

**DRIVERS OF LAND USE, LAND COVER CHANGE,
CLIMATE CHANGE VULNERABILITY AND
ADAPTATION OPTIONS IN NAROK NORTH SUB-
COUNTY, KENYA**

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AGRICULTURE AND TECHNOLOGY**

2026

**Drivers of Land Use, Land Cover Change, Climate Change
Vulnerability and Adaptation Options in Narok North Sub-County,
Kenya**

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**A Thesis Submitted in Partial Fulfilment of the Requirements for
the Degree of Master of Science in Environmental Legislation and
Management of the Jomo Kenyatta University of Agriculture and
Technology**

2026

DECLARATION

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

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DEDICATION

I dedicate this thesis to my Lord and Savior, Jesus Christ, who has been my anchor, guide, and strength through every season of this journey. To my beloved family, especially my husband and children your patience, love, and unwavering support made this possible. To my dear parents Mr. and Mrs. Kodonyo whose wisdom, prayers, love, sacrifices and legacy of community leadership inspire me every day. To the resilient people of Narok, whose challenges, courage, and connection to the land gave this research both purpose and meaning, I am truly grateful.

ACKNOWLEDGEMENT

I am sincerely grateful to everyone who supported and encouraged me throughout the course of this thesis. Above all, I give thanks to God for blessing me with the wisdom, strength, and good health that sustained me during this academic journey. His grace has been my constant source of peace and perseverance. My heartfelt appreciation goes to my supervisors, Prof. Erastus Gatebe and Dr. Paul Njogu. Their expert guidance, consistent feedback, and unwavering support played a vital role in shaping the direction and quality of this work. I also thank the county officials and community members of Narok North Sub-County, whose openness and cooperation were key to the successful collection of data and implementation of this study. To my dear family, close friends, and colleagues, your faith in me, words of encouragement, and support in countless ways have meant everything. You walked this path with me, and I am forever grateful. Lastly, I acknowledge every person who contributed in any form to the completion of this research. Your kindness and input did not go unnoticed.

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ABBREVIATIONS AND ACRONYMS

ASAL	Arid and Semi-Arid Land
CBEWS	Community-Based Early Warning Systems
CFA	Community Forest Association
CIDP	County Integrated Development Plan
COPs	Conferences of Parties
EbA	Ecosystems-based Adaptation
EMCA	Environmental Management and Coordination Act
ESIA	Environmental and Social Impact Assessment
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GoK	Government of Kenya
IPCC	Intergovernmental Panel on Climate Change
KMC	Kenya Meat Commission
KMD	Kenya Meteorological Department
LULC	Land Use, Land Cover Change
NAP	National Adaptation Plan
NCCAP	National Climate Change Action Plan
NCCC	National Climate Change Council
NDMA	National Drought Management Authority
NGO	Non-Governmental Organization
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OLI	Operational Land Imager
SDG	Sustainable Development Goals
SLM	Sustainable Land Management

TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
UHIs	Urban Heat Islands
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Program
WMO	World Meteorological Organization

ABSTRACT

Narok North Sub-County is experiencing significant changes in land use that are increasing its vulnerability to climate-related hazards, such as floods and droughts. These changes have weakened traditional coping mechanisms, exposing local communities to greater socio-economic and ecological risks. Despite the crucial role of land use in shaping environmental resilience and adaptation, there is limited understanding of its specific impacts on local livelihoods and adaptation options. Specifically, this study sought to: (i) examine current land use practices and identify the key drivers of land use and land cover change (LULCC) in Narok North Sub-County; (ii) analyze LULCC over the past 32 years using Landsat 5, Landsat 7, and Landsat 8/9 imagery and assess its influence on the occurrence of floods and droughts; and (iii) propose evidence-based strategies for enhancing community resilience and climate change adaptation. This study adopted a mixed-methods approach, combining remote sensing analysis of Landsat imagery (1990–2022) with household surveys and key informant interviews. Household surveys and KIIs were used to identify the key drivers of land use and land cover change, while satellite imagery analysis assessed the extent and patterns of these changes. The study also examined the impacts of land use transformations on extreme weather events such as floods and droughts, along with available adaptation options. Landsat 5, Landsat 7, and Landsat 8/9 imagery were utilized to detect and quantify shifts in LULCC, focusing on transitions from forests and grasslands to agricultural and urban land uses. The findings reveal the drivers of land use and land cover change as agricultural expansion, population growth and urbanization. These transformations are leading to a shift from sustainable land management practices to more intensive agricultural activities, resulting in the fragmentation of land, deforestation, and degradation of natural habitats. Such changes are exacerbating the region's vulnerability to climate-related hazards, which are projected to intensify due to climate change. Remote sensing analysis indicated that forest cover loss was most pronounced between 2000 and 2010, with 183.81 ha (7.3%) lost in that decade alone, and continued declining post-2010, resulting in a total loss of 329.46 ha (12.8%) over the 32-year study period, driven by increasing farmland demand and settlement expansion. While cropland showed fluctuations due to evolving land management practices, built-up areas steadily expanded in line with urban growth. The study identifies gaps in land use planning, including the absence of integrated spatial frameworks and weak inter-agency coordination, zoning enforcement, and disaster risk reduction. Plans for community preparedness and multi-hazard assessments are absent from disaster risk reduction initiatives which have contributed to further environmental degradation. The lack of access to real-time climate data and insufficient investment in climate-resilient infrastructure has heightened vulnerability in the region. These findings highlight the need for implementation of stronger governance frameworks and sustainable land management strategies to mitigate climate risks and enhance long-term resilience by both the

National and County Government of Narok.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Over the years, human Influence on the Earth's surface has significantly increased due to various land use activities. These include converting forests, wetlands, and other natural ecosystems into agricultural fields, expanding urban infrastructure, and industrial developments (Gupta et al., 2024). Additionally, shifts in how human-dominated lands are managed have contributed to this transformation. Examples such as widespread deforestation, small-scale subsistence farming, intensified food production, and growing cities continue to alter global land patterns (Winkler et al., 2021). While these practices vary across regions, most are driven by the immediate need to extract resources for human benefit, which often results in ecological damage. Scientific studies conducted over several decades have established a strong connection between land use changes and adverse environmental outcomes. These include changes to the Earth's atmosphere, carbon cycle, and ecosystem health (Horan, 2022). A substantial portion, approximately 35% of carbon dioxide emissions linked to human activity since the mid-19th century, is attributed to how land is used (IPCC, 2022). Moreover, the way land is managed affects local climate conditions by influencing heat exchange and water dynamics (Velasco-Muñoz et al., 2021).

Land conversion and overuse also disrupt the water cycle, as freshwater is increasingly diverted for irrigation, household, and industrial use (FAO, 2020). Excessive fertilizer and chemical inputs from farming surpass natural nutrient levels, degrading water quality in both freshwater and coastal zones (Gupta et al., 2024). The destruction of natural habitats, declining soil health, and unsustainable harvesting of native species have led to biodiversity loss (UNEP, 2021). Despite these challenges, global dependency on natural resources continues to grow. Current estimates suggest that humans utilize nearly one-

third to one-half of the Earth's biological productivity (IPCC, 2022). As both population and development demands increase, pressure on natural ecosystems is expected to rise even further. The role of land use in supporting human well-being presents a paradox: while it is essential for securing food, water, materials, and shelter, some land-use activities simultaneously degrade the very ecosystems that sustain life.

Countries in East Africa, including Kenya, face heightened exposure to climate-related hazards such as droughts, floods, fluctuating rainfall patterns, and extreme temperatures. These impacts are intensified by limited adaptation capacity in many communities. As a result, there is an urgent need for effective and context-specific approaches to manage the dual challenges of climate change and land degradation in the region. Narok North Sub-County, situated within Narok County, Kenya, is characterized by its diverse landscapes, including the fertile Mau Forest and expansive pastoral lands traditionally inhabited by the Maasai community. This region has experienced notable shifts in land use patterns in recent years, largely influenced by agricultural expansion, rising population numbers, urban development, and infrastructure projects.

Historically, Narok North Sub-County was predominantly covered by natural vegetation and forests that supported pastoralism as the primary livelihood for the Maasai community, (County Government of Narok (CGN, 2018). The Maasai traditionally practiced extensive grazing, which maintained ecological balance and biodiversity. However, increasing population pressure in Narok North Sub-County, whose population was projected to reach approximately 69,000 by 2025 (CGN, 2018), has contributed to a gradual shift from traditional pastoralism toward sedentary agriculture and increased land subdivision. This transition has resulted in the conversion of grazing lands into agricultural fields and expanding urban settlements, leading to significant land fragmentation and disruption of natural drainage systems (CGN, 2023). Consequently, these land-use changes have heightened environmental vulnerabilities by increasing flood risks during rainy seasons and exacerbating drought impacts during prolonged dry periods

(IPCC, 2022).

Empirical evidence indicates that flooding incidents in Narok Town have increased by more than 25% over the past decade (Kenya Forest Service (KFS, 2023). This trend has been closely associated with declining vegetation cover and changes in land surface conditions. Furthermore, deforestation in ecologically sensitive areas, particularly the Mau Forest, a critical water catchment for the region, has contributed to a substantial reduction in forest cover, adversely affecting biodiversity and hydrological processes (UNEP, 2021). The degradation of these ecosystems has increased both the frequency and intensity of flooding in downstream areas, especially Narok Town, which experienced several severe flood events between 2018 and 2021. These events displaced thousands of residents and caused extensive damage to infrastructure, property, and livelihoods (World Bank, 2022).

Climate projections further indicate an increasing likelihood of extreme weather events across Narok County. According to County Government of Narok (2023), the maximum five-day precipitation (P5D) value is projected to increase by at least 15 mm, particularly in the northern part of the county. This projection suggests an elevated risk of flooding and associated socio-economic impacts in vulnerable areas. The anticipated increase in precipitation intensity, combined with ongoing land-use changes and environmental degradation, is likely to exacerbate flood hazards and undermine community resilience unless effective adaptation and mitigation measures are implemented.

This aligns with observed patterns of climate variability and reinforces the vulnerability of Narok North Sub-County to extreme hydrological events. As climate change exacerbates these challenges, the interplay between land use changes and climate variability is likely to further expose local populations to natural hazards. Vulnerability assessments indicate that the adaptive capacity of communities in Narok North is diminishing, primarily due to reduced access to resources and shifting climatic patterns,

emphasizing the urgent need for effective adaptation strategies to enhance resilience (IPCC, 2022).

1.2 Statement of the Problem

Narok North Sub-County is characterized by diverse ecosystems, including savannah grasslands, dryland shrubland, riparian corridors along seasonal rivers, and pockets of indigenous forest cover, particularly in areas bordering the Mau Forest (CGN, 2023). However, it is undergoing significant land use and land cover changes (LULCC) driven by population pressure, agricultural expansion, settlement development, and infrastructure growth. These changes are contributing to environmental degradation, weakening ecosystem integrity, and increasing vulnerability to climate-related hazards such as floods and droughts.

While previous studies have examined the socio-economic impacts of LULCC in the region (CGN, 2023), there remains a critical gap in understanding how these land changes interact with climate variability to influence community vulnerability and resilience. Furthermore, limited attention has been given to evidence-based adaptation strategies that could support sustainable land management and strengthen local adaptive capacity. This study sought to address the existing knowledge gap regarding the specific drivers of land use and land cover change (LULCC), alongside climate change impacts, on vulnerability and the adaptation options available to communities in Narok North Sub-County.

1.3 Rationale

Land use and land cover change is one of the most significant yet least systematically documented environmental challenges in Kenya's arid and semi-arid lands (ASALs) and transitional agro-pastoral zones. Narok North Sub-County sits at a critical intersection, it hosts part of the globally significant Mau Forest Complex while simultaneously undergoing rapid agricultural expansion, land subdivision, and settlement growth.

Despite its ecological importance, no study has comprehensively examined the three-way relationship between LULCC drivers, climate hazard intensification, and community adaptation options in this specific locality. Existing studies on LULCC in Narok County have focused primarily on socio-economic impacts without integrating remote sensing analysis or community-level vulnerability assessments (CGN, 2023). This study addresses that gap by combining spatial analysis of 32 years of Landsat imagery with primary household and key informant data to produce a locally grounded, evidence-based assessment that can directly inform county-level land use planning and climate adaptation policy.

1.4 Justification

The justification for this study is grounded in empirical, policy, and community-based considerations. Evidence indicates a growing environmental risk: flooding incidents in Narok Town have increased by over 25% in the last decade, while remote sensing analysis shows a decline in forest cover of 329.46 ha (12.8%) between 1990 and 2022, with the most significant loss occurring between 2000 and 2010 (Kenya Forest Service, 2023). These trends reflect the cumulative effects of unmanaged land use and land cover change (LULCC), with direct implications for hydrological stability and ecosystem services.

At the policy level, the Narok County Integrated Development Plan (CIDP) 2023–2027 identifies climate vulnerability as a priority concern; however, it lacks a spatially explicit and data-driven baseline to guide targeted interventions. At the community level, pastoral and agro-pastoral livelihoods in Narok North are increasingly exposed to climate stress, while traditional coping mechanisms are eroding faster than formal adaptation responses are being implemented.

This study addresses these gaps by integrating remote sensing and spatial analysis to quantify LULCC, identify its key drivers, and develop evidence-based adaptation

strategies. In doing so, it contributes both to academic knowledge on land use dynamics and to practical policy formulation for climate resilience in Narok County.

1.5 Objectives

1.5.1 General Objective

To analyse land use and land cover change in Narok North Sub-County between 1990 and 2022, assess its contribution to climate vulnerability, and inform evidence-based land management and adaptation strategies for the region.

1.5.2 Specific Objectives

- i. To examine current land use practices and analyse the key drivers of land use and land cover changes in Narok North Sub-County.
- ii. To analyse land use and land cover changes over the past 32 years using Landsat 5, Landsat 7, and Landsat 8/9 imagery and assess their influence on the occurrence of floods and droughts.
- iii. To identify and recommend land management and climate adaptation strategies, grounded in remote sensing findings and community-level survey data, that address the specific drivers of LULCC-induced vulnerability to floods and droughts in Narok North Sub-County.

1.6 Research Questions

- i. What are the current land use practices in Narok North Sub-County, and what are the main drivers contributing to land use and land cover changes in the area?

- ii. How have land use and land cover patterns changed over the past 32 years, and what impacts have these changes had on the frequency and intensity of floods and droughts in Narok North Sub-County?
- iii. What targeted land management and climate adaptation strategies, informed by LULCC evidence and community data, can reduce vulnerability to climate-related hazards in Narok North Sub-County?

1.7 Hypotheses

This study was guided by the following hypotheses:

H₁: Agricultural expansion, population growth, and infrastructure development are the primary drivers of land use and land cover change (LULCC) in Narok North Sub-County between 1990 and 2022.

H₂: Land use and land cover changes between 1990 and 2022 have significantly increased the frequency and severity of flood and drought events in Narok North Sub-County.

H₃: Evidence-based land management and adaptation strategies informed by LULCC data can meaningfully reduce community vulnerability to climate-related hazards in Narok North Sub-County.

1.8 Significance of the Study

The findings of this study demonstrate that land use and land cover change (LULCC) is a key driver of increasing climate vulnerability in Narok North, particularly through its effects on the adaptive capacity of pastoral and agro-pastoral households. By combining spatial analysis with locally grounded insights, the study provides an empirical basis for more targeted and context-specific resilience interventions. The spatial datasets and LULCC trends generated offer a practical foundation for improved land use planning,

including zoning, forest conservation, and the integration of climate risk into development frameworks such as the Narok County Integrated Development Plan (CIDP). In doing so, the study also supports the implementation of national and global climate priorities, including the Climate Change Act (2016), the National Climate Change Action Plan, and the Sustainable Development Goals.

More broadly, the research contributes to ongoing scholarly discussions on the relationship between land use change and climate vulnerability in East Africa, while demonstrating the value of integrating remote sensing and participatory approaches within a mixed-methods framework.

1.9 Conceptual Framework

This conceptual framework illustrates the relationship between land use practices, land use/cover change (LULCC), and climate variability as key drivers of environmental change in Narok North Sub-County. These interactions contribute to environmental degradation, which in turn reduces agricultural productivity and increases community vulnerability, particularly in relation to food and water insecurity.

The Independent Variables include demographic pressure, agricultural expansion, charcoal production, and weak institutional governance. These drivers influence land use dynamics, resulting in Intervening Variables such as forest loss, grassland fragmentation, cropland expansion, and built-up area growth.

The resulting changes contribute to Dependent Variables, which are expressed as climate-related hazards including drought, flooding, biodiversity loss, and livelihood disruption. Moderating Variables such as governance capacity, institutional coordination, community awareness, and access to climate information influence the severity and direction of these impacts.

Finally, Response Variables include adaptation and mitigation strategies such as reforestation, rangeland management, water harvesting, and policy interventions aimed at strengthening community resilience.

1.9.1 Drivers–Pressures–State–Impact–Response (DPSIR) Analytical Framework

The DPSIR (Drivers–Pressures–State–Impact–Response) framework is a widely applied environmental management model used to explain the interactions between human activities and environmental change processes. It provides a structured cause–effect relationship that helps in understanding how socio-economic activities influence environmental conditions and the resulting implications for ecosystems and human well-being.

In this study, the DPSIR framework is used as a supporting analytical lens to complement the conceptual framework presented in Chapter One. It helps to explain how land use dynamics and climate-related factors interact to produce environmental change and vulnerability outcomes in Narok North Sub-County.

The Drivers in this framework represent the underlying socio-economic and demographic forces such as population growth, livelihood dependence on natural resources, and economic activities that increase demand for land and natural resources. These drivers influence land use decisions at the household and community level.

The Pressures refer to the direct human activities arising from these drivers, including land conversion for agriculture, deforestation, overgrazing, and unsustainable farming practices. These activities exert stress on land resources and ecosystems. The State describes the resulting condition of the environment, particularly changes in land use and land cover such as vegetation loss, soil degradation, and fragmentation of landscapes. These changes reflect the evolving ecological condition of the study area.

The Impacts are the consequences of environmental state changes on both ecological systems and human livelihoods. These include reduced agricultural productivity, increased exposure to climate variability, water scarcity, and heightened vulnerability of communities. The Responses represent the measures taken by institutions and communities to address these challenges. These include land management policies, climate adaptation strategies, conservation initiatives, and sustainable land use interventions.

In summary, the DPSIR framework provides a useful systems-based perspective for interpreting the interactions between human activities, environmental change, and vulnerability. In this study, it strengthens the interpretation of land use change processes while aligning with the conceptual framework developed in Chapter One.

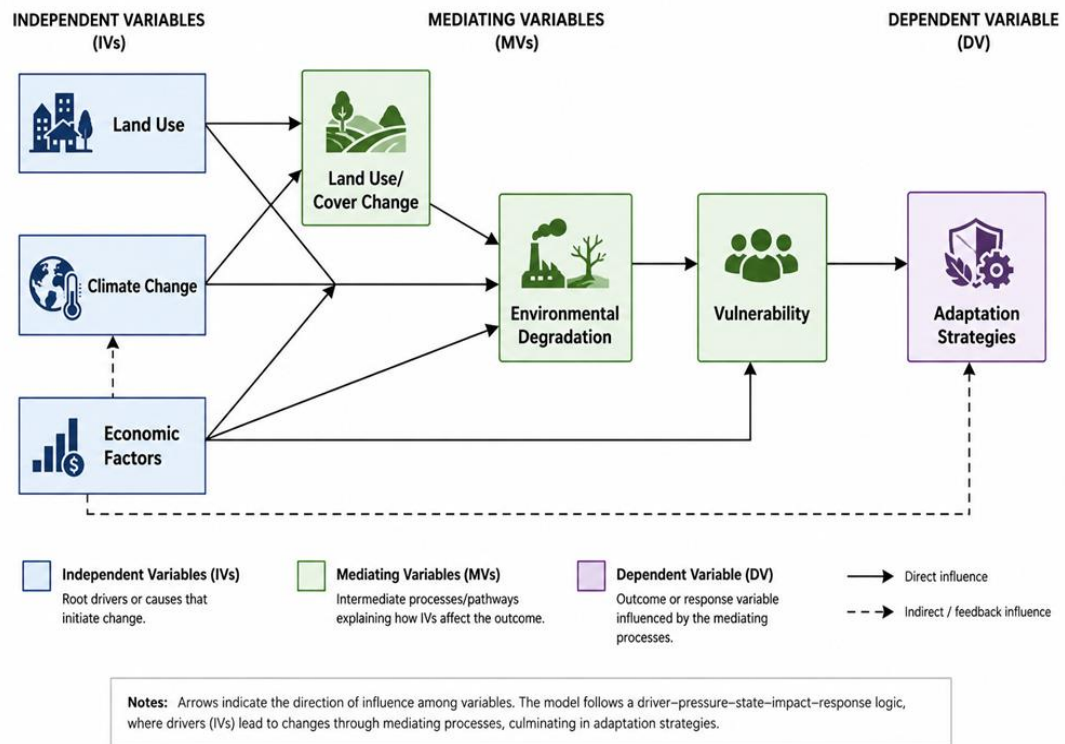


Figure 1.1: Conceptual Framework

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction to Land Use and Land Cover Change (LULCC)

Land use patterns have shifted dramatically worldwide over the past century, with recent estimates indicating that these changes are far more extensive than previously thought (IPCC, 2021). The rapid growth of the global population has intensified demand for land for agriculture, housing, and infrastructure development, resulting in the widespread conversion of natural landscapes into built environments and a sustained decline in land available for diverse ecological functions over the past six decades (FAO, 2020). This transformation is bidirectional in its relationship with climate: while land use change contributes significantly to greenhouse gas emissions accounting for approximately 35% of anthropogenic CO₂ since the mid-19th century climate change in turn alters the very land systems on which human populations depend, through rising temperatures, unpredictable precipitation, and intensified extreme weather events (IPCC, 2022).

Globally, land use change is recognized as a primary driver of environmental degradation. Deforestation reduces the capacity of ecosystems to sequester carbon while simultaneously increasing surface runoff, disrupting hydrological cycles, and heightening vulnerability to floods and droughts (IPBES, 2023). Urban expansion further compounds this by displacing natural vegetation and diminishing the climate-regulating functions of ecosystems (IPCC, 2022). These dynamics are not confined to any one region; comparable trends have been documented across tropical and subtropical zones, from the Amazon Basin in Brazil to forest-adjacent agricultural frontiers in Southeast Asia, where large-scale land conversion continues to accelerate (Curtis et al., 2018).

Across sub-Saharan Africa, the drivers are broadly similar but the mechanisms are more localized: smallholder agricultural expansion, fuelwood extraction, charcoal production,

and population-driven settlement growth are the dominant forces reshaping landscapes at the expense of forest and grassland cover (UNEP, 2021; IPCC, 2022). The region's rapid and often unregulated urbanization has placed additional pressure on land resources and ecosystem services, particularly around secondary towns and peri-urban zones (UN-Habitat, 2023). These pressures are compounded by weak land governance, insecure tenure systems, and limited enforcement of environmental regulations, which together accelerate land fragmentation and degradation (World Bank, 2022).

In Kenya, these continental trends manifest with particular intensity. Since independence, forest cover has declined from approximately 10% of national land area to around 6%, with the country losing an estimated 12,000 hectares annually to deforestation driven primarily by agriculture, charcoal production, and infrastructure development (GFW, 2024). Between 2013 and 2020 alone, 80% of Kenya's tree cover loss occurred within natural forest, equivalent to 45.8 Mt of CO₂ emissions (GFW, 2024). Land tenure transitions particularly the shift from communal to individual ownership have accelerated subdivision of rangelands and encroachment into ecologically sensitive areas, a pattern well documented across the Rift Valley and ASAL regions (Government of Kenya, 2023). At the local scale, Narok County exemplifies these pressures: the Mara–Mau landscape has experienced accelerating land cover transformation since the 1990s, driven by agricultural expansion, population growth, and pastoral land subdivision (Gichenje & Eunice, 2024). Within Narok County specifically, deforestation for small-scale agriculture, charcoal production, and settlement encroachment in the Maasai Mau Forest continues unabated, with existing legal enforcement and community forest governance mechanisms proving insufficient to halt forest loss (Mwiwawi & Chepkong'a, 2022). These cumulative changes have direct consequences for climate vulnerability, hydrological stability, and livelihood resilience in Narok North Sub-County, the focus of this study.

2.2 Key Drivers of Land Use and Land Cover Change in Narok North Sub-County

Land use and land cover change (LULCC) is a major contributor to environmental degradation, biodiversity loss, and climate vulnerability at global, regional, and local scales. It arises from the interaction between socio-economic pressures and environmental processes.

Key global drivers of LULCC include agricultural expansion, infrastructure development, urbanization, commodity markets, and natural resource extraction (Curtis et al., 2018; World Bank, 2021). Research using satellite imagery across the period 2001 to 2015 found that shifting agriculture accounted for 24% of global forest loss, while commodity-driven deforestation accounted for 27%, with marked regional variation in the dominance of each driver (Curtis et al., 2018). In sub-Saharan Africa specifically, deforestation is driven predominantly by subsistence agriculture and fuelwood extraction; between 2010 and 2020, Africa recorded the largest annual rate of net forest loss globally at 3.9 million hectares per year, with cropland conversion accounting for the majority of observed forest removal (FAO, 2020). In temperate and boreal regions such as North America and Russia, wildfires increasingly intensified by climate change are a leading cause of forest degradation, with fires estimated to have affected approximately 98 million hectares of forest globally in 2015 alone (FAO, 2020). In addition to human activities, natural disturbances such as droughts, floods, pest infestations, and storms also contribute to LULCC. These factors interact with human-induced vulnerabilities, reducing landscape resilience and accelerating degradation (IPCC, 2022; IPBES, 2023).

In Kenya, LULCC is primarily driven by deforestation for agriculture, charcoal production, infrastructure development, and urban expansion, largely influenced by population growth and changing consumption patterns (World Bank, 2023). Narok County reflects these national trends. The transition from communal to private land tenure systems has led to increased land fragmentation, encroachment into forested areas, and

conversion of rangelands into croplands and settlements. Similar patterns have been observed in East African countries such as Ethiopia and Tanzania, where land tenure changes and agricultural expansion have significantly altered traditional land use systems and increased pressure on natural resources (IPCC, 2022). Additionally, the shift from traditional pastoralism to sedentary farming and commercial agriculture has intensified pressure on land and water resources. Critical ecosystems such as the Mau Forest Complex one of Kenya's key water towers are under increasing pressure due to illegal logging, charcoal production, and settlement encroachment. These changes have contributed to declining forest cover, reduced river flows, and heightened vulnerability to floods and droughts (UNEP, 2021; Kenya Forest Service (KFS, 2023).

2.2.1 Forest and Tree Cover Loss

Forest and tree cover loss is a major driver of land use and land cover change (LULCC), often resulting in deforestation, habitat degradation, and the loss of ecosystem services. These losses are largely caused by human activities such as agricultural expansion, fuelwood extraction, charcoal production, and settlement development.

Globally, tree cover loss is driven by commercial agriculture, infrastructure development, urban expansion, and climate-related factors such as drought and wildfires (IPCC, 2022; GFW, 2024). For instance, in Latin America and Southeast Asia, large-scale agricultural expansion for commodities such as palm oil and cattle ranching has been identified as a dominant driver of deforestation (Curtis et al., 2018).

In sub-Saharan Africa, tree cover is frequently cleared for subsistence and small-scale agricultural expansion rather than industrial logging, making the impact widespread and difficult to reverse (UNEP, 2021). Forests play a critical role in regulating water cycles, storing carbon, and supporting biodiversity (CGN, 2018). Their degradation therefore directly undermines climate resilience, soil fertility, and food security (IPCC, 2022). According to Global Forest Watch (GFW, 2024), approximately 34% of global tree cover

loss between 2001 and 2024 resulted from permanent land use change, where forested land was converted into agriculture or urban areas. In tropical primary forests, this proportion rises to 61%, indicating largely irreversible ecosystem transformation.

In Kenya, tree cover loss is primarily driven by unsustainable fuelwood harvesting, charcoal production, agricultural expansion, and settlement growth, particularly in highland and arid and semi-arid land (ASAL) regions. Between 2001 and 2024, Kenya lost approximately 400,000 hectares of tree cover, representing a 12% decline (GFW, 2024). This loss has occurred alongside relatively low levels of reforestation, indicating a persistent imbalance between forest depletion and restoration efforts.

Narok County reflects these national trends. Between 2002 and 2024, the county lost approximately 32,200 hectares of humid primary forest, representing a 24% reduction (GFW, 2024). Narok North Sub-County, in particular, has experienced increasing pressure from land subdivision, agricultural expansion, and charcoal production. The loss of forest ecosystems has significant implications for water regulation, biodiversity conservation, and soil stability. Declining forest cover in areas connected to the Mau Forest Complex has contributed to reduced river flows and increased susceptibility to flooding and drought.

Table 2.1 presents a comparative summary of tree cover loss between 2001 and 2024 at global, national (Kenya), and county (Narok) levels. It outlines the extent of loss, key characteristics, and the primary drivers across these spatial scales.

Table 2.1: Tree Cover Loss (Ha), Key Characteristic and Main Drivers Trends (2001–2024)

Level	Tree Cover Loss as from 2001-2024	% Loss	Key Characteristics	Main Drivers
Global	26.8 million	N/A	34% loss is permanent; 61% permanent in tropical rainforests	Agriculture, urbanization, mining, wildfires, infrastructure
Kenya	400,000	12%	56,500 ha of humid primary forest lost; minimal reforestation	Charcoal burning, agriculture, urban expansion
Narok	32,200	24% (primary)	43% of loss from humid primary forests; tree cover now at 14%	Land subdivision, charcoal demand, grazing, settlement growth

Source: Adapted from WRI (2024)

As shown in Table 2.1, tree cover loss varies significantly across spatial scales, with more pronounced impacts observed at the local level. While global trends indicate widespread and often permanent land conversion, the Kenyan context reflects continued forest loss alongside limited reforestation efforts.

In Narok County, the proportion of primary forest loss is notably high relative to national averages, driven by localized pressures such as land subdivision, charcoal production, grazing, and settlement expansion. These patterns highlight the increasing intensity of land use pressures at the sub-county level and underscore the need for spatially explicit analysis to inform targeted land management and climate adaptation strategies.

2.2.2 Environmental Degradation and Land Degradation

Rural landscapes across Africa, including Kenya, are increasingly affected by environmental degradation resulting from the interaction between socio-economic pressures and climatic variability. Unsustainable natural resource use such as overgrazing, charcoal production, and agricultural intensification has contributed to land degradation characterized by deforestation, declining soil fertility, and water scarcity (UNEP, 2021; World Bank, 2021).

Climate change further exacerbates these conditions by altering rainfall patterns and increasing the frequency and intensity of extreme weather events. In East Africa, prolonged droughts and episodic flooding have reduced agricultural productivity, increased land degradation, and heightened food insecurity (IPCC, 2022). In Kenya, erratic rainfall patterns and extended dry spells have disrupted agricultural cycles, particularly in climate-sensitive regions such as Narok County. The degradation of key ecosystems, especially within the Mau Forest catchment, has reduced river flows and increased downstream flood risks. These interacting pressures demonstrate that environmental degradation in Narok is not solely climate-driven but is reinforced by land use practices that reduce ecological resilience. Adaptation strategies therefore need to extend beyond technological solutions to include sustainable land management, water conservation, and integrated landscape planning. Embedding climate adaptation within local governance structures is essential for building long-term resilience (UNEP, 2023).

2.2.3 Population Growth and Demographic Pressure

Population growth remains a significant driver of land use and land cover change in sub-Saharan Africa. Rapid population increase continues to generate growing demand for agricultural land, settlement expansion, and natural resources, thereby accelerating land conversion and environmental change (Bullock et al., 2021). In many parts of East Africa, high population densities have increased pressure on land resources, contributing to the

conversion of forests, grasslands, and other natural ecosystems into agricultural and settlement areas.

In Kenya, population growth combined with land inheritance practices has contributed to increasing land fragmentation. Studies have shown that the subdivision of land into smaller parcels reduces farm efficiency and places additional pressure on land resources (Ndirangu, 2021). Similar trends have been associated with changing land-use patterns, declining land productivity, and increasing competition for natural resources in rural areas. The emergence of medium- and large-scale farms alongside increasingly fragmented smallholder holdings has further intensified land-use pressures and socio-economic disparities.

2.2.4 Urbanization and Rural-Urban Migration

Globally urbanization has increased significantly over the past decades, with the urban population rising from 28.8% in 1950 to approximately 56% in 2020, and projected to reach nearly 70% by 2050 (UN-Habitat, 2023; Ritchie et al. 2025). In sub-Saharan Africa, rapid and often unregulated urban expansion has contributed to significant land use and land cover changes, placing pressure on water resources and ecosystem services (UNEP, 2023).

In Kenya, urban growth and rural–urban migration are reshaping land use patterns. (National Council for Population and Development [NCPD], 2021). According to recent spatial studies, agricultural land in counties like Narok is increasingly converted for residential and commercial uses (Mootian et.al, 2020). This conversion exacerbates land speculation, driving up prices and reducing access for local communities (Omasire, 2021). Simultaneously, rural-to-rural migration driven by the search for fertile, arable soil has heavily intensified local land pressure (NCPD, 2021). Informal land use arrangements, including sharecropping, are increasingly common but often lead to disputes between host communities and migrants (UN-Habitat, 2023). These dynamics highlight the need for

land governance systems that are inclusive, well-regulated, and responsive to climate risks.

2.2.5 Agricultural Expansion and Cropland Encroachment

Agricultural expansion is widely recognized as the leading driver of land use and land cover change globally, accounting for nearly 90% of deforestation in tropical regions (FAO, 2022). In Kenya, and particularly in Narok County, both smallholder and commercial farmers continue to convert forests and grasslands into cropland (Mootian et.al, 2020). This conversion often occurs in ecologically sensitive areas, including the Mau Escarpment, leading to the loss of indigenous vegetation and disruption of water regulation functions (Albert, 2023).

Studies across East Africa indicate that agricultural expansion is closely linked to population growth and market demand, with farmers increasingly prioritizing short-term productivity over long-term sustainability (Shilibwa et al., 2024). Unsustainable farming practices such as mono-cropping, excessive use of agrochemicals, and inadequate soil conservation further exacerbate land degradation (Opiyo, 2024). These practices reduce soil fertility, increase erosion, and heighten vulnerability to climate variability (Kiplagat, 2023).

2.2.6 Livestock Farming and Rangeland Pressure

Across sub-Saharan Africa, overgrazing has been identified as a major contributor to desertification and the degradation of rangeland ecosystems (UNEP, 2021; IPCC, 2022). Livestock production remains a dominant land use system in pastoral and agro-pastoral regions such as Narok County. However, increasing livestock populations have contributed to land degradation, particularly through overgrazing.

Grazing pressure often exceeds the ecological carrying capacity, particularly during dry seasons. This leads to vegetation loss, soil exposure, and increased susceptibility to erosion. The decline in pasture quality further reduces livestock productivity, creating a feedback loop that encourages further land expansion and degradation.

2.2.7 Infrastructure Development

Roads and other infrastructure projects are major drivers of land use change. While infrastructure enhances market access and connectivity, it can also open up previously undisturbed areas to deforestation, settlement, and commercial agriculture. County Government of Narok (2023) shows that road construction in forested regions is often followed by land conversion and habitat loss. In Narok, the expansion of road networks and feeder roads particularly those linked to tourism and agriculture has increased accessibility but also catalyzed land fragmentation and informal settlements (CGN, 2023)). Without adequate land use controls, infrastructure development contributes to unchecked landscape transformation.

2.2.8 Economic Transformation and Investment Flows

Economic liberalization and land market reforms have attracted both domestic and foreign investment into rural areas of Kenya (Raycraft et al., 2026). In Narok County, the growth of commercial agriculture and tourism has significantly increased land values (Mootian, et al., 2020). This has encouraged speculative land acquisition, often by elites, resulting in land concentration and the marginalization of smallholder farmers (Kanyinga & Odote, 2024). The resulting inequalities in land access, combined with insecure tenure systems, have increased the vulnerability of local communities. Similar trends have been observed in other developing regions, where investment-driven land use changes have altered traditional land systems and reduced community resilience (Laltaika & Kelly, 2021).

2.3 Climate Change, Land Use Change, and Interconnected Impacts

The relationship between land use and climate change is complex and mutually reinforcing. Land use change contributes to climate change through greenhouse gas emissions resulting from deforestation and soil degradation, while climate change intensifies land degradation through increased temperatures, drought, and extreme weather events (IPCC, 2022).

In Kenya's Rift Valley region, rising temperatures and declining rainfall have reduced agricultural productivity while increasing the frequency of floods and droughts. Narok County has experienced declining forest cover, increasing livestock populations, and intensified land subdivision all of which reduce the landscape's capacity to buffer climatic shocks (UNEP, 2021).

These interconnected dynamics highlight the need for a systems-based approach that integrates land use planning, climate adaptation, and natural resource management. Effective responses require policies that align local land use practices with national climate adaptation strategies, while also incorporating indigenous knowledge systems.

2.3.1 Land Use and Land Cover and their Effects on Climate Change

Land use and land cover (LULC) change is a key driver of environmental degradation and plays a central role in influencing local and global climate systems. The expansion of agricultural land, deforestation, settlement development, and infrastructure expansion disrupt natural ecosystems, contributing to increased greenhouse gas emissions, soil erosion, and altered hydrological cycles (IPCC, 2021). These transformations also reduce the land's ability to regulate temperature and retain moisture, further exacerbating climate stress (Winkler et al., 2021).

Changes in LULC contribute to shifts in precipitation patterns; some regions receive more

intense rainfall while others experience prolonged dry periods, placing additional strain on already vulnerable ecosystems (Desta & Fetene, 2020).

Sub-Saharan Africa, particularly its tropical and semi-arid regions, is especially sensitive to these alterations. Projections for Kenya suggest an ambient temperature rise of up to 2.5°C by 2050, intensifying climate extremes such as prolonged droughts and flash floods, especially in Arid and Semi-Arid Lands (ASALs), which already face chronic climate stress (Mumo et al., 2023). In many parts of Eastern Africa, including Ethiopia, LULC changes have been associated with accelerated soil erosion and sedimentation in watersheds (Negese, 2021). For example, over the past three decades, cultivated and residential land in Ethiopia's Lake Tana Basin has expanded, contributing to the loss of forest, bushland, and grassland cover despite afforestation efforts (Tewabe & Fentahun, 2020). These trends are mirrored in Kenya, where land conversion, especially near critical ecosystems like the Mau Forest and Ewaso Nyiro Basin, has disrupted water regulation, biodiversity, and carbon sequestration services (Mbaabu et al., 2021). As LULCC and climate dynamics reinforce one another, the need for integrated land management and climate adaptation becomes critical. Interventions must combine ecological restoration with climate-smart planning to reduce emissions and build landscape-level resilience (Githongo et al., 2024)

2.4 Vulnerability to Climate Change

2.4.1 Exposure to Extreme Weather Events

Kenya is classified as a climate-vulnerable country, with its ASALs bearing the brunt of increasing climate hazards. Recurrent droughts, delayed rainy seasons, and fluctuating temperatures have weakened rural livelihoods, especially those reliant on rain-fed agriculture and livestock (Government of Kenya, 2023; World Bank, 2024). Resource scarcity has deepened competition for water and pasture, sparking both intra- and inter-community tensions. According to the Office for the Coordination of Humanitarian

Affairs (WMO, 2023), the frequency of climate-related disasters is on the rise. Between 2000 and 2020, Kenya experienced an average of 2.8 disasters per year, compared to 0.5 annually between 1964 and 1999. The past decade (2011–2020) was the warmest on record globally, with surface temperatures averaging approximately 1.09°C above pre-industrial levels (WMO, 2023). Future projections indicate that extreme weather events, including heatwaves, droughts, and floods, are likely to increase in frequency and intensity, disproportionately affecting low-income rural populations with limited adaptive capacity (IPCC, 2022).

2.4.1.1 Flooding in Kenya

Floods are the most recurrent and damaging climate-related disasters in Kenya, impacting lowland regions such as western Kenya, Nyanza, Tana River, and Narok County (Njogu, 2021). These areas experience flash floods, riverine floods, and coastal flooding. Climate change amplifies flood risks by intensifying rainfall and disrupting seasonal precipitation patterns (Nying'uro et al., 2025). Deforestation, land degradation, and unregulated settlements in flood-prone areas exacerbate flood impacts in river basins (Avery, 2024). The 1997-1998 El Niño event highlighted Kenya's vulnerability to extreme flooding, displacing over one million people and causing substantial economic losses. In 2018, heavy rains led to widespread flooding in western and coastal regions, displacing over 300,000 people and damaging critical infrastructure (Owuor, 2021).

In 2024, severe flooding affected low-lying and informal urban areas, such as Nairobi's Mathare and river basin towns in western and coastal regions. The flooding, worsened by the 2023–2024 El Niño event, brought above-average rainfall, overwhelming communities with inadequate drainage systems and leading to significant displacement, fatalities, and infrastructure damage. The floods disrupted education as schools were damaged or converted into shelters for displaced populations, affecting hundreds of thousands of students (Onyango et al., 2024).

In response, the Kenyan government allocated funds for disaster relief and mobilized emergency services, although criticisms were raised regarding preparedness and response speed. Humanitarian organizations, including the UN and Kenya Red Cross, provided essential supplies and temporary shelters in heavily impacted counties like Kisumu and Tana River. This flooding underscores the need for resilient infrastructure in urban informal settlements and comprehensive disaster management strategies to mitigate the effects of severe weather events. Long-term adaptation measures, improved urban planning, and community-based flood management strategies are recommended to reduce future risks. Rapid population growth in urban areas such as Nairobi and Mombasa caused increased settlement in flood-prone regions. Informal settlements, which often lack sufficient drainage systems and infrastructure, exacerbate flood risks. Low-income communities are disproportionately affected, frequently residing in high-risk zones and lacking the resources needed for recovery (Kinyanjui et al., 2024)

2.4.1.1.1 Impact on Flood Hazards

Flood hazards in Kenya are increasingly frequent and severe. Intense rainfall events often in areas unaccustomed to heavy downpours, overwhelm natural drainage systems, particularly in arid zones such as northern and southeastern Kenya. This is exacerbated by LULCC including deforestation, river encroachment, and urban sprawl, which reduce the land's natural ability to absorb and channel water (UNEP, 2021). Studies indicate that flooding is caused by both climatic and anthropogenic factors. Rapid urbanization without adequate planning, poorly designed drainage systems, and the destruction of natural buffers like wetlands have increased flood risk in both rural and peri-urban areas. For example, the expansion of human settlements into riverine zones and the degradation of catchment forests in Narok North have contributed to more severe seasonal flooding (UNEP, 2021; IPCC, 2022). Addressing these vulnerabilities requires a coordinated approach involving climate-resilient infrastructure, watershed protection, and early warning systems tailored to the needs of vulnerable communities.

2.4.1.2 Droughts in Kenya

From 2010 to 2023, the timeline of droughts in Kenya illustrates a complex interaction of climate factors affecting agricultural productivity and food security. While drought frequency declined in the earlier part of this period, recent years have seen an escalation in both the severity and recurrence of droughts, particularly in arid and semi-arid regions. These droughts have drastically reduced surface and groundwater recharge, worsening water scarcity across the country. The 2020–2022 drought, the most severe in four decades across the Horn of Africa, surpassed previous events in both duration and severity, affecting 4.2 million people in 20 of Kenya's 23 arid and semi-arid counties as of October 2022 (UNDP, 2021). These water declines threaten the availability and stability of water resources needed for agricultural irrigation, hydropower production, and sanitation (NDMA, 2023). Arid and semi-arid areas are especially vulnerable due to their heightened susceptibility to extended drought periods. The sections below detail significant drought events and trends over this period.

2.4.1.2.1 Drought Events and Trends (2010-2023)

Drought is a recurring climate hazard in Kenya, particularly in arid and semi-arid lands (ASALs), with significant impacts on agriculture, water availability, and livelihoods. This subsection outlines key drought events and trends observed between 2010 and 2023.

- 2010-2012: A notable drought occurred, impacting crop yields significantly, particularly in the ASALs, leading to food insecurity (NDMA, 2023).
- 2013-2015: Drought frequency decreased, with fewer severe events reported, allowing for some recovery in agricultural production (NDMA, 2023).
- 2016-2019: A resurgence of drought conditions was observed, with severe impacts on livestock and crop yields, exacerbated by failed rainy seasons (WMO, 2022).
- 2020-2023: The country faced recurrent droughts, with five consecutive failed rainy seasons reported, leading to widespread crop failures and water scarcity

(UNDP, 2021).

2.4.1.2.2 Impact of Climate Change on Drought Hazards

In Kenya, recurring droughts, with severe episodes approximately once a decade, significantly impact the population and inflict greater economic losses than floods, often causing substantial reductions in GDP (Opiyo et al., 2020). These events disproportionately affect agricultural output in Arid and Semi-Arid Lands (ASALs), intensifying food insecurity, and causing infrastructure damage that increases essential service costs, thus lowering overall economic resilience (Filho et al., 2022; Mutsotso et al., 2023).

Moreover, the macroeconomic effects of drought can be long-lasting, hindering GDP recovery and constraining economic growth. In fragile economic settings like Kenya, reduced agricultural productivity can stifle investments and push more individuals into poverty and hunger, exacerbating the economic crisis and deepening vulnerabilities over time (World Bank, 2024). Alarming, drought cycles have accelerated in recent years, now occurring every 2 to 3 years instead of the previous 5 to 10 years (World Bank, 2021). Since the 2000s, these droughts have not only become more frequent but also longer and more severe, disrupting expected rainy seasons in arid and semi-arid regions.

The recent drought cycles between 2020 and 2023 illustrate this intensification, with some areas experiencing failed or below-average rainy seasons for up to six consecutive instances. The severity and persistence of these droughts have severely impacted water availability, food security, and livelihoods, leaving millions of Kenyans facing acute food shortages. This trend indicates a significant escalation of drought hazards, likely caused by climate change, which poses even greater challenges for vulnerable populations in regions such as Turkana and Marsabit (UNDP, 2021)

2.5 Environmental Effects of Land Use and Climate Change

2.5.1 Rainfall Patterns and Variability

In Narok County, rainfall patterns have become increasingly erratic, primarily influenced by climate change and altered land use. The March–April–May (MAM) long rain season has experienced a consistent decline in total rainfall amounts relative to historical averages, reducing soil moisture and disrupting crop germination and growth cycles (WMO, 2022). Conversely, the October–November–December (OND) short rains have become more intense, leading to localized flooding, particularly in low-lying areas like Narok town, where poorly drained soils and infrastructure aggravate runoff impacts (Kenya Meteorological Department (KMD,2023). In Narok North Sub-County, rainfall variability is particularly reflected in agro-pastoral areas where short-season crops are increasingly failing due to shifts in onset and cessation dates of rainfall. The unpredictability of rain caused suboptimal timing of planting and harvesting, directly threatening food security and reducing household resilience. Rainfall intensity events have also accelerated topsoil erosion on sloped landscapes and in riparian zones, especially where tree cover has declined.

2.5.2 Temperature Trends and Implications

Kenya has undergone a measurable warming trend over the last four decades. Between 1979 and 2021, average surface temperatures increased by approximately 0.23°C per decade, amounting to nearly a 1°C rise nationally, with ASALs and highland areas, including Narok, among the most affected (World Bank, 2021). According to the Kenya Meteorological Department, the mean maximum temperature rose from 28.6°C in 2022 to 28.7°C in 2023, while the mean minimum temperature marginally decreased from 18.1°C to 18.0°C. Such small shifts are significant for ecosystems and agriculture that are finely tuned to climatic thresholds (KMD, 2023). Higher temperatures accelerate evapotranspiration, reducing water retention in soils and surface reservoirs. This is

especially critical in Narok, where agriculture and livestock depend heavily on seasonal rivers and shallow groundwater. Rising heat also contributes to the decomposition of soil organic matter, increasing vulnerability to degradation and lowering fertility (IPCC, 2022). These impacts are compounded in overgrazed rangelands, where vegetation recovery is limited, further decreasing resilience to climate shocks.

In addition, climate modeling for Kenya indicates that by 2050, temperatures could rise by 2.5°C, exacerbating drought intensity and increasing the frequency of heatwaves, particularly in arid and semi-arid counties (UNEP, 2023). This has implications for public health, livestock survival, and hydrological stability in catchments such as the Mau Forest Complex, which is a water source for Narok and neighboring regions.

2.6 Impact on Biodiversity and Conservation

Climate change and LULCC significantly threaten biodiversity in Kenya and across sub-Saharan Africa. These pressures are reshaping ecosystems, driving species loss, and necessitating urgent conservation interventions. In Narok-North Sub-County, biodiversity-rich landscapes like the Mau Forest are increasingly fragmented due to agricultural expansion, settlement encroachment, and infrastructure development. These trends are reducing species richness, disrupting wildlife migration corridors, and weakening ecosystem resilience (Albert, 2023; Mbaabu et al., 2021). Climate change intensifies these challenges by altering precipitation patterns, increasing temperatures, and amplifying the frequency of extreme weather events. Such conditions stress ecological systems, disrupt plant-pollinator relationships, and threaten species adapted to specific temperature and moisture regimes (Mumo et al., 2023; Shilibwa et al., 2024).

2.6.1 Biodiversity Loss

Kenya's biodiversity hotspots face heightened pressure from land conversion for agriculture and livestock. In Narok, land formerly used for communal grazing is

increasingly subdivided and converted into croplands. This shift is associated with the loss of native vegetation and critical habitats for species such as zebras, gazelles, and numerous bird species. According to Boakes et al., (2024), agricultural expansion and related methane emissions are responsible for up to 70% of the global greenhouse gas-related biodiversity footprint. In Central and South America, a similar trend of deforestation and fragmentation is evident, providing global parallels for Kenya's challenges. In Kenya, the drive toward high-value crop production and settlement development has resulted in habitat degradation in areas adjacent to Maasai Mara and Mau Forest, directly impacting wildlife populations. Without sustainable land-use practices, the risk of species extinction and loss of ecosystem services will escalate.

2.6.2 Climate Change, Land Use & Biodiversity Interactions

The interaction between climate change and land use can exacerbate or mitigate biodiversity impacts depending on management practices. For instance, in some areas, reforestation and increased canopy cover may enhance microclimates and species richness. However, monoculture plantations, often promoted as reforestation may reduce biodiversity by displacing native species (UNEP, 2023). In Narok County, land use patterns are shifting due to demographic pressure and economic transformation. Overgrazing, land fragmentation, and charcoal burning continue to degrade biodiversity. At the same time, climate change is intensifying soil degradation and water scarcity, pushing land users to encroach on remaining forest patches and wetlands, further destabilizing fragile ecosystems. Integrated land use planning is essential to reverse these trends. Conservation strategies should include habitat restoration, biodiversity corridors, agro ecological farming, and incentives for community-based conservation.

2.7 Environmental and Social Impact Assessments (ESIA) Frameworks

In Kenya, Environmental and Social Impact Assessments (ESIAs) are a key regulatory tool mandated by the National Environment Management Authority (NEMA) to guide

sustainable land use planning. However, the number of ESIA licenses issued declined from 1,604 in 2022 to 1,056 in 2023, with notable reductions in the human settlements and infrastructure sectors. While approvals related to energy, mining, and quarrying increased over the same period, this overall decline raises concerns about weakened environmental oversight in critical sectors such as agriculture and urban development. This trend suggests that land use changes in these sectors may increasingly be occurring outside formal regulatory review, pointing to a broader gap in ESIA compliance.

2.8 Impacts on Socio-Economic Systems

2.8.1 Agriculture and Livelihood Vulnerability

Climate variability, land degradation, and shifting land use patterns pose direct threats to agriculture-dependent livelihoods in Kenya. Increased frequency of extreme weather events, particularly prolonged droughts and erratic rainfall, has led to reduced agricultural productivity and income instability. This is especially reflected in arid and semi-arid lands (ASALs), where climate-sensitive livelihoods such as pastoralism are highly exposed to shocks (Filho et al., 2022; Mutsotso et al., 2023). In Ethiopia, inconsistent rainfall has reduced yields (Desta & Fetene, 2020), while in Kenya, delayed planting seasons due to unpredictable rain disrupt the food production cycle (Mumo et al., 2023). Long-term soil degradation caused by unsustainable practices further undermines productivity (Negese, 2021). The Kenya Climate Smart Agriculture Strategy (2020) emphasizes the need for widespread adoption of drought-tolerant crops, rainwater harvesting, and soil conservation techniques.

2.8.2 Climate-Driven Impacts on Livelihoods

Across East Africa, smallholder farmers, particularly women and youth, are disproportionately affected by climate-induced risks (Ngigi et al., 2020). As rainfall patterns shift and temperatures rise, traditional income sources become less reliable. In

Kenya, 70% of rural households depend on rain-fed agriculture, making them particularly vulnerable. Consequently, diversification into non-farm activities and the adoption of climate-smart practices are being promoted as resilience strategies (Githongo et al., 2024).

2.8.3 Health Impacts

Land use and climate changes are escalating public health challenges. Rising temperatures and altered precipitation patterns have expanded the range of disease vectors like mosquitoes, increasing the incidence of malaria and other vector-borne diseases (Sewe et al., 2021). In Kenya, there is growing evidence that extreme heat events are contributing to cardiovascular stress, especially among vulnerable populations (Gudka et al., 2024). Additionally, land degradation and deforestation increase exposure to zoonotic diseases due to increased contact between humans and displaced wildlife. Air quality is also affected as land conversion disrupts the atmospheric microbiome and elevates particulate matter, worsening respiratory conditions. Malnutrition rates are expected to rise with declining crop yields and food availability, particularly among children under five (Muga et al., 2022).

2.8.4 Food Security

Climate-driven declines in water availability and changes in nutrient cycles are jeopardizing food production systems. In Kenya, frequent droughts in ASAL regions reduce water for irrigation, leading to yield losses and heightened food insecurity (Mutsotso et al., 2023). Agricultural runoff from intensified land use increases nitrogen and phosphorus loads in water bodies, causing eutrophication and further undermining food system sustainability (Opiyo, 2024).

2.8.5 Housing and Infrastructure

Kenya's rapidly expanding urban areas are increasingly exposed to climate-related

hazards. Flooding and heat stress are exacerbated by poor drainage systems, unregulated construction, and limited green spaces. Infrastructure failures during recent floods in Nairobi underscore the consequences of poor planning and unchecked urban sprawl (Avery, 2024; Kinyanjui et al., 2024). The National Climate Change Action Plan (2023–2027) stresses the urgency of climate-resilient urban planning. Retrofitting housing and expanding green infrastructure can enhance the adaptive capacity of urban populations, especially informal settlements disproportionately affected by climate extremes (Owuor, 2021).

2.9 Legal, Policy and Legislative Framework for Climate Change

Kenya has developed a comprehensive legal and policy framework to address climate change, aligning national priorities with global commitments. These instruments are crucial in guiding climate adaptation and sustainable land use at both national and county levels, particularly in climate-vulnerable areas such as Narok North Sub-County. The Constitution of Kenya (2010) lays the foundation for environmental governance. Articles 42, 69, and 70 guarantee the right to a clean and healthy environment, mandate sustainable natural resource management, and provide mechanisms for environmental protection. These principles underpin local efforts to conserve critical ecosystems like the Mau Forest. The Climate Change Act (2016) operationalizes climate governance by establishing the National Climate Change Council and mandating the integration of climate action into county planning. It also provides for a Climate Change Fund to support adaptation and mitigation. This is particularly relevant in Narok North, where community-based actions such as reforestation and flood control infrastructure depend on decentralized climate planning. The Environmental Management and Coordination Act (EMCA) (1999, revised 2023) is Kenya's principal environmental law. It mandates Environmental and Social Impact Assessments (ESIAs) for development projects, helping to safeguard fragile ecosystems from unsustainable land use. In counties like Narok, compliance with EMCA is vital to balancing development with conservation. The

National Climate Change Action Plan (NCCAP) provides Kenya's medium-term strategy for climate action. It emphasizes ecosystem protection, climate-resilient agriculture, and water resource management, strategies that are directly applicable in Narok's climate-sensitive zones. The Forest Conservation and Management Act (2016) reinforces the role of forests in carbon sequestration and water regulation. It supports afforestation and reforestation efforts in critical areas like the Mau Forest. Community Forest Associations (CFAs) are empowered under this Act to promote participatory forest governance. Kenya's climate commitments are further reflected in international frameworks, including the Paris Agreement (2016) and the United Nations Framework Convention on Climate Change (UNFCCC). These frameworks commit Kenya to reducing greenhouse gas emissions by 32% by 2030 and promoting low-carbon, climate-resilient development. Sustainable Development Goal 13 (SDG 13) on Climate Action is also embedded in national and county development plans. The County Governments Act (2012) enables counties to integrate climate change into their development plans. In Narok North, this has translated into localized interventions such as flood barrier construction, soil rehabilitation, and farmer training on sustainable practices. While these frameworks offer a robust policy environment, implementation remains uneven due to limited enforcement, financial constraints, and institutional fragmentation.

2.9.1 Remote Sensing in Environmental Analysis

Effective environmental management, particularly in regions experiencing significant land-use changes, increasingly relies on advanced systems to monitor and analyze environmental changes. Remote sensing has emerged as a critical tool in this domain, offering the capability to capture up-to-date and detailed information about land cover characteristics and their changes over time at various spatial and temporal scales.

Remote sensing technologies enable the analysis of LULCC, which is particularly relevant in studying the impacts of agricultural expansion, deforestation, and urban development

in areas such as Narok North. Techniques like image classification and change detection are commonly employed to monitor these dynamics, providing insights into patterns of land degradation, loss of forest cover, and the encroachment of urban settlements. The application of remote sensing extends beyond monitoring changes. It plays a key role in ecological planning and management, where ecological units, such as forests, wetlands, agricultural lands, and urban areas, are mapped and classified. By combining remote sensing with Geographic Information Systems (GIS), researchers can gather spatial and attribute data to create detailed ecological unit maps.

These maps inform land-use planning and decision-making, guiding efforts to conserve vital ecosystems like the Mau Forest and rehabilitate degraded lands in Narok North. Furthermore, remote sensing supports environmental monitoring amid climate change. It facilitates the detection of urban heat islands (UHIs), estimates impervious surface areas, and assesses ecological security. These applications are crucial in regions vulnerable to climate-induced risks, enabling stakeholders to develop targeted adaptation and mitigation strategies.

2.9.2 Satellite Imagery Interpretation

Satellite imagery interpretation is fundamental to remote sensing, offering high-resolution spatial and spectral information critical for understanding environmental and land-use changes in Narok North Sub-County. With the increasing availability of satellite data and advancements in sensor technologies, satellite imagery has become indispensable for analyzing complex environmental challenges. For instance, using satellite imagery, researchers can identify land cover changes, such as the conversion of forests to agricultural land or the expansion of urban areas. Advanced techniques like spectral analysis allow for distinguishing vegetation types, detecting deforestation hotspots, and monitoring the health of ecosystems like the Mau Forest. These insights are invaluable for developing evidence-based conservation strategies.

The interpretation of satellite imagery often involves several key steps:

- i. Data Collection: Acquiring high-resolution imagery from sources like Landsat, Sentinel, and commercial satellites.
- ii. Preliminary Analysis: Interpreting features based on tone, color, texture, and shape to identify ecological units such as forests, water bodies, and urban areas.
- iii. Classification: Grouping land cover types (example, vegetation, water, built-up areas) based on spectral signatures and supervised/unsupervised algorithms.
- iv. Change Detection: Analyzing temporal data to monitor land cover transformations over time.
- v. Field Validation: Verifying satellite-based observations through ground trothing to ensure accuracy and reliability. By leveraging these processes, satellite imagery interpretation provides a clear understanding of how land-use changes interact with environmental factors like climate variability.

In Narok North, this approach supports efforts to address challenges such as increased flooding due to vegetation loss, declining agricultural productivity from soil degradation, and the impact of urban expansion on water resources. As global environmental challenges escalate, integrating satellite imagery interpretation into environmental management frameworks is essential.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter gives a description of the methodology that was used in this study. It starts with the area of study followed by research design, sampling size and sampling process, data collection techniques and data analysis.

3.2 Area of Study

3.2.1 Location and Size

This study was conducted in Narok North Sub-County, one of the six sub-counties within Narok County in Kenya's Rift Valley region. Narok North covers an area of approximately 2,603 km² and includes both urban and rural zones, with a diverse landscape comprising forested areas, agricultural land, and pastoral zones. The sub-county is located between latitudes 0° 50' and 1° 50' south, and longitudes 35° 28' and 36° 25' east. It borders Narok East, Narok West, and Narok South sub-counties and hosts the county headquarters in Narok Town, which also serves as its administrative and commercial center. Narok North comprises six electoral wards: Olposimoru, Olokurto, Narok Town, Nkareta, Olorropil, and Melili. These wards represent varied ecological zones from the high-altitude Mau Forest region in Olposimoru and Melili, to the urbanized and rapidly growing Narok Town ward. The topography is characterized by undulating hills and river valleys particularly in the northern zones. Elevation varies but averages around 1,827 meters above sea level, making it one of the cooler sub-regions in Narok County.

The following table presents the six wards that constitute Narok-North Constituency along with their respective land areas in square kilometers, as documented in the (CGN, 2023).

Table 3.1: Wards in Narok-North Constituency and area

Constituency	Ward	Area in Square kilometers
Narok North	Olposimoru	270.2
	Olokurto	527.6
	Narok Town	373.7
	Nkareta	462.9
	Olorropil	412.2
	Melili	556.7

Source: Adopted from County Government of Narok (CGN, 2023-2027)

The wards vary considerably in size, with Melili being the largest at 556.7 km² and Olposimoru the smallest at 270.2 km². Olokurto is the second largest ward at 527.6 km², while Narok Town, despite being the urban center of the constituency, covers a comparatively modest 373.7 km². This spatial variation is significant from a land use perspective, as the larger wards particularly Melili and Olokurto are likely to encompass extensive rangelands characteristic of the broader Narok region, while Narok Town ward reflects a more compact, peri-urban land use pattern.

Figure 3.1 presents the administrative map of Narok North Sub-County showing the various wards within the study area. The administrative wards also provided a basis for sampling and data collection during the study.

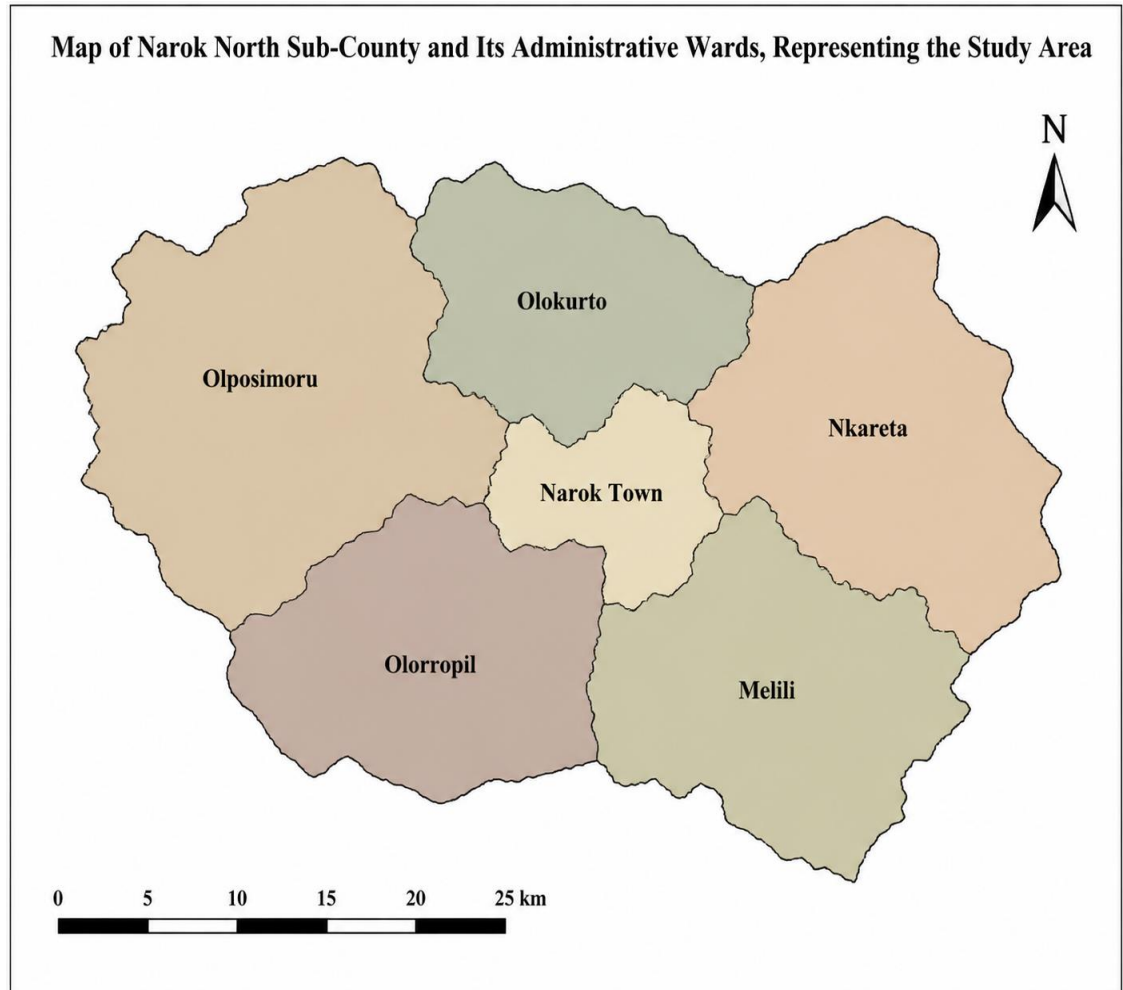


Figure 3.1: Narok North Sub-County and Administrative Ward

3.2.2 Population

Narok County is characterized by cultural diversity, with a projected population of 1,284,204 in 2023, up from 1,157,873 recorded in the 2019 Kenya Population and Housing Census (CGN, 2023). The Maasai and Kalenjin communities form the majority, alongside other ethnic groups such as the Kisii, Luo, Kuria, Luhya, Kamba, Kikuyu, Somali, and the indigenous Ogiek community. According to the County Integrated Development Plan (2023–2027), about 82% of the county population is below 34 years,

indicating a youthful population with implications for resource use and development planning (CGN, 2023).

Table 3.2 presents the population distribution by sex and household characteristics for Narok County and Narok North Sub-County based on the 2019 Kenya Population and Housing Census.

Table 3.2: Population Distribution and Household Characteristics in Narok County

Region	Male	Female	Inter sex	Total	No. of Households	Average Household Size
Narok County	579,042	578,805	26	1,157,873	241,125	4.8
Narok North Sub-County	128,024	123,829	9	251,862	59,996	4.2

The table shows a nearly equal distribution between males and females in both Narok County and Narok North Sub-County. Narok North Sub-County accounted for a substantial proportion of the county population, with 59,996 households and an average household size of 4 persons. The relatively large household sizes are likely to increase pressure on land and natural resources within the study area.

3.2.3 Economic Activities

There are four livelihood zones in the county namely: Pastoral, agro-pastoral, mixed farming, tourism and /trade/business. The main economic activities in the sub-county include crop farming, tourism and trade among other activities undertaken in small scale. Agriculture (both pastoralism and crop farming) is the most prevalent one among all the main economic activities. Crop farming is done on both a large and small scale depending on the land availability. The main crops grown in the county are cash crops (sugarcane, wheat, barley, pyrethrum, coffee, tea and maize), beans, and horticultural crops (Irish

potatoes, cabbages, tomatoes, French beans, indigenous vegetables and onions).

Some of the farmers have also set up ranches where they keep large herds of cattle and goats which they sell to the Kenya Meat Commission (KMC). A section of the Mau Forest Complex Kenya's largest closed-canopy forest extends into Narok North Sub-County. This area hosts a rich and vital ecological system that supports local livelihoods through agriculture, water resources, and other ecosystem services. However, the region faces several interlinked challenges that hinder economic development, including the impacts of climate change, recurrent land conflicts, high unemployment rates, and prolonged underinvestment. These factors contributed to Narok being classified among the most marginalized counties at the onset of Kenya's devolution process (Ministry of Environment and Forestry (MoE&F), 2022, CGN, 2023).

3.3 Research Design

This study employed a mixed methods research approach guided by a cross-sectional survey design. Research design serves as the blueprint for the collection, measurement, and analysis of data, which is essential for systematically conducting research (Saunders, Lewis, & Thornhill, 2019).

According to Bryman (2021), a well-structured research design enables effective allocation of limited resources and assists in making crucial methodological decisions. Research design includes an outline of the research process, from hypothesis formulation to the final data analysis, ensuring that the study addresses its research questions comprehensively (Almusaed et al., 2025).

Mixed methods research combines elements of qualitative and quantitative research approaches, allowing researchers to capitalize on the strengths of both methods while compensating for their individual weaknesses (Creswell & Plano Clark, 2018). This approach is particularly effective in providing a comprehensive understanding of complex

research problems (Fetters, Curry, & Creswell, 2019). Cross-sectional survey design, on the other hand, is valuable for formulating and testing hypotheses and analyzing relationships between variables at a specific point in time (Setia, 2016). This design is appropriate for this study as it facilitates the exploration of current conditions and the relationships between land use, land use change, and climate change impacts in Narok North Sub-County.

Geospatial Information Systems (GIS), specifically Quantum Geographical Information Systems (QGIS), were used as a primary analytical tool in this study, enabling the acquisition, management, and analysis of spatial data critical for understanding land use change patterns in Narok North Sub-County (Goodchild & Li, 2021).

3.4 Data Sources

Data for this research was obtained from both primary and secondary sources to ensure a holistic understanding of the impacts of land use, land use change, and climate variability in Narok North Sub-County. Secondary data was collected through an extensive review of existing literature, including published scientific papers, books, journal articles, policy documents, symposium proceedings, and workshop reports. This review established a robust theoretical framework and contextual background for the study. References were made to maps and aerial photographs specific to Narok North Sub-County to obtain relevant secondary data. Additionally, data from key informant organizations regarding the causes, effects, and management of floods were included to supplement the literature review (CGN, 2023).

Primary data were collected from the field using various methods aimed at providing a detailed assessment of flooding, its effects on the environment, and the livelihoods of people in Narok North Sub-County. These methods included structured questionnaire administration, which gathered quantitative data on residents' experiences and perceptions of flooding and climate change. Face-to-face interviews were conducted with key

informants and community members to obtain qualitative insights into local knowledge and practices related to land use and climate adaptation. Guided transect observations were conducted to directly observe land use changes and their impacts on the landscape. Oral history narratives from long-term residents were collected to understand past land use practices and climate events. Additionally, systematic observations of environmental conditions and human activities were made to complement the other data collection methods.

For this study, satellite imagery covering Narok North Sub-County was acquired for 8 key periods: 1990_1995_2000_2005_2010_2015_2020 and 2022. The imagery was sourced from Landsat 5, Landsat 7, and Sentinel-2B satellites to facilitate temporal land use and land cover change analysis. Landsat 5, operational since 1984, is equipped with the Thematic Mapper (TM) sensor, which provides seven spectral bands at a spatial resolution of 30 meters, alongside a panchromatic band with a 15-meter resolution. Landsat 7, launched in 1999, features the Enhanced Thematic Mapper Plus (ETM+), which offers similar spectral characteristics and spatial resolution. Additionally, imagery from Sentinel-2B, launched in 2017, was utilized. This satellite carries the Multi-Spectral Instrument (MSI) with 13 spectral bands and spatial resolutions ranging from 10 to 60 meters, with Band 8 offering a finer resolution of 5 meters. The high spectral and spatial resolution of these sensors significantly enhanced the quality and accuracy of land cover classification and change detection. These satellite images were instrumental in analyzing land use changes over the specified periods and understanding their impacts on Narok North Sub-County.

3.5 Sample Size and Sampling Procedure

Narok North Sub-County, which served as the sampling frame for this study, consists of six wards: Olposimoru, Melili, Olokurto, Nkareta, Olorropil and Narok Town. Data was collected from all six wards. Narok North Sub-County was selected due to its pronounced land use and land cover change (LULCC) dynamics relative to other sub-counties,

particularly in terms of the extent and intensity of landscape transformation. Moreover, Narok Town, a major flood hotspot within the sub-county, features diverse livelihood activities among its residents. The sub-county's blend of urban, peri-urban, and rural areas provided varied contexts for experiencing the impacts of flooding.

The sample size for surveys administered to residents representing households and business owners was calculated using the widely adopted Cochran's Formula (Cochran 1991).

$$n = \frac{(N * Cv^2)}{dx (Cv^2 + (N - 1) * e^2)}$$

Where:

n = sample size,

N = population size

Cv = Coefficient of variation (often taken as 0.5)

e = acceptable sampling error (typically 0.05 at 95% confidence level)

The population of the five wards comprises approximately 59,996 people (GoK, 2019). Using Cochran's Formula, the expected sample size was calculated as 100 households.

Random sampling was employed to select respondents from the sample population. The questionnaires were administered in six urban centers or markets within the six wards. This approach was practical for reaching people in these centers, especially considering the remoteness of some areas. Respondents were chosen based on their willingness to participate when approached. Organizations for the key informant interviews were purposively selected because of their involvement in environmental management in Narok County. The key informants who participated in the study represented the following organizations: Ewaso Nyiro South Development Authority (ENSDA), Narok County Water

and Sewerage Company (NARWASCO), Narok County Government, National Environmental Management Authority (NEMA), Kenya Forest Service (KFS).

3.6 Data Analysis

The statistical analysis examined the impacts of land use and land cover change using descriptive statistics (means, frequencies, and percentages) and inferential statistics (correlation, ANOVA, and chi-square tests at a 5% significance level). Data were organized and coded in Excel, then analyzed using SPSS version 23, with results presented in frequency tables, charts, and graphs. Questionnaires collected information on demographics, local environmental knowledge, flooding impacts, and climate change perceptions, while analysis included temperature and rainfall variations, sea-level rise effects, and flood prediction possibilities. The process followed Creswell and Creswell's (2023) guidelines, ensuring consistency and linking findings to key study themes.

A summary of the study objectives, data requirements, analytical methods, and expected outputs is presented in Table 3.3 (Appendix II).

3.7 Ethical Considerations

This study was conducted in accordance with established ethical principles governing research involving human participants. Prior to data collection, ethical approval was sought from Jomo Kenyatta University of Agriculture and Technology (JKUAT). County-level administrative authorization was also obtained from the Narok County Government before fieldwork commenced. Informed consent was obtained from all study participants before their involvement in household surveys, key informant interviews, and focus group discussions. Participants were clearly informed of the purpose of the study, their right to withdraw at any time without consequence, and the voluntary nature of their participation. No incentives were offered that could have unduly influenced participation.

To protect participant privacy, all responses were treated with strict confidentiality. No personal identifying information was recorded in the data, and individual responses were not attributed to named individuals in any part of this report. Data collected were used exclusively for academic research purposes and stored securely with access limited to the researcher and supervisors.

The study involved communities from the Maasai indigenous group, and sensitivity to local cultural practices, gender dynamics, and community leadership structures was observed throughout the data collection process. Female enumerators were used where appropriate to facilitate comfortable participation by women respondents. All interviews and discussions were conducted in the language preferred by participants, with translation support provided where necessary. No deception was used at any stage of the research process, and participants were debriefed on the overall purpose of the study upon request. The remote sensing component of the study relied entirely on publicly available satellite imagery and secondary data sources, which did not raise additional ethical concerns.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Overview of the Chapter

This chapter presents the results and discussion of data collected from households, key informants, and satellite imagery in Narok North Sub-County. The chapter is organized into two main parts. Section 4.2 presents the demographic characteristics of respondents. Section 4.3 presents the results of all data collected, including survey findings, satellite-derived land cover statistics, and key informant interview data. Section 4.4 provides a discussion of those results, interpreting their significance in relation to existing literature and the broader context of land use change and climate vulnerability. This structure ensures a clear demarcation between empirical findings and analytical interpretation throughout the chapter.

4.2 Demographic Characteristics of Respondents

4.2.1 Gender Distribution

The study found that 62% of respondents were male while 38% were female, as shown in Figure 4.1.

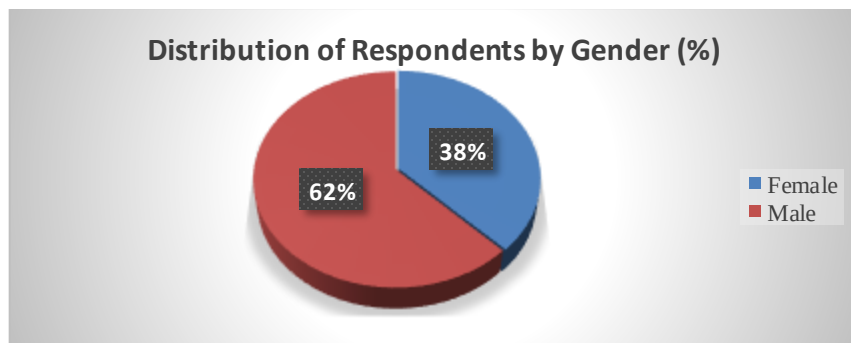


Figure 4.1: Gender Distribution of Respondents in Narok North Sub-County

4.2.2 Age Distribution

The findings in Figure 4.2 indicate that the majority of respondents were aged between 18–28 years (39%), followed by those aged 29–39 years (34%). Respondents aged 40–49 years accounted for 16%, while those aged 50 and above formed smaller proportions, with the least represented category being 60–69 years (2%) and those aged 70 and above at 3%.

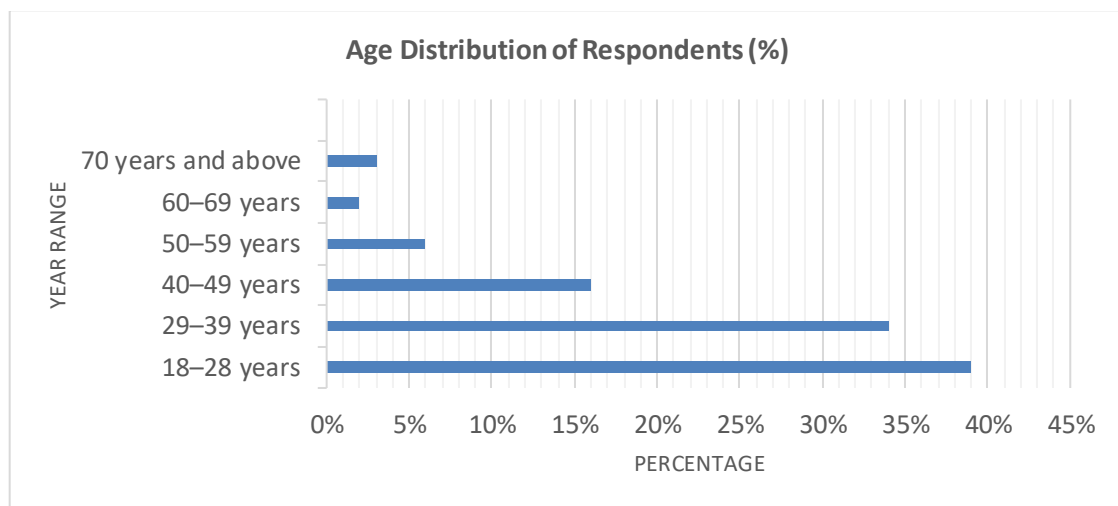


Figure 4.2: Age Distribution of Respondents in Narok North Sub-County

4.2.3 Duration of Residence

The findings in Figure 4.3 indicate that the majority of respondents (50.9%) had lived in the study area for between 20 and 50 years. Respondents who had lived in the area for 10–20 years accounted for 18.8%, while those who had resided for less than 10 years formed a smaller proportion. Only 4.5% had lived in the area for more than 50 years.

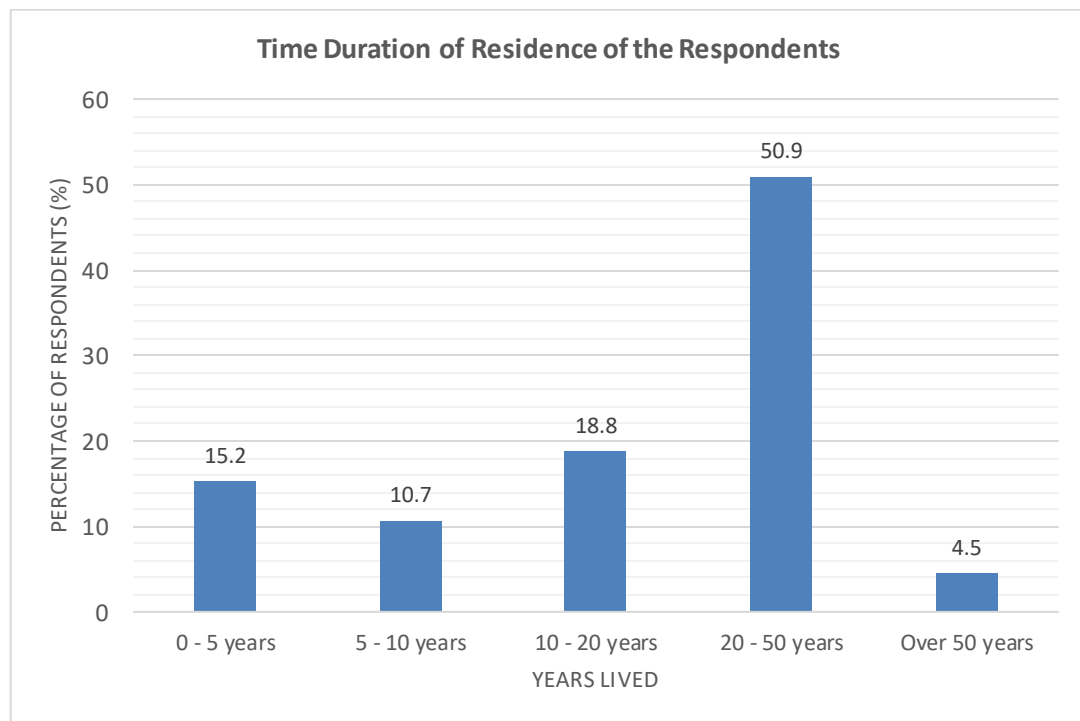


Figure 4.3: Duration of Residence of Respondents in Narok North Sub-County

4.2.4 Education Levels

The findings in Figure 4.4 indicate that the majority of respondents had attained secondary education, followed by those with primary education. A smaller proportion held diploma or certificate qualifications and bachelor's degrees, while some respondents had no formal education.

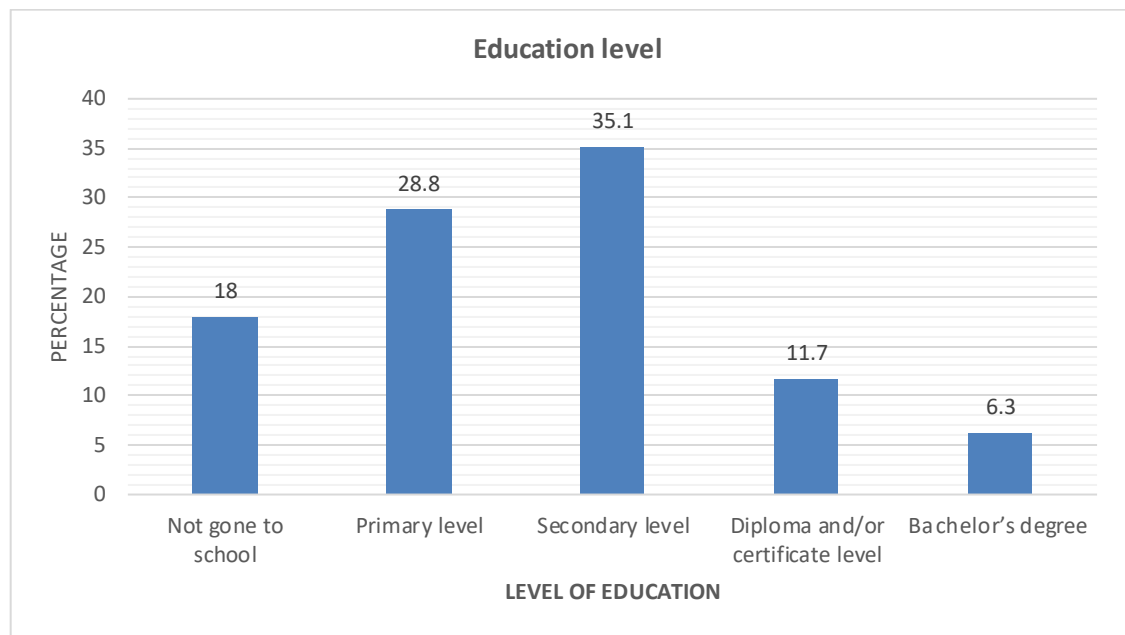


Figure 4.4: Education Levels of Respondents in Narok North Sub-County

4.3 Empirical Findings

This section presents the empirical findings of the study organized according to the three main research objectives: current land use practices and their drivers; land use and land cover changes over the past 32 years as derived from satellite imagery; and existing community coping and adaptation strategies. Findings are presented without interpretive commentary, which is reserved for Section 4.4.

As a reference point for all satellite-derived statistics cited throughout this section, Table 4.1 below presents the complete land use and land cover area statistics for Narok North Sub-County derived from supervised maximum likelihood classification of Landsat 5, Landsat 7, and Landsat 8/9 imagery across all eight time periods. The total classified study area is 4,695.84 hectares. All hectare figures and percentage values cited in sections 4.3.1 to 4.3.4 are drawn from this table

Table 4.1: LULC Area Statistics for Narok North Sub-County (1990–2022)

Land Cover Class	1990 Ha	1990 %	1995 Ha	1995 %	2000 Ha	2000 %	2005 Ha	2005 %	2010 Ha	2010 %	2015 Ha	2015 %	2020 Ha	2020 %	2022 Ha	2022 %
Forest	2566.02	54.64	2566.02	54.64	2513.99	53.54	2490.87	53.04	2330.18	49.62	2260.94	48.15	2243.20	47.77	2236.56	47.63
Cropland	668.89	14.24	668.89	14.24	720.59	15.35	713.91	15.20	732.48	15.60	811.33	17.28	913.42	19.45	914.38	19.47
Grassland	1457.03	31.03	1456.99	31.03	1451.85	30.92	1480.71	31.53	1618.95	34.48	1607.11	34.22	1518.48	32.34	1525.39	32.48
Built-Up	2.05	0.04	2.08	0.04	7.66	0.16	8.59	0.18	11.94	0.25	14.30	0.30	17.63	0.38	16.55	0.35
Bare Land	1.86	0.04	1.86	0.04	1.75	0.04	1.75	0.04	2.30	0.05	2.15	0.05	3.12	0.07	2.95	0.06
Total	4695.85	100.00	4695.84	100.00	4695.84	100.00	4695.83	100.00	4695.85	100.00	4695.83	100.00	4695.85	100.00	4695.83	100.00

Source: Supervised Classification of Landsat 5, Landsat 7, and Landsat 8/9 Imagery,

Note: Percentage (%) values are calculated as: $(\text{Class Area Ha} \div \text{Total Classified Study Area 4,695.84 Ha}) \times 100$. All columns sum to 100%.

4.3.1 Current Land Use Practices

4.3.1.1 Agriculture

Agriculture is the dominant land use practice in Narok North Sub-County. Key informant interviews established that wheat and maize are the most widely cultivated crops, while barley, potatoes, and vegetables are grown in specific agro-ecological zones at higher altitudes. Smallholder farmers cultivate primarily for household food security, while larger landowners engage in mechanized wheat production for commercial markets. The expansion of road networks and market infrastructure has incentivized a progressive shift from subsistence to cash crop production, facilitated by NGO-supported extension services and improved seed variety programmes.

Satellite-derived land cover statistics (Table 4.1) indicate that cropland in the classified study area increased from 668.89 hectares (14.24% of total study area) in 1995 to 720.59 hectares (15.35%) in 2000 a gain of approximately 51.70 hectares within five years. A modest decline to 713.91 hectares (15.20%) was recorded in 2005, attributable to drought stress and rising input costs that temporarily reduced farming viability. Cropland subsequently expanded consistently, reaching 914.38 hectares (19.47%) by 2022. This represents a net increase of 245.49 hectares approximately 36.7% above the 1990 baseline over the 32-year study period.

4.3.1.2 Livestock Keeping

Livestock keeping is the primary livelihood activity among the Maasai community of Narok North, where cattle and small ruminants represent wealth, social status, and community identity. Survey data indicate that 34.5% of respondents considered livestock keeping to have a moderate impact on LULCC, while 25.3% rated it as having a great impact. Satellite-derived grassland statistics indicate that grassland cover remained broadly stable from 1990 to 2005, ranging between 1,451.85 hectares (30.92%) in 2000

and 1,480.71 hectares (31.53%) in 2005 (Table 4.1). A notable increase was recorded between 2005 and 2010, with grassland cover expanding to 1,618.95 hectares (34.49%) the peak value across the entire study period. This was followed by a gradual decline to 1,607.11 hectares (34.23%) in 2015, 1,518.48 hectares (32.34%) in 2020, and 1,525.39 hectares (32.48%) by 2022.

4.3.1.3 Fuelwood Harvesting and Charcoal Production

Fuelwood harvesting encompassing both firewood collection and charcoal burning is a dominant land use activity and a critical driver of vegetation loss. Survey findings, presented in Figure 4.5, indicate that 53.6% of households rely on the traditional three-stone fireplace, while 51.8% depend on charcoal as their primary cooking fuel. Traditional jikos account for 16.4% of household energy use, and solar energy is used by 22.7% of respondents. Improved cooking stoves are used by only 2.7% of the population.

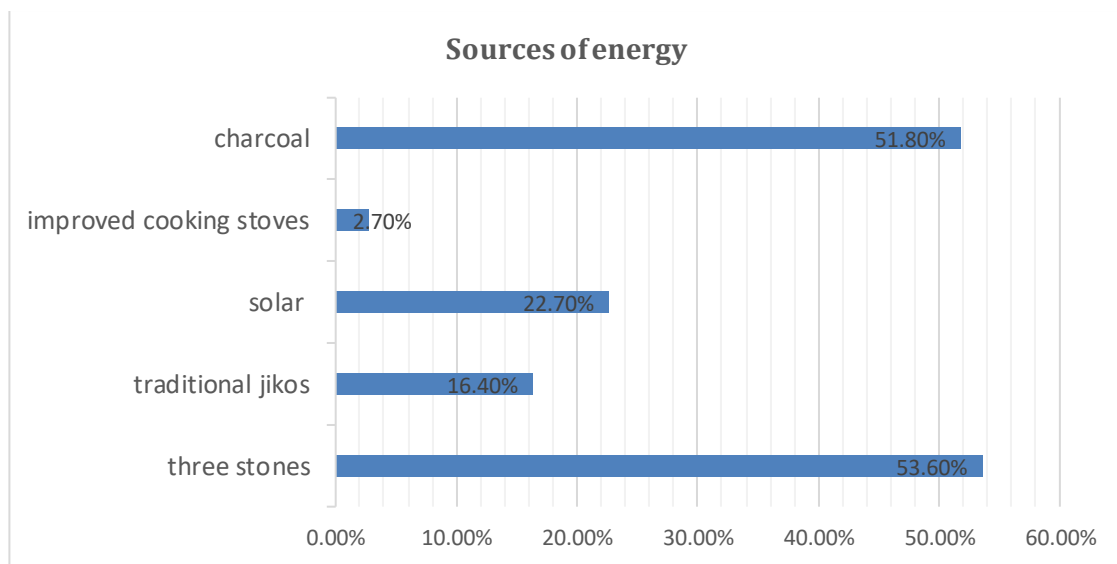


Figure 4.5: Main Sources of Energy Used by Households in Narok North Sub-County

Fuelwood harvesting encompassing both firewood collection and charcoal burning is a dominant land use activity and a critical driver of vegetation loss. Survey findings,

presented in Figure 4.5, indicate that 53.6% of households rely on the traditional three-stone fireplace, while 51.8% depend on charcoal as their primary cooking fuel. Traditional jikos account for 16.4% of household energy use, and solar energy is used by 22.7% of respondents. Improved cooking stoves are used by only 2.7% of the population. KII respondents confirmed that charcoal production targets mature, large-girth indigenous tree species, with operations concentrated in forest fringe areas of the Maasai Mau and along river catchment zones.

4.3.1.4 Settlement Expansion

Settlement expansion has emerged as an accelerating land use practice across Narok North Sub-County, driven by population growth and the administrative and commercial status of Narok Town as the county headquarters. Satellite data indicate a steady increase in built-up area from 2.08 hectares (0.04% of total study area) in 1995 to 16.55 hectares (0.35%) in 2022 an eightfold increase over 27 years (Table 4.1). This expansion has been concentrated around Narok Town and along major transport corridors, progressively encroaching on land formerly used for grazing, cultivation, and conservation.

4.3.2 Drivers of Land Use and Land Cover Change

Survey respondents were asked to rate the contribution of each identified driver to LULCC using a five-point Likert scale. Figure 4.6 presents a comparative summary of the combined 'great' and 'very great' impact ratings for all drivers assessed, providing an integrated overview of their relative perceived significance.

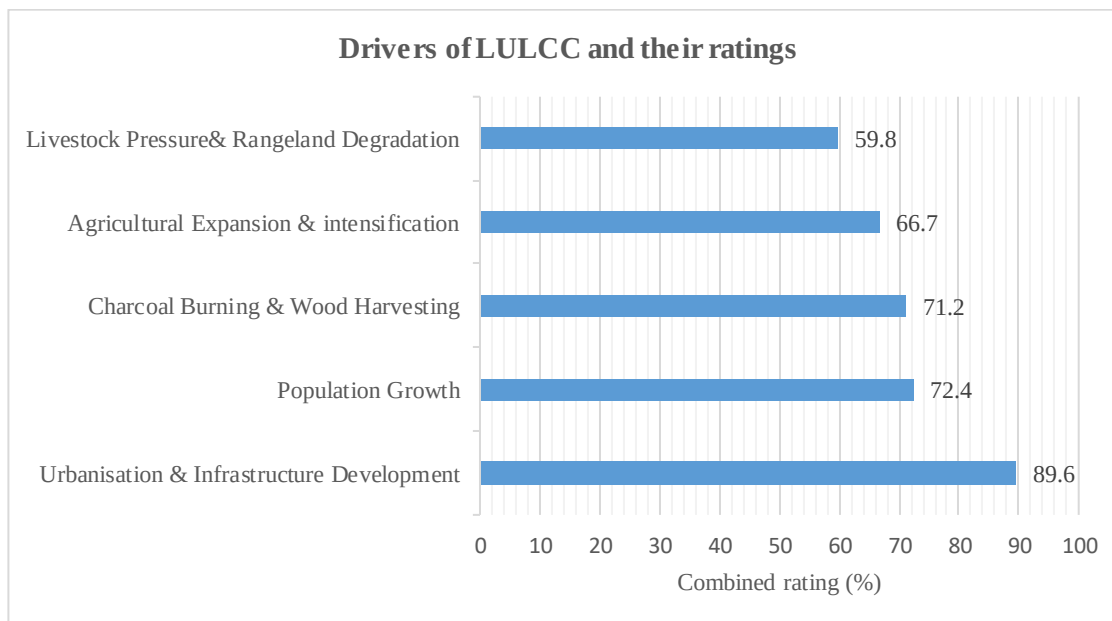


Figure 4.6: Perceived Significance of LULCC Drivers as Rated by Household Survey Respondents, Narok North Sub-County

4.3.2.1 Population Growth

Population growth was rated as a driver of LULCC by 14.9% of respondents at 'great extent' and 57.5% at 'very great extent,' yielding a combined high-significance rating of 72.4%. Narok County's population grew by 126,331 persons between 2019 and 2023, reaching a projected total of 1,284,204 (CGN, 2023). Communal lands are being progressively subdivided to accommodate expanding families, intensifying land fragmentation across the sub-county.

4.3.2.2 Urbanization and Infrastructure Development

Urbanization and infrastructure development was rated as a driver of LULCC by 33.3% of respondents at 'great extent' and 56.3% at 'very great extent,' yielding the highest combined high-significance rating among all drivers assessed at 89.6%. As documented in Section 4.3.1.4, built-up area expanded eightfold between 1995 and 2022 (Table 4.1).

A further 43.7% of respondents reported that vegetation clearance for infrastructure development had a great impact on land degradation.

4.3.2.3 Agricultural Expansion and Intensification

Agricultural expansion and intensification was rated as a driver of LULCC by 48.3% of respondents at 'great extent' and 18.4% at 'very great extent,' yielding a combined significance rating of 66.7%. Both subsistence and commercial farming have driven the conversion of rangelands, seasonal wetlands, and forest margins into cultivated land. Satellite data confirm that cropland expanded from 668.89 hectares in 1990 to 914.38 hectares in 2022 (Table 4.1). KII respondents noted that intensive cultivation on marginal soils is depleting soil fertility and contributing to accelerated erosion.

4.3.2.4 Livestock Pressure and Rangeland Degradation

Livestock pressure and rangeland degradation was rated as a driver of LULCC by 34.5% of respondents at 'great extent' and 25.3% at 'very great extent,' yielding a combined significance rating of 59.8%. KII responses confirmed that mobile pastoralism has been increasingly constrained by land subdivision and privatization of formerly communal grazing corridors, concentrating grazing pressure and accelerating rangeland deterioration. The consequences include vegetation depletion, soil compaction, and heightened susceptibility to erosion.

4.3.2.5 Charcoal Burning and Wood Harvesting

Charcoal burning and wood harvesting was rated as a driver of LULCC by 35.0% of respondents at 'great extent' and 36.2% at 'very great extent,' yielding a combined significance rating of 71.2% the highest recorded for any individual driver. Satellite data show that between 2000 and 2010, forest cover declined by 183.81 hectares equivalent to 7.3% of the 1990 baseline forest area coinciding with the period of most intensive charcoal

extraction documented through field observations and KII data.

4.3.2.6 Climate Variability and Change

Climate variability was identified by KII respondents as both a direct and indirect driver of LULCC. Erratic rainfall patterns, increasing drought frequency, and occasional flooding have disrupted planting calendars, increased dependence on irrigated agriculture, and led to the abandonment of previously cultivated areas. Prolonged dry spells also force pastoralists into forested and protected areas, intensifying overgrazing and soil erosion. The distribution of household income losses attributed to flood events is presented in Table 4.2.

Table 4.2: Loss of Income Resulting from Floods in Narok North Sub-County, Kenya

Income Loss (KES)	Percentage of Respondents (%)
0 – 50,000	28.4%
50,001 – 100,000	20.7%
100,001 – 200,000	15.9%
200,001 – 500,000	18.2%
500,001 – 1,000,000	11.3%
Above 1,000,000	5.5%

The findings show that 28.4% of respondents reported income losses of up to KES 50,000, while nearly one-third fell within higher loss categories exceeding KES 200,000. Losses were primarily attributed to crop failure, livestock mortality, and reduced market access due to damaged infrastructure.

4.3.2.7 Socio-Economic Pressures: Poverty and Institutional Gaps

Approximately 50.6% of respondents identified poverty as influencing land use decisions to a moderate extent, and 42.5% to a great or very great extent. KII respondents noted that weak institutional frameworks including limited enforcement of land use policies and absence of alternative income-generating opportunities allow informal land markets and encroachments to persist across the sub-county.

4.3.3 Land Use and Land Cover Changes: Satellite Imagery Evidence

The LULC classification maps for 1990, 1995, 2000, 2005, 2010, 2015, 2020, and 2022, derived from supervised maximum likelihood classification of Landsat 5, Landsat 7, and Landsat 8/9 imagery, are presented in Figures 4.7 to 4.14. Class boundaries were validated through field-based ground-truthing conducted during field surveys in 2023. The complete land cover area statistics for all five classes across all eight time periods are presented in Table 4.1 above. Each map description below should be read in conjunction with Table 4.1.

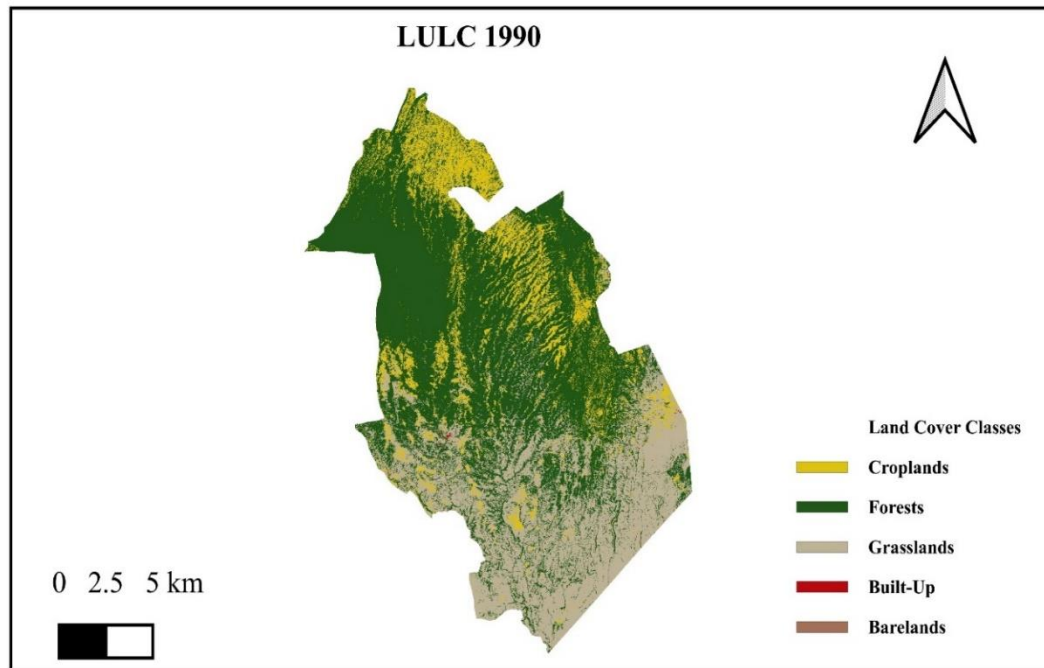


Figure 4.7: Land Use and Land Cover Map of Narok North Sub-County, 1990

The 1990 map represents the baseline landscape condition. Forest is the dominant land cover, occupying 2,566.02 hectares (54.65% of the study area), concentrated along the Mau Escarpment. Grassland is the second largest class at 1,457.03 hectares (31.03%). Cropland occupies 668.89 hectares (14.24%), mostly concentrated around established settlement nodes and accessible agricultural zones. Built-up areas (2.05 ha, 0.04%) and bare land (1.86 ha, 0.04%) are negligible at this baseline, reflecting low population density, limited infrastructure development, and largely intact natural ecosystems. The dominance of forest cover at baseline is consistent with the largely intact condition of the Maasai Mau Forest Complex prior to large-scale land adjudication and subdivision. The minimal cropland extent reflects subsistence farming confined to areas of established settlement, characteristic of pre-adjudication land use systems in Kenya's forest-adjacent communities (County Government of Narok, 2023).

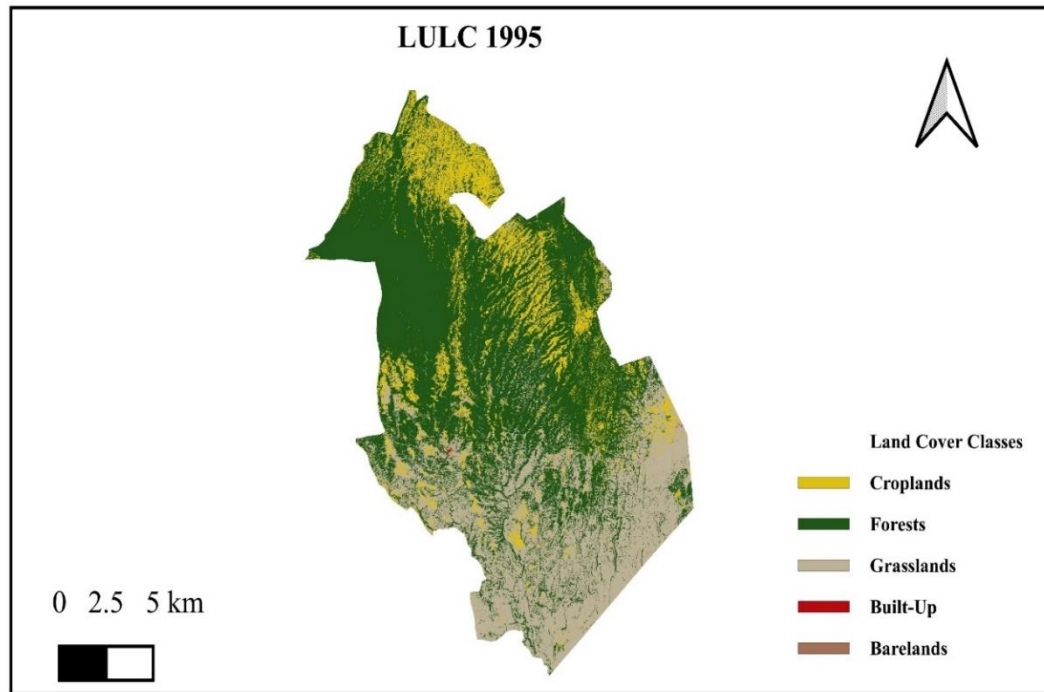


Figure 4.8: Land Use and Land Cover Map of Narok North Sub-County, 1995

The 1995 classification shows a landscape still largely dominated by natural vegetation. Forest cover remains unchanged at 2,566.02 hectares (54.65%), confirming that no measurable deforestation had occurred by this point. Grassland cover is essentially stable at 1,456.99 hectares (31.03%). Cropland (668.89 ha, 14.24%) and built-up area (2.08 ha, 0.04%) remain at near-baseline levels, with pastoralism the dominant land use across the rangelands.

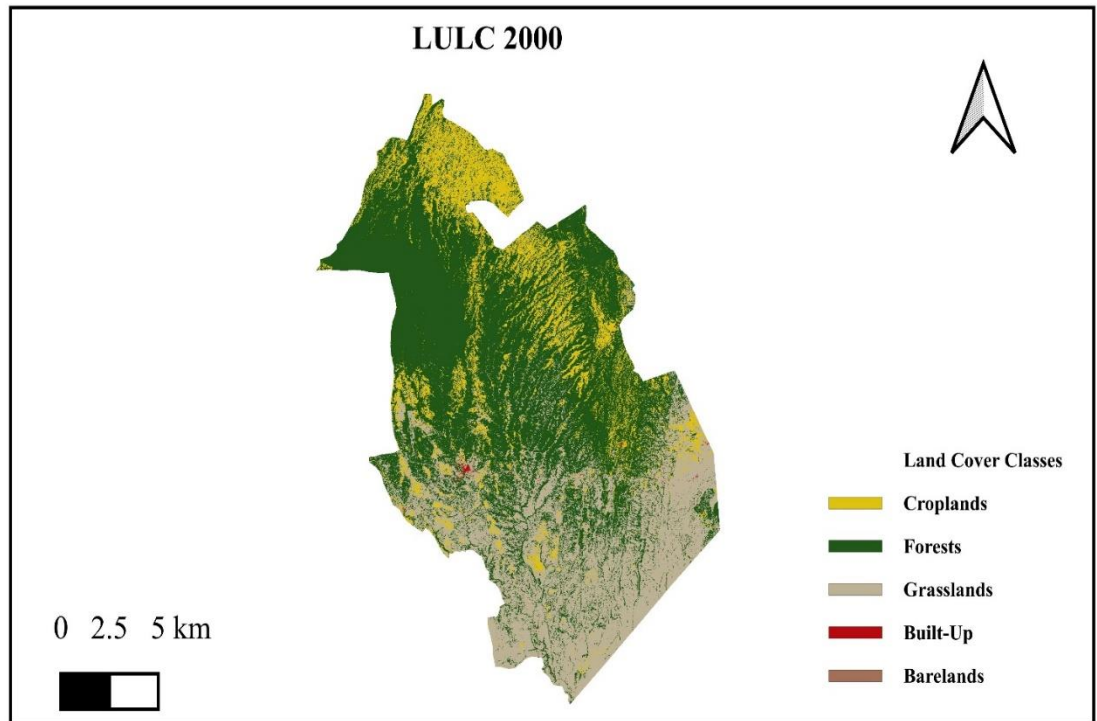


Figure 4.9: Land Use and Land Cover Map of Narok North Sub County, 2000

By 2000, the first measurable shift in forest cover is evident. Forest declined to 2,513.99 hectares (53.54%), a reduction of 52.03 hectares from the 1990 baseline, signaling the onset of deforestation at forest margins. Cropland expanded to 720.59 hectares (15.35%), while built-up areas increased to 7.66 hectares (0.16%), indicating the beginning of settlement expansion around emerging trading centres. Grassland remained broadly stable at 1,451.85 hectares (30.92%). The stability of all land cover classes between 1990 and 1995 is scientifically consistent with the lag period typically observed before land tenure changes translate into measurable land cover transformation. Following Kenya's 1990s land adjudication policies in Narok County, subdivision of group ranches had begun but physical clearing and conversion had not yet reached scales detectable through Landsat classification at 30-metre resolution.

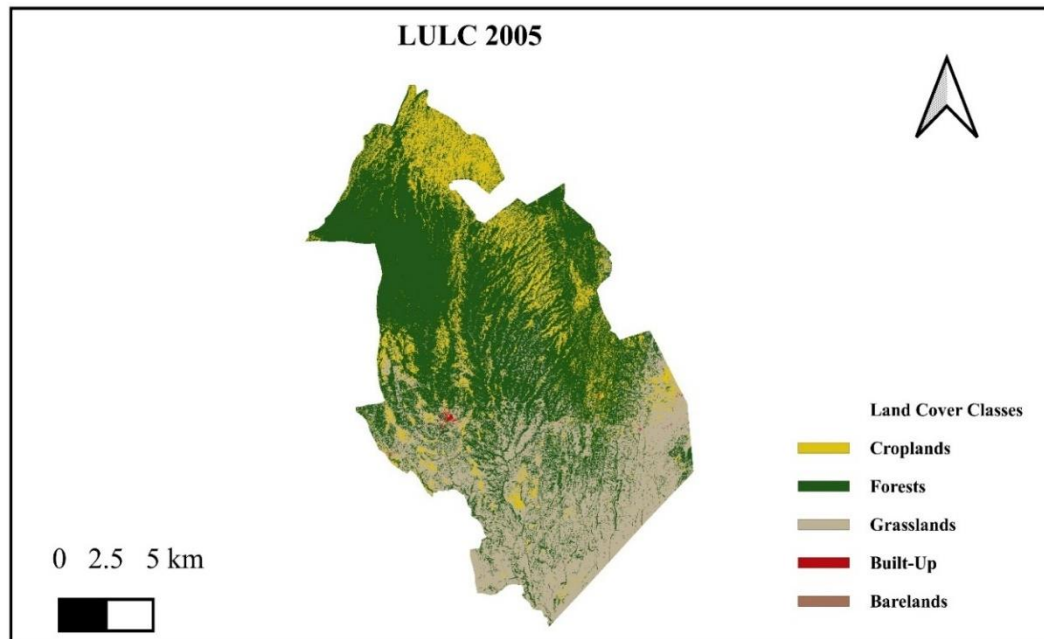


Figure 4.10: Land Use and Land Cover Map of Narok North Sub-County, 2005

By 2005, forest cover continued to decline to 2,490.87 hectares (53.05%), with forest edge degradation intensifying due to small-scale farming and informal settlement encroachment. A slight reduction in cropland to 713.91 hectares (15.20%) reflects the impact of drought stress and rising input costs during this period. Built-up areas increased to 8.59 hectares (0.18%). Grassland showed a modest increase to 1,480.71 hectares (31.53%), possibly reflecting transitions from degraded cropland at the margins of cultivation.

The onset of measurable forest loss by 2000 coincides with the post-adjudication period when newly titled landholders began converting forest margins for agriculture and settlement. The 52-hectare forest decline represents early-stage edge degradation, a pattern well-documented in fragmented tropical forest landscapes where deforestation initiates at boundaries between protected and unprotected areas (IPCC, 2022).

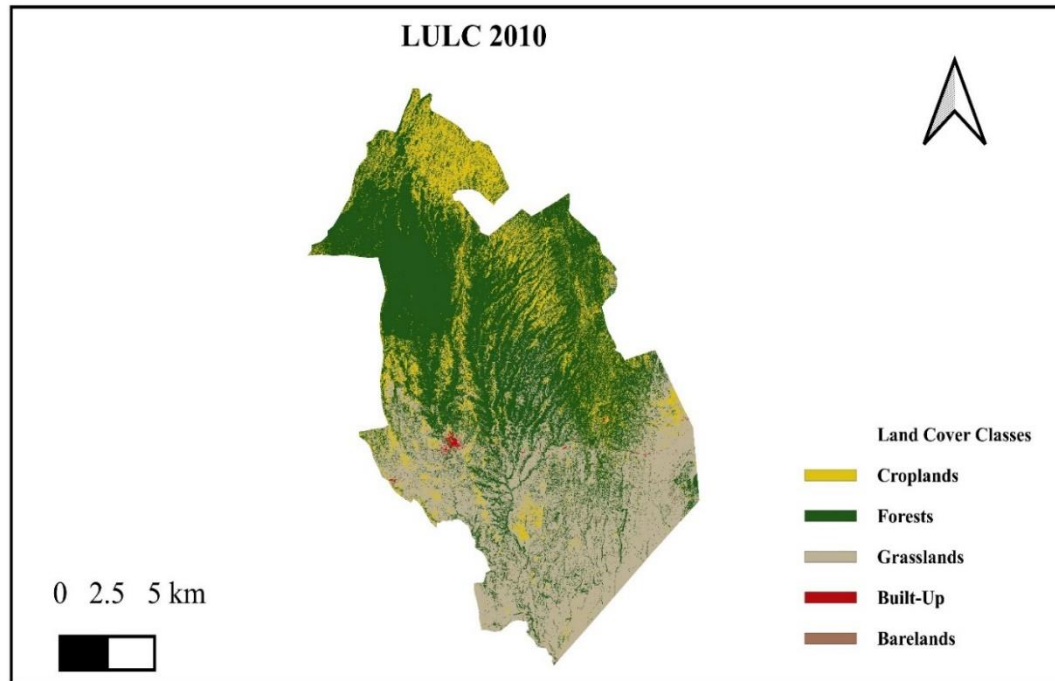


Figure 4.11: Land Use and Land Cover Map of Narok North Sub-County, 2010

The 2010 classification records the most accelerated forest loss of any single decade in the study period. Forest cover declined substantially to 2,330.18 hectares (49.63%), a loss of 183.81 hectares from 2000 equivalent to 7.3% of the 1990 baseline forest area. Grassland cover reached its peak across the study period at 1,618.95 hectares (34.49%), reflecting transitions from degraded forest margins and some cropland areas into grassland. Cropland continued to expand to 732.48 hectares (15.60%), and built-up areas grew to 11.94 hectares (0.25%).

The accelerated forest loss between 2000 and 2010 is the most ecologically significant finding of this study. A net decline of 183.81 hectares represents a deforestation rate of approximately 18.4 ha/year significantly above the 1990–2000 rate of 5.2 ha/year. This acceleration is consistent with the documented intensification of charcoal production in

the Mau Forest during this period, driven by rising urban energy demand and inadequate enforcement of forest protection regulations. The peak grassland extent in 2010 reflects a landscape in transition, where degraded forest margins and fallow cropland were classified as grassland prior to subsequent conversion.

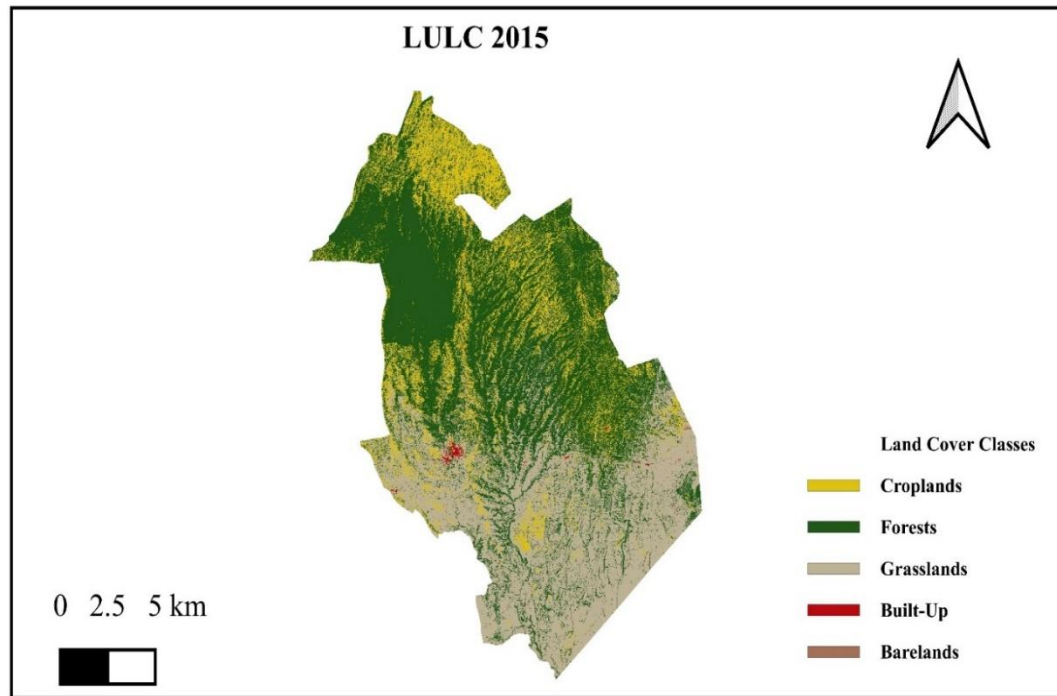


Figure 4.12: Land Use and Land Cover Map of Narok North Sub-County, 2015

By 2015, forest cover continued to decline to 2,260.94 hectares (48.15%), driven by encroachment for farming, charcoal production, and settlement. Grassland decreased slightly from its 2010 peak to 1,607.11 hectares (34.23%), while cropland expanded significantly to 811.33 hectares (17.28%), reflecting agricultural intensification following the drought-related contraction of 2005. Built-up areas increased to 14.30 hectares (0.30%), becoming more densely clustered in peri-urban zones and near market centres. The continued forest decline alongside significant cropland expansion reflects a dual-

pressure dynamic: direct conversion of forest margins for agriculture, and indirect pressure through grassland encroachment. The increase in built-up area around peri-urban zones is consistent with the infrastructure investments along the Narok–Nairobi corridor during Kenya's Vision 2030 development period, which stimulated secondary settlement and commercial activity.

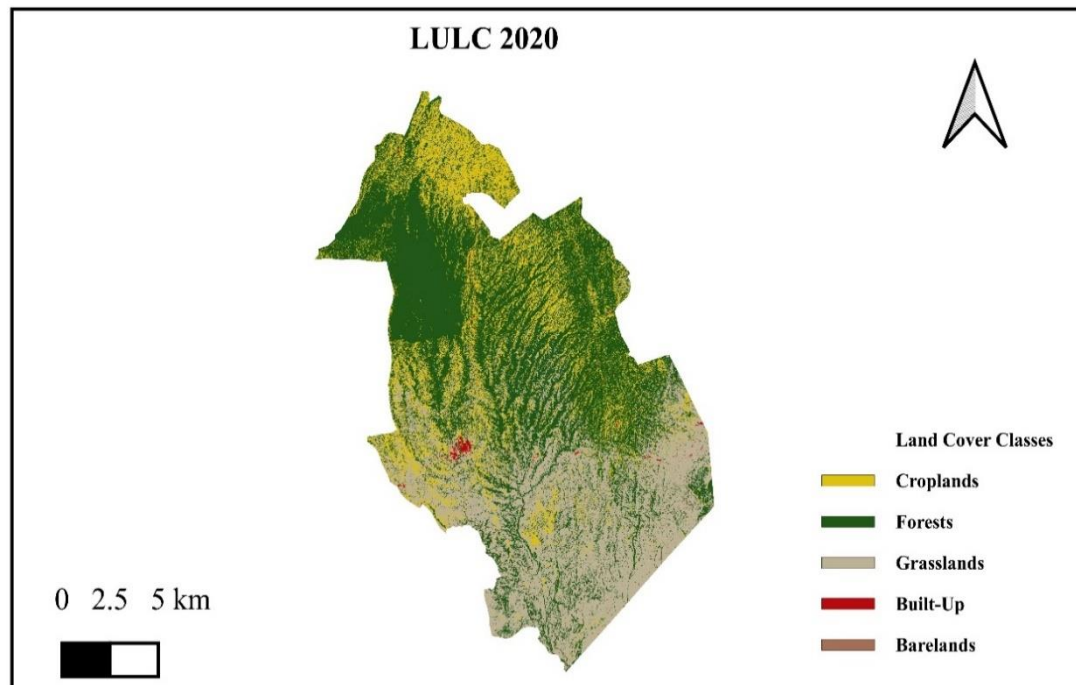


Figure 4.13: Land Use and Land Cover Map of Narok North Sub-County, 2020

The 2020 classification reveals continued landscape transformation. Forest declined further to 2,243.20 hectares (47.77%). Cropland expanded substantially to 913.42 hectares (19.45%), reflecting continued conversion of grassland and forest margins. Grassland declined to 1,518.48 hectares (32.34%). Built-up areas reached 17.63 hectares (0.38%), concentrated around Narok Town and along key transport corridors.

The post-2015 trajectory confirms landscape stabilization in forest loss rate, though

decline continues. The near-plateau in forest cover between 2020 and 2022 may partly reflect conservation interventions within the Mau Complex, though the data cannot isolate this effect from natural forest recovery on previously disturbed patches. Cropland approaching 20% of total study area represents a structurally transformed landscape compared to the 1990 baseline.

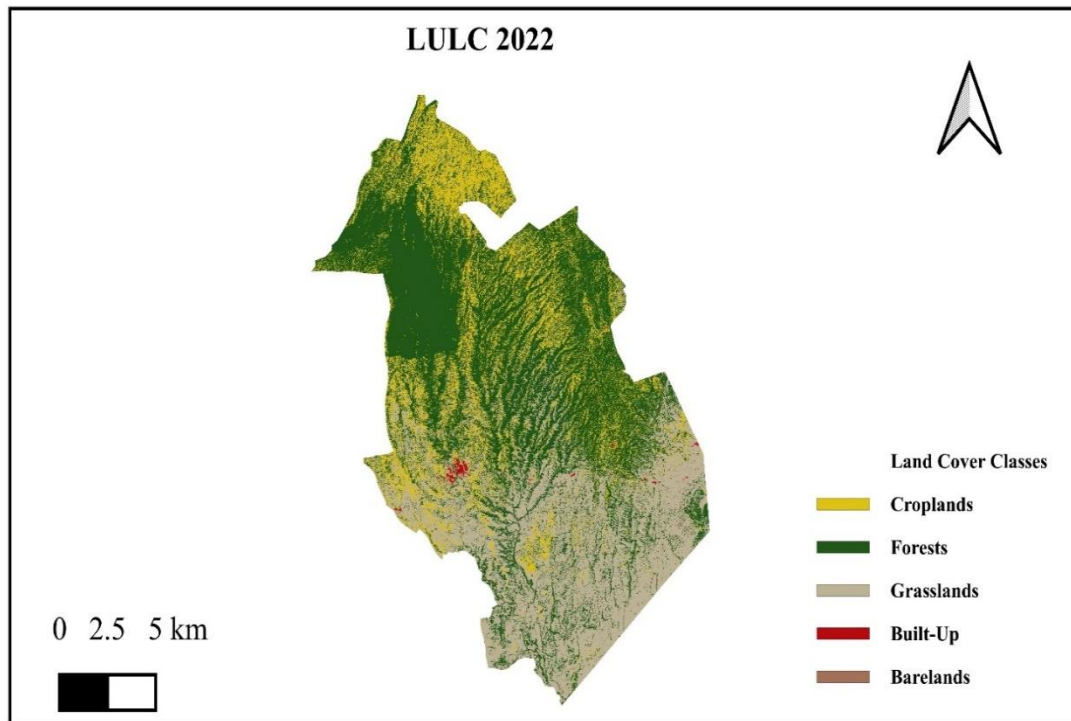


Figure 4.14: Land Use and Land Cover Map of Narok North Sub-County, 2022

The 2022 map records the endpoint of the 32-year study period. Forest cover stands at 2,236.56 hectares (47.63%), representing a total loss of 329.46 hectares equivalent to 12.84% of the 1990 baseline over the study period. Cropland has reached 914.38 hectares (19.47%), a net increase of 245.49 hectares (36.7%) from the 1990 baseline. Grassland stands at 1,525.39 hectares (32.48%). Built-up areas have expanded to 16.55 hectares (0.35%), an eightfold increase from the 1995 figure of 2.08 hectares. Bare land remains

minimal at 2.95 hectares (0.06%), reflecting the predominantly forested and vegetated character of the sub-county's landscape, particularly in the upper Mau Forest region. The 2022 endpoint represents a net loss of 329.46 hectares of forest equivalent to a 12.84% reduction in the 1990 forest baseline over 32 years. Scientifically, this rate of loss (approximately 10.3 ha/year averaged over the full study period) is lower than deforestation rates recorded in comparable Kenyan forest-adjacent sub-counties, suggesting that the Mau Forest's protected status has exercised some restraining influence. However, the eightfold increase in built-up area and 36.7% cropland expansion confirm an irreversible structural shift in the landscape's ecological character.

4.3.3.1 Overlay-Based Binary Change Detection of Land Use and Land Cover (1990–2022)

To provide an integrated spatial summary of land cover transformation across the full 32-year study period (1990–2022), a binary Land Use and Land Cover Change Detection map was generated through overlay analysis in QGIS. This map classifies every pixel in the study area as either “Change” or “No Change” based on a comparison between the 1990 baseline classification and the 2022 endpoint classification. The resulting map, presented as Figure 4.15 below, provides a spatially explicit representation of where land cover transitions occurred, complementing the time-series LULC maps in Figures 4.7–4.14 and the area statistics in Table 4.1.

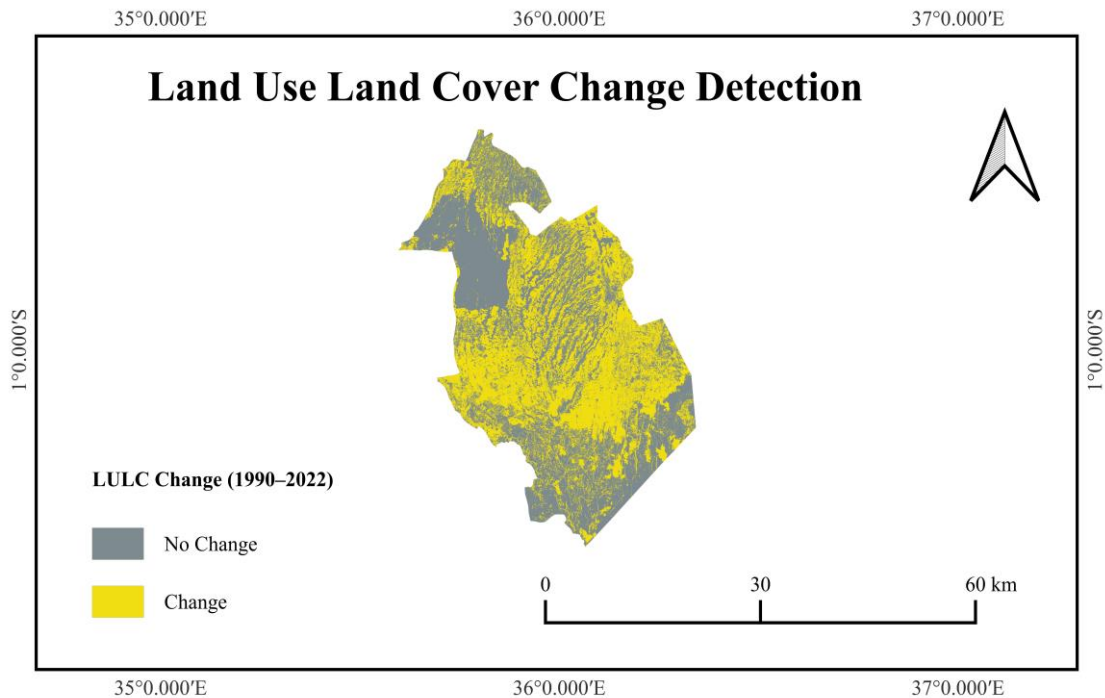


Figure 4.15: Land Use Land Cover Change Detection Map, Narok North Sub-County 1990-2022

The change detection map reveals that the majority of the classified study area experienced measurable land cover transitions between 1990 and 2022. Yellow pixels, denoting “Change,” are predominantly distributed across the central and southeastern portions of the sub-county, corresponding spatially to areas of documented cropland expansion, settlement growth, and grassland-to-agriculture conversion identified in the time-series analysis. Grey pixels, denoting “No Change,” are concentrated in the northwestern zone of the study area, consistent with the location of the upper Mau Forest Complex, where forest cover has remained comparatively stable across the study period, and in the southern zone where some rangeland patches retained their classification across the 32-year period. The spatial pattern confirms that land cover change has been geographically uneven: the lower-lying and more accessible areas of the sub-county experienced the most extensive transformation, while the upper escarpment retained

greater land cover stability, likely reflecting both the protective influence of the Mau Forest reserve boundary and the lower agricultural suitability of steeper terrain. This binary change layer supports the quantitative findings presented in Table 4.1, providing visual confirmation of the net landscape transformation documented over the study period.

4.3.4 Land Use Change Interconnections

The observed land use and land cover changes demonstrate strong interconnections among forest cover, cropland, grassland, built-up areas, and bare land within Narok North Sub-County. Over the study period, the decline in forest cover was closely associated with the expansion of cropland and, to a lesser extent, settlement development. Grassland exhibited fluctuating trends throughout the study period, with notable increases during periods of reduced cultivation and post-drought recovery, followed by subsequent declines as agricultural and settlement pressures intensified. Built-up areas, although spatially limited, showed a gradual but consistent increase over time, concentrated around Narok Town and along major transport corridors. Bare land remained minimal throughout the study period; field observations indicate that land degradation manifested primarily through vegetation thinning and soil compaction rather than widespread bare soil exposure, with degraded surfaces frequently classified under grassland during image classification. The full ecological interpretation of these interconnections is provided in Section 4.4.4.

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4.3.5 Land Use Change and Climate Hazard Impacts

4.3.5.1 Forest Decline and Surface Runoff Dynamics

The progressive decline in forest cover within Narok North Sub-County has implications for watershed stability and surface runoff regulation. Forest ecosystems play an important role in intercepting rainfall, promoting infiltration, reducing runoff velocity, and maintaining soil stability. The reduction in forest vegetation therefore decreases the landscape's natural capacity to regulate water flow during periods of intense rainfall.

KII respondents reported that areas previously covered by dense forest now experience faster surface runoff during heavy rainfall events, particularly within upper catchment zones. The findings suggest that forest degradation has altered local hydrological processes by increasing overland flow and reducing infiltration capacity. Such changes may contribute to soil erosion and downstream sediment transport, especially during high-intensity storms.

However, the findings further indicate that flooding within urban centres such as Narok Town cannot be attributed solely to forest decline. Respondents observed that recurrent flooding in the town was historically aggravated by blocked waterways and inadequate drainage systems that restricted the movement of runoff into the main river channels. The construction of larger drainage systems within the town center has since reduced the

frequency and severity of flood events. This demonstrates that urban flood vulnerability is influenced by both environmental and infrastructural factors.

Overall, the interaction between upstream land cover change and inadequate storm water drainage infrastructure increases vulnerability to flooding within downstream settlements during periods of extreme rainfall.

4.3.5.2 Grassland Dynamics and Drought Vulnerability

Grassland cover exhibited a non-linear trend throughout the study period, reflecting the combined influence of climatic variability and land use change. KII respondents reported that major drought episodes experienced in 1999–2000, 2005–2006, 2008–2009, and 2016–2017 had severe impacts on pasture availability and pastoral livelihoods within the sub-county. During prolonged dry periods, reduced pasture quality and declining vegetation cover increased pressure on grazing lands and contributed to localized land degradation.

Field observations further indicated that degraded grasslands characterized by sparse vegetation and compacted soils contributed to increased surface runoff during heavy rainfall events in low-lying areas. This suggests that grasslands within the sub-county perform a dual ecological role by supporting pastoral livelihoods during normal climatic conditions while also influencing hydrological processes under conditions of degradation and climatic stress.

The fluctuations observed in grassland extent may therefore reflect changing interactions between drought conditions, grazing intensity, vegetation recovery, and land conversion processes within the landscape.

4.3.5.3 Built-Up Areas and Flood Exposure

Built-up areas expanded gradually over the study period as a result of settlement growth,

infrastructural development, and increasing socio-economic activities within the sub-county. Although the spatial extent of built-up land remained relatively small, field observations and KII responses indicated that some settlements developed within low-lying and flood-prone areas adjacent to drainage pathways and river channels. Field observations documented in Plate 4.7 showed structures affected by flood inundation during periods of intense rainfall.



Plate 4.7: Built-Up Structures Submerged in Flood Water, Narok North Sub-County

Respondents further noted that unplanned settlement expansion, encroachment on natural waterways, and inadequate drainage infrastructure increased exposure to flooding within parts of Narok Town and surrounding built-up areas. The findings indicate that the expansion of impervious surfaces associated with built-up development may contribute to increased runoff generation by reducing infiltration capacity. Consequently, the interaction between settlement expansion, inadequate drainage systems, and upstream runoff increases flood vulnerability within urban and peri-urban areas.

4.3.5.4 Bare Land Extent and Land Degradation Patterns

Bare land remained consistently minimal throughout the study period, reflecting the predominantly vegetated nature of Narok North Sub-County. Field observations and KII responses indicated that land degradation processes such as overgrazing, vegetation thinning, and soil compaction were present within parts of the sub-county. However, these degraded surfaces were often characterized by sparse vegetation cover and were therefore largely classified under grassland rather than bare land during image classification. This pattern suggests that land degradation within the study area primarily occurs through gradual vegetation decline and ecosystem disturbance rather than widespread exposure of bare soil surfaces.

4.3.6 Existing Community Coping and Adaptation Strategies

Field observations, household survey responses, and Key Informant Interviews (KIIs) identified several coping and adaptation strategies employed by households in Narok North Sub-County in response to climate variability and environmental change. These strategies largely reflect the dependence of local communities on pastoralism, rain-fed agriculture, and natural resource-based livelihoods.

Seasonal migration of livestock emerged as one of the main coping strategies during drought periods due to declining pasture availability and unreliable water sources. However, respondents indicated that increasing land subdivision, settlement expansion, and agricultural encroachment have reduced traditional grazing mobility within parts of the sub-county. Similar findings have been reported in studies conducted within the Maasai Mau ecosystem, where population pressure and competing land use systems have altered pastoral livelihood patterns (CGN, 2023).

Livelihood diversification into charcoal burning, casual labor, and small-scale business activities was also identified as an important coping mechanism during periods of drought

and livestock losses. While these activities provide short-term household income, some practices such as charcoal production may contribute to forest degradation and environmental decline within the Mau catchment (County Government of Narok, 2023). Water harvesting through shallow wells, water pans, and earth dams was commonly practiced as a response to increasing water scarcity during prolonged dry periods. Respondents associated declining forest cover with reduced river flow, drying springs, and seasonal water shortages. Studies conducted within the Maasai Mau ecosystem have shown that ongoing deforestation has contributed to the degradation of water catchments and reduced water availability.

Crop diversification and livestock destocking were also reported as adaptive measures aimed at reducing climate-related risks. Some households indicated that they had adopted drought-tolerant crops and mixed farming practices to reduce dependence on a single livelihood source.

The majority of respondents identified drought as the most severe climate hazard affecting the sub-county due to its impacts on pasture availability, livestock productivity, food security, and household income. Flash floods, although less frequent, were also reported to damage infrastructure, cropland, and settlements, particularly within low-lying areas and sections of Narok Town characterized by inadequate drainage systems.

Community members further emphasized the need for sustainable water sources, reforestation, climate information services, and livelihood diversification support as important long-term adaptation priorities. Overall, the findings indicate that existing adaptation strategies in Narok North Sub-County remain largely reactive and household-based. The significance and implications of these strategies are discussed in Section 4.4.5.

4.3.7 Validation of Findings

The validity of the study findings was enhanced through data triangulation using household surveys, key informant interviews, focus group discussions, and Landsat satellite imagery analysis. Information obtained from one source was compared with findings from other sources to ensure consistency and reliability. Research instruments were reviewed by supervisors and experts in environmental management to improve clarity and relevance to the study objectives. In addition, the questionnaire was pilot tested in a nearby area with similar characteristics before the actual data collection. The remote sensing analysis followed standard GIS and image classification procedures, while field observations and community responses were used to confirm land use and land cover patterns. These approaches improved the credibility and reliability of the study findings.

4.4 Interpretation and Discussion of Findings

This section interprets the findings presented in Section 4.3 in relation to existing literature and situates them within the broader context of land use change and climate vulnerability in Sub-Saharan Africa. The discussion follows the thematic structure of the results.

4.4.1 Current Land Use Practices

4.4.1.1 Agriculture

The observed 36.7% increase in cropland between 1990 and 2022 reflects sustained pressure from both subsistence needs and market-oriented agriculture in Narok North Sub-County. Although cropland remains relatively limited compared to forest and grassland cover, its steady expansion indicates a clear shift toward intensified land use, interrupted only briefly in 2005 due to drought conditions and rising input costs.

This pattern aligns with findings by CGN (2023), who report similar agricultural expansion into rangelands and forest margins. More broadly, agricultural expansion is

widely recognized across Sub-Saharan Africa as a major driver of land cover change. In Narok North, this expansion is reinforced by declining soil fertility and continued cultivation of marginal lands, creating a cycle of land degradation and further expansion.

4.4.1.2 Livestock Keeping

Grassland dynamics reflect the interaction between pastoral livelihoods, land subdivision, and climate variability. Grassland cover remained relatively stable until 2005, increased to a peak in 2010, and declined thereafter to 2022. The temporary increase likely reflects shifts from cultivated or degraded land back to grassland during periods of reduced cultivation and livestock mobility changes linked to drought.

The subsequent decline is consistent with studies across the Mara ecosystem that associate grassland fragmentation with increasing livestock pressure and reduced grazing mobility. Overgrazing remains a key driver of rangeland degradation in savannah systems, where cultural and economic values attached to herd size often limit sustainable grazing practices.

4.4.1.3 Fuelwood and Charcoal Production

Charcoal production emerged as a dominant driver of land cover change, with over 70% of respondents identifying it as having a major impact. Dependence on fuelwood remains high due to limited access to alternative energy sources and low adoption of improved cooking technologies.

Satellite trends confirm that peak forest loss coincided with periods of intense charcoal production, particularly between 2000 and 2010. These findings align with regional studies identifying fuelwood demand as a significant contributor to forest conversion in Sub-Saharan Africa. Continued reliance on charcoal, combined with weak energy transitions, sustains pressure on forest ecosystems.

4.4.1.4 Settlement Expansion

Settlement growth has increased steadily, particularly around Narok Town and transport corridors. Although built-up areas remain small in spatial extent, their growth from 2.08 hectares in 1995 to 16.55 hectares in 2022 reflects accelerating urbanization.

Similar patterns are observed across East African secondary towns, where peri-urban expansion alters drainage systems and increases flood risk. In Narok North, settlement concentration in sensitive catchment areas amplifies environmental impacts despite its relatively small footprint.

4.4.2 Drivers of Land Use and Land Cover Change

4.4.2.1 Population and Socio-Economic Pressure

Population growth is the most fundamental driver of land use change in Narok North, increasing demand for land, fuelwood, and agricultural resources. Land subdivision and fragmentation have intensified pressure on remaining communal and natural landscapes.

Across Sub-Saharan Africa, similar demographic trends are strongly linked to land conversion and ecosystem degradation. In Narok North, population pressure interacts closely with poverty, reinforcing dependence on natural resources for survival.

4.4.2.2 Urbanization and Infrastructure Development

The 89.6% combined significance rating for urbanization and infrastructure development the highest of any driver assessed reflects a community awareness that physical development is both a direct cause and an enabler of broader land use transformation. Roads and market infrastructure do not merely occupy land; they open previously inaccessible areas to agricultural conversion, speculative settlement, and resource extraction, creating a multiplier effect on landscape change beyond their immediate

footprint. This perception aligns with the satellite evidence, which shows that built-up expansion has proceeded in tandem with cropland growth, particularly along the Narok-Nairobi transport corridor.

Although built-up areas occupy a small proportion of land, their ecological impact is significant due to their location in hydrologically sensitive zones. Infrastructure development also triggers secondary land conversion beyond its direct footprint, reinforcing landscape transformation.

4.4.2.3 Agricultural Expansion

Agricultural expansion remains a central driver of land cover change, driven by food demand, income needs, and improved market access. This has led to the conversion of grasslands and forest edges into cultivated land.

This pattern is consistent with broader East African trends, where agricultural expansion contributes to soil degradation, biodiversity loss, and declining ecosystem resilience.

4.4.2.4 Livestock Pressure

Livestock pressure contributes to rangeland degradation, particularly under conditions of restricted mobility due to land subdivision. Concentrated grazing increases pressure on available pasture, accelerating vegetation decline. While ranked lower than other drivers in the survey, livestock remains ecologically significant due to its cumulative long-term impact on rangeland health.

4.4.2.5 Charcoal and Wood Harvesting

Charcoal production remains a critical driver of forest loss, strongly supported by both survey responses and satellite evidence. The overlap between peak charcoal activity and forest decline reinforces the reliability of these findings. Despite conservation efforts,

continued reliance on charcoal indicates persistent energy insecurity and weak enforcement of forest protection measures.

4.4.2.6 Climate Variability and Change

Climate variability intensifies existing land use pressures by affecting household livelihoods. Floods and droughts cause significant economic losses, forcing households to rely more heavily on resource extraction. Rather than acting independently, climate stress interacts with socio-economic conditions to accelerate environmental degradation, particularly through increased charcoal production and land expansion into marginal areas.

4.4.2.7 Poverty and Institutional Constraints

Poverty strongly influences land use decisions, with most households relying on natural resources for survival. Weak institutional enforcement further exacerbates land degradation by allowing informal land conversion and unregulated resource use. These governance gaps reduce the effectiveness of environmental management strategies and increase vulnerability to climate shocks.

4.4.3 Land Use and Land Cover Change Patterns and Trajectories

4.4.3.1 Forest Cover

Although forest remains the dominant land cover in Narok North, the steady decline recorded over the study period has important ecological implications for the Mau Forest catchment. Forest loss reduces water infiltration, biodiversity, and ecosystem stability while increasing susceptibility to flooding and soil erosion.

The most severe forest decline coincided with periods of intensive charcoal production and agricultural expansion. While conservation initiatives appear to have slowed forest

loss in some protected areas, long-term sustainability will depend on addressing underlying drivers such as poverty, energy demand, and weak policy enforcement.

4.4.3.2 Grasslands and Shrubs

Changes in grassland cover reflect the combined effects of grazing pressure, climate variability, agricultural expansion, and settlement growth. The temporary increase observed around 2010 may indicate recovery in degraded areas or reduced cultivation during drought periods, while the later decline points to renewed encroachment into grazing land.

These findings highlight the importance of sustainable rangeland governance and protection of communal grazing systems in maintaining ecosystem resilience.

4.4.3.3 Croplands

The expansion of cropland over the study period demonstrates the growing dependence on agriculture as both a livelihood and economic activity. However, much of this expansion has occurred at the expense of natural vegetation, particularly grasslands and forest margins. Continued cultivation without adequate soil conservation measures risks further land degradation, threatening long-term agricultural productivity and food security.

4.4.3.4 Built-Up Areas

The rapid increase in built-up areas represents one of the most permanent forms of land transformation within the sub-county. Urban expansion around Narok Town has altered natural drainage patterns and increased the proportion of impermeable surfaces, contributing to greater flood risk.

This pattern reflects broader urbanization trends across East Africa, where unplanned peri-urban growth often occurs without adequate environmental planning or climate-resilient infrastructure.

4.4.3.5 Bare Land

Bare land remained relatively limited throughout the study period, reflecting the largely vegetated nature of Narok North. However, the gradual increase observed over time points to localized land degradation associated with overgrazing, vegetation clearance, and settlement activities.

Most degraded surfaces were still captured within the grassland classification due to the presence of sparse vegetation, suggesting that environmental degradation in the area is expressed more through vegetation thinning than complete soil exposure.

4.4.4 Interconnections between LULCC and Climate Hazards

4.4.4.1 Loss of Ecological Buffering Capacity

The combined reduction in forest cover alongside increases in cropland and built-up areas reflects a gradual replacement of natural vegetation with surfaces that absorb less water. This transformation weakens the landscape's natural ability to regulate water flow, increasing vulnerability to flooding and other climate-related hazards.

4.4.4.2 Forest Decline and Flood Risk

Forest loss within the Mau catchment has reduced canopy cover and soil infiltration capacity, leading to faster surface runoff during heavy rainfall events. Local observations from key informants support this finding, with respondents reporting more rapid flooding and runoff in deforested areas.

4.4.4.3 Bare Land and Land Degradation

Although bare land occupies a small spatial area, the degradation processes associated with it have broader ecological consequences. Exposed soils are more vulnerable to erosion and sediment transport, particularly during intense rainfall events.

4.4.4.4 Grassland Degradation and Climate Vulnerability

Declining grassland cover has reduced pasture availability and weakened the capacity of soils to retain moisture, increasing vulnerability to both drought and flooding. Sustainable rangeland management and grassland restoration are therefore important strategies for improving climate resilience in the sub-county.

4.4.4.5 Built-Up Areas and Impervious Surfaces

Expansion of built-up areas around Narok Town has altered natural hydrological processes by replacing permeable surfaces with roads, buildings, and other infrastructure. This reduces water infiltration and increases surface runoff, contributing to more frequent urban flooding, particularly in poorly planned settlements and flood-prone zones.

4.4.5 Evidence-Based Strategies for Enhanced Community Resilience and Adaptation

The findings documented in Section 4.3.6 reveal a significant structural gap in Narok North Sub-County's adaptive capacity: available strategies are predominantly reactive, household-driven, and concentrated in a narrow set of natural resource-dependent responses. This pattern is ecologically significant because the very practices households rely on most livestock mobility, water harvesting, and livelihood diversification into charcoal are simultaneously constrained by the land use changes this study has documented and, in the case of charcoal production, actively contribute to further environmental degradation. The result is a compounding vulnerability cycle in which

climate stress forces resource extraction that deepens the environmental conditions driving that stress. Addressing this cycle requires moving beyond household-level responses toward integrated approaches combining ecosystem restoration, sustainable water management, climate information services, and improved land use governance. The community-identified adaptation priorities documented in Section 4.3.6 reflect a well-grounded understanding of the landscape-climate nexus and provide the evidence base for the following strategies.

i. Climate-Smart Rangeland and Pasture Management

The decline in grassland cover from its 2010 peak (Table 4.1) calls for formalized community-based rangeland governance integrating rotational grazing, rangeland reseeding, and community grazing management plans. The partial recovery observed between 2005 and 2010 demonstrates the feasibility of improvement through community-led management (CGN, 2018).

ii. Restoration of Degraded Forests and Riparian Corridors

The 329.46 ha forest loss documented over the 32-year study period with the most severe decade of loss established in Section 4.4.1.3 makes ecosystem-based adaptation (EbA) the highest-priority structural intervention for climate resilience. Reforestation, agroforestry, and formal protection of riparian buffers can restore hydrological function and reduce soil erosion (UNEP, 2021). Community Forest Associations (CFAs) represent the most appropriate governance vehicle for implementation.

iii. Water Resource Development and Management

The income losses documented in Table 4.2, with nearly one-third of respondents reporting losses exceeding KES 200,000, highlight the need for multi-source climate-resilient water infrastructure including solar-powered boreholes, sand dams, rainwater

harvesting tanks, and community-led desilting of water pans, supported by water user associations (WMO, 2022).

iv. Strengthening Early Warning Systems and Climate Services

Access to timely and actionable climate information remains limited in rural Narok. Establishing community-based early warning systems (CBEWS) linked to the Kenya Meteorological Department (KMD) and disseminated through mobile platforms can enable timely preparation for and response to climatic shocks (WMO, 2022).

v. Sustainable Land Use Planning and Enforcement

Encroachment into ecologically sensitive zones has been a primary mechanism of LULCC across the study period. County authorities must promote land use zoning, enforce environmental regulations, and support participatory land use planning incorporating satellite-derived land cover data and local ecological knowledge (GoK, 2018).

vi. Livelihood Diversification and Nature-Based Enterprises

Given charcoal burning's dominance as the highest-rated LULCC driver (Section 4.3.2.5), reducing dependence on biomass energy requires accessible alternative livelihoods including beekeeping, eco-tourism, value-added livestock products, and drought-tolerant crop farming (World Bank, 2022).

vii. Capacity Building and Institutional Strengthening

Long-term resilience requires training on climate-smart agriculture, environmental governance, and natural resource management, with explicit targeting of women and youth, and strengthened land tenure security to underpin Community Forest Associations and rangeland governance frameworks (IPCC, 2022).

4.4.6 Integration with Policy and Institutional Frameworks

The strategies proposed above align with: the Kenya Climate Change Act (2016), which mandates mainstreaming of climate change into county planning; the National Adaptation Plan (NAP) 2015–2030, which emphasizes community-led resilience, ecosystem restoration, and risk-informed development; the Narok County Integrated Development Plan (CIDP) 2023–2027, which prioritizes sustainable natural resource use, water access, and rangeland management; and the African Union’s Climate Resilience Framework, which supports decentralized, nature-based solutions. Securing multi-stakeholder engagement including county government, NGOs, community groups, and the private sector is essential to translating these strategies into sustained, equitable outcomes for Narok North Sub-County.

4.4.7 Comparative Analysis of Findings with Prior Studies

This section situates the empirical findings of this study within the context of prior research conducted in Narok North Sub-County, the wider Mau–Mara landscape, and comparable East African settings. The comparison is organized thematically to assess convergence, divergence, and change over time across the three research objectives.

4.4.7.1 Agricultural Expansion and Cropland Change

This study recorded a net cropland increase of 245.49 hectares (36.7%) between 1990 and 2022, rising from 668.89 ha to 914.38 ha within the classified study area of 4,695.84 ha. Mootian et al. (2020), who examined socio-economic drivers of land use change specifically in Narok North Sub-County, similarly identified agricultural expansion as a primary mechanism of land cover transformation, driven by the conversion of rangelands and forest margins into cultivated land. The present study extends and quantifies that earlier qualitative assessment: cropland continued to grow after Mootian et al.’s study period, with the most pronounced expansion occurring between 2015 and 2022, when

cropland increased from 811.33 ha (17.28%) to 914.38 ha (19.47%). This confirms that the agricultural pressure documented by Mootian et al. (2020) has not only persisted but intensified in the years since their study. At the wider landscape scale, Gichenje and Eunice (2024), studying the Mara–Mau landscape, documented accelerating agricultural encroachment into forest and grassland areas since the 1990s, attributing it to land subdivision, population growth, and shifting livelihood systems consistent with the drivers identified in this study. Albert (2023), examining the greater Mau Forest Complex, similarly recorded progressive conversion of natural vegetation to farmland along forest margins, and a spatial pattern that this study’s change detection map (Figure 4.15) corroborates for Narok North specifically.

4.4.7.2 Forest Cover Decline

This study documented a total forest loss of 329.46 ha (12.84%) over the 32-year study period, with the most severe decade of loss occurring between 2000 and 2010, when 183.81 ha were lost at a deforestation rate of approximately 18.4 ha per year. At the county level, Global Forest Watch (GFW, 2024) records that Narok County lost approximately 32,200 hectares of humid primary forest between 2002 and 2024, representing a 24% reduction. The sub-county deforestation rate documented in this study is proportionally lower, which may partly reflect the protective influence of the Mau Forest reserve boundary within the classified study extent. At the national level, GFW (2024) records a 12% decline in Kenya’s tree cover between 2001 and 2024 closely aligned with this study’s 12.84% forest loss figure, suggesting that Narok North’s trajectory is broadly representative of national dynamics. Mbaabu et al. (2021), examining forest cover change across the wider Mau River Basin using Landsat imagery, documented progressive forest loss driven by agricultural encroachment, charcoal extraction, and settlement expansion the same combination of drivers identified in this study. Mwiwawi and Chepkong’a (2022), focusing specifically on Maasai Mau Forest encroachment in Narok County, documented continued deforestation despite existing legal enforcement mechanisms,

consistent with this study's finding that forest loss persisted throughout the study period even as its rate slowed after 2010. Together, these comparisons confirm that Narok North's forest decline is part of a well-documented sub-regional trend, while the specific quantification provided by this study particularly the identification of 2000–2010 as the peak loss decade adds locally grounded temporal resolution not previously available for this sub-county.

4.4.7.3 Drivers of Land Use and Land Cover Change

This study identified urbanization and infrastructure development as the highest-rated driver of LULCC (89.6% combined significance rating), followed by population growth (72.4%), charcoal burning and wood harvesting (71.2%), agricultural expansion (66.7%), and livestock pressure (59.8%). Mootian et al. (2020) identified broadly the same driver hierarchy in Narok North, with agricultural expansion and urbanization ranked as the leading socio-economic forces reshaping land use. The present study confirms this ranking while providing updated survey-based evidence and satellite quantification absent from the earlier study. Notably, charcoal burning emerges more prominently as a driver in this study, with 71.2% of respondents rating it as having a major impact the highest single-item agreement rate. This is consistent with Mwiwawi and Chepkong'a (2022), who documented intensifying charcoal demand and weak enforcement as key contributors to Mau Forest degradation, and with UNEP (2021), which identifies fuelwood extraction as the dominant driver of sub-Saharan Africa's forest conversion. Shilibwa et al. (2024), examining spatial-temporal drivers of land use change across Kenyan landscapes, similarly found that population growth, agricultural intensification, and urban expansion interact cumulatively to accelerate landscape transformation in transitional agro-pastoral zones a multi-driver dynamic directly mirrored in the Narok North findings.

4.4.7.4 Grassland Dynamics and Pastoral Land Use

This study recorded a non-linear grassland trajectory: broadly stable (approximately 31%)

between 1990 and 2005, peaking at 1,618.95 ha (34.49%) in 2010, and declining to 1,525.39 ha (32.48%) by 2022. Bullock et al. (2021), studying three decades of land cover change across East Africa, documented similar fluctuating grassland trends in pastoral regions, attributing them to the interplay between drought cycles, cultivation patterns, and livestock management practices. The 2010 grassland peak in this study corresponds to the documented post-drought vegetation recovery period following the 2008–2009 drought, consistent with Bullock et al.'s (2021) finding that post-drought recovery can temporarily expand grassland extent before subsequent agricultural or settlement encroachment resumes. Gichenje and Eunice (2024) similarly noted grassland instability in the Mara landscape, where grasslands function as a buffer category subject to conversion in both directions depending on socio-economic and climatic conditions directly consistent with this study's finding that grassland functioned as a transitional cover type absorbing changes from both forest degradation and fallow cropland recovery.

4.4.7.5 Urbanization, Settlement Expansion, and Flood Vulnerability

The eightfold increase in built-up area between 1995 and 2022 documented in Section 4.3.1.4, and the associated flood exposure reported in Section 4.3.5.3, aligns with Kiplagat (2023), who examined land use change and hydrology in the Enkare Narok Watershed and documented how urban expansion and impervious surface growth alter runoff dynamics and increase downstream flood risk. Avery (2024), examining Kenya's flooding events in a policy context, attributed heightened urban flood vulnerability directly to decades of inadequate land use planning and settlement expansion into drainage corridors a governance failure clearly evident in Narok North's peri-urban development pattern. Kinyanjui et al. (2024), studying structural vulnerabilities to urban flooding in Kenyan informal settlements, identified the same combination of unplanned settlement growth, inadequate drainage infrastructure, and encroachment on natural waterways documented in this study, confirming that the pattern in Narok North reflects a nationally prevalent dynamic in secondary towns undergoing rapid, unplanned growth.

4.4.7.6 Community Adaptation Strategies

The findings documented in Section 4.3.6 household-based reactive strategies centered on livestock migration, livelihood diversification, water harvesting, and limited crop diversification closely mirror those of Mutsotso et al. (2023), who documented similar adaptive responses among smallholders in Kenya's arid lands, noting the predominance of reactive coping over proactive planned adaptation and the erosion of traditional mechanisms under compounded climate and livelihood stress. Filho et al. (2022), synthesizing evidence on indigenous and traditional knowledge for climate adaptation in Africa, highlighted that pastoral communities' adaptive capacity depends critically on the preservation of mobility, communal resource access, and intergenerational knowledge transfer all of which this study found to be progressively constrained by land subdivision and settlement growth in Narok North. The income loss data in Table 4.2, with nearly one-third of respondents reporting flood-related losses exceeding KES 200,000, is consistent with Njogu (2021), who quantified the economic burden of climate-induced flooding in Kenyan riverine communities and emphasized the disproportionate impact on smallholder and pastoral households with limited insurance and safety net coverage. Together, these comparisons confirm that Narok North's adaptation deficit is structurally embedded and will not be resolved through household-level responses alone.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study concludes that Narok North Sub-County has experienced significant land use and land cover changes over the past decades, mainly driven by population growth, agricultural expansion, urbanization, and unsustainable land management practices. These changes have contributed to environmental degradation, including loss and fluctuation of forest, grassland, and cropland areas. The findings also show that climate variability has intensified these impacts by increasing the frequency of droughts and floods, reducing agricultural productivity, and heightening community vulnerability, particularly in relation to water and food security. Although some adaptation measures such as community conservation efforts and improved farming practices are emerging, they remain insufficient to fully address the challenges. The study therefore concludes that integrated land management and strengthened climate adaptation strategies are necessary to enhance environmental sustainability and community resilience in the area.

5.2 Recommendations

The study recommends the following:

- i. **Strengthen Land Use Governance and Community Participation.** The County Government should enforce zoning regulations and protect ecologically sensitive areas through effective land use policy implementation. Community participation in land use planning should be enhanced through resource management committees to improve accountability and sustainability.
- ii. **Improve Disaster Risk Management and Early Warning Systems.** The County Government should strengthen disaster risk management by improving

hazard mapping, integrating GIS in planning, and enhancing early warning systems. Communities should also be sensitized on preparedness measures such as rainwater harvesting and flood-resilient practices.

- iii. **Promote Capacity Building and Knowledge Sharing.** Training programs should be expanded for county officials, extension officers, and communities on sustainable land management, climate-smart agriculture, and disaster risk reduction. Knowledge-sharing platforms should also be strengthened to improve adoption of best practices.
- iv. **Enhance Climate-Resilient Infrastructure and Ecosystem Restoration.** Investment should be prioritized in climate-resilient infrastructure and ecosystem restoration initiatives such as afforestation, soil conservation, agroforestry, and sustainable grazing practices to restore degraded landscapes and reduce vulnerability.
- v. **Mobilize Climate Finance and Strengthen Adaptation Support.** The County Government should improve access to climate finance from national and international sources to support adaptation projects. Collaboration with NGOs and the private sector should also be enhanced to support vulnerable households through financial and technical assistance.

5.3 Areas of Further Studies

Based on current studies, several critical gaps have been identified that, if properly addressed, could significantly enhance sustainable land management and climate resilience in Narok County. First, there are notable gaps in the effectiveness of existing land use policies and regulations, particularly in relation to zoning, enforcement mechanisms, and institutional coordination. These implementation gaps hinder the proper regulation of land use and contribute to unplanned and often unsustainable land transformations. Secondly, there is a lack of comprehensive economic valuation of ecosystem services lost due to land use change. Forest loss, rangeland conversion, and

wetland degradation have led to the erosion of vital ecosystem services such as water regulation, carbon storage, and biodiversity conservation, yet the economic implications of these losses remain under-quantified and underappreciated in policy and planning processes. Lastly, the research highlights limited access to and utilization of climate financing opportunities by both the county government and local stakeholders. Barriers to international and domestic climate finance mechanisms continue to impede effective investment in climate adaptation and mitigation measures. Addressing these gaps could significantly strengthen policy effectiveness, inform economic decision-making, and unlock financial resources necessary for building climate-resilient land use systems.

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APPENDICES

Appendix I: Questionnaire

FOR HOUSEHOLD SURVEY

SECTION A: RESPONDENT INFORMATION

Section A: Respondent Information

Gender: ☐Male ☐Female ☐Prefer not to say

Age Group:

☐18–30 ☐31–45 ☐46–60 ☐60 and above

Marital Status:

☐Single ☐Married ☐Widowed ☐Other

Are you a resident of Narok North Sub-County?

☐Yes ☐No

Duration of residence:

☐ <5 yrs ☐ 5–10 yrs ☐ 11–20 yrs ☐ >20 yrs

Main livelihood source:

☐Crop farming ☐Livestock ☐Business/trade ☐Formal employment

☐Charcoal/firewood ☐Other: .

Monthly household income:

☐ <KSh10,000 ☐ KSh10–20k ☐ KSh20–30k ☐ >KSh30,000

Section B: Agricultural & Livestock Practices

Do you farm crops?

☐ Yes

☐ No

Main crops: ____

Land size:

☐ <1 acre ☐ 1–5 acres ☐ 6–10 acres ☐ >10 acres

Do you keep livestock?

☐ Yes ☐ No

Type:

☐ Cattle ☐ Goats ☐ Sheep ☐ Poultry ☐ Other:

Approx. number: ____

Challenges in farming/livestock (tick all):

Erratic rainfall ☐ Soil infertility ☐ Pests/diseases Inadequate grazing ☐ Poor markets

☐ Insecurity

Other: _

Section C: Land Use Change & Community Perception

Have you observed land use changes in last 20–30 years?

☐ Yes ☐ No ☐ Not sure If yes (tick all):

Forest cleared

☐ Grassland to cropland ☐ More settlements Wildlife decline

☐ Land sales/subdivision

☐ Other: _____

Please rate the importance of the following factors in contributing to land use changes in your area. (Use the scale: 1 = Not Important, 5 = Very Important)

Potential Driver of Land Use Change | 1 | 2 | 3 | 4 | 5 |

Population growth | ☐ | ☐ | ☐ | ☐ | ☐ |

Overstocking of livestock | ☐ | ☐ | ☐ | ☐ | ☐ |

Expansion of crop farming | ☐ | ☐ | ☐ | ☐ | ☐ |

Sale and subdivision of land | ☐ | ☐ | ☐ | ☐ | ☐ |

Urbanization and housing development | ☐ | ☐ | ☐ | ☐ | ☐ |

Changing climate and rainfall patterns | ☐ | ☐ | ☐ | ☐ | ☐ |

Charcoal burning and deforestation | ☐ | ☐ | ☐ | ☐ | ☐ |

Has your household experienced land degradation (e.g., soil erosion)?

Yes ☐ ☐ No

If yes, consequences: _

Do cultural practices contribute to land use change?

Yes ☐ No ☐ Not sure ☐

If yes, how? __

Section D: Climate Change Impacts & Adaptation

1. Have you observed climate changes over the last 10–30 years?

☐ Yes ☐ No ☐ Not sure

If yes, what changes?

☐ Hotter temperatures ☐ Less rain ☐ Droughts ☐ Unpredictable seasons

☐ Floods ☐ Shorter growing

☐ Other: _____

2. How has your household been affected?

☐ Crop/livestock loss ☐ Income loss (drought/flood) ☐ Migration ☐ Water shortage

☐ Higher expenses ☐ No impact ☐ Other: _____

Has your household experienced income loss due to droughts or floods in the past 10 years?

☐ Yes ☐ No

If yes, estimate the total income lost during the worst year:

☐ KES 0 – 50,000 ☐ KES 50,001 – 100,000 ☐ KES 100,001 – 200,000

☐ KES 200,001 – 500,000 ☐ KES 500,001 – 1,000,000 ☐ Above KES 1,000,000

5. What coping strategies have you used?

☐ Drought/flood-tolerant crops ☐ Changed planting/crop type ☐ Irrigation/drainage

☐ Sold livestock/assets ☐ Relocated ☐ New income source ☐ Early warning/preparedness ☐ None

☐ Other: _____

6. Do you receive climate/weather info?

☐ Yes ☐ No

If yes, source:

☐ Radio ☐ TV ☐ Extension officer ☐ SMS/phone ☐ Meetings ☐ NGO/CBO

☐ Religious leader

☐ other: _____

7. How serious is climate change to your livelihood?

☐ not a threat ☐ Minor ☐ Moderate ☐ Major ☐ don't know

Section E: Adaptation, Management & Outlook

Are any land management practices used in your community?

☐ Yes ☐ No

If yes (tick all):

Tree planting

☐ Rotational grazing ☐ Agroforestry ☐ Hay production ☐ Terracing

☐ Other: _____

What should be done to improve land use and reduce degradation?

Any additional comments on land use, environment, or community well-being?

ANNEX:

KII QUESTIONNAIRE (Key Informant Interview Guide)

SECTION A:

RESPONDENT DETAILS

Name (optional): ____

Designation/Role: ____

Organization/Institution: ____

Years of experience in this role: ____

SECTION B: LAND USE AND ENVIRONMENTAL CHANGES

In your view, what are the most significant land use changes observed in Narok North over the past 30 years?

What are the main drivers of these land use changes?

How have these changes affected the community (e.g., livelihoods, migration, conflicts)?

What role do cultural practices play in influencing land use patterns?

How is climate change perceived and experienced locally in Narok North?

SECTION C: ADAPTATION, POLICY, AND STRATEGIES

What measures have been taken at the community/county level to respond to land degradation and climate hazards?

In your opinion, are current strategies sufficient? What gaps exist?

What evidence-based strategies would you recommend to enhance community resilience in Narok North?

Are there any ongoing programs, projects, or policies supporting sustainable land use or climate adaptation?

What partnerships or collaborations are needed to support adaptation and resilience efforts?

Any other comments or suggestions?

Appendix II: Summary of Study Objectives, Data Collected, Analytical Methods, and Expected Outputs

Objective	Data Collected	Type of Data	Analytical Method Employed	Expected Output
To assess the current land use practices and analyze the drivers of land use and land cover change (LULCC) in Narok North Sub-County	Household survey data Key informant interviews Focus group discussions Satellite imagery (Landsat 1990, 2000, 2010, 2020)	Qualitative (interviews, FGDs) Quantitative (survey responses) Spatial (remote sensing data)	Descriptive statistics (SPSS/Excel) Thematic analysis Remote sensing and GIS (classification, change detection)	Baseline land use practices Key drivers of LULCC LULC change maps

To evaluate the impacts of LULCC on climate-related hazards such as droughts and floods	Secondary data on climate events	Qualitative	Overlay analysis in GIS	Spatial relationship between LULCC and hazards
	Community perception data	Quantitative Spatial	Correlation analysis between LULCC and climate data	Community-level vulnerability trends
	LULCC maps (from satellite imagery)		Thematic analysis of perceptions	
To identify and recommend appropriate land use and climate adaptation strategies for sustainable landscape management	Expert interviews	Qualitative	Content and thematic analysis	Adaptation and land use policy recommendations
	Policy documents	Document review	SWOT analysis	Locally driven best practices
	Community suggestions (FGDs, surveys)			