.9

	> 80	5	1.3
	Total	**382**	**100.0**
Education level	No formal education	45	11.8
	Primary	144	37.7
	Secondary	150	39.3
	Tertiary	27	7.1
	University	16	4.2
	Total	**382**	**100.0**
Marita status	Married	349	91.4
	Single	5	1.3
	Widowed	28	7.3
	Total	382	100.0
Main occupation	Business	34	8.9
	Casual laborer	4	1.0
	Farmer	302	79.1
	Public servant	21	5.5
	Teacher	21	5.5

	Total	**382**	**100.0**
Household's average monthly income	Below,10 000	166	43.5
	10,000 20 000	123	32.2
	20,000 30 000	48	12.6
	40,000 50 000	40	10.3
	Above 50 000	5	1.3
	Total	**382**	**100.0**
Number of years lived in the area	31-40	160	41.9
	41-50	76	19.9
	51-60	54	14.1
	61-70	70	18.3
	`71-80	15	3.9
	> 80	7	1.9
	Total	**382**	**100.0**
Household Size	<4 people	33	8.6
	4-10people	339	88.7
	above 10 people	10	2.6

Distance from your home to Kipkunurr forest in Km	<1 km	17	0.3
	1-5 km	365	95.5
	Total	**382**	**100.0**

4.2.1 Land ownership

Land ownership is important as it defines who is legally in control of the land and who is responsible for the land. An accurate understanding of the identity of the land owner makes it easy to bring out the key players in land use determination, protection of forests and managing resources. The second reason is that the ownership of land also affects the use of land, protection and management. Thus, understanding the issue of land ownership is significant in assessing land use land cover changes and initiatives for forest conservation.

The study found that the majority of respondents (99%) were landowners whereas the remaining 1%) leased land from original owners.

4.2.2 Land size

Land size determines how land is used for instance, smaller portions of land may be utilized for mixed or subsistence farming, whereas bigger portions may be used for grazing or commercial farming. Land size also influences the extent of environmental pressure and different land use. Therefore, understanding land size aids in determining the scope of human activity and its possible effects on forest resources and changes in land cover.

In the study most of the respondents owned relatively small parcels of land, with majority (86.4%) reporting land sizes of less than five acres (Figure 4.1).

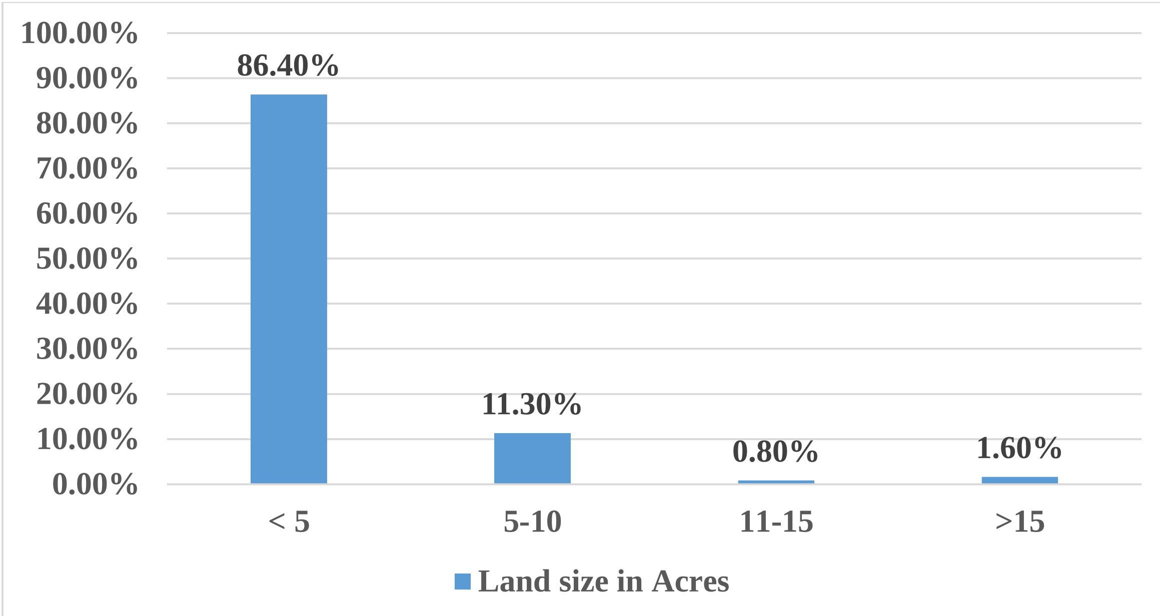

Figure 4.1: Land Size

4.2.3 Land Tenure Type

The kind of tenure system whether freehold, leasehold, and communal shapes land users' confidence in making long-term conservation or sustainable practices investments. Land tenure type influences how resources are exploited which could be sustainable or unsustainable. As a result, understanding type of land tenure makes it easier to know how the various land management techniques contribute to either the conservation or degradation of forests.

Regarding land tenure documentation in the study, a large proportion (90.3%) held official title deeds, while a smaller percentage relied on letters of reservation (7.3%) or informal agreements (2.4%), as illustrated in Figure 4.2.

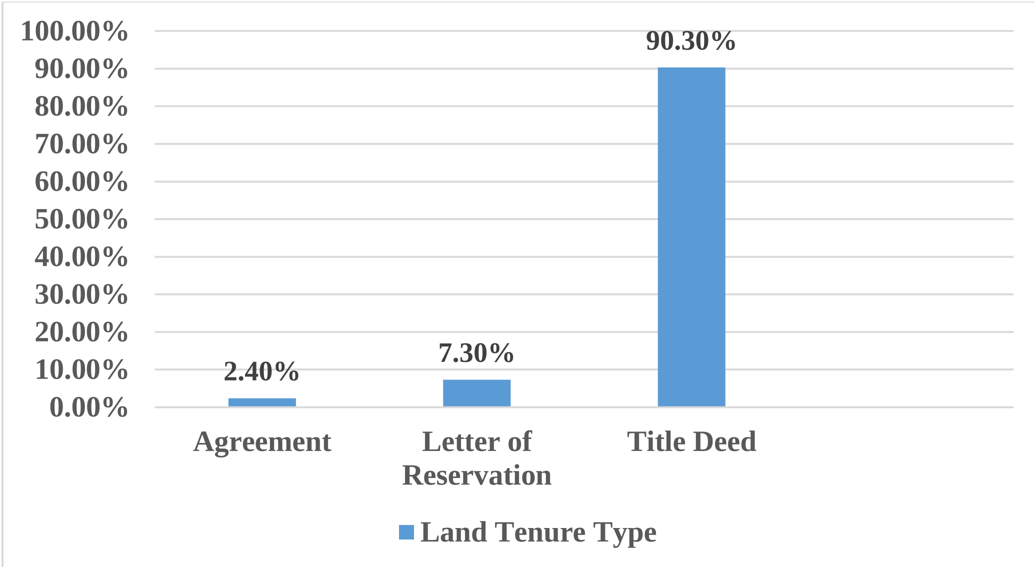

Figure 4.2: Land Tenure Type

4.2.4 Number and the type of trees in the respondents' woodlots

The number and type of trees within the woodlots belonging to the respondents provide insights on the utilization of the local forests by the surrounding communities. This information is useful to understand whether these communities are exerting pressure on natural forests or whether they are supporting their fuel and wood needs on a sustainable basis. The information also helps in ascertaining how privately grown trees help in conservation of forests. Therefore, an examination of the amount and kind of trees will help in the distribution of the degree to which woodlots succeed in satisfying household needs, reducing dependence on natural forests, and in establishing forest revival or deforestation patterns.

Table 4.2 provides data on types of trees in the respondents' woodlots. Few respondents (2.4%) had more than 250 trees in their woodlots, but the majority (80.6%) reported having less than 50 trees. Cypress was the most prevalent tree species, followed by cedar, as well as combinations of cypress with cedar and cypress with grevillea.

Table 4.2: Number and the type of trees in the respondents' woodlots

Question	Attribute	Frequency	Percentage frequency
Number of trees in respondent's woodlot	<50	308	80.6
	50-100	42	11.0
	101-150	14	3.7
	151-200	2	0.5
	201-250	7	1.8
	> 250	9	2.4
	Total	**382**	**100**
Types of trees in woodlot	None	115	30.1
	Blue gum	1	0.3
	Blue Gum, Cypress and Cedar	1	0.3
	Blue Gum and Grevillea	3	0.8
	Cedar	1	0.3
	Cedar and Cypress	41	10.7
	Cypress	130	34.0
	Cypress, blue gum	5	1.3

Cypress and Blue Gum	21	5.5
Cypress, Blue Gum and Grevillea	3	0.8
Cypress, Cedar and Grevillea	19	5.0
Cypress and Grevillea	35	9.2
A mixture of Cypress, Grevillea, Rosewood, Cedar, Pine and Blue gum	1	0.3
Cypress, white oak, blue Gum, Grevillea	1	0.3
Cypress, Rose wood and Grevillea	1	0.3
Grevillea	4	1.0
Total	**382**	**100.0**

4.2.5 Land Allocation through Shamba System

The Shamba System (PELIS) especially in plantation forests enables households to cultivate crops on forest land as they care for young trees. It helps in establishing forests as well as in food production. However, when rules are in violation or an absence of control exists, then this may cause the destruction of forests. Therefore, understanding about land allocation in form of the Shamba System helps to know level of human activity within forest areas, the balance between agricultural use and forest conservation, and the consequences for either forest encroachment or recovery.

All respondents indicated that they did not have land allocated through the Shamba System, with no respondents reporting otherwise.

4.2.6 Livestock Kept

Livestock potentially affect the well-being of forests, particularly in areas that are near forests since they are able to graze, browse seedlings, and trample. This is perhaps more so when animals are allowed to roam and given free range to feed on forest reserves. The number and kind of animals influence the amount of pressure exerted on the forest. Therefore, understanding the type and number of livestock kept helps in determining the level of forest degradation caused by livestock, the reliance of households on forest grazing, and the need to sustainable grazing methods.

As shown in Figure 4.3, cattle were the most commonly kept livestock, with 36% of respondents indicating ownership, while donkeys were the least kept, at just 2%.

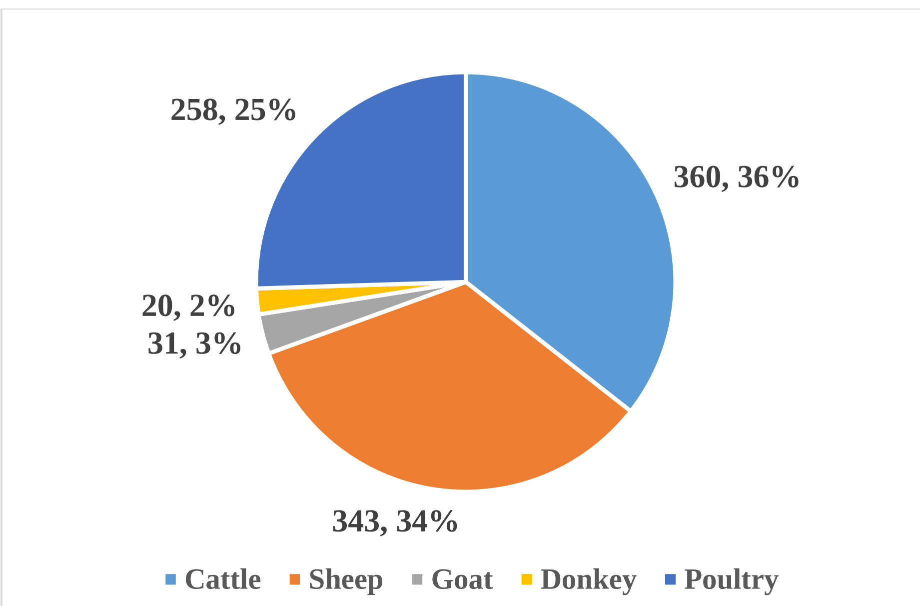

Figure 4.3: Livestock Kept

4.2.7 Existence of Beacon between the Farm and the Forest

The parcel of private land and the forest land is demarcated with beacon or the boundary marker. The zones with these markers are less prone to encroachment. Confusion of borders, on the other hand, can often lead to conflicts and gradual destruction of forests. Therefore, beacon presence research contributes to the discovery of locations at risk to boundary conflict, assessment of the effectiveness of forest conservation and management measures, and directing activities designed to guard forest borders and inhibit encroachment.

Figure 4.4 indicates absence of beacon by majority of the respondents (50.6%).

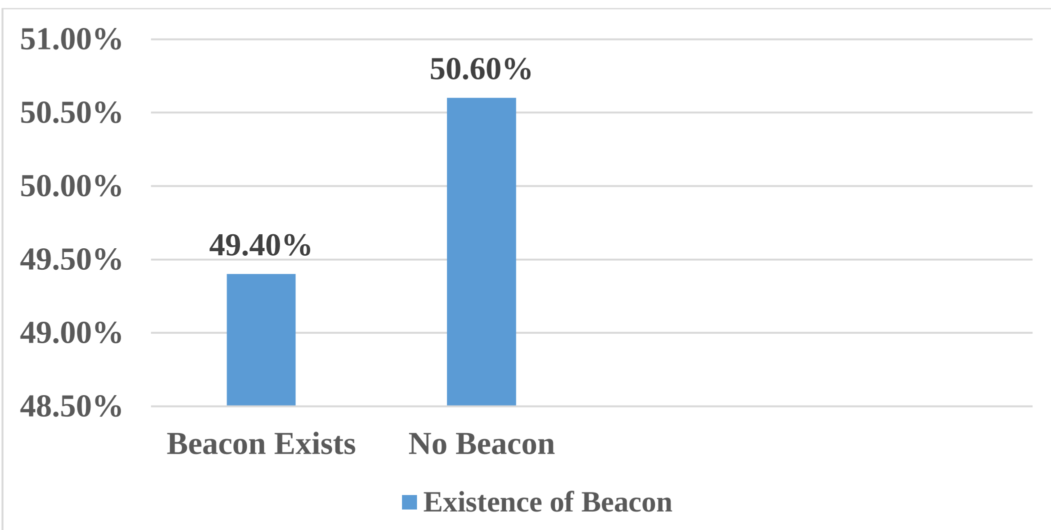

Figure 4.4: Existence of Beacon between Farm and the Forest

4.2.8: Source of Energy

The type of energy used for cooking such as electricity, firewood, and charcoal shows directly how a household relies on natural resources. For instance, the most common source of energy in rural places is firewood or charcoal. Therefore, understanding the energy source for cooking helps in knowing the extent of dependency on forest biomass and directs the designing of sustainable or alternative sources of energy to lessen the pressure on forests.

Figure 4.5 shows that firewood is the primary household energy source for cooking, with nearly all (99.5%) respondents relying on it.

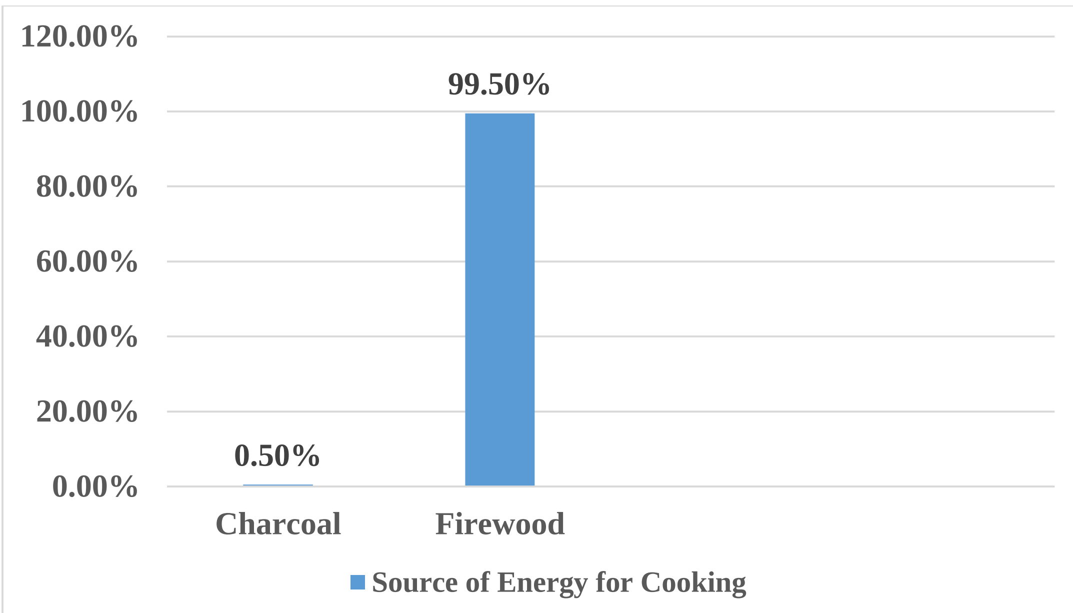

Figure 4.5: Source of Energy for Cooking

4.2.9 Wood Fuel Source

The nature of the use of forests is also deduced on the basis of whether the wood fuel is acquired from the nearby natural forests, from personal woodlots or buying it from other people's farms. This is an indication of whether harvesting methods are deforestation-causing or sustainable. Understanding the source of wood fuels therefore helps in quantifying the pressure on forests, identifying illicit harvesting, and promoting alternatives such as woodlots managed by the community.

Figure 4.6 indicates that the vast majority (98%) of respondents source their firewood directly from Kipkunurr Forest.

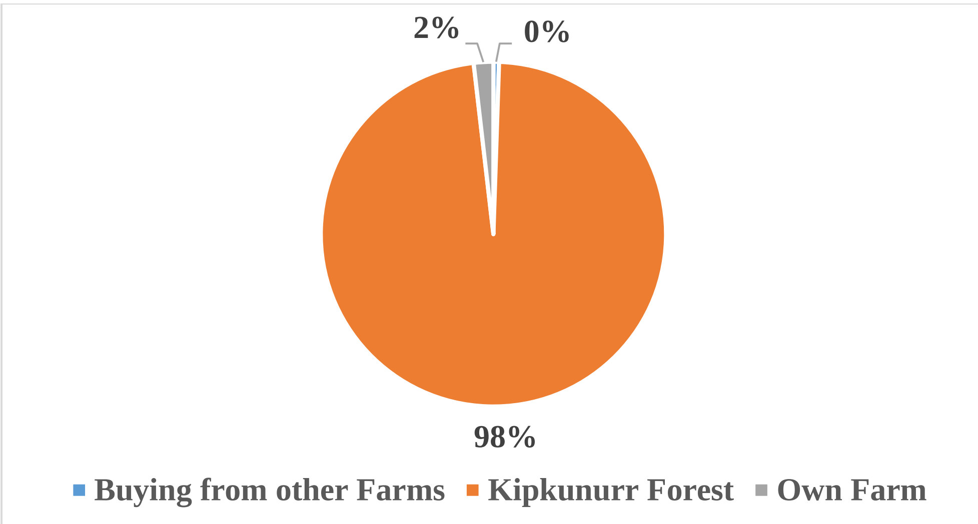

Figure 4.6: Source of Wood Fuel

4.2.10 Quantity of Wood Fuel in Bundles used per Month

The amount of biomass consumed by a household is represented by the number of firewood bundles used per month. Major consumption would mean a larger household or a stronger dependence on forest resources. Therefore, assessing the number of bundles consumed each month helps in estimating the demand for fuel wood within a particular location, determining the pressure on forest resources, and providing directions meant to enhance energy efficiency efforts or forest resource management.

As shown in Figure 4.7, the most common quantity of firewood used was 10–20 bundles per month, reported by 53.1% of respondents (Bundle is the amount of firewood an individual can carry on their back).

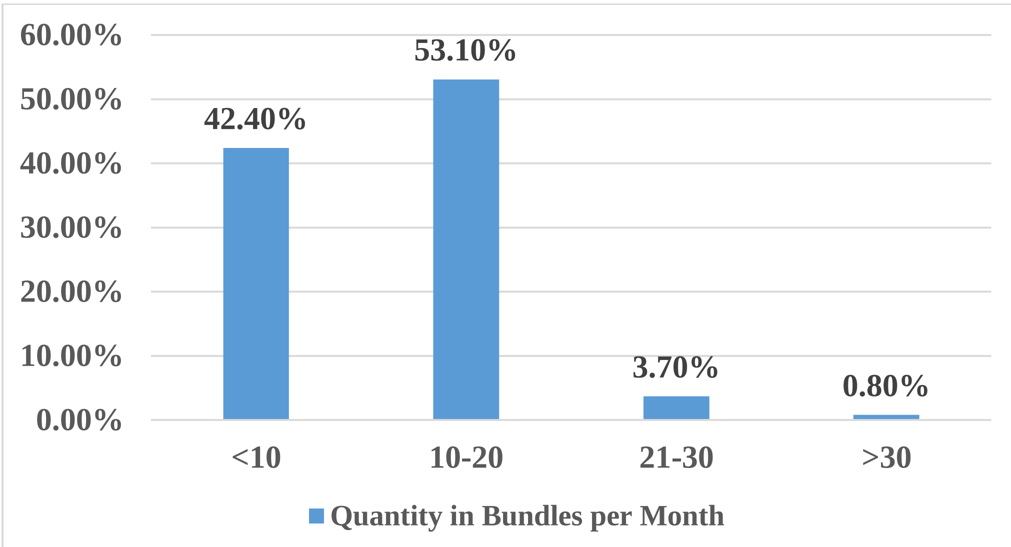

Figure 4.7: Quantity Bundles used per Month.

4.2.11 Building materials obtained from Kipkunurr Forest

Harvesting of building materials constitutes one of the vital human activities, which contribute to forest degradation. Acquiring information concerning the type of materials directly gathered from Kipkunurr Forest makes one comprehend more on the extent to which the building methods affect the sustainability and wellbeing of the forest. Such information is vital for determining the pressure being placed on forest resources as well as for directing actions that enhance sustainable utilization of forest resources.

Figure 4.8 details the types of building materials that respondents reported obtaining from Kipkunurr Forest. The most commonly mentioned resources were Timber (31%) and Bamboo (23%).

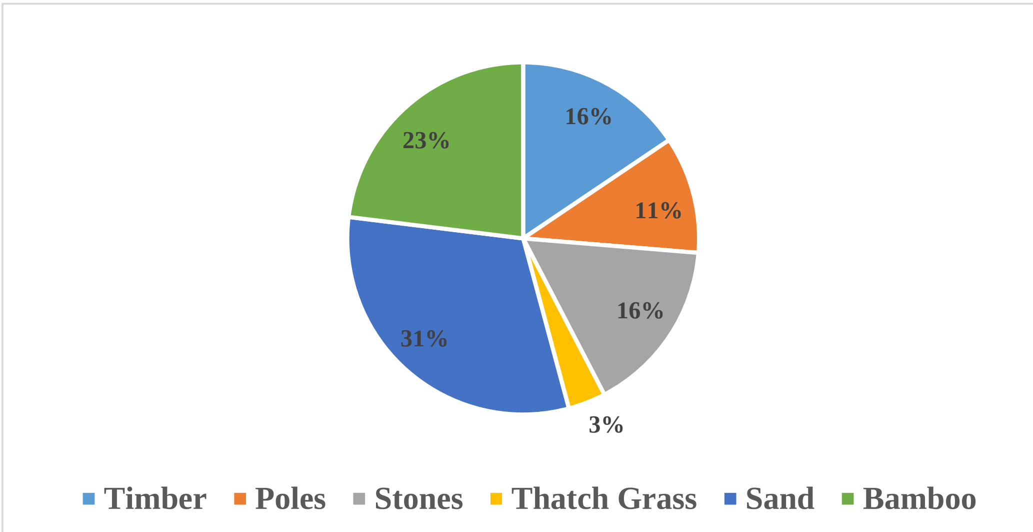

Figure 4.8: Building Materials from Kipkunurr Forest

4.3 Spatio-temporal changes in land use and land cover in Kipkunurr forest between 1995 and 2024

The first objective of the study was to assess the spatio-temporal changes in Kipkunurr forest between 1995 and 2024. The findings of this objective are shown in Figure 4.9 which shows LULC maps for the years 1995, 2004, 2014 and 2024. The maps illustrate the trend of LULC change over 29-year study period.

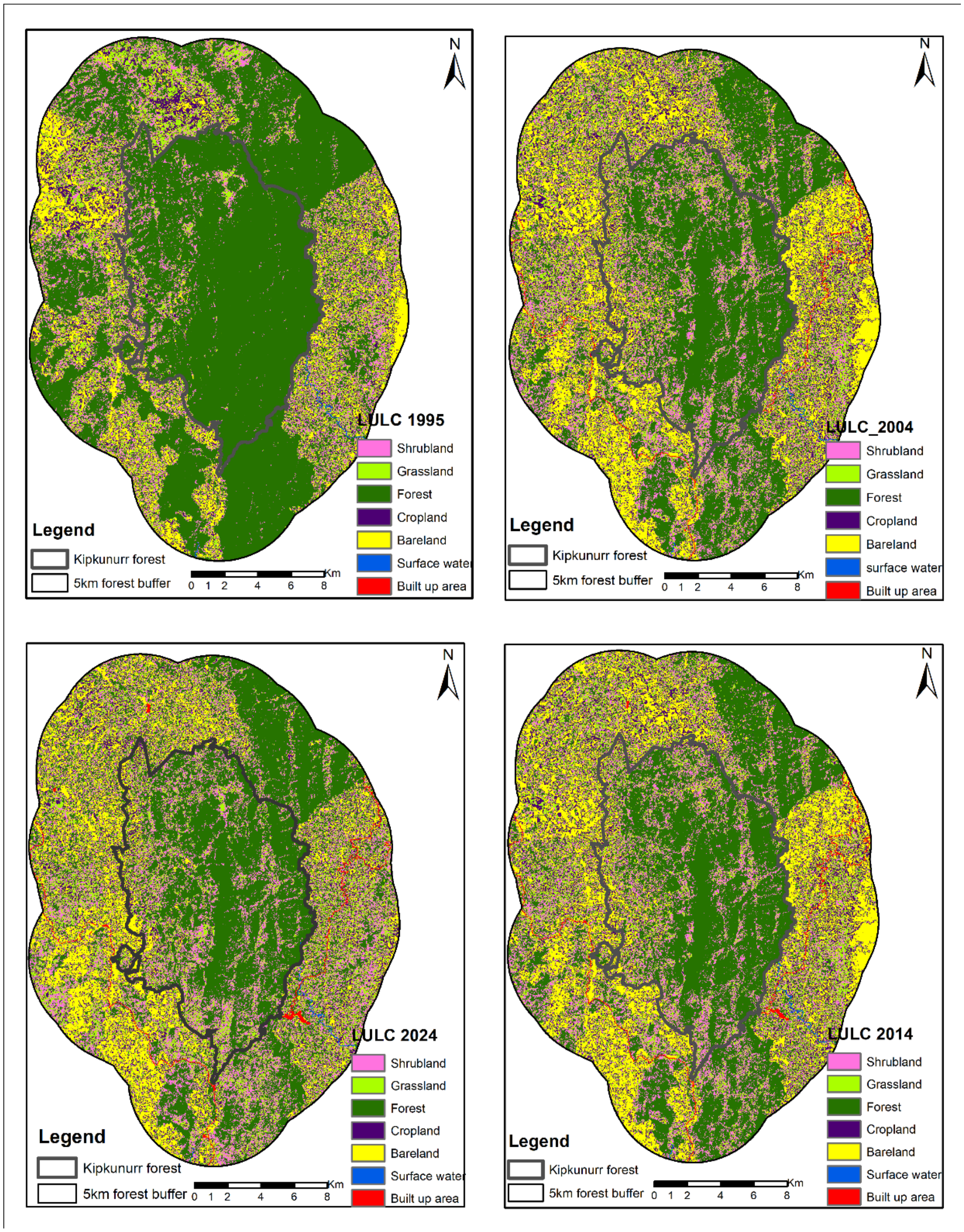

Figure 4.9: Spatio-temporal changes in land use and land cover in Kipkunurr forest between 1995 and 2024

The changes in land use and land cover (LULC) in Kipkunurr Forest during the period of 1995 to 2024 are provided in Table 4.3. In 1995, forest cover accounted for 56.3% of the area. Bareland increased from 7.9% in 1995 to a peak of 17.2% in 2004. Cropland rose steadily from 8.2% in 1995 to 13.0% in 2014. Grassland and shrubland showed an overall growth during the study period, with grassland reaching 16.9% and shrubland 18.9% by 2024.

Table 4.3: Land use and land cover in hectares and percentages

	Year			
LULC	**1995**	**2004**	**2014**	**2024**
Bareland	4229.25	9147.52	8691.16	5834.00
	(8.08%)	(17.48%)	(16.61%)	(11.15%)
Cropland	4385.34	6918.48	6919.02	5999.67
	(8.38%)	(13.22%)	(13.23%)	(11.47%)
Grassland	6286.95	8187.57	8168.67	9009.09
	(12.02%)	(15.65%)	(15.61%)	(17.22%)
Shrubland	6541.12	8823.87	8824.59	10050.19
	(12.50%)	(16.87%)	(16.87%)	(19.21%)
Forest	30053.79	18340.01	18368.01	19349.50
	(57.45%)	(35.06%)	(35.11%)	(36.98%)
Built up area	21.00	89.00	545.00	1276.00
	(0.04%)	(0.17%)	(1.04%)	(2.44%)
Surface water	800.00	811.00	801.00	799.00
	(1.53%)	(1.55%)	(1.53%)	(1.53%)
Total area in hectare	**52317.45**	**52317.45**	**52317.45**	**52317.45**
	(100.00%)	**(100.00%)**	**(100.00%)**	**(100.00%)**

4.3.1 Percentage change in Land Use/ Land Cover from 1995-2024

The changes in land use and land cover (LULC) in Kipkunurr Forest and its surroundings in 1995 to 2024 are provided in Table 4.4. The forest cover showed the highest level of change decreasing by -20.47%%, followed by shrub land which increased by 6.71%% and grassland by 5.21%. Another increase was noted in the cropland and bare land where the percentage grew by 3.09 and 3.07 respectively with variations over the decades. There was also a modest rise in the built-up areas by 2.40%, but there was no change in surface water throughout the study.

Table 4.4: Percentage change in land use and land cover

Classes	1995-2004	2004-2014	2014-2024	1995-2024
Bare Land	9.4%	-0.87%	-5.46%	3.07%
Crop Land	4.84%	0.01%	-1.76%	3.09%
Grass Land	3.63%	-0.04%	1.61%	5.21%
Shrub Land	4.37%	0%	2.34%	6.71%
Forest	-22.39%	0.05%	1.87%	-20.47%
Built-up Area	0.13%	0.87%	1.4%	2.4%
Surface Water	0.02%	-0.02%	0	0

4.3.2 Accuracy Assessment

To determine the precision of the land use/land cover (LULC) classification, a confusion matrix was developed out of the ground truth data as indicated in table 4.5. The results indicate that the accuracy scores were high in all the classes with producer and user accuracy varying between 85% and 100% hence indicating high percentage of reliability of classification of each land cover type. The overall accuracy was 94.34%**,** which is well above the 85% threshold typically considered acceptable for LULC classification (Congalton & Green, 2019).

Table 4.5: Confusion Matrix

Classes	Shrub Land	Grass Land	Forest	Crop Land	Bare Land	Surface Water	Built-up Area	Total of reference ground truth	User Accuracy (%)	Kappa Coefficient
Shrub Land	13	0	1	0	0	0	0	14	93	
Grass Land	0	15	0	0	0	0	0	15	100	
Forest	1	0	11	0	0	0	1	13	85	
Crop Land	0	0	0	14	0	1	0	15	93	
Bare Land	0	0	0	0	17	0	0	17	100	
Surface Water	0	0	0	1	0	11	0	12	92	
Built-up Area	0	0	1	0	0	0	19	20	95	
Total of classified pixels	14	15	13	15	17	12	20	106		
Producer Accuracy (%)	93	100	85	93	100	92	95	0.00		
Kappa Coefficient										90%

4.3.3 Change detection matrix from 1995 to 2024

Table 4.6 provides an overview of land cover change in the study area between 1995 and 2024 in the 52,076 hectare study area. Shrubland remained the most stable class with 11,282 ha, followed by Forest with 3,170 ha and Cropland with 2,540 ha. Notable conversions include 3,578 ha of shrubland to grassland, 2,010 ha of cropland to forest, and 2,639 ha of bareland to shrubland. The matrix highlights both persistence and significant changes in land cover over the 29-year period.

Table 4.6: Change detection matrix (ha) (1995-2024)

1995/2024	Shrubland	Grassland	Forest	Cropland	Bareland	Total 1995
Shrubland	11,282.22	3,577.59	2,235.78	222.03	908.73	18,226.35
Grassland	1,480.05	1,662.39	874.53	408.24	623.70	5,048.91
Forest	1,120.00	820.00	3,170.16	960.00	750.00	6,820.16
Cropland	723.33	1,952.10	2,009.88	2,539.80	521.37	7,746.48
Bareland	2,639.07	2,117.25	993.96	409.77	701.10	6,861.15
Total 2024	17,244.67	9,629.33	9,284.31	4,539.84	3,504.90	52,075.98

Figure 4.10 shows different land cover change detection that occurred in and around Kipkunurr forest between 1995 and 2024. Every color depict a particular transition between land cover types for example from bare land to crop land or shrub land to forest, providing insight into the intensity and nature of land cover dynamics over the 29-year period.

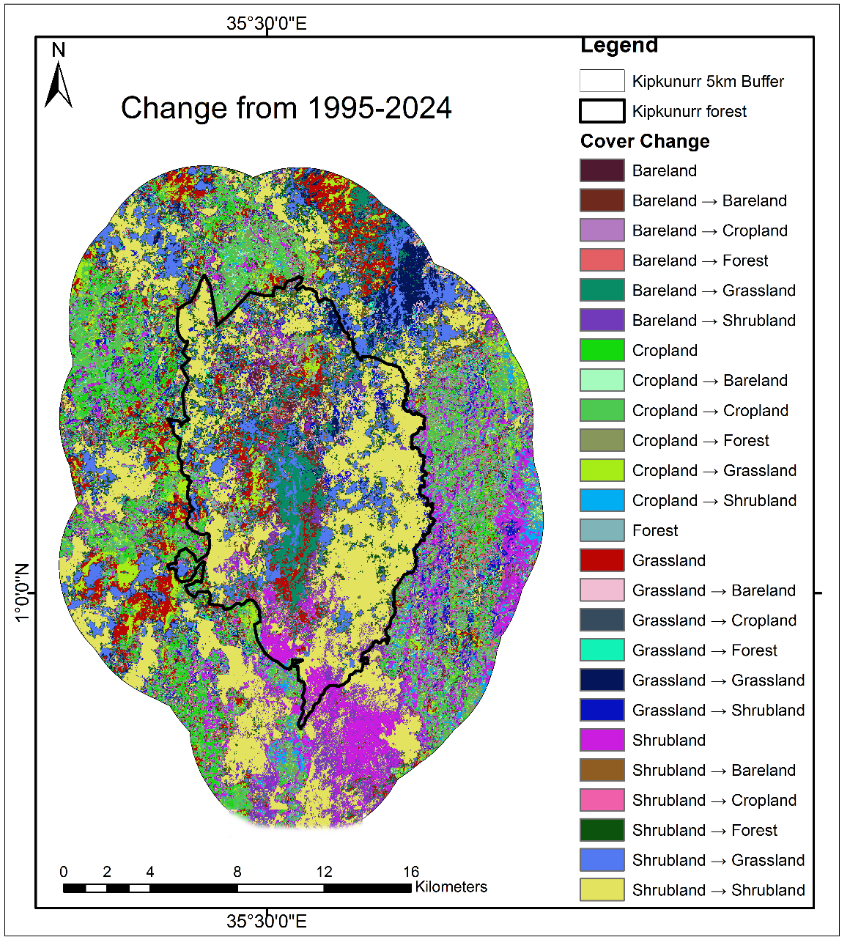

Figure 4.10: Change detection map from 1995 to 2024

4.3.4 Drivers of Land Use/Land Cover Change

The study determined the drivers of land use and land cover change in Kipkunurr forest and its adjacent landscapes and the results are presented in Table 4.7 where according to the respondents, agricultural expansion accounted for (73.3%), population growth 67.0%) and logging and resource extraction (65.7%) were most highly rated as high or very high drivers by majority of the respondents**.** Climate change was rated moderate by 56.3% of respondents. The 41.1% gave high scores to urbanization and infrastructure development. Natural disasters were not considered significant by most people as only 16.5% rated it as high, and 52.4% considered it very low.

Table 4.7: Drivers of Land Use/Land Cover Change

Driver of Land Use/Land Cover Change	Very low	Low	Moderate	High	Very high	Total
Agricultural expansion	1	19	39	280	43	382
	(0.3%)	(4.9%)	(10.2%)	(73.3%)	(11.3%)	(100.0%)
Logging and resource extraction	10	4	26	251	91	382
	(2.6%)	(1.0%)	(6.8%)	(65.7%)	(23.8%)	(100.0%)
Urbanization & infrastructure development	1	61	89	157	74	382
	(0.3%)	(16.0%)	(23.3%)	(41.1%)	(19.3%)	(100.0%)
Population growth	0	10	42	256	74	382
	(0.0%)	(2.6%)	(11.0%)	(67.0%)	(19.4%)	(100.0%)
Climate change	0	50	215	110	7	382
	(0.0%)	(13.1%)	(56.3%)	(28.8%)	(1.8%)	(100.0%)
Natural disasters	5	200	114	63	0	382
	(1.3%)	(52.4%)	(29.8%)	(16.5%)	(0.0%)	(100.0%)

In the Key Informant interview conducted with a forester representing Kipkunurr forest block located in Cheptongei specifically Katee, there are significant land use and land cover changes that have taken place in Kipkunurr forest block which include deforestation, encroachment into the forest land, illegal logging, charcoal burning and artisanal gold mining as indicated in the figures 4.11 and 4.12. They were seconded by forest rangers within the block based in Yemit, Kapsigoria, and Kapsowar who insisted that these activities have been enhanced even more by an increasing population, poverty and in some cases due to idleness especially among the idle youth who are unemployed. This is because the NEMA representative at Kapsowar expressed his worries about unchecked mining and the possibility of land degradation and forest degradation particularly in Kapyego and Sambirir ward. The forester further indicated that *shamba system* is not applied in Kipkunurr Forest as it is a natural forest as compared to plantation forests, where the practice is at times allowed.

The forester interviewed stated that some of the control measures they have included afforestation and reforestation programs within the forest.

Figure 4.11: Evidence of illegal logging

Figure 4.12: Evidence of gold mining

4.4 Changes in forest health in Kipkunurr forest between 1995 and 2024

The second objective of the study was to evaluate the changes in forest health using NDVI in Kipkunurr forest between 1995 and 2024.

The Normalized Difference Vegetation Index (NDVI) was used to measure the health of Kipkunurr Forest over the study period (1995–2024). The NDVI values range between -1 to +1, where higher values indicate healthier vegetation, while lower values signify degraded or barren land as illustrated in Figure 4.13.

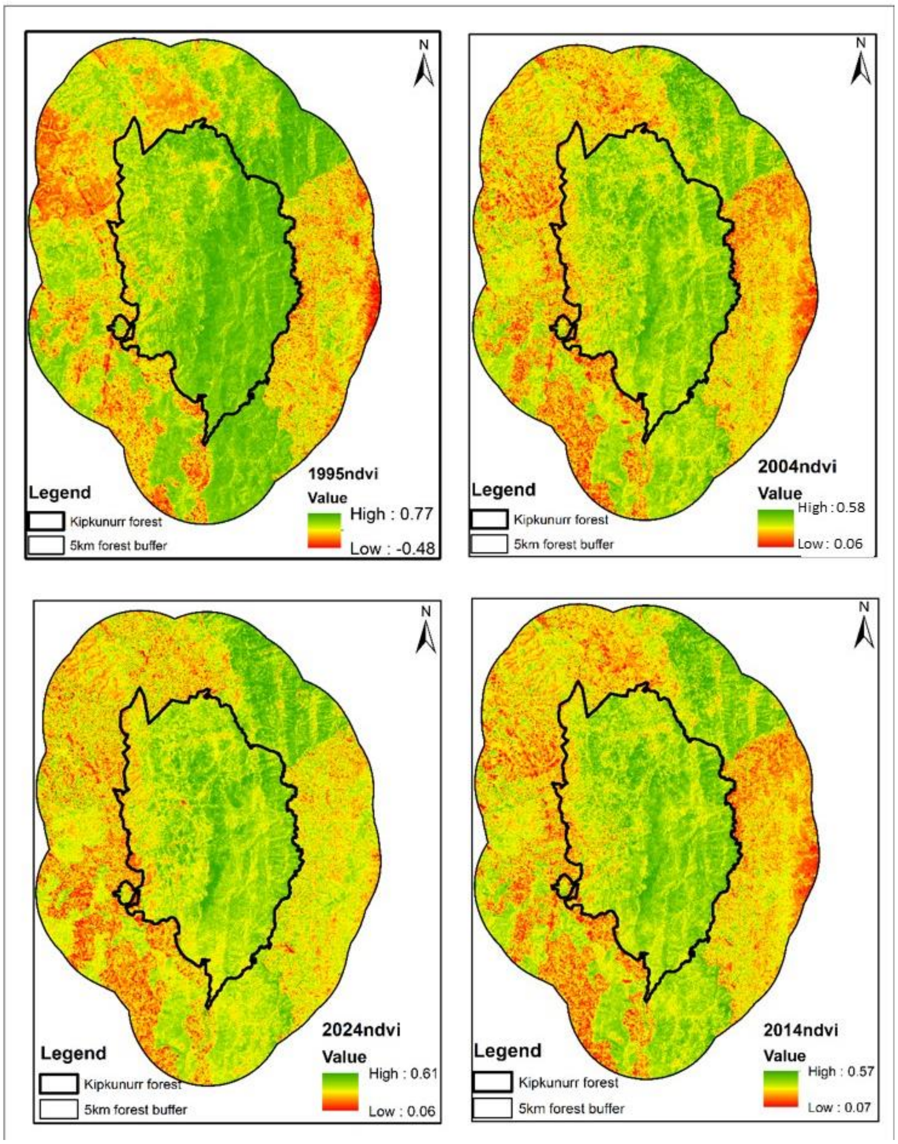

Figure 4.13: Changes in forest health in Kipkunurr forest between 1995 and 2024 using NDVI

As shown in Table 4.8, NDVI findings portray a general change in vegetation status of Kipkunurr Forest between the study years. The peak in the NDVI was measured in 1995 and lowest values were witnessed in the same year. Following years revealed narrower NDVI ranges, with a relatively stable trend from 2004 to 2014. In 2024, a gradual change in the upper NDVI range was recorded as opposed to the last decade.

Table 4.8: Changes in forest health in Kipkunurr forest between 1995 and 2024 using NDVI

Year	low NDVI values	high NDVI values
1995	-0.48	0.77
2004	0.06	0.58
2014	0.07	0.57
2024	0.06	0.61

The interviewed forester revealed that Kipkunurr forest's health is monitored by indicators that include tree density, seedling regeneration, soil condition, and presence of pests and diseases. The forester also reported the problem of monkeys debarking trees causing localized damage of trees. According to forest rangers and also the forester**,** illegal grazing**,** logging as well as charcoal burning are some of the causes of declining forest health. Such threats mostly occur in forest edges and around human settlements.

4.5 Trends in temperature and rainfall of Kipkunurr forest between 1994 to 2024

The third objective of this study was to analyze the trend in temperature and rainfall in Kipkunurr forest between 1994 and 2024.

In Figure 4.14, the outcome of the analysis of the temperature data of Kipkunurr Forest between 1994 and 2024 is presented with a relation described by the regression equation y = 0.0215x + 20.155 and R^2 = 0.2701 which represents a rising trend. The Mann-Kendall test had tau value of 0.145 and p-value of 0.137, tested at a significance level of 0.05. This result indicate that the trend value is not statistically significant because the p-value is more than 0.05.

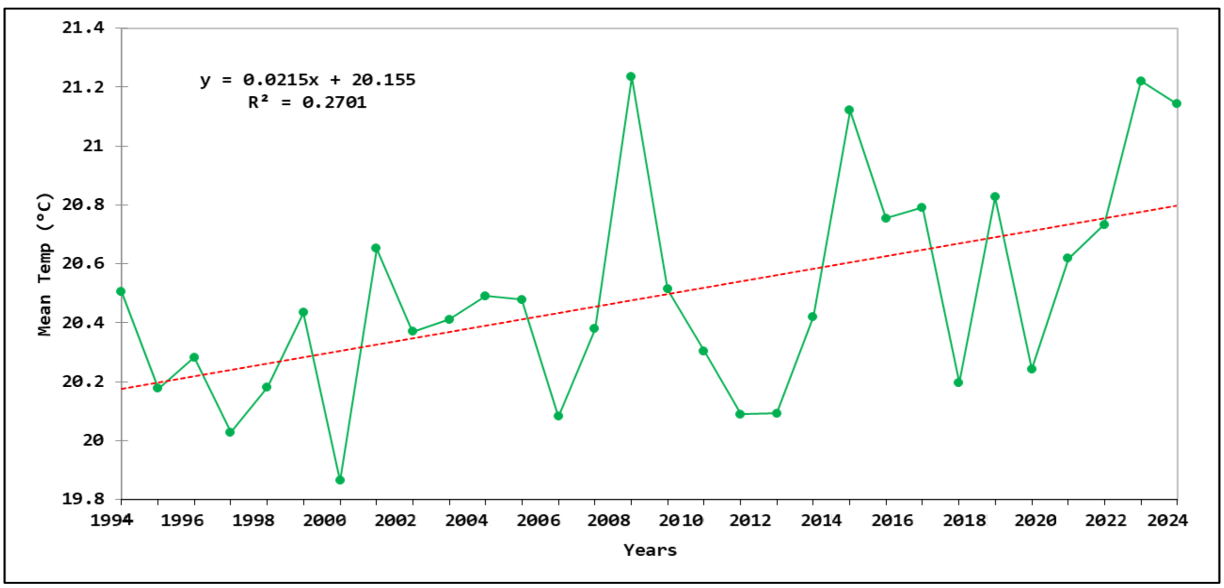

Figure 4.14: Trend of the mean temperature of Kipkunurr forest (1994-2024)

The results of an analysis of the rainfall data are displayed in Figure 4.15 revealing the changes in rainfall patterns during the study period. The trend is slightly increasing but statistically insignificant trend that indicates a p -value = 0.0717, R^2 = 0.0973 and a significance level of 0.05

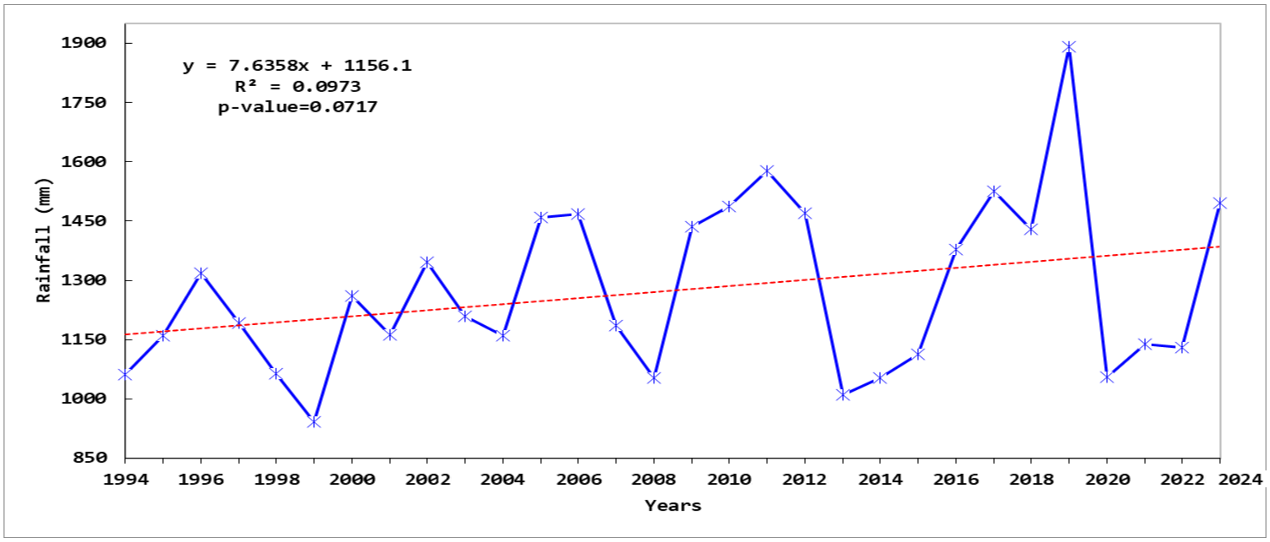

Figure 4.15: Trend in rainfall of Kipkunurr forest (1994- 2024)

4.5.1 Community perceptions on temperature and rainfall trends

This part presents household survey findings on objective three which analyzed the trends of temperature and rainfall patterns in Kipkunurr forest between 1994 and 2024.

The knowledge of the local communities' perspective on climatic variability is crucial in the planning of forest conservation since they directly interact with the forests and can be the first people to realize some changes in the environment. Therefore, by taking into consideration their observations, it would give interesting information on the long term patterns of environment which would not be otherwise comprehensible using meteorological data only.

Table 4.9 displays detail analysis of the community perceptions regarding the changes in climate in Kipkunurr Forest and its surroundings in the last 30 years. Most of the respondents (99.2%) stated that they had observed temperature changes. The most commonly observed temperature-related changes were increased temperatures (57.9%). On the same note, 99.5% of respondents acknowledged modifications in precipitation patterns. The common observations such as erratic rainfall (96.1%). April (79.1%) and July (75.4%) were mentioned frequently as months with the heaviest rainfall. Majority of the respondents (90.3%) reported that the observed temperature and rainfall changes had impacted on the growth or health of Kipkunurr Forest.

Table 4.9: Community perceptions on trends in temperature and rainfall patterns

Question	**Attribute**	**Frequency**	**Percentage frequency**
Changes noticed in temperature in Kipkunurr Forest and adjacent landscapes over the past 30 years?	No	3	0.8
	Yes	379	99.2
	Total	382	100.0
Type of changes observed	increased temperatures	221	57.9
	decreased temperatures	34	8.9
	hotter nights	11	2.9
	colder mornings	193	50.5
	longer hot or cold seasons	184	48.2
	others like Prolonged rainfall	7	1.8
	Total	382	100.00
	No	2	0.6

Changes noticed in rainfall patterns in Kipkunurr Forest and adjacent landscapes over the past 30 years?	Yes	380	99.5
	Total	382	100.0
Kind of changes observed	increased rainfall	211	55.2
	decreased rainfall	76	19.9
	longer drought periods	83	21.7
	unpredictable rainfall	367	96.1
	shorter rainy seasons	54	14.1
	longer rainy seasons	34	8.9
	others like Prolonged rainfall	8	2.1
	Total	382	100.00
Months of the year experiencing the heaviest rainfall	January	34	8.9
	March	126	33.0
	April	302	79.1
	May	53	13.9
	June	89	23.3
	July	288	75.4

	August	64	16.8
	September	11	2.9
	October	150	39.3
	November	179	46.9
	December	18	4.7
	Total	382	100.00
Whether changes in temperature and rainfall have affected the growth or health of the forest?	No	35	9.2
	Yes	345	90.3
	Total	382	100.0

According to the forester Key Informant interviewed, rising temperatures and more erratic rainfall recorded in the last few decades characterized with extended dry seasons and shorter wet periods were observed. This was supported by **r**angers, who recorded frequent forest fires during the month of January to early March, especially due to charcoal burning in the dry season. The NEMA representative further said that seasonal flooding, particularly from the Moiben River, has increasingly become worse than before and this has affected not only the forest soils but also vegetation during heavy rains. The impact of these changes of climate on forest dynamics is that they have caused slower growth of trees, low survival of seedlings, as well as erosion and flash flood which destroys the soil.

4.6 Relationship between climate change, land use/land cover, and Forest Health

The fourth objective was to establish the relationships between climate change, LULC change, and the health status of Kipkunurr forest, and findings are as detailed below.

The Pearson's correlation was conducted to test the strength and direction of linear relationships between forest health determined by NDVI and climatic and land use/land cover variables. According to the correlation matrix as presented in Table 4.10, there is a positive but not significant relationship between NDVI and surface water ($r = 0.141$, $p >0.05$) and a positive and significant correlation with forest cover ($r = 0.995$, $p < 0.01$). On the other hand, bareland ($r = -0.844$, $p < 0.01$), cropland ($r = -0.977$, $p <0.01$), grassland ($r = -0.864$, $p < 0.01$, and shrubland ($r =-0.833$, $p = < 0.01$) have a negative and significant correlation with NDVI.

Table 4:10: Correlation table

High NDVI		High NDVI	Rainfall	Temperature	Bareland	Cropland	Grassland	Shrubland	Forest	Built-up Area	Surface water
	Pearson correlation	1	-0.044	-.268	-.844**	-.977**	-.864**	-.833**	.995**	-.443*	-.141
	Sig (2-tailed)		.816	.153	0.000	0.000	0.000	0.000	0.000	0.014	0.459
	N	30	30	30	30	30	30	30	30	30	30

A multiple linear regression was done to find out the combined predictive power or potential on the climatic and LULC variables on forest health measured using NDVI. According to the ANOVA results, the regression model is statistically significant at ($F = 712.967$, $p < 0.001$), as Table 4.11 shows.

Table 4:11: ANOVA table

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.096	5	.019	712.967	.000[b]
	Residual	.000	24	.000		
	Total	.096	29			

To evaluate the independent effect of climatic and LULC variables on forest health (NDVI), multiple linear regression analysis was employed. Forest cover was the variable with the highest standardized beta coefficient ($\beta = 1.282$, $p < 0.001$) followed by surface water ($\beta = 0.067$, $p < 0.001$) and grassland ($\beta = 0.308$, $p < 0.001$) as Table 4.12 indicates. Temperature and rainfall were not significant ($p>0.05$).

Table 4:12: Regression coefficients table

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.837	.000		-764.448	.000
	Rainfall	1.618E-011	.000	.000	.012	.991
	Temperature	-3.396E-008	.000	.000	-.337	.739
	Grassland	2.518E-005	.000	.308	168.599	.000
	Forest	2.126E-005	.000	1.282	732.310	.000
	Surfacewater	.001	.000	.067	868.451	.000

4.6.1 The perceptions of the communities or households on the Interrelations between Climate change, LULC Change, and Forest Health

In order to understand the sustainability of forest ecosystems, it was important to establish the interrelation between climate change, land use and land cover (LULC) changes, and forest health. Understanding such interplays is crucial in developing effective conservation measures and mitigating the negative effects of both climate change and human activities on forest ecosystems.

As Table 4.13 indicates, most of the respondents (83.2%) were of the understanding that land use changes including the conversion of forest land to farmland have led to change in local climate. High tree mortality (65.4%) and modifications of species composition (49.2%) were frequent responses. Furthermore, 90.3% of respondents suggested that change of LULC had influenced the local climate, with most effects cited being erratic rainfall (91.6%) and declining soil moisture (54.5%). On the effects of climate change on forest health, soil erosion (76.2%), altered water sources (66.2%), and loss of trees (65.2%) were the most reported effects. A considerable proportion (76.7%) acknowledged that the current forest conservation efforts, especially the planting of trees (55.0%) and community participation (46.9%). With regard to perceived effectiveness, 35.1% rated the interventions as slightly effective.

Table 4.13: Interrelations between Climate, LULC Change, and Forest Health

Question	**Attribute**	**Frequency**	**Percentage frequency**
Did changes in land use (e.g., converting forest to farmland) contributed to shifts in local climate?	No	64	16.8
	Yes	318	83.2
	Total	382	100.0
If yes, explain how?	Reduced forest growth	123	32.2
	Increased tree mortality	250	65.4

	Increased spread of pests	188	49.2
	Increased frequency of forest fires	40	10.5
	Change in species composition	188	49.2
	Reduced forest regeneration	134	35.1
Do the changes in LULC contribute to shifts in local climate	No	37	9.7
	Yes	345	90.3
	Total	382	100.0
If yes how do they affect the	increased temperatures	135	35.3
	decreased rainfall	120	31.4
	unpredictable rainfall	350	91.6
	increased drought incidence	188	49.2
	reduced soil moisture	208	54.5
	Reduced forest cover	104	27.2

Impacts do climate changes have on forest cover and health of Kipkunurr forest and adjacent landscapes?	Tree mortality	249	65.2
	Loss of biodiversity	233	61.0
	Reduced tree health	79	20.7
	Increased wildfires	26	6.8
	Soil erosion	291	76.2
	Altered water sources	253	66.2
Have there been any forest conservation efforts to mitigate the impacts of climate change or land use changes?	No	85	22.3
	Yes	293	76.7
Types of conservation efforts	tree planting or reforestation programs	210	55.0
	Soil and water conservation practices	100	26.2
	awareness or education programs on forest	139	36.4

	regulation and enforcement of land use and	33	8.6
	community involvement	179	46.9
If yes, how effective have they been?	Highly effective	60	15.7
	Moderately effective	114	29.8
	Not effective	31	8.1
	Slightly effective	134	35.1
	Total	382	100.0

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter presents a discussion of the results with reference to literature. The discussion is done based on the study objectives. The first objective focused on assessing spatio-temporal changes of LULC change in Kipkunurr forest and its surroundings between 1995 and 2024. The second objective evaluated changes in forest health using NDVI over the same period. The third objective analyzed trends in temperature and rainfall in Kipkunurr forest between 1994 and 2024. Lastly, the fourth objective established the relationships between climate change, LULC change, and the health status of Kipkunurr forest.

5.2 Spatio-temporal changes in land use and land cover in Kipkunurr forest between 1995 and 2024

The first objective entailed the analysis of land use and land cover changes which show that Kipkunurr forest's cover declined between 1995 and 2024, from 57.45% in 1995 to 35.06% in 2004, before a modest recovery to 36.98% in 2024. This trend indicates an initial period of deforestation followed by some regeneration, which aligns with findings by Kamau et al. (2018) and Otieno et al. (2017), who observed similar trends in other Kenyan forests due to deforestation pressures and later conservation efforts. However, unlike the sustained forest loss reported in Mau Forest by Jebiwott et al. (2021), Kipkunurr shows signs of partial recovery in recent years. The change detection matrix, which showed both stability and changes among the land cover classes, provided further information about the spatial dynamics. While forest remained constant over

3,170 hectares, shrubland remained the most stable at 11,282 hectares. Among the notable conversions were 2,010 hectares of cropland becoming forest, 2,639 hectares of bareland becoming shrubland, and 3,578 hectares of shrubland becoming grassland. Around 3,650 hectares of forest, on the other hand, were lost to other land uses, primarily grassland, shrubland, and cropland. These findings show both deterioration and indications of vegetation recovery, pointing to intricate relationships between natural processes and human activity in the landscape.

The reduction has been mainly attributed by agricultural encroachment, illegal logging, and fuel wood collection, as confirmed by household survey and Key Informant Interviews. The recovery in forest cover after the year 2014 is explained by enhanced protection, reforestation programs including the government initiative of planting 15 billion trees by 2032, and the greater awareness of the conservation of forests. However, this recovery is still fragile as the communities continue to heavily rely on forest resources and lack of alternative livelihoods.

Furthermore, the study found that Shamba System is not practiced in Kipkunurr forest, as 100% of respondents confirmed. According to the Kipkunurr forest block forester, it is because the forest is categorized as a natural forest. These findings contrast with research conducted by Wanjira et al. (2020), who documented the practice of agroforestry in other Kenyan forests, for instance, Kakamega and Mt.Elgon. The prohibition in Kipkunurr is because of its status and the significance as a conservation area, with a priority on watershed and biodiversity preservation. Although this helps in the conservation of the ecosystem, it also hinders the capacity of the communities to utilize forest land, thereby increasing pressure on the surrounding landscapes for food production and encouraging encroachment.

The most common land use was livestock keeping, with most common forms of livestock keeping being cattle (36%), sheep (34%), and poultry (25%). The sheep and cattle kept by local communities living around Kipkunurr forest graze entirely within the forest. The finding align with the results of Njenga et al., (2020) and Mutai et al., (2021), who reported similar trends in other Kenya protected forests. The unavailability of pasture and water are the primary reasons that make the people depend on the forest areas to graze. This practice endangers the sustainability of the forest ecosystem, it impedes regeneration of the forest, and accelerates land degradation, converting wooded land into grassland or shrubland.

Boundary demarcation is another significant issue, with 49.4% of the respondents saying that they were able to see forest boundary beacons within their locality whereas 50.6% said that they could not. This aligns with the research by Florence (2021), which noted that most Kenyan forests often have poorly marked borders, resulting in encroachment and conflicts between forest managers and the locals. The unclear boundary beacons around Kipkunurr forest may be attributed to factors such as limited community involvement in boundary maintenance and insufficient financial resources. This situation lessens the effectiveness of forest conservation measures and hinders the Kenya Forest Service the ability to enforce them. It also contributes to a high rate of encroachment, especially among the community members who reported not having seen the boundary beacons.

Another major challenge facing Kipkunurr forest is the widespread fuelwood gathering. Most of the households (99.5%) use firewood as their primary cooking fuel, with nearly all of it being sourced from Kipkunurr forest. In most of the households, firewood is collected either daily or weekly in small bundles because it is readily available and does not cost any money as compared to the alternative sources of energy. Based on the responses, 53.1% of respondents, the common amount of firewood being used was 10-20 bundles per month. These findings are in line with national statistics data from KNBS (2019) and research by Golar et al. (2020), which confirms that rural part of Kenya is heavily dependent on forest biomass. This underlines the need for forest conservation strategies that promote the adoption of affordable and readily available sources of energy.

Apart from firewood, the local communities also rely heavily on other forest materials for construction, including bamboo (61.3%), timber (41.4%), and sand (42.7%). This aligns with the study carried out by Golar et al. (2020), who noted that the rural people who are poor and lack most resources tend to rely on forest resources to find construction materials. The heavy reliance on these resources with the lack of control and monitoring raises concern about their long-term sustainability and underscores the need for conservation initiatives that major on both economic growth and environmental sustainability.

Therefore, according to the findings, the primary causes of forest degradation in Kipkunurr forest and its surroundings are socio-economic factors, including high fuelwood demand, livestock grazing, and lack of alternative livelihoods. Despite partial recovery of forest cover,which reflects the success of conservation efforts, the increase is still fragile and could be reversed. Grassland and shrubland increase indicates a declining forest health and ongoing ecological disruption. These changes reduce the forests' ability to store carbon, alter hydrological processes, and impact biodiversity negatively.

5.3 Drivers of land use and land cover change in Kipkunurr forest and its surroundings

Agricultural expansion in the surrounding areas was the major driver influencing land use and land cover change in Kipkunurr forest and its surroundings, as mentioned by 73.3% of the respondents. This is similar with the findings of Lopez et al. (2021) and Chirwa & Adeyemi (2020), who observed that the main driver of deforestation in rural African areas is driven by agricultural expansion as more people demand land for commercial and subsistence farming. Moreover, similar trends are reflected globally. For example, commercial agriculture such as cattle ranching and soybean plantation, is a central driver of deforestation in Latin America, specifically in the Amazon Basin (FAO, 2016; Maeda et al., 2021). These global trends emphasize that agricultural loss of forests is not a local issue alone since it is driven by both large-scale commercial agriculture demands and the subsistence needs of the locals.

Another mentioned driver was population growth, as cited by 67.0% of the respondents, which indicates that the major driver of forest change is demographic pressure. This is similar to findings of Chirwa & Adeyemi (2020) and Hasan et al. (2020), who noted that population growth increases pressure on ecosystems and intensifies competition for land. Population growth in Kipkunurr results in increased demand for houses, fuelwood, cropland, and water, all of which fuel encroachment into forested areas. The population expansion in Kipkunurr, however, seems to be more natural (i.e., births), which makes it predictable and controllable if handled through land use planning and family-based education, in contrast to the larger continental studies where migration plays a significant role.

In addition, according to the findings, 65.7% of the respondents cited logging and resource extraction as a driver of the changes in land use and land cover. This highlights the substantial impact that extraction such as cutting of trees for poles, timber, charcoal, and firewood have on changing forest ecosystems leading to degradation. For instance, one of the impact is that it lowers the canopy cover, which exposes the forest floor to sunlight hence causing microclimatic and soil conditions which then cause ecological disturbances. This findings align with existing literature, for example, Jebiwott et al. (2021) who found that logging and agricultural expansion were major drivers of forest loss in the Mau complex . Similarly, in other parts of Africa like Zambia, Kaponda (2024) also discovered that increasing forest degradation was caused by unsustainable wood harvesting for fuel wood and construction especially in places with limited access to alternative sources of energy.

Urbanization and infrastructure development were also perceived as drivers of LULCC by 41.1% of respondents. Fischer et al. (2021) and Sang et al. (2022) found that increasing infrastructure, especially roads, towns, and utilities, frequently causes forest fragmentation and speeds up land conversion. This trend validates their findings. Both legal and illicit land use changes in Kipkunurr have probably been encouraged by the opening of formerly inaccessible areas due to market expansion and road construction. Conservation efforts are made more difficult by the fact that infrastructure-driven changes are oftenly externally influenced by development plans or policy, in contrast to agriculture, which reflects everyday sustenance demands. Even minor upgrades might hasten land use changes in sensitive areas, even if Kipkunurr's infrastructure development may not be as comprehensive as that of urbanizing regions.

Also, it is interesting to see that disasters were mentioned by 16.5% of respondents, and climate change by just 28.8% of respondents. This result contrasts with the growing body of scientific literature that highlights how climate variability affects ecosystems. The low attribution in this study, however, is not wholly unexpected. According to FAO (2020), tangible demands like food and shelter have a greater direct impact on land use decisions in many African communities than do long-term or abstract climate patterns. Despite increasing climatic impacts, communities may not immediately associate these changes with observable shifts in land cover due to the gap between scientific discourse and local knowledge. This explains why climate education is necessary, particularly in the development of adaptive forest management plans.

Thus, the findings indicate that land use and land cover dynamics (LULCC) in Kipkunurr is primarily as a result of human activities, with logging and resource extraction, population pressure, and agriculture being the main drivers that contribute to landscape change

5.4 Changes in forest health in Kipkunurr forest between 1995 and 2024 using NDVI

The second objective evaluated changes in forest health using the Normalized Difference Vegetation Index (NDVI), which indicated that Kipkunurr forest's vegetation health has significantly changed over the past twenty-nine years. In 1995, the NDVI values was 0.77, which is a sign of healthy and dense vegetation, particularly around the central and northwestern portions of the forest. The results confirm the study of Ojwala et al. (2022), which indicated that NDVI above 0.6 represents strong and healthy forests in the mountain settings. This implies that Kipkunurr forest was stable and undisturbed during this period Nevertheless, NDVI values reduced in the period between 2004 and 2014, with the highest value being 0.57. This loss shows the decline of the forest health, which is probably due to a reduction in the density of canopy and an increase in ecological pressure. This is similar to findings by Jackson (2022), who discovered that lower NDVI values in Kenyan highland forests are due to human-induced disturbances, including illegal logging, grazing, charcoal burning, and encroachment. These stressors were also confirmed by the forest officers interviewed, who identified that some of the common in Kipknurr forest include logging, illegal grazing, charcoal burning, and debarking by monkeys. Over the twenty nine years, lower NDVI values were observed in the Northeastern and Southeastern areas, particularly the buffer zones. These spatial distributions are similar to global studies such as that of Lees et al. (2022), which showed that forest edges closer to human settlements are mostly at risk of degradation owing to human activities most vulnerable to degradation owing human activities.

In 2024, the health of Kipkunurr forest had slightly improved since NDVI values increased to 0.61. This recovery may be linked to the current conservation measures, including community involvement in management and tree planting. Similar trends of recovery have been noted in semi-humid forests in Africa, where the recovery in terms of restoration action and policies results in an increase of NDVI values (Das et al., 2024). However, Kipkunurr forest has not recovered uniformly to return to 1995 levels, despite the recovery, which indicates that the forest is still vulnerable. Persistent moisture stress, illegal activities, and native tree regeneration following a delay, especially in the forest edges hinder the process of recovery.

These impacts of edge-related problems and core forest integrity importance may be seen in the distribution of the NDVI, where healthy vegetation is concentrated in the core areas, and disturbed vegetation can be seen on the edges. These results underscore the need to take more account of social and ecological variables into the forest conservation strategies. They further assert that NDVI is a viable tool for long-term monitoring, especially in instances where comprehending temporal and spatial changes of forest conditions is important

In summary, the NDVI of the Kipkunurr Forest implies that the forest, under increasing pressure, experienced a decline from 1995 to 2014, followed by signs of slight recovery by 2024 attributed to conservation efforts

5.5 Trends in temperature and rainfall of Kipkunurr forest between 1994 and 2024

The third objective of this study analyzed trends in temperature and rainfall in Kipkunurr forest and its surroundings over the past 30 years (1994-2024). The analysis, showed an increase in temperature during the period of study, with a moderate positive trend ($R^2 = 0.2701$), indicating a statistically significant rise. Rainfall patterns, were more erratic and unpredictable over the study period, showing a slight moderate positive trend (R^2 =0.0973), which was not statistically significant ($p = 0.0717$). The annual temperature increased from about 20.2°C in 1994 to approximately 20.8°C in 2024, which demonstrates a warming trend in line with global observations. The warming aligns with findings by Lindsey & Dahlman (2020), IPCC (2021), and Valipour et al. (2021), who observed the same increase in temperature caused by climate change. Local land use changes such soil degradation and deforestation, reduces evaporative cooling and increase ground heat, however, the temperature rise observed in Kipkunurr is most likely driven by global climate change.

These changes in temperature were confirmed by key informant interviews as well as appearing in the scientific records. The local forester and rangers reported noticeable increases in temperatures and erratic rainfall patterns in recent decades. They particularly emphasized that wet seasons are now shorter and less predictable, while dry seasons are now longer. Forest fires have also become frequent, especially between January to early March. According to forest rangers, the instances of burning charcoal during the dry months is one of the contributors to forest fires. These results suggest that there is an increased occurrence of heat stress in the forest ecosystem, which may lead to reduced soil moisture retention, alteration in species composition and risk of pests, diseases, and loss of biodiversity.

An increasing trend in rainfall data was observed, with annual totals rising from about 1,100 mm in 1994 to 1,350 mm in 2024. However, the increase was accompanied by shifts in onset of rainfall and a large inter-annual variability. This pattern is similar with the findings of Assede et al. (2023), who observed that the variability in rainfall in African forests is due to climate change. On the other hand, other studies such as that of Ochieng et al. (2020), reported rainfall decrease in other forested areas, indicating that topography and land use significantly influence regional climate changes.

Local environmental authorities further highlight the impacts of unpredictable rainfall in Kipkunurr. The NEMA key informant interviewed emphasized that during times of high rainfall, seasonal flooding, especially from the Moiben River, has gotten worse, deteriorating forest soils and vegetation. Such floods, combined with prolonged dry spells, have reportedly slowed tree growth, reduced seedling survival, and caused soil erosion and flash floods. These results suggest that drought and flood events are posing an increasing danger to the ecosystem, making regeneration more difficult and endangering the long-term health of the forest.

Community perceptions offer additional insights to the climate narrative. While 57.9% of local respondents noticed rising temperatures, which align with documented warming trends, views in rainfall were more varied and detailed. Although 99.5% acknowledged that rainfall patterns have changed, a significant number believed there had been an overall increase in rainfall. This perception aligns with the long-term data but may reflect community memory of extreme rainfall events, such as floods, more than a balanced understanding of annual averages. These findings illustrate that communities tend to interpret climate variability through the lens of extreme events like storms or river overflows, emphasizing the value of incorporating both scientific and experiential knowledge in climate assessments.

Overall, the climate trends in Kipkunurr Forest suggest a forest ecosystem under significant stress. Forest regeneration, soil stability, and species resilience are under stress due to rising temperatures and more unpredictable, but typically increasing, rainfall patterns. A coherent picture of the impacts of climate change is painted by the combination of key informant insights, meteorological information, and community views.

5.6 Interrelations between climate change, LULC change, and health status of Kipkunurr forest.

The fourth objective examined the relationship between climate changes, LULC change and health status of Kipkunurr forest. The findings show that land use and land cover (LULC) changes and forest health in Kipkunurr forest correlate strongly, with climate variables having little impact. NDVI and forest cover showed a statistically significant relationship ($r = 0.995$, $p < 0.01$), implying that better vegetative health is usually occurring in areas with a dense forest cover. This relationship agree to the results of Wilson and Norman (2018), who noted that dense intact forest ecosystems have higher NDVI values because of dense canopies and little disturbance. On the contrary, NDVI revealed negative and significant relationships with other LULC categories, including cropland ($r = -0.977$), grassland ($r = -0.864$) and shrubland ($r = -0.833$), suggesting that regions dominated by these uses have lower vegetation health. Similar patterns have also been reported in other East African landscapes, where declines in NDVI values are as a result of and logging, grazing pressures and agricultural encroachment have cause habitat loss and NDVI changes due to decreased NDVI values (Tadese et al., 2020). Interestingly, there were modest and statistically insignificant correlations between NDVI and climate factors, rainfall ($r =-0.044$) and temperature ($r= -0.268$). These findings differ from research conducted in arid and semi-arid areas, where vegetation cover is more susceptible to variations in rainfall due to limited water availability (Fayech & Tarhouni, 2021). Nonetheless, the forest environment in Kipkunurr is probably sustained by rather consistent and enough rainfall all year long, which lessens the sensitivity of the vegetation to little fluctuations in precipitation. They do, however, align with studies conducted in tropical and sub-humid regions, like Munkhdulam et al. (2022), who contended that LULC changes frequently have a greater impact on vegetation health than climate variations, especially in areas where deforestation and land degradation are common. The forest structure of Kipkunurr Forest may reduce direct climate-NDVI connections by offering some resilience against short-term climate fluctuation.

The regression analysis further reinforced the dominance of land use factors. The model explained 100% of the variance in NDVI ($R^2 = 1.000$), and was highly significant ($F = 712.967$, $p < 0.001$), although the unusually high R^2 raised concerns of overfitting or multicollinearity issues partly addressed by removing variables with high variance inflation factors (VIF). Forest cover emerged as the strongest predictor ($\beta = 1.282$, $p < 0.001$), followed by grassland ($\beta = 0.308$) and surface water ($\beta = 0.067$). These findings imply that preserving forest cover has a direct and measurable benefit on forest health, while other land uses exert pressure that reduces vegetative vigor.

Community survey responses supported these quantitative results. A large majority (91.6%) of households reported increasingly erratic rainfall patterns, while 83.2% believed land use changes were affecting the local climate. Additionally, 66.2% observed water scarcity and 76.2% noted increased soil erosion both of which are consequences of land degradation and loss of vegetation cover, as previously documented by Richardson et al. (2022). Although 76.7% of respondents acknowledged conservation efforts, only 15.7% deemed them highly effective. This suggests that current conservation strategies face challenges such as low community involvement and poor alignment with local realities, reflecting similar findings in other parts of Kenya and sub-Saharan Africa (Chomba et al., 2016).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter highlights key findings, conclusions, and recommendations of the study, that should have an impact on policy, advance existing knowledge on the area as well as recommend areas for further study.

6.2 Summary of findings

This research study was set to assess the impacts of climate change and land use land cover changes on Kipkunurr forest and its surroundings in Elgeyo Marakwet County, Kenya.

6.2.1 The spatio-temporal changes in land use and land cover in Kipkunurr forest between 1995 and 2024

The first objective which analyzed land use and land cover (LULC) changes in Kipkunurr forest and its surrounding areas between 1995 and 2024 revealed some key findings. Over the 29 years, forest declined from 57.45% in 1995 to 36.98% in 2024. However, the amount of forest cover recovered between 2014 and 2024, which was attributed to conservation efforts and the introduction of policies like the national program of planting 15 billion trees by 2032. Other classes such as shrubland and grassland continued to increase indicating ongoing land use pressure in spite the improvements in forest cover. It was also discovered that the Plantation Establishment and Livelihood Improvement Scheme (PELIS) is not undertaken in Kipkunurr Forest since it is classified as a natural forest. The majority of households use firewood as the main source of cooking energy, and 99.5% source it directly from Kipkunurr Forest. Also, the majority of the respondents (50.6%) indicated that the forest boundary beacons are either not visible or unclear.

6.2.2 Drivers of land use and land cover change in Kipkunurr forest and adjacent its surroundings

The primary driver of land use and land cover (LULC) changes in Kipkunurr forest and the surrounding areas is agricultural expansion as mentioned by 73.3% of the respondents. The other commonly cited drivers include population growth (67.0%) and logging and resource extraction (65.7%). Additionally, respondents identified other drivers with less impact such as urbanization and infrastructure development (41.1 %), climate change (28.8%) and natural disasters at (16.5%).

6.2.3 Changes in forest health in Kipkunurr forest between 1995 and 2024 using NDVI.

The second objective assessed Kipkunurr forest's health from 1995 to 2024 using the Normalized Difference Vegetation Index (NDVI). The findings of the analysis indicated that the health of Kipkunurr forest and its surroundings decreased over the period of study, with NDVI values being reduced to 0.77 in 1995 to 0.61 in 2024. Nevertheless, the NDVI values increased between 2014 (0.57) to 2024 (0.61), which reveals an improvement in forest health. The central and northwestern parts had high values of NDVI, implying healthy vegetation. Conversely, there was low NDVI values in the northeastern and southeastern parts of the forest, reflecting that there was a stress on the vegetation. The health of the forest was affected by factors such as illegal grazing, illegal logging, burning of charcoal, and destruction by monkeys that debark trees, and contribute deterioration. The major indicators of forest health, according to the local forester in Kipkunurr forest include, density of trees, soil moisture, natural regeneration and existence of pests and diseases.

6.2.4 Trends in temperature and rainfall of Kipkunurr forest between 1994 and 2024.

The third objective focused on analyzing temperature and rainfall trends in Kipkunurr forest and its surroundings between 1994 and 2024**.** The average annual temperature was 20.2°C in 1994 but showed an increasing trend, reaching about 20.8°C by 2024. On the other hand, rainfall increased from 1,100 mm to 1,350 mm, though it became more erratic and irregular, accompanied by a large variation in seasonal distribution. Shorter wet seasons and longer dry spells were also experienced in the area, which increased forest fires in, particularly during the dry season. Extreme weather occurrences like frequent floods from the Moiben River were linked to soil erosion, tree stress, and seedling loss. These findings were supported by community responses, with 57.9% reporting rising temperatures, and 99.5% confirming that rainfall patterns have changed, with many describing the impacts of extreme weather events as worrying and disruptive.

6.2.5 Interrelations between Climate change, LULC change and health status of Kipkunurr forest.

The fourth objective explored the relationship between climate change, land use land cover change, and the health status of Kipkunurr forest. The findings revealed a significant and positive ($r = 0.995$, $p < 0.01$) correlation between forest cover and NDVI, an indication that the vegetation health was higher in the forested locations. In contrast, NDVI and LULC types, including bareland ($r = -0.844$), cropland ($r = -0.977$), grassland ($r = -0.864$), and shrubland ($r = -0.833$), had negative and significant relationships, suggesting that the vegetation health was lower in regions dominated by these land uses. Temperature and rainfall had modest and non-significant relationships with NDVI ($r = -0.268$ and -0.044, respectively), indicating that climate variables had a limited influence on forest health. The regression model explained 100% of the variance in the NDVI (R2 = 1.000), and was statistically significant ($F = 712.967$, $p < 0.001$). However, the unusually high number suggests that there may be problems with the data or the model (e.g., overfitting or multicollinearity, which was addressed by deleting high-VIF variables). Forest cover ($\beta = 1.282$) was the most important and powerful predictor of NDVI ($p < 0.001$, followed by grassland ($\beta = 0.308$) and surface water ($\beta = 0.067$). In this study, LULC factors had a greater impact on forest health than climate variables, as temperature and rainfall were not significant predictors of NDVI in the model ($p > 0.05$). In terms of community perception, 91.6% of households observed erratic rainfall patterns, and 83.2% believed land use change has altered the local climate. In addition, 66.2% of the respondents noticed water scarcity, and 76.2% saw increased soil erosion, linking soil degradation and water stress to forest decline. Though 76.7% acknowledged conservation efforts, only 15.7% found them highly effective, citing issues such as limited community involvement and poor local adaptation.

6.3 Conclusions

This study set out to assess the impacts of land use and land cover changes (LULCC) and climate variability on forest cover and health in Kipkunurr Forest between 1995 and 2024. The analysis revealed a significant decline in forest cover from 57.45% in 1995 to 35.06% in 2004, primarily driven by agricultural expansion, settlement, and illegal logging. However, a modest recovery between 2014 (35.11%) and 2024 (36.98%) indicates that reforestation efforts and conservation measures are beginning to yield positive results. The most significant drivers of land use and land cover change, according to community respondents, were agricultural expansion (73.3%), population growth (67.0%), and logging and resource extraction (65.7%).

Using NDVI, forest health was observed to deteriorate steadily up to 2014, with edge areas particularly vulnerable, before showing signs of improvement by 2024. This pattern corresponds with intensified human activities and climatic stressors. Climate data and community perceptions both highlighted increasing temperatures and erratic rainfall, which in turn affect both forest and agricultural systems. Regression analysis revealed that land use/land cover changes particularly forest reduction and agricultural expansion were the strongest predictors of NDVI changes over the study period, while climate variables (temperature and rainfall) had a comparatively weaker but still notable influence. These results affirm that human-driven land use changes are the dominant factor affecting forest health, although climatic stressors exacerbate vegetation degradation, especially in drier years.

The main contribution of this research lies in its integrated approach, combining geospatial data, climatic trends, and socio-economic factors to present a comprehensive picture of forest dynamics in Kipkunurr forest and the surrounding landscapes. Theoretically, it enriches the understanding of forest-climate-human interactions in highland water tower ecosystems. On a practical point of view, it provides data that can guide targeted conservation efforts. From a policy perspective, the findings support the need for improved enforcement of forest protection laws to deal with issues of encroachment and illegal logging, especially in areas where beacons are not visible. It also stresses the promotion of alternative livelihoods to reduce the dependence on forest resources. Moreover, the study supports the investment in modern monitoring tools like remote sensing and GIS, to enable continuous tracking of land use changes and strengthen evidence-based decision making in forest management.

In summary, the study contends that although Kipkunurr Forest has shown modest signs of recovery in forest cover and vegetation health particularly between 2014 and 2024, it remains vulnerable to ongoing threats like unsustainable land use and overexploitation of resources. The strong correlation between land cover change and forest health, coupled with community reliance on forest resources, highlights the urgent need for targeted, site-specific interventions. These should include visible and better boundary demarcation, agroforestry promotion, regulated harvesting, reforestation of degraded areas, and enforcement of land use regulations.

6.4 Recommendations

The results of this study lead to the following recommendations;

1. According to the study findings, more than half (50.6%) of the respondents reported that the boundary of Kipkunurr Forest, as marked by beacons, is unclear or not visible. This lack of clarity hinders effective monitoring and enforcement of legal forest boundaries, thereby increasing the risk of encroachment and other illegal activities. Therefore, it is recommended that the Kenya Forest Service in collaboration with Elgeyo Marakwet County Government carry out proper boundary demarcation using durable, visible, long lasting markers.

2. The conversion of 3,650 ha of forest to shrubland and grassland led to their significant increase in the 5km buffer zone and even inside the forest, according to the results from the first objective. This is a sign of continued land degradation and human pressure and thus the earliest indications of forest loss. Therefore, in response to this, focused reforestation and regeneration initiatives should be given priority to grassland and shrubland areas particularly the ones close to forest boundaries by the County Government, KFS and NGOs.

3. Forest health generally decreased over the 29- year period from 0.77 in 1995 to 0.61 in 2024, according to the NDVI values. The most affected regions of the forest are the northeastern and the southeastern which had low NDVI values, suggesting vegetation stress. Therefore, site specific forest health interventions such as fencing or grazing control measures should be prioritized in these zones to restore vegetation cover by the KFS and KWS.

4. According to the study findings, 99.5% of families rely on firewood for cooking and 98% of them get it straight from Kipkunurr forest, placing stress on the forest biomass which is unsustainable. Therefore, it is recommended that alternative sources of energy/green energy should be introduced to surrounding communities to lessen their dependence on Kipkunnur Forest for wood fuel. In addition, the County Government and KFS should provide fast-maturing seedlings to be planted in their farms through agroforestry.

5. Increased climate variability characterized by rising temperatures, erratic rainfall, river flooding (particularly Moiben River), and dry-season forest fires (linked to illegal charcoal burning) have exacerbated vegetation stress, soil erosion, and seedling mortality. To address these issues, the implementation of climate-resilient land management strategies is crucial. These include restricted forest access during high-risk periods, soil erosion control techniques like terracing and check dams, and watershed protection efforts like vegetation buffer strips and riverbank stabilization. These interventions should be coordinated by KFS and the County Government in collaboration with environmental NGOs.

6. The results indicate increased agricultural activities within and around Kipkunurr Forest and most of the respondents (73.3%) cited agricultural expansion as a driver of LULC change, suggesting ongoing encroachment that threatens forest integrity. Therefore, it is recommended that the County Government in partnership with the KFS enforce land use zoning regulations more strictly to prevent unauthorized land conversions and promote sustainable land use practices.

6.5 Areas of further research

1. The amount of forest cover in Kipkunurr forest improved slightly; however, issues such as illegal logging and illegal grazing still exist. It is recommended that a study carried out to examine the success of present forest management initiatives including the Forest Conservation and Management Act (2016), Participatory Forest Management (PFM), and Community Forest Association (CFAs). The study should also evaluate the impact of afforestation and reforestation efforts and identify gaps to improve the management of the forests and to facilitate the proper utilization of natural resources.
2. Since community use of forest resources remains high, future research could assess the level of community awareness and participation in conservation, and how this affects the success of Participatory Forest Management (PFM).
3. Low NDVI values in some areas of Kipkunurr, especially near the edges and prolonged dry seasons may indicate high fire risk. Therefore, it is recommended that future studies

model risk of forest fires and identify suitable locations for the establishment of fire watch towers for the protection of Kipkunurr forest.

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APPENDICES

APPENDIX I: Household Questionnaire

NAME OF INTERVIEWER ____

COUNTY ____

LOCATION _____________________________________

SUB-LOCATION______________________________DATE (D/M/Y): ____________________________

GPSX___________________________GPSY____________________Z___________________

Part A: General Information

1. **Gender**: (1) Male (2) Female
2. **Age**: -----
3. **Education level:** (1) No formal education (2) Primary (3) Secondary (4) Tertiary 5) University

4. **Marital status**: (1) Single (2) Married (3) Divorced (4) Widowed 5) Other (specify)…………

5. **Main occupation**: (1) Farmer (2) Business (3) Teacher (4) Public servant (5) Casual labourer (6) Others (specify) …………………

6. **What is your household's average monthly income?**

   1) Below 10,000 (2) 10,000–20,000 (3) 20,000–30,000 (4) Above 30,000

7. How long have you lived in this area? ------- (Years)
8. Size of household …………(Number of people)
9. Distance from your home to Kipkunurr forest………(Km)

Part B: Land use and land cover changes

10. Do you own land?

    1) Yes 2) No

11. What is the size of your land?.............(acres)
12. State the type of land tenure security of your land

    1) Title deed 2)Agreement 3) Letter of reservation 4) Other (specify)------

13. How many acres of your land is used for farming? .... (acres)
14. What types of crops do you grow?

    1) Maize 2) Beans 3) Vegetables 4) Fruits 5) Others (specify) …………

15. How many acres are used for your house and compound? ……..

16. How many acres is used for grazing? …………

17. How many acres is used for woodlots? …………….

18. How many trees are in your woodlot? …………

19. What types of trees are in your woodlot? …………….

20. Have you been given a portion of land inside the forest under shamba system (PELIS)?

    1) Yes 2) No

    If Yes, specify the area and total farm acreage …………………………..

21. What type of livestock do you keep and how many in number?

    1) Cattle ……2) Sheep …..3) Goats ……4) Donkeys……5) Poultry ….. 6) Others (specify)………

22. Is your land directly bordering the forest?

    1) Yes 2) No

    If yes, is there a beacon between you farm and the forest?

    (1) Beacon exists (2) No beacon

23. What benefits do you get from Kipkunurr forest?

    1) Firewood
    2) Timber
    3) Pasture/grazing land
    4) Water sources
    5) Honey
    6) Medicinal plants
    7) Rain
    8) Wildlife

9) Others (specify)-----

24. State your main source of energy for lighting

1) Electricity
2) Solar power
3) Kerosene lamp
4) Generator
5) Others (specify)……………

25. State your main source of energy for cooking

1) Firewood
2) Charcoal
3) Gas
4) Biogas
5) Others (specify) ………….

26. If fuel wood is your main source of energy, where do you get your wood fuel from?

1) Own farm
2) Buying from other farms
3) Kipkunurr forest
4) Other (specify) ……..

27. If your source of wood fuel is Kipkunurr forest, please state:

a) How much wood fuel do you use per month?(Please specify the quantity in bundles): ___________

b) If applicable, how much do you pay to the Kenya Forest Service (KFS) for the wood fuel?

(Please specify the amount in Kenyan Shillings): ___________

28. What type of building materials is your main house made of?

a) Roof …………….

b) Walls ……………

c) Floor ……………

29. Which building materials do you obtain from Kipkunurr Forest?

1) Timber

2)

30. a) Over the last 30 years, have you observed any changes in land use or land cover in Kipkunurr Forest and the adjacent landscapes?

(1) Yes (2) No

b) If yes, explain the changes

……………………………………………….

Part D: Drivers of Land Use Land Cover Change

The table below lists various factors that may be driving changes in land use land cover changes in Kipkunurr Forest. For each factor, please indicate the extent to which you consider it a driver of change of land use/land cover by selecting Low, Very low, Moderate, High, Very high and None.

Driver of Land Use/Land Cover Change	Low	Very low	Moderate	High	Very high	None
1. **Agricultural expansion** (e.g., crop farming, livestock grazing)						
2. **Logging and resource extraction** (e.g., timber, charcoal, firewood						
3.**Urbanization & infrastructure development** (e.g., roads, housing, schools)						
4.Population growth in surrounding areas						
5.Climate change						
6. **Natural disasters** (e.g., floods, landslides, wildfires)						

Part E: Trends in temperature and rainfall (Community perceptions on climate changes)

31. Have you noticed any changes in temperature in Kipkunurr Forest and its surroundings over the past 30 years?

    1) Yes 2) No

If yes, what kind of changes have you observed?

1) Increased temperatures
2) Decreased temperatures
3) hotter nights
4) colder mornings
5) longer hot or cold seasons
6) Others (specify) …………..

32. Have you noticed any changes in rainfall patterns in Kipkunurr Forest and its surroundings over the past 30 years?

1) Yes 2) No

If yes, what kind of changes have you observed?

1) Increased rainfall
2) Decreased rainfall
3) Longer drought periods
4) Unpredictable rainfall
5) Shorter rainy seasons
6) Longer rainy seasons
7) Others (specify) …………

33. a)What months of the year do you experience the heaviest rainfall?

……………………………………………

b) Has this changed compared to the past?

1) Yes 2) No

If yes, explain how? ....

34. Have these changes in temperature and rainfall affected the growth or health of the forest?

1) Yes 2) No

If yes, explain how?

…………………………………………………………………………………………………

………..

Part F: People Perception on the Relationship between Climate change, LULC Change, and Health Status of Kipkunurr Forest an its surroundings

35. Have the changes in land use (e.g., converting forest to farmland) contributed to shifts in local climate?

1) Yes 2) No

If yes, explain how? ....

…………………………………………………………………………………………………

36. What impacts have climate changes had on the forest cover, health, and adjacent surroundings of Kipkunurr Forest? (Choose all that apply)

37. Have there been any forest conservation efforts to mitigate the impacts of climate change or land use changes on Kipkunurr forest and its surroundings?

1) Yes 2) No

If yes, how effective have they been?

……………………………………………………………………………

38. What other important information do you have on Kipkunurr forest relevant to this research? ....

Thank you so much for answering my questions.

APPENDIX II: Key Informant Interview Schedule

1. What are the significant changes in land use / land cover of Kipkunurr forest and adjacent landscapes?
2. What are the drivers of LULC change in Kipkunurr Forest and adjacent landscapes in Elgeyo Marakwet County?
3. How much wood is collected from the forest? (in bundles)
4. What indicators do you use to assess forest health (e.g., tree density, leaf color)?
5. What factors do you believe have the most significant impact on the forest's health?
6. Can you describe any noticeable changes in temperature and rainfall patterns over the past 30 years?
7. How do you think changes in temperature and rainfall have affected the forest?
8. Are there any specific incidents (e.g., droughts, floods) that have had a significant impact on the forest?
9. What do you think is the combined impact of climate change and land use changes on forest health and cover?
10. What other information do you have concerning Kipkunurr forest and adjacent landscapes

APPENDIX III: Research Permit

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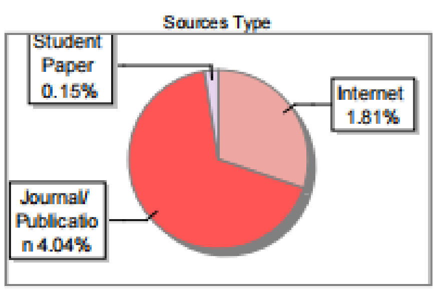

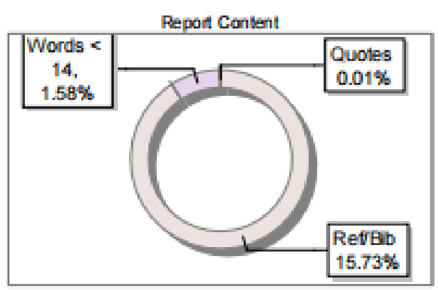

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