ASSESSMENT OF THE IMPACT OF LAND USE/LAND COVER CHANGE ON HUMAN-WILDLIFE CONFLICT IN MUKOGODO LANDSCAPE, LAIKIPIA COUNTY, KENYA

BY

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ASSESSMENT OF THE IMPACT OF LAND USE/LAND COVER CHANGE ON HUMAN-WILDLIFE CONFLICT IN MUKOGODO LANDSCAPE, LAIKIPIA COUNTY, KENYA

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A thesis submitted in partial fulfilment of the requirements for the award of the degree of Master of Science Environment and Natural Resource Management in the Department of Environment and Natural Resource Management and the School of Science and Technology

of Africa Nazarene University

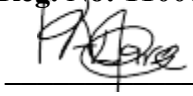
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DECLARATION

I declare that this document and the research that they describe are my original work and that they have not been presented in any other university for academic work.

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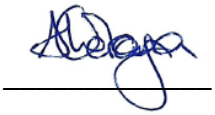
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EXAMINERS' SIGNATURES

We have examined this document and the research has met or exceeded the requirement for the degree sought, in addition, the candidate has sufficiently defended the material presented to merit the awarding of the degree of (the name of the degree being awarded)

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DEDICATION

I dedicate this work to my entire family and friends who stood by me and encouraged me throughout the research period.

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ABSTRACT

Land Use and Land Cover (LULC) change is a global phenomenon with far-reaching implications for ecosystems, biodiversity, and human–wildlife interactions. Across East Africa, rapid agricultural expansion, settlement growth, and rising human and livestock populations have intensified Human–Wildlife Conflict (HWC), already one of the most pressing conservation and livelihood challenges. The Mukogodo Landscape in Laikipia County, Kenya, provides an ideal setting to examine how landscape transformations between 2009 and 2024 influence conflict patterns. These changes, driven by agricultural expansion, population pressure, and habitat fragmentation, have heightened HWC manifested in crop raids, livestock predation, infrastructure damage, human injuries, and even deaths—threatening both biodiversity and community wellbeing. Guided by three specific objectives, (1) to map the extent of LULC changes in Mukogodo Landscape between 2009 and 2024; (2) to assess the correlation between these LULC changes and the frequency of HWC incidents; and (3) to evaluate existing land management and conflict mitigation strategies and recommend sustainable management approaches for reducing HWC. This study employed a mixed-methods approach, integrating geospatial analysis of Landsat imagery with qualitative data from 98 household surveys, key informant interviews, and focus group discussions. Spatial mapping revealed a 48.3 km² increase in human impact zones and a 27.0 km² decline in forest cover between 2019 and 2024, with elephants responsible for 75.9% of the 3,112 recorded HWC incidents. Kernel Density Estimation and Global Moran's I (0.617, $p < 0.001$) confirmed spatial clustering of conflict hotspots around settlement clusters and degraded habitats. Regression analysis showed a strong negative correlation between forest cover and HWC ($r = -0.93$), while seasonal variation analysis identified the cool & dry season as the peak conflict period. Social surveys further revealed that community members perceive HWC as increasingly severe, particularly regarding property destruction and livestock losses, and express limited confidence in existing mitigation strategies such as fencing and compensation. Based on these findings, the study recommends: ecosystem-based land use planning incorporating designated zones of interaction that balance human livelihoods with wildlife needs and protection and restoration of degraded forests, grasslands, and critical wildlife corridors (particularly elephant migratory routes). The findings underscore the combined influence of LULC change and climate variability in shaping conflict dynamics and highlight the socio-ecological complexity of managing coexistence in arid and semi-arid landscapes. Outputs from this research, including LULC maps, statistical models, and policy recommendations provide actionable insights for sustainable land management and conflict reduction. By linking ecological change with community perspectives, the study contributes to broader efforts to manage HWC and supports the design of integrated conservation and development strategies for the Mukogodo region and beyond.

DEFINITION OF OPERATIONAL TERMS

Human Wildlife Conflict: Interactions between human beings and wildlife that bring about losses, injuries, discomfort and resentment to individuals and the community.

Human Impact (as a land cover class): A spectrally classified land cover category encompassing anthropogenically modified surfaces within the Mukogodo landscape, including built-up settlements, agricultural fields, cleared or degraded vegetation, roads, and other infrastructure. This class was identified using the Normalized Difference Built-up Index (NDBI), Index-Based Built-up Index (IBI), and Human Impact Index (HI_Index) derived from Landsat surface reflectance imagery, and was distinguished spectrally from natural forest and open vegetation cover.

Compensation: Payment in cash or in kind done to a person(s) as result of HWC related damages, losses, injuries, or loss of life.

Remote Sensing: This is the art, science and technology of gathering information about a phenomenon, object and/or area using devices called sensors mounted on satellites without physically coming into contact with a phenomenon, object and/or area under investigation as occasioned by differences in interactions between earth surface materials and electromagnetic energy.

Geographic Information System: A computer assisted system for the acquisition, storage, analysis, and display of geographic data or can be defined simply as a computer system designed to work with geo-referenced data

Land Use: This relates to the economic functions (utility) associated with a specific piece of land such as agriculture, industrialization, residential, transportation, public purpose, recreation, public utility and education.

Land Cover: This is the biophysical state of the earth’s surface and immediate subsurface". In other words, "landcover" describes the physical state of the land surface i.e. cropland, mountains, vegetation, bare ground or forests.

Land use and land cover change: The dynamic alteration of the Earth's surface, encompassing both natural and human-induced transformations.

Land Use and Land Cover change detection: The process of identifying differences in the state of land use and land cover by observing variations of their state at different times

ABBREVIATIONS/ ACRONYMS

GEE - Google Earth Engine

GIS - Geographic Information System

GIT - Geospatial Information Technologies

GPS - Global Positioning System

HIV - Human Immunodeficiency Virus

KWS - Kenya Wildlife Service

LC - Land cover

LU - Land use

LULC - Land Use Land Cover Change

NDVI - Normalized Difference Vegetation Index

NGO - Non-Governmental Organization

NIR - Near Infrared

RS - Remote Sensing

SIV - Simian immunodeficiency virus

SWIR - Shortwave Infrared

WRTI - Wildlife Research and Training Institute

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This study assessed the impact of Land Use and Land Cover change (LULC) on human-wildlife conflict in the Mukogodo landscape in Laikipia, Kenya. This chapter presents the background of the study, the statement of the problem, the research objectives, and the definition of relevant variables.

1.2 Background of the Study

Land use and land cover (LULC) change is a global phenomenon driven by a combination of natural and anthropogenic factors (Hailu et al., 2020). These changes have profound implications for ecosystems, biodiversity, and the interactions between humans and wildlife. Land cover (LC) refers to the biophysical state of the earth surface, which may include vegetation, bare ground and water, while Land Use (LU) refers to the utilization of land resources by human beings (Nedd et al., 2021). LULC change is propelled by a myriad of driving factors, including population growth, economic development, infrastructure expansion, and the intensifying effects of climate change. These processes exert significant pressure on ecosystems, erode biodiversity, and disrupt ecosystem services such as water regulation, soil fertility, and carbon storage, ultimately altering the balance of human–wildlife interactions, particularly in regions rich in wildlife (Wang et al., 2021).

One of the critical consequences often associated with LULC change is its impact on HWC; a growing challenge in many biodiversity hotspots worldwide (Sharma et al., 2018). However, the precise link between LULC change and HWC remains less clear in arid and semi-arid lands (ASALs), where large spatial and temporal variations in rainfall and other environmental conditions can complicate conflict dynamics. HWC arises when the needs and activities of humans intersect with the natural behaviors of wildlife, often leading to crop destruction, livestock predation, property damage, and sometimes human or wildlife casualties (Mekonen, 2020). Across wildlife-rich regions in Africa, including Laikipia County, the prevalence of HWC is escalating as expanding human populations and intensifying land use practices encroach upon critical wildlife habitats (Dupuis-Desormeaux et al., 2023). Beyond direct losses, HWC undermines conservation

by fueling negative attitudes toward wildlife and eroding local support for protection efforts. For rural households, who often depend heavily on livestock and subsistence farming, these conflicts exacerbate poverty, food insecurity, and resentment toward conservation initiatives.

LULC change is now recognized as one of the major drivers of global biodiversity decline over the last four decades (Anthony et al., 2024) (Sharma et al., 2018). Urbanization, agricultural expansion, deforestation, and infrastructure development have dramatically altered habitats, reducing wildlife populations and their connectivity (Pretty & Bharucha, 2014). This global loss of biodiversity has great potential to interrupt relevant ecological processes and hinder ecosystem services that are essential for humans. For instance, studies in South America have shown how forest clearing for agriculture disrupts large mammal corridors, leading to increased human-wildlife interactions and conflicts (Naughton-Treves et al., 2003). Similarly, in Asia, rapid urbanization in tiger habitats has escalated incidences of livestock depredation and human fatalities due to habitat fragmentation (Wierucka et al., 2023). Somu & Palanisamy (2023) also identified that patterns of wildlife migration were significantly altered by land use changes, which in turn heightened conflict incidents in Asia. However, in the ASALs, such as those in East Africa, the relationship between LULC change and HWC remains less well understood. While some evidence points to fragmentation and resource competition as drivers, localized dynamics differ, creating uncertainty about the exact mechanisms linking land change to conflict. These dynamics are rarely the product of land-use change alone; they are moderated by broader factors such as climatic variability, demographic pressures, and land-use policies, which interact in complex ways to shape patterns of conflict. Recognizing these multiple drivers is essential for disentangling the specific contribution of LULC change. This knowledge gap underscores the importance of examining the Mukogodo landscape as a case study to better understand these interactions in ASAL contexts.

In Africa, the coexistence of humans and wildlife is a defining characteristic of many landscapes, particularly in savannah ecosystems. However, LULC changes, including agricultural intensification and land subdivision, together with the impacts of climate change, have placed immense pressure on these ecosystems and are expected to intensify such pressures in the future. Research in East and Southern Africa has highlighted how the expansion of agriculture and fencing has fragmented rangelands, reducing wildlife movement and increasing HWC incidents, especially with elephants and carnivores (Ogutu et al., 2016; Reid et al., 2004). Across the continent, wildlife

corridors and dispersal areas outside protected zones are increasingly encroached upon, making them conflict hotspots. For example, in Tanzania's Tarangire-Manyara ecosystem, LULC changes have reduced elephant movement, intensifying crop-raiding incidents in surrounding communities (Lohay et al., 2022). Similarly, studies in Botswana have demonstrated that wildlife species like lions and hyenas face increasing conflict with pastoralists due to the loss of natural prey and shrinking habitats (Dunnink et al., 2020).

In Laikipia County, the subdivision of group ranches and agricultural expansion have led to habitat fragmentation, reduced wildlife corridors, and escalated conflict between humans and wildlife (Nyumba, 2017). Recent studies in Laikipia highlight that elephants are particularly vulnerable to these changes, frequently damaging crops as they traverse fragmented landscapes (Bond, 2015). Similarly, predators such as lions and hyenas are increasingly preying on livestock due to the loss of natural prey and shrinking rangelands (Nyumba, 2017).

Although many studies have examined LULC change and HWC, fewer have focused on transition zones between rangelands and forest ecosystems, where competing pressures from pastoralism, settlement, and biodiversity conservation often collide. The Mukogodo landscape represents such a transitionary area, making it a valuable case for examining these dynamics. Previous studies have rarely integrated spatial and temporal analyses of LULC change with household-level social data, particularly people's perceptions of wildlife. Yet it is these perceptions that determine whether an encounter with wildlife is tolerated as coexistence or experienced as conflict. This study addresses this gap by combining spatial analysis of LULC changes with household surveys and key informant interviews to assess how both ecological change and community perceptions shape patterns of HWC in the Mukogodo landscape. Particular attention is given to the Mukogodo Maasai, a community transitioning from traditional pastoralism to agro-pastoralism, whose livestock management practices, and land-use decisions are central to the conflict dynamics.

1.3 Statement of the Problem

HWC is widely recognized as a major conservation and livelihood challenge across Africa and other biodiversity-rich regions of the world. In East Africa, where pastoralism, farming, and expanding settlements overlap with critical wildlife habitats, HWC has escalated in frequency and severity. Laikipia County, Kenya, is one of the areas most affected by these conflicts, with

escalating incidents reported over the years (Sintayehu & Kassaw, 2019). Despite the establishment of conservancies, wildlife corridors and physical barriers, conflicts persist. This persistence reflects not only ecological pressures but also the socio-political realities of Laikipia, where pastoralist communities that are often politically and economically marginalized, bear a disproportionate share of the costs of living alongside wildlife.

Studies have shown that changes in land use and land cover (LULC) such as agricultural expansion, deforestation and urbanization are significant drivers of HWC, as they disrupt natural habitats and force wildlife into closer contact with human settlements (Syombua, 2013; Taye et al., 2023; Mbaga et al., 2017). In East Africa, HWC is linked not only to population growth and increasing pressure on resources such as water and pasture but also to deeper social and historical contexts. Research shows that land tenure changes, colonial-era land allocations, and the marginalization of pastoralist livelihoods have created structural vulnerabilities that intensify conflicts today (Ogutu et al., 2016). Further, Ogutu et al. (2016) found that competition for water and grazing resources during drought periods intensifies livestock depredation by predators, particularly in landscapes with fragmented habitats. While many studies document livestock losses and associated mitigation measures, fewer have examined the underlying drivers of conflict. In particular, little is known about how land use and land cover change interacts with community perceptions and livelihood strategies to shape the frequency and severity of HWC

In Laikipia County, research has concentrated on mitigation strategies such as wildlife corridors and predator-proof fencing. For instance, Manoa & Mwaura, (2016) evaluated the effectiveness of predator-proof bomas in reducing livestock losses and noted a significant decline in predation incidents when the barriers were maintained. Similarly, Green et al. (2018) examined the functionality of wildlife corridors in mitigating HWC and found that while corridors improve connectivity, they are often compromised by encroachment and unsustainable land-use practices. While these are important, they often overlook the broader drivers of conflict. There is still limited integration of ecological factors, such as land use and land cover change, with the social dimensions of conflict, particularly community perceptions of risk and tolerance toward wildlife.

The Mukogodo Landscape, a critical area supporting diverse wildlife and pastoralist communities, remains understudied in this regard. Specifically, there is a lack of comprehensive

analysis of how LULC changes driven by factors such as population growth, settlement expansion and overgrazing, interact with ecological and social systems to influence the frequency and severity of HWC. This study addressed this gap by employing remote sensing (RS) and geographic information system (GIS) techniques with household surveys and key informant interviews, providing an integrated ecological and social perspective on HWC dynamics in the Mukogodo landscape. The findings provide a nuanced understanding of the spatial and temporal dynamics of HWC, identify key drivers of conflict, and propose land management strategies that promote coexistence between humans and wildlife. This research contributes to efforts ranging from the local to global scale, to develop sustainable solutions to HWC, while filling a critical knowledge gap in the Mukogodo Landscape.

1.4 Significance of the Study

This research is significant as it contributes to the broader understanding of how LULC change influences HWC, a challenge of growing concern globally and across East Africa's arid and semi-arid landscapes. Laikipia County, and specifically the Mukogodo landscape, provides a unique setting with the conditions to explore this problem in detail. Understanding the interrelation between HWC and LULC is important as it aids in designing natural resource management and land use policies. Understanding the dynamics and the driving force behind the LULC changes in the Mukogodo landscape is fundamental for predicting land use changes for future planning processes. This study also benefits the community by providing practical recommendations for the local community in mitigating HWC, which affects livelihoods, safety and access to critical resources. This will in turn contribute to harmonious coexistence between humans and wildlife, improving the quality of life for those residing in the Mukogodo landscape.

A distinctive strength of this study is the use of long-term HWC data, spanning more than a decade, which allows for the assessment of conflict trends across varying climatic conditions and over a larger temporal scale than most previous studies. When combined with remote sensing analyses, this long-term perspective provides deeper insights into the cumulative impacts of LULC change on HWC, setting this study apart methodologically and offering a valuable reference point for future research. This research also advances knowledge within academia, providing a case study on the interplay between LULC changes and HWC in the context of arid and semi-arid

landscapes. The study findings are relevant for predictive modeling to anticipate future trends and their implications for human-wildlife interactions.

The study offers new insights into how landscape degradation, water scarcity, and human expansion contribute to the frequency and intensity of these conflicts. The findings inform policy makers and conservationists on effective mitigation strategies, particularly in the design of wildlife corridors and the restoration of degraded lands. Furthermore, the study contributes to sustainable landscape management and biodiversity conservation in Mukogodo, Laikipia County, with practical recommendations for using ecological restoration to reduce human-wildlife conflict.

1.5 Research Objectives

Main Objective

To analyze the relationship between land use and land cover changes and human–wildlife conflict in the Mukogodo Landscape, Laikipia County (2009–2024), with a view to evaluating the effectiveness of existing mitigation strategies and generating recommendations for sustainable land management and conflict reduction.

Specific Objectives.

1. To map the extent of land use/land cover changes in Mukogodo Landscape, Laikipia County between 2009-2024.
2. To assess the correlation between land use/land cover changes and the frequency of human-wildlife conflict incidents.
3. To evaluate existing land management and conflict mitigation strategies and recommend sustainable management approaches for reducing human–wildlife conflict in areas affected by land use/land cover changes.

1.6 Research Questions

1. What are the key land use/land cover changes that have occurred in the Mukogodo landscape between 2009 - 2024?
2. How do changes in land use/land cover correlate with the frequency and intensity of human-wildlife conflicts and varying environmental factors in the region?
3. How effective are current land management and conflict mitigation strategies in reducing human-wildlife conflict in areas affected by land use/land cover changes?

1.7 Scope of the Study

The study was conducted in the Mukogodo landscape, covering Naibunga, Ilpolei, Mukogodo Forest, Dol Dol, and parts of Il Ngwesi in Laikipia North County. This landscape is inhabited mainly by the Mukogodo Maasai community, whose livelihoods are traditionally pastoralist but are increasingly shifting toward agro-pastoralism and small-scale cultivation. Their dependence on livestock, mobility patterns, and communal grazing practices play a central role in shaping land use dynamics and their interactions with wildlife. The study focused on assessing how historical and current LULC trends including grazing patterns, settlement expansion, and changes in natural vegetation influence the frequency and intensity of human–wildlife interactions in this socio-ecological setting.

1.8 Delimitation(s) of the Study

This study was delimited to analyzing LULC changes over the past two decades and their relationship to HWC incidents, particularly those involving key wildlife species such as African elephants (*Loxodonta africana*), lions (*Panthera leo*), spotted hyenas (*Crocuta crocuta*), and African buffalos (*Syncerus caffer*). The study did not extend to other aspects of HWC, such as cultural or socioeconomic drivers unrelated to LULC changes, as these factors, while important, fell outside the primary focus of this research. Additionally, the research excluded smaller-scale HWC incidents involving rodents or birds, as they were not directly relevant to the larger ecological and conservation challenges faced in Mukogodo. The decision to exclude these elements was based on feasibility constraints, including time and resource limitations, as well as their lower significance in the context of large mammalian species interactions with changing landscapes.

1.9 Limitations of the Study

Data constraints, such as the availability and accuracy of historical LULC data, affected the precision of detecting long-term trends. To mitigate this, the study utilized multiple data sources, including validated satellite imagery from reputable platforms such as Landsat and Sentinel, and cross-referenced findings with available ground-truthing data. Remote sensing data were limited to publicly available satellite imagery, as acquiring high-resolution private datasets was not feasible for this study. This limitation was addressed by using spatial modeling techniques and existing wildlife tracking data to better understand movement patterns and their interactions

with changing land cover. Efforts were made to enhance resolution through image processing techniques and data fusion methods. Additionally, the study faced challenges in obtaining reliable reports of HWC incidents, as these conflicts are often underreported or inconsistently documented. To address this, the study incorporated multiple data collection approaches, including key informant interviews, community surveys, and reports from local authorities and conservation organizations, ensuring a more comprehensive dataset.

There were also difficulties in isolating LULC change as the sole contributor to HWC, given that other factors like climate change, human population growth, and policy shifts simultaneously influenced conflict patterns. To account for this, the study adopted a multi-variable analysis approach, integrating climate data, demographic trends, and land-use policies to distinguish their respective impacts. Furthermore, the dynamic nature of wildlife behavior and movement complicated the direct correlation between LULC change and HWC, requiring advanced modeling techniques and extensive field data to ensure accurate analysis. This limitation was addressed by using spatial modeling techniques and existing wildlife tracking data to better understand movement patterns and their interactions with changing land cover.

1.10 Assumptions of the Study

This study assumed that respondents were honest and transparent in providing information during surveys and interviews, ensuring the reliability of the collected data. It also assumed that the available land use and land cover data accurately represented the historical and current state of the Mukogodo landscape, providing a dependable foundation for analysis. The study presumed that the observed trends in land use and land cover changes had a direct or indirect influence on patterns of human-wildlife conflict, and these influences were effectively identified and quantified.

1.11 Theoretical Framework

The study on LULC in the Mukogodo landscape was based on the foundation of landscape ecology and conflict theory (Makhzoumi, 2000). Landscape ecology focuses on the spatial relationships between various land uses, habitats, and species, while conflict theory explores the tensions that arise when different groups, such as humans and wildlife, compete for shared resources (Yeshey et al., 2024). In this case, rapid changes in LULC such as urbanization and degradation disrupt natural habitats and migration corridors, forcing wildlife into closer proximity with human settlements (Fida et al., 2024). These disturbances not only reduce the availability of

natural resources but also fragment ecosystems, leading to increased encounters between humans and wildlife, such as elephants, lions, and herbivores, resulting in conflict (Mekonen, 2020).

In the Mukogodo landscape traditional pastoralism, conservation efforts, and changing land uses coexist (Muok et al., 2021). Human-wildlife conflict here is not only an ecological issue but also a deeply social one, as highlighted by the IUCN SSC guidelines on human-wildlife conflict and coexistence (IUCN SSC Human-Wildlife Conflict and Coexistence Specialist Group, 2023). Local livelihoods depend heavily on livestock and access to grazing land, making communities highly sensitive to predation and competition with wildlife. At the same time, cultural values and histories shape how different groups perceive and respond to species such as elephants, lions, or hyenas. For instance, some species carry symbolic or traditional importance, while others may be strongly vilified due to repeated losses, creating tensions both within and between communities. Governance and land tenure further influence conflict dynamics, with power imbalances sometimes fueling mistrust between communities, conservation organizations, and state actors.

As wildlife habitats shrink and human activities encroach on these spaces, wildlife may seek food and shelter in cultivated fields or livestock areas, exacerbating conflict. The human dimension of conflict, rooted in socio-economic factors such as livelihood dependence on land, is also critical in shaping the intensity of interactions. By integrating these ecological and social aspects, the framework sought to understand the spatial and temporal patterns of LULC changes and how they exacerbated human-wildlife conflict, thereby informing mitigation strategies that can balance conservation goals with human livelihoods.

1.12 Conceptual Framework

The study examined how LULC change served as a key independent variable that directly affected the level of HWC in the Mukogodo landscape. LULC changes such as deforestation, agricultural expansion, and infrastructure development lead to habitat fragmentation and degradation, reducing the space available for wildlife. As a result, wildlife was forced to move closer to human settlements in search of food and water, increasing the likelihood of conflict. Grazing and livestock practices further exacerbated this interaction, as competition for pasture intensified between livestock and herbivorous species like elephants and zebras (Singh et al., 2025).

The relationship between LULC change and HWC is influenced by several intervening variables grouped into ecological, socio-environmental, and management factors (Figure 1.1). Ecological factors include habitat suitability for key species, corridor integrity, prey and livestock availability, and drought intensity or rainfall anomalies. These factors influence how wildlife responds to landscape changes. Socio-environmental factors such as human population density and water stress increase spatial overlap between humans and wildlife. Management and governance factors, including fencing, response time to HWC incidents, compensation performance, and frequency of community engagement meetings, may either mitigate or exacerbate conflict depending on their effectiveness.

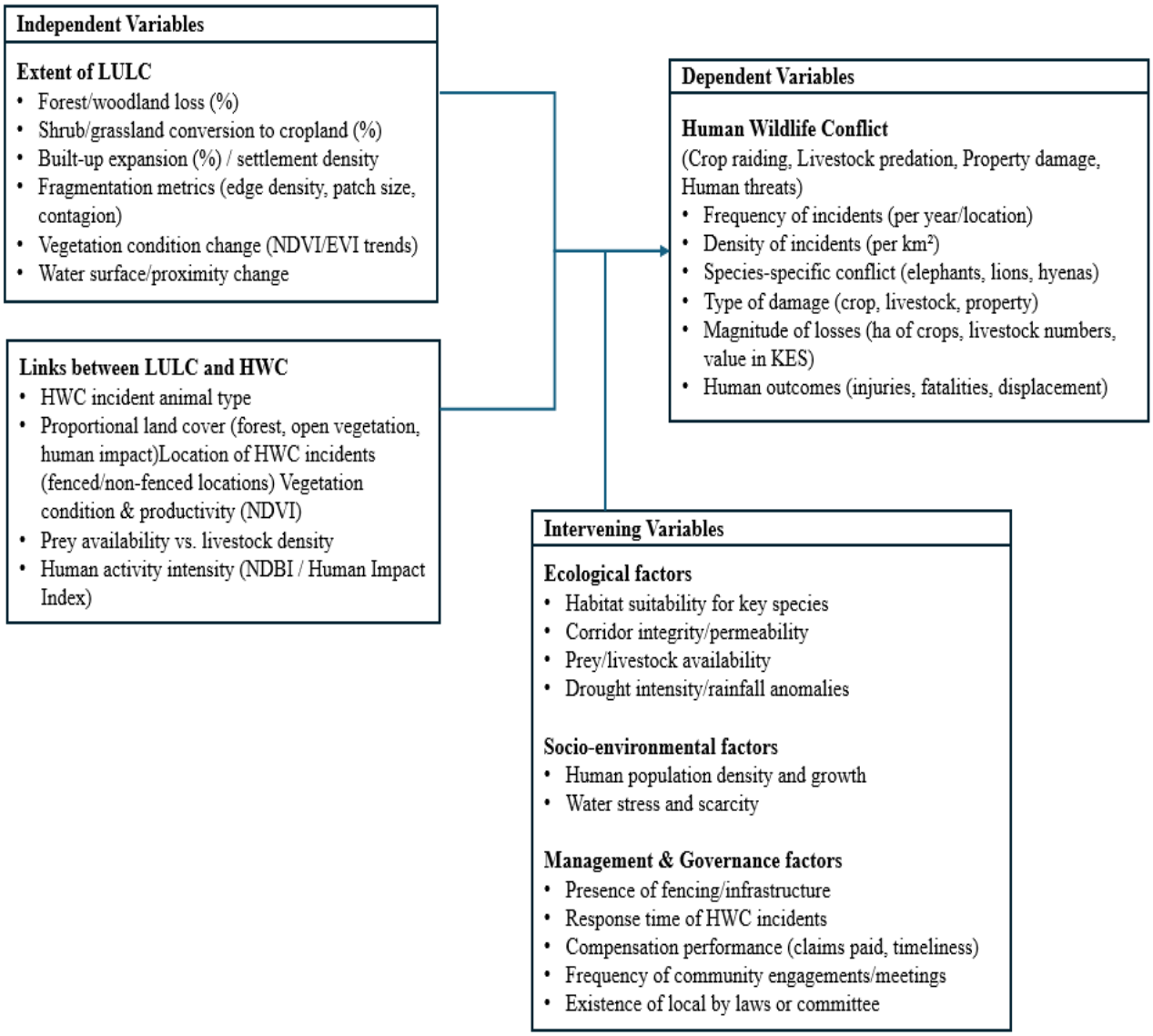


Figure 1.1: Conceptual Framework showing the LULC factors leading to HWC

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This section is a review of the relevant literature pertaining to Land Use and Land Cover Changes and their impact of such changes on human wildlife conflict.

2.2 Review of the Literature

2.2.1 Land Use Land Cover Changes

Land cover refers to the characteristics of the Earth's surface, encompassing the distribution of vegetation, water, deserts, ice, and the underlying subsurface features such as biota, soil, topography, surface and groundwater (Seyam et al., 2023). It also includes human-made structures like settlements and mining sites (Nedd et al., 2021). On the other hand, land use is the intended application and management approach implemented by humans or land managers to utilize the land cover, encompassing activities such as industrial areas, residential zones, farming, grazing, logging, and mining, among others (Fatima & Javed, 2021). Land use change is defined to be any physical, biological or chemical change attributable to management, which may include conversion of grazing to cropping, change in fertilizer use, drainage improvements, installation and use of irrigation, plantations, building farm dams, pollution and land degradation, vegetation removal, changed fire regime, spread of weeds and exotic species, and conversion to non-agricultural uses (AbdelRahman, 2023). According to (Rotich et al., 2022), the main causative agent for change in land use and land cover are anthropogenic factors as well as natural factors in political or socio-economic contexts, land usage can interfere with ecosystem services.

Changes in LULC are a key aspect of global environmental transformation, significantly affecting the Earth's climate, ecosystems, and human societies (Anthony et al., 2024). This issue is a major concern for both national and international policymakers. To develop effective policies, they rely on scientists to identify the underlying causes of LULC changes, aiming to address root processes rather than just symptoms. However, the factors influencing LULC changes are complex, requiring diverse analytical approaches and a thorough examination of social data to understand the driving forces and consequences over time and across different spatial scales (Wang et al., 2021).

Predominant land uses in Kenya rangelands are extensive livestock production, forestry and wildlife conservation (Herrick et al., 2012). If a community is too poor to raise the capital needed for restoration of degraded land, then degradation is likely to continue and accelerate. This has been recognized in the United States for many years where it has been Federal policy for the state to provide the capital for restoration (Feng et al., 2022).

Factors Influencing Land Use and Land Cover Change

Economic factors, such as increased tourism and viable timber markets, significantly drive land use and land cover changes (Sitati et al., 2024). For instance, in the Maasai Mara ecosystem, tourism development led to land fragmentation and the establishment of tourist facilities (Mundia & Murayama, 2009). Similarly, deforestation has been linked to profitable timber markets (Chaudhry, S. 2021). Beyond economic incentives, demographic pressures from rapid human population growth, accelerating urbanization, and the effects of climate change particularly shifting rainfall patterns and recurrent droughts are now among the most important drivers of LULC change across Africa (Sarfo et al., 2024). Institutional factors, including government policies, also contribute to these changes, either by enabling or constraining how land and resources are used. Policies that discourage nomadic pastoralism, promote agriculture, or privatize communal grazing lands have drastically altered landscapes in Kenya, reducing expansive grazing areas into fragmented farmlands (Mundia & Murayama, 2009; Boles et al., 2019). These policy shifts were reinforced by changes in land tenure, particularly the subdivision and individualization of formerly communal lands. The breakdown of collective grazing systems has reduced mobility, undermined customary rangeland management, and intensified degradation in areas where herders are now confined to smaller parcels. Notably, the creation of wildlife conservation areas in the 1940s restricted access to grazing resources, further transforming traditional Maasai lands (Beinart & McKeown, 2024).

Cultural, technological, and demographic factors also play critical roles. Cultural practices, such as preserving sacred sites or maintaining dry season grazing reserves, can either protect or alter landscapes (Boles et al., 2019). Customary land use practices among pastoralists historically emphasized mobility, rotational grazing, and the preservation of dry season grazing reserves, which helped maintain rangeland productivity. However, the imposition of formal land tenure systems and subdivision of communal lands have disrupted these practices, reducing mobility and

contributing to rangeland degradation and resource conflicts. Technological advancements, particularly in agriculture, drive changes through intensification and extensification of farming (Pretty & Bharucha, 2014). Demographic pressures from natural population growth and in-migration have converted pastoral grazing lands into farmlands and settlements, significantly impacting habitats through forest clearing and human settlement (Sitati et al., 2024). Among pastoralist communities, including those in Mukogodo, the rising human and livestock populations have increased demand for water, pasture, and cultivable land. This has led to forest clearing in Mukogodo's dryland forests and accelerated settlement growth around Dol Dol, Kimanju and Il Polei. These demographic dynamics, combined with declining mobility and shrinking communal lands, have intensified grazing pressure, weakened traditional management systems, and heightened the risk of human–wildlife conflict.

Relationship Between Land Use Land Cover Change and Human Wildlife Conflict

Changes in land use and land cover significantly influence HWC and the availability of suitable habitats for wildlife. Globally, this relationship has been documented across diverse ecosystems. In South America, Naughton-Treves et al. (2003) demonstrated that slash-and-burn agriculture and forest clearing in Tambopata, Peru, disrupted large mammal corridors and intensified hunting-related conflicts. In Asia, Wierucka et al. (2023) documented how rapid urbanization in tiger habitats escalates livestock depredation and human fatalities due to habitat fragmentation, while Somu and Palanisamy (2023) identified that altered wildlife migration patterns from land use changes significantly heighten conflict incidents. Similarly, Singh et al. (2025) assessed forest fragmentation around Ranthambhore Tiger Reserve in India and found that agricultural encroachment and land cover conversion directly amplify human-wildlife encounters. These studies confirm that LULC-driven habitat loss, fragmentation, and blocked movement corridors are universal precursors to HWC.

At the regional level, African landscapes illustrate these dynamics with particular severity. Dunnink et al. (2020) showed that in northern Botswana, socio-ecological landscape transformations intensify conflicts between pastoralists and large carnivores as natural prey declines and rangelands shrink. In Tanzania's Tarangire-Manyara ecosystem, Lohay et al. (2022) found that LULC changes reduced elephant movement and intensified crop-raiding in adjacent communities. Across East Africa, Reid et al. (2004) traced how habitat loss and fragmentation

simultaneously threaten pastoral livelihoods and wildlife viability, while Ogutu et al. (2016) linked declining wildlife populations and rising livestock numbers in Kenya to land subdivision and agricultural expansion. Green et al. (2018) further demonstrated that even where wildlife corridors exist in Kenyan landscapes, their functionality depends on preventing encroachment and unsustainable land use.

Changes in land use and land cover significantly influence HWC and the availability of suitable habitats for wildlife (Sitati et al., 2024). In Kenya, the recent surge in conflicts can largely be attributed to shifts in land use driven by population growth, the expansion and intensification of agriculture, and the growing tendency of pastoralist communities in rangelands to adopt a more settled lifestyle (Mukeka et al., 2019). Utilizing natural water sources for irrigation and establishing artificial ones frequently results in conflict, as these water sources tend to attract wildlife, heightening the chances of human-wildlife interactions (Montero-Botey et al., 2024). Beyond irrigation, the rapid sinking of boreholes has opened up previously water-scarce areas to year-round grazing, while improved access to veterinary care has boosted livestock survival and herd sizes. Together, these changes have expanded both the numbers and the spatial distribution of livestock, intensifying competition for water and forage with wildlife and thereby increasing the likelihood of conflict. LULC changes have become significant drivers of HWC in many landscapes, including the Mukogodo area in Laikipia County. As human populations grow and agricultural activities expand, natural habitats are increasingly converted into farming, grazing, and urban areas. These changes disrupt the traditional movement patterns of wildlife, often forcing them into closer contact with human settlements (Mukeka et al., 2019). For instance, wildlife may wander into crop fields, leading to crop destruction, or into livestock areas, where they may prey on domestic animals. Such incidents of conflict create tensions between local communities and conservationists, often resulting in retaliatory killings of wildlife, further exacerbating the problem.

The shift from extensive grazing and natural vegetation to more intensive land use can also affect the availability of water and forage for wildlife, pushing them into areas that are increasingly dominated by human activities (Greiner et al., 2021). As wildlife loses access to their natural feeding and watering grounds, they are more likely to venture into nearby human settlements in search of resources, thereby increasing the frequency of HWC incidents. This is particularly

critical in semi-arid regions like Mukogodo, where water scarcity and limited grazing land for livestock make communities more vulnerable to wildlife encroachment. Furthermore, land use changes often result in fragmented habitats, which limit wildlife movement and reduce access to important migration corridors. Without these essential passageways, wildlife may be forced into conflict-prone areas when they seek food or shelter (Wandaka & Francis, 2019). Agricultural expansion in Kenya is strongly shaped by environmental constraints, particularly rainfall variability. Much of the land is classified as arid or semi-arid, with limited suitability for rain-fed cultivation. As a result, farming in marginal lands and rangelands is risky, often leading to land degradation and intensifying interactions with wildlife. In Mukogodo, the conversion of forests and grasslands into agricultural land, combined with the encroachment of human settlements into wildlife corridors, has contributed to the increased frequency of conflict, particularly with larger herbivores like elephants and giraffes that require extensive rangelands and connected habitats for grazing.

In addressing the impact of land use change on HWC, it is essential to incorporate sustainable land use practices that balance the needs of human populations with the conservation of wildlife. This can include better planning and zoning of agricultural areas, the restoration of wildlife corridors, and the promotion of community-based conservation efforts. By understanding and mitigating the effects of LULC changes, more effective strategies can be developed to reduce human-wildlife conflict and ensure the coexistence of people and wildlife not only in the Mukogodo landscape but also across other arid and semi-arid regions facing similar challenges.

2.2.2 Human Wildlife Conflict

Human-Wildlife Conflict (HWC) is defined as the interaction between humans and wildlife that leads to negative consequences for people, wildlife species, or both (Mekonen, 2020). These conflicts appear in various forms, such as death or injury to individuals, destruction of crops and property, predation on livestock, and the transmission of diseases between wildlife and humans (Matseketsa et al., 2019). Over time, HWC has emerged as a critical concern in wildlife management and conservation (Mukeka et al., 2019).

HWC is a universal problem, with historical roots tracing back to centuries. Fossil records, for example, indicate that early hominids were preyed upon by predators such as eagles two million years ago (Berger & Clarke, 1995; Seoraj-Pillai, 2016). In ancient Egypt, hippopotamuses fed on

crops along the Nile, while crocodiles preyed on livestock and humans by 2000 BCE (Lamarque, 2009). Similarly, human-elephant conflicts have been documented in Africa since the advent of agriculture (Lobban & Liedekerke, 2000; van Houdt & Traill, 2022).

In modern contexts, HWC is influenced by geography, land-use patterns, human behaviors, and the habitat and behavior of specific wildlife species (Li et al., 2022). The intensification of agriculture, urbanization, and resource exploitation has intensified conflicts, particularly in developing countries. These regions are characterized by higher dependency on agriculture and livestock, making local communities more vulnerable to wildlife-related damages.

HWC has both ecological and socio-economic dimensions (Yeshey et al., 2024). Ecologically, conflicts may result in the displacement, injury, or death of wildlife, which disrupts ecological processes. Socio-economically, conflicts can lead to significant financial losses, food insecurity, and strained human-wildlife relationships, which often manifest as retaliatory killings of wildlife.

Global Context of Human-Wildlife Conflict

HWC is a global phenomenon, with its nature and intensity varying across regions based on environmental conditions, wildlife species, and human livelihoods. In the United States, for example, automobile collisions involving deer frequently result in injuries and substantial economic losses (Acharya et al., 2023). In a similar context, wolves in regions like Idaho, Montana, and Wyoming were responsible for numerous livestock losses over a span of years between the late 1980s and early 2000s (Wielgus & Peebles, 2014). In Europe, species such as wild boar, red deer, and roe deer damage crops and forests, while large carnivores like bears, wolves, and lynx prey on livestock and transmit diseases like bovine tuberculosis to cattle (Linnell et al., 2020). In Asia, large mammals like elephants, tigers, and leopards are major contributors to human-wildlife conflicts. Elephants often cause extensive damage to crops, while tigers and leopards are known to prey on livestock, particularly in areas near wildlife reserves like the Bhadra Tiger Reserve in India (Acharya et al., 2023).

Africa faces some of the most severe HWC issues due to the close proximity of human settlements to wildlife habitats and the economic reliance on agriculture and livestock. Large herbivores like elephants and buffalo, and carnivores such as lions, hyenas, and crocodiles, are

frequently implicated in conflicts. These conflicts are often intensified by community perceptions of wildlife as government property, reducing local incentives to tolerate wildlife impacts (Makumbe et al., 2022; Mokenon, 2020).

Globally, HWC is shaped by socio-economic disparities. Vulnerability to conflicts is more pronounced in developing countries where economic resilience is low, and local communities depend heavily on natural resources for survival (Yeshey et al., 2024). In contrast, developed countries often have greater institutional capacity to mitigate HWC through compensation schemes and effective land-use planning. Despite these differences, the impacts of HWC ranging from crop destruction and livestock predation to human casualties emphasize the universal need for integrated management strategies (Mekonen, 2020).

Types and Nature of Human Wildlife Conflict

The type and nature of conflicts experienced vary with animal species that cause damage, and mainly consist of predation of livestock, attack on humans, crop raiding and disease transmission (Mukeka et al., 2019). One of the most common types of HWC in the region is crop raiding, where wildlife, particularly elephants, baboons, and antelopes, enter farmlands to forage on crops. Hermira & Michalski (2022) highlighted that in Latin America, birds and monkeys are significant contributors to crop destruction, with Quelea quelea birds being particularly notorious for inflicting severe damage and posing major challenges for farmers. This type of conflict can have devastating effects on farmers' livelihoods, especially when staple crops such as maize, sorghum, and beans are damaged (Jaleta & Tekalign, 2023). As agricultural land expands into wildlife habitats due to land use changes, these conflicts are intensifying, with wildlife populations increasingly encroaching into human settlements in search of food and water.

Another significant form of HWC in Mukogodo is human threats posed by wildlife. Certain species, including elephants, buffaloes, and predators such as lions, pose direct threats to human safety. Ogutu (2018) highlighted that wildlife-related incidents, particularly those involving elephants, led to numerous cases of human injuries and fatalities from 2001-2016. Such incidents, though infrequent, are the most severe form of human-wildlife conflict, often instilling fear and animosity toward wildlife, which can sometimes trigger retaliatory actions. The presence of large carnivores also leads to fear and loss of life among local communities. Such threats lead to increased tensions between wildlife conservationists and local communities, with humans often

resorting to retaliatory measures, including poisoning or poaching, in response to these perceived threats.

Livestock predation, as highlighted by (Matseketsa et al., 2019), is one of the most widespread triggers of human-wildlife conflict globally. In Mukogodo, this issue is particularly pronounced, with large carnivores like lions and hyenas targeting livestock, which serves as a vital livelihood source for pastoralist communities. The scale and impact of livestock losses due to predation vary worldwide. For instance, lynx is responsible for such conflicts in France (Dickman, 2008), brown bears in Norway, pumas in Brazil, golden jackals in Israel, and tigers in India. Changes in land use and diminishing natural prey populations drive predators closer to human settlements, increasing the likelihood of livestock attacks.

The risk of disease transmission to the people or their livestock has led to a lot of hostility towards wildlife conservation. The other major threats to people are for example primates which are thought to be carriers of Simian immunodeficiency virus (SIV) that is implicated as the original source of Human Immunodeficiency Virus (HIV) that has infected and caused deaths to many people (Jasinska et al., 2023). Carnivores on the other hand, act as reservoirs for diseases such as rabies that are responsible for a lot of human deaths worldwide each year. Domestic dogs were believed to cause an outbreak of canine distemper virus and rabies diseases in Serengeti and Masai Mara National Parks (Lushasi et al., 2021).

Finally, property damage caused by wildlife also contributes to the broader issue of HWC in the region. Elephants and other large herbivores, while foraging for food, can damage fences, water tanks, and buildings, which are critical for the livelihoods of local communities (Munyao et al., 2020). This type of damage further strains the relationship between humans and wildlife, with property owners seeking compensation or more aggressive deterrents. As land use patterns evolve, such as the expansion of farms and settlements into wildlife corridors, the frequency and severity of these conflicts are likely to increase, requiring urgent mitigation strategies (Mekonen, 2020).

Management of Human Wildlife Conflict Associated with Land Use Land Cover change

HWC is one of the most pressing challenges to biodiversity conservation and sustainable land management, especially in regions where rapid LULC changes disrupt wildlife habitats and corridors. Across the globe, the rapidly growing human population has created significant demand

for arable land, resulting in the conversion of forest habitats into settlements and farmland. This has caused habitat fragmentation, severely impacting wildlife populations and escalating HWC. Consequently, various initiatives have been implemented to address HWC and foster harmonious coexistence between humans and wildlife. These initiatives are part of a multifaceted project that prioritizes local communities as key stakeholders (Nkansah-Dwamena, 2023). In Kenya, HWC pose significant obstacles to conservation, particularly in areas where wildlife relies heavily on dispersal areas beyond protected parks, often leading to interactions with local communities (Munyao et al., 2020). These interactions often result in economic losses, human injuries or fatalities, and the retaliatory killing of wildlife, creating significant obstacles to conservation goals.

2.2.3 Current Strategies for HWC Management

HWC in Kenya have continued to escalate despite various attempts to address the issue. Kenya and other African countries have adopted several strategies to manage conflict. Physical barriers, such as electric fences, game moats, vegetation screens, stone walls, high-tensile fencing, and trenches, are commonly used to restrict wildlife movements into human-dominated areas (Mukeka et al., 2019). For instance, the erection of predator-proof fencing around livestock enclosures has significantly reduced livestock predation in certain areas.

Other strategies include translocation of animals, the creation of sanctuaries, problem animal control, organized animal drives (particularly for elephants), and community awareness campaigns (Mukeka et al., 2019). However, these approaches are resource-intensive, may cause stress to animals, and are often met with limited success in addressing long-term conflict dynamics. For instance, translocated animals may return to their original range or become problematic in their new habitats. Traditional deterrent and mitigation techniques have also been incorporated into these efforts.

An alternative strategy for conflict management involves compensation schemes. Compensation refers to the payment made by wildlife authorities and other stakeholders to victims of wildlife damage or their kin in case of death (Sifuna, 2005). Compensation is an effective tool for minimizing impacts wildlife causes to people, it also helps reduce negative consequences of HWC (Upadhyay, 2013). Compensation in a way increases people's tolerance towards wildlife as it minimizes the financial losses incurred during wildlife invasions (Ravenelle & Nyhus, 2017). In India, the enactment of the Wildlife (Protection) Act of 1972, which established protected areas,

prohibited the export of wildlife products, and revitalized conservation efforts, was criticized for exacerbating "social animosity" toward conservation. This was because the initiatives were seen as harmful to local livelihoods. To address this, compensation programs were introduced to mitigate the costs of HWC and reconcile the underlying drivers of such conflicts (Johnson et al., 2018). However, these schemes have faced significant criticism for failing to address the underlying causes of conflicts and are often regarded as a "flawed concept" that merely addresses the symptoms rather than the core issues.

The role of LULC changes in HWC necessitates a paradigm shift from reactive to proactive management approaches. Restoring degraded habitats and maintaining ecological connectivity can provide wildlife with suitable spaces to thrive, reducing their dependence on human-dominated landscapes (Rotich et al., 2022). Habitat restoration initiatives, such as reforestation, grassland restoration, and the protection of water sources, are particularly effective in mitigating HWC, as they improve the carrying capacity of wildlife areas and minimize the likelihood of conflict (Mekonen, 2020). In order to mitigate HWC more effectively, it is necessary to understand the temporal and spatial factors that predispose it. It is also necessary to identify correctly those species that cause the greatest amounts of damage, because community‟ perceptions may be influenced by factors other than one type of conflict (Ji et al., 2022).

Technologies in Land Use/Land Cover Change and Human-Wildlife Conflict

The rapid advancement of geospatial information technologies (GIT) has revolutionized the study of LULC changes (Gitima et al., 2022). Remote sensing and GIS are among the most widely used tools in this field. Through the integration of satellite imagery and spatial analysis techniques, researchers can assess historical and current LULC patterns, predict future trends, and monitor changes with high precision. Remote sensing allows for the detection of changes in vegetation cover, forest loss, and land degradation, which are crucial for assessing the impacts of these changes on the local wildlife population and their habitats (Matyukira & Mhangara, 2024).

In recent years, satellite imagery from platforms such as Landsat, Sentinel, and MODIS has been widely used to map LULC changes over time. These images provide high-resolution data on vegetation, water bodies, and urban development, offering insights into how human activities and climate variations are reshaping the landscape (Yin et al., 2014). In employing tools such as land cover classification and change detection, researchers can quantify the extent of habitat loss

or fragmentation, which is particularly important in the context of HWC. LULC data derived from remote sensing can reveal areas where human activities, such as farming or infrastructure development, have encroached on wildlife corridors or critical habitats, potentially increasing the risk of conflict between humans and wildlife (Buchholtz et al., 2020).

GIS allows for the integration and analysis of spatial data, enabling researchers to identify patterns and trends in land use, such as urban expansion, agricultural encroachment, or the degradation of natural habitats (Krivoguz, 2024). GIS further enhances the analysis by allowing spatial modeling and visualization of LULC changes and their relation to wildlife movement and conflict hotspots. Through overlaying wildlife distribution data with LULC maps, it becomes possible to identify areas where wildlife is most vulnerable to human activities (Edosa & Erena, 2024). This spatial relationship helps in designing mitigation strategies for human-wildlife conflict. For example, GIS-based analysis can highlight areas where fences or wildlife corridors could be constructed to reduce conflicts. In Laikipia, where the Mukogodo landscape is home to a diverse range of species, such spatial analysis is crucial for sustainable land management and wildlife conservation efforts.

Technologies have become instrumental in addressing HWC, offering innovative solutions for both conflict prevention and mitigation. Global Positioning System (GPS) technology, for example, has been extensively employed to track the movements of wildlife, enabling the identification of high-conflict zones and critical habitats (Tomkiewicz et al., 2010). GPS collars placed on key species, such as elephants or lions, enable managers to monitor their locations and movements, providing early warnings when animals approach human settlements or farmlands (Weise et al., 2019). When coupled with GIS, GPS data can be used to create heat maps that highlight areas prone to human-wildlife interactions, aiding in targeted interventions. These technologies not only facilitate better planning and decision-making but also contribute to ongoing efforts to mitigate the negative impacts of land use changes on both wildlife populations and local communities (Buchholtz et al., 2020). In Mukogodo, these technologies could play a transformative role in balancing human livelihoods with the conservation of biodiversity, especially given the landscape's unique ecological and cultural significance.

Challenges in Managing Human-Wildlife Conflict Due to Land-Use and Land-Cover Changes

HWC management in areas experiencing significant LULC changes faces multiple challenges that hinder effective mitigation efforts. Limited funding and resources remain a critical barrier, as many conservation programs struggle to secure consistent financial support for proactive measures such as community outreach, compensation schemes, and the construction of wildlife corridors (Gupta et al., 2023). Reactive measures, like fencing, are often prioritized due to their immediate effectiveness, but their high costs and limited long-term sustainability intensify the resource strain (Lindsey et al., 2012). This lack of adequate funding is further compounded by insufficient technical capacity to implement innovative approaches, such as integrated land-use planning or advanced monitoring systems.

Conflicts of interest among stakeholders further complicate HWC management in LULC affected areas (Okech, 2011). For example, conservationists often advocate for measures like habitat restoration and wildlife corridors, which may reduce conflict in the long term but require significant land and resources (Matejcek & Verne, 2021). In contrast, farmers and pastoralists prioritize their immediate livelihood needs, resisting interventions perceived as restricting land access or increasing wildlife proximity (Dickman, 2010). These competing priorities create tension, slowing the adoption of collaborative strategies that balance conservation and human needs. Inadequate policy frameworks and weak enforcement mechanisms amplify these challenges, as regulations governing wildlife protection and land use often lack specificity or are poorly implemented. As a result, communities are left without clear guidelines or support to mitigate conflict effectively (Mekonen, 2020).

Reactive methods like fencing can have profound long-term ecological impacts. While fencing may temporarily reduce interactions between humans and wildlife, it fragments habitats and disrupts migration patterns, threatening biodiversity and reducing genetic exchange among wildlife populations (Lindsey et al., 2012). Over time, such measures may inadvertently worsen conflict as wildlife populations become confined to smaller areas, increasing pressure on limited resources (Naha et al., 2023). Addressing these challenges requires a multi-faceted approach that integrates adequate funding, stakeholder collaboration, effective policies, and ecologically sound mitigation strategies to ensure sustainable coexistence between humans and wildlife.

2.3 Summary of Review of Literature and Research Gap(s)

Understanding the relationship between LULC changes and HWC is critical for developing effective management strategies in landscapes like Mukogodo, Laikipia County. This section summarizes key studies relevant to the topic, highlighting their findings and the knowledge gaps that remain. The review focuses on the drivers of LULC changes, their impact on wildlife habitats, and the socio-economic dimensions of HWC. While existing studies provide valuable insights into these areas, gaps in contemporary drivers, spatial analysis, and technological solutions remain evident. The table below outlines the findings of selected studies and the research gaps they leave unaddressed, emphasizing the need for further research specific to Mukogodo's landscape.

Table 2.1. Gap in Knowledge

Year and Author	Title	Findings	Knowledge Gap
Ladan (2014)	Examining HWC in Africa	Identified anthropogenic and natural factors driving LULC change.	Limited focus on contemporary drivers like climate change and urbanization affecting wildlife habitats.
Mundia & Murayama (2009)	Land Fragmentation in Maasai Mara	Tourism-led land fragmentation affects wildlife corridors.	Lack of a spatial analysis linking LULC and wildlife conflict zones.
Mekonen (2020)	Coexistence between human and wildlife	Explores ecological and socio-economic dimensions of HWC globally.	Limited analysis of economic resilience in Kenya's rangeland communities and their role in managing conflicts caused by LULC changes.
Sitati (2024)	Drivers of LULC in Kenya	Highlights demographic and technological factors influencing LULC.	No exploration of using emerging technologies for HWC mitigation in changing landscapes.

Montero-Botey (2024)	Deforestation and Water availability	Examines the role of water use in escalating HWC.	Insufficient exploration of management strategies for balancing water use between humans and wildlife in Kenya.
Pretty & Bharucha (2014)	Sustainable intensification of Agriculture systems	Demonstrates how agricultural technology contributes to land use intensification.	Lack of research on how agricultural technologies can be adapted to minimize HWC in agriculturally dominated landscapes.
Mukeka et al. (2019)	HWC Dynamics in Kenya	Discussed human-wildlife interactions in Kenya, emphasizing the role of LULC changes.	Lacked in-depth examination of HWC dynamics specific to Laikipia County's Mukogodo area.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the study area and sources of information used in the study. It provides details of how information was extracted from the various sources and the methodology used to analyze the data obtained from the different sources.

3.2 Research Design

This study adopted a mixed-methods research design, combining descriptive and longitudinal study designs approaches within the overarching framework. The descriptive component involved spatial analysis to characterize and quantify the changes in LULC using GIS and Remote Sensing technologies. This provided a comprehensive overview of the LULC changes occurring within the Mukogodo Landscape, from 2009 to 2024. The longitudinal design focused on assessing changes over time in HWC patterns and their correlation with LULC changes, enabling the evaluation of trends and their implications for the local ecosystem and communities.

To complement the quantitative analysis, qualitative methods were employed, including key informant interviews and focus group discussions. These approaches aim to provide insights into community perceptions and attitudes towards wildlife and conservation efforts, as well as to document local experiences with existing conflict mitigation strategies.

3.3 Study Site

Mukogodo forest landscape is composed of a forest reserve, group ranches and conservancies and traverses Laikipia and Isiolo Counties of Kenya (Leley et al., 2022). The Mukogodo landscape covers an area of 30,189 ha. In Laikipia County, the landscape encompasses the gazetted Mukogodo forest reserve (26,000 ha) and four surrounding group ranches namely; llngwesi (9,470 ha), Lekurruki (15,872 ha), Kurikuri (3,340 ha) and Makurian/ Mayanat (5,390 ha). It is found at an elevation of 1200-2000 meters above sea level, and consists of large plains and extensive rugged, hilly terrain (KFS, 2008). There is more mountainous terrain in the east of the district, mostly within the Mukogodo Forest Reserve (Pearl, 2004). Located between 37o 14'and 37o 35' E latitude and 00o 35' to 00o 40' longitude, it lies on an important historical elephants' migration route between the northern rangelands and Laikipia, traversing Borana and

Lewa Conservancies, Ngare Ndare forest, and is part of the elephant corridor leading to Mount Kenya (KFS, 2008).

Mukogodo consists of land classified by Pratt and Gwynne (1977) as eco-climatic zone IV (semi-arid with marginal agriculture) and zone V (arid with ranching and pastoralism). The annual mean rainfall for the area is 400-600 mm, with a bimodal rainfall pattern consisting of long rains in March/April and short rains in October/ November (Muiruri, 2008). The daily temperatures range from 18˚C to 29˚C. The landscape is drained by seasonal rivers, the main ones being Sieku and Kipsing (KFS, 2008).

Mukogodo landscape is characterized by seven broad vegetation types: closed forest, closed woodland, open forest, open grassland, open scattered trees, very open scattered trees, and degraded grassland. The most abundant trees in the landscape are *Olea europaea ssp. africana*, *Acacia tortilis* and *Juniperus procera* (KFS, 2008). The forest landscape is a habitat for 209 species of birds, 11 small mammals, and 34 large mammal species. The large mammal species include Elephant (*Loxodonta africana*), Buffalo (*Syncarus caffer*), Lion (*Panthera leo*), Leopard (*Panthera pardus*) and the endangered Grevy's Zebra (*Equus grevyi*) (KFS, 2008).

The residents of Laikipia North are primarily the Mukogodo Maasai, former hunter-gatherers (or Il-torrobo) who adopted the Maa language and a pastoralist lifestyle early in the 20th century. They now identify themselves as Maasai, distinct from the Samburu who neighbor them to the north (Cronk & Cronk, 2018). While land use in Mukogodo to the present has been largely compatible with wildlife conservation, there is increasing pressure to modernize the local economy in ways that could compromise wildlife viability. Discussions about actively promoting conservation are relatively new, but the appeal of conservation options is based, at least in part, on presumed economic benefits. If decisions taken in support of conservation do not provide the expected, appropriate benefits, the future of wildlife support is at best insecure.



Figure 3.1. Map of Study Area: Mukogodo Landscape, within Laikipia County, Kenya

3.3.1 Administrative Division and Population

Mukogodo landscape falls under Mukogodo Location in Laikipia North Subcounty. Mukogodo location is divided into Ilngwesi, Ilpolei, Makurian, Mukogodo, Mumonyot and Sieku sub-locations with an area of 939.7km^2 and a population of 16,915 people consisting of 8,390 male and 8,525 female in 3551 households. The population density is 18 persons/sq.km (KNBS, 2019).

Table 3.1. Population characteristics of Mukogodo Location (KNBS 2019)

Sub-Location	Total population	Male	Female	HH	Sq.km	Person/ Sq. km
Ilngwesi	1,364	659	705	286	154	9
Ilpolei	3,310	1,752	1,568	758	190	17

Makurian	3,030	1,493	1,537	557	94	32
Mukogodo	3,690	1,795	1,895	849	165.8	22
Mumonyot	4,276	2,086	2,190	864	147	29
Sieku	1,245	615	630	237	188.9	7
Total Mukogodo Location	**16,915**	**8,390**	**8,525**	**3,551**	**939.7**	**18**

3.3.2 Economic Activities

The primary sources of income among the communities in Mukogodo are livestock and bee keeping. Other sources of income are business, formal employment and subsistent farming, hunting and gathering (Kinuthia, 2005).

3.4 Target Population

The target population for this study includes the residents of the Mukogodo Landscape who have experienced human-wildlife conflicts, wildlife conservation officers, and land management authorities operating in Laikipia County. The study focused on households within a five (5) **K**ilometer radius of identified wildlife habitats to ensure diverse perspectives on conflict occurrences and mitigation strategies. Additionally, the target population included spatial data covering the Mukogodo Landscape from 2009 to 2024, providing a temporal lens on land use and wildlife patterns.

3.5 Study Sample

This study employed a probabilistic sampling approach to ensure a representative sample of households from the Mukogodo Landscape was obtained. The target population for this study comprised all 3,551 households within the six sub-locations of Mukogodo Location (Ilngwesi, Ilpolei, Makurian, Mukogodo, Mumonyot, and Sieku), as per the 2019 Kenya National Bureau of Statistics (KNBS) census (KNBS, 2019).

Household surveys were designed to collect social data on community experiences, perceptions, and coping strategies related to human–wildlife conflict. This information was critical in complementing the spatial analysis of land use and land cover changes by providing insights into how local people interpret and respond to conflict dynamics. Integrating household-level data therefore ensured that the study captured both ecological changes and the human dimensions of

conflict, which are central to understanding coexistence and identifying practical mitigation strategies.

3.5.2 Study Sample Size

The sample size was determined using Slovin's formula (Slovin, 1960), which is designed for calculating sample sizes from finite populations. The formula is specified as:

$$n = N / (1 + N(e)^2)$$

Where: **n** = required sample size

N = total population size (3,551 households)

e = margin of error (expressed as a decimal)

A margin of error (e) of 0.10 (10%) was selected to balance statistical precision with the logistical constraints of field data collection. Applying the formula yielded the following calculation:

$$n = 3,551 / (1 + 3,551 * (0.10)^2)$$

$$n = 3,551 / (1 + 35.51)$$

$$n = 3,551 / 36.51$$

$$n \approx 97.26$$

The result was rounded up to the nearest whole number, yielding a final sample size of 98 households. To contextualize this decision, sample sizes for margins of error of 8% and 12% were also calculated, resulting in 150 and 69 households, respectively. The 10% margin was deemed the most appropriate for this study.

Sample Allocation

To ensure proportional representation across the landscape, the total sample size (n = 98) was allocated to each sub-location based on its proportion of the total number of households. The formula for allocation was:

$$n_{sub} = (HH_{sub} / N) * n$$

Where: **n_sub** = sample size for the sub-location

HH_sub = number of households in the sub-location

A minimum threshold of 5 households per sub-location was applied to ensure even the smallest sub-locations were adequately represented. The allocations were then proportionally adjusted to sum precisely to the total sample size of 98. The resulting sample allocation is presented in Table 3.2 below.

Table 3.2. Proportional Allocation of Household Sample Size across Sub-Locations

Sub-Location	**Total Households**	**Proportion of Total Households (HH)**	**Sample Size (n = 98)**
Ilngwesi	286	0.081	8
Ilpolei	758	0.213	21
Makurian	557	0.157	16
Mukogodo	849	0.239	23
Mumonyot	864	0.243	24
Sieku	237	0.067	6
Total	**3,551**	**1.000**	**98**

3.6 Data Collection

3.6.1 Data Collection Instruments

This study relied on a combination of satellite-based remote sensing data and ancillary environmental datasets to assess land use and land cover (LULC) changes and their relationship with human-wildlife conflict in the Mukogodo landscape between 2009 and 2024. Primary data for this study was collected using structured questionnaires and Key Informant Interviews (KIIs), targeting households, community leaders, conservation officers, and local government representatives within the Mukogodo landscape. The questionnaires captured quantitative data on the frequency, nature, and spatial distribution of Human-Wildlife Conflict (HWC) incidents, while KIIs provided qualitative insights into land use practices, conflict perceptions, and the effectiveness of mitigation strategies such as predator-proof bomas, electric fencing, and wildlife corridors. Data collection was conducted over a three-month period between May and July 2025.

Quantitative data were analyzed using descriptive statistics, regression models, and spatial mapping tools including Kernel Density Estimation and Global Moran's I to identify conflict hotspots and spatial clustering. Qualitative responses from KIIs were subjected to thematic analysis to extract patterns related to governance, policy influence, and community attitudes toward wildlife.

3.6.2 Pilot Testing of Research Instruments

Prior to the main data collection, pilot testing of the research instruments was conducted in March 2025 to assess clarity, relevance, reliability, and logistical feasibility. The pilot was carried out in Kieni West a neighboring area with socio-ecological characteristics similar to the Mukogodo landscape but outside the selected sample households to avoid bias. A total of 10 households (approximately 10% of the final sample size) were randomly selected, and two Key Informant Interviews were conducted to test the structure and flow of the interview guide. The exercise evaluated the clarity and sequencing of questions, the time required to complete the survey, the sensitivity of conflict-related questions, and the functionality of GPS-based spatial data recording. Based on the feedback received, ambiguous items were revised, technical terms were simplified, redundant questions were removed, and the logical flow of the questionnaire was improved. Minor adjustments were also made to field procedures and data entry templates. The pilot testing therefore strengthened the reliability and validity of the research instruments and ensured their suitability for application within the Mukogodo landscape.

3.6.3 Instrument Reliability

Instrument reliability refers to the consistency and stability of the research tools in measuring the intended variables. For the household questionnaires, reliability was enhanced through pilot testing, refinement of ambiguous items, and the use of structured, standardized questions to ensure uniform data collection across respondents. Consistency in data collection procedures was maintained through the use of trained enumerators and standardized interview protocols. For the spatial component, reliability was ensured through consistent image preprocessing procedures in Google Earth Engine, standardized supervised classification techniques, and repeated validation using independent training and validation samples across all study years. These measures ensured that both the socio-economic and spatial datasets produced stable and reproducible results.

Accuracy Assessment

The classification accuracy for the Land Use Land Cover maps was consistently high across all four study years, indicating substantial to almost perfect agreement between classified maps and validation data. Overall accuracy ranged from 89.2% in 2024 to 95.3% in 2019, while Kappa coefficients (κ) varied between 0.84 and 0.93, suggesting substantial to almost perfect agreement between the classified outputs and reference data. Specifically, the accuracies were 90.1% (κ = 0.85) in 2009, 92.5% (κ = 0.89) in 2014, 95.3% (κ = 0.93) in 2019, and 89.2% (κ = 0.84) in 2024.

For each year, 12 spectral bands were verified and used in the classification process. The number of samples used for training and validation increased steadily over time, with 195 training and 81 validation samples in 2009**,** and 239 training and 82 validation samples in 2024**.** Each dataset maintained a balanced distribution across the three land cover classes: Forest*,* Open Vegetation*,* and Human Impact.

3.6.4 Instrument Validity

Instrument validity refers to the extent to which the research instruments accurately measured the intended variables. Content validity of the questionnaires and interview guides was ensured through alignment of the questions with the study objectives and key variables on HWC, land use practices, and mitigation strategies. The instruments were reviewed and refined after pilot testing to confirm clarity, relevance, and contextual appropriateness. Construct validity was enhanced by integrating multiple data sources, including household surveys, Key Informant Interviews, and spatial datasets, allowing for triangulation of findings. For the remote sensing component, validity was supported through the use of established spectral indices (e.g., NDVI and NDBI), supervised classification methods, and independent accuracy assessment using validation samples. These measures ensured that the instruments effectively captured both the socio-economic and spatial dimensions of human–wildlife conflict in the Mukogodo landscape.

3.6.5 Data Collection Procedures

Supervised Classification of Satellite Imagery for Land Cover Mapping

Primary land cover mapping was conducted using multi-temporal surface reflectance imagery from Landsat sensors. Specifically, Landsat 7 Enhanced Thematic Mapper Plus (ETM+), Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS), and Landsat 9 OLI-2 were used to represent the years 2009, 2014/2019, and 2024 respectively. These datasets were accessed through GEE and pre-processed to correct for atmospheric distortions, cloud cover, and shadows using quality assurance (QA_PIXEL) bands. The use of GEE was preferred because it allows for ease of access and capabilities to leverage the platform for processing as it offers cloud computing functionalities in a free-to-use approach in the explorer web app. It has a parallel high-speed processing capability with Google computational machine algorithms and Application Programming Interfaces (APIs) which support the common coding languages.

The selection of imagery focused on January–February periods for all years to reduce seasonal variation and maintain temporal consistency. This period has been demonstrated to be optimal for rangeland and savannah ecosystems, as vegetation signals are most distinct and less affected by seasonal noise (Borges et al., 2020). To enhance LULC classification, bands were combined into both natural color (SR_B4, SR_B3, SR_B2) and false color composites optimized for vegetation monitoring.

Table 3.3. Landsat Data and Classification

Year	Sensor	Bands Used	Composite Type	Spatial Resolution
2009	Landsat 7 ETM+	SR_B2, SR_B3, SR_B4, SR_B5, SR_B6	Natural color, False color for vegetation (NDVI)	30 m
2014	Landsat 8 OLI	SR_B2, SR_B3, SR_B4, SR_B5, SR_B6, SR_B7	NDVI, IBI, NDBI, HI Index	30 m
2019	Landsat 8 OLI	SR_B2, SR_B3, SR_B4, SR_B5, SR_B6, SR_B7	NDVI, IBI, NDBI, HI Index	30 m
2024	Landsat 9 OLI-2	SR_B2, SR_B3, SR_B4, SR_B5, SR_B6, SR_B7	NDVI, IBI, NDBI, HI Index	30 m

Ancillary Data

Ancillary data refers to non-satellite information that supplements remote sensing data to improve classification accuracy, enrich spatial analysis, and support correlation with socio-ecological variables. While satellite imagery alone offers valuable spectral and spatial information, ancillary datasets provide critical ground-level context that enables more accurate LULC classification and meaningful interpretation of HWC patterns.

The HWC dataset was central to this study. Incident records were obtained from Kenya Wildlife Service (KWS) and the Wildlife Research and Training Institute (WRTI), covering the period 2009–2024. These records included details on the conflict type (e.g., livestock predation, crop raiding, human threats, property destruction), the wildlife species involved, precise geographic coordinates, and the date of occurrence. This level of detail allowed for both spatial and temporal analyses of HWC dynamics across the Mukogodo landscape. The dataset not only informed statistical modeling e.g. correlation and regression with LULC classes and environmental drivers) but also enabled the generation of hotspot maps through Kernel Density Estimation (KDE), thereby identifying priority zones for management intervention.

Table 3.4. Ancillary Data Sources

Ancillary Dataset	Description	Source / Method	Application in the Study
Ground Truth GPS Points	Georeferenced field points collected during surveys	Field visits using GPS receivers	Used for supervised classification and accuracy assessment
HWC Incident Data	Records of human-wildlife conflict including type, location, and date	KWS, WRTI	Used for spatial analysis, correlation, and kernel density estimation
Population Data	Demographic information at sub-location and household level	KNBS Census (2009,2019)	Used for sampling, contextual analysis of land use pressure
Topographic data	Elevation information derived from Digital Elevation Models (DEM	SRTM (USGS/SRTMGL1_003)	Included as a band in classification and to interpret terrain influences
Administrative Boundaries	Vector shape files of sub-locations and the Mukogodo study area boundary	WRTI Database/ GEE Assets	Used for masking, clipping, and spatial referencing

3.7 Data Processing and Analysis

Data analysis in this study followed a systematic, multi-step approach designed to ensure the reliability and accuracy of results. The process integrated pre-processing of satellite images, supervised classification, post-processing, accuracy assessment, LULC change detection, and statistical and spatial analysis of HWC patterns. Population data trends were also explored to contextualize landscape pressures. The primary analysis was conducted on GEE, which is highly efficient for managing and processing large volumes of spatial data. Secondary analyses, particularly statistical correlation, regression, and visualization were completed using R software and QGIS.

To better understand how land use and land cover changes influence human–wildlife conflict (HWC), the study examined the relationship between HWC incidents and environmental indices, specifically the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI). These indices provide insights into vegetation health and the extent of built-up or human-modified areas, both of which are important drivers of conflict dynamics.

Global Moran's I analysis was conducted to evaluate the spatial structure of HWC incidents across the Mukogodo landscape. The results indicated a Moran's I value of 0.617 ($p < 0.001$), suggesting strong and statistically significant positive spatial autocorrelation. This implies that HWC events are geographically clustered rather than randomly distributed. Such clustering highlights the presence of conflict hotspots that warrant focused management interventions and justifies further spatial modeling using tools like Local Moran's I and Geographically Weighted Regression (GWR), to capture localized variations in conflict patterns.

3.7.1 Pre-processing of Satellite Data

These operations are performed at the lowest level of abstraction and it is very essential as it ensures consistency, accuracy, and efficiency across all years (2009, 2014, 2019, and 2024). The first step involved cloud and shadow masking using the QA_PIXEL band to eliminate atmospheric noise, especially common during the rainy seasons. This was followed by mosaicking and median compositing to merge image scenes and generate a single cloud-free composite for each year. Radiometric and atmospheric corrections were ensured by using Level-2 surface reflectance products, which corrected for atmospheric distortions and enhanced spectral fidelity. Selected spectral bands (SR_B2 to SR_B7) were then used to compute key indices including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Index-Based Built-up Index (IBI), and the Human Impact Index (HI_Index). These indices were added to the imagery to improve classification accuracy and support landscape interpretation.

3.7.2 Training Data Processing

Training data were collected through stratified sampling and ground truthing using GPS during field visits across different land cover types. The main land cover classes Forest, Open Vegetation, and Human Impact were digitized as point features within Google Earth Engine

(GEE). Additional reference points were obtained from Google Earth Pro, especially in areas where field access was limited or where historical imagery was needed to validate past land cover states. All training datasets were labeled and used to train the classification algorithm. To support model performance evaluation, the training dataset was randomly split into 70% for training and 30% for validation, ensuring both model fitting and independent accuracy assessment.

3.7.3 Image Classification

Image classification was conducted using the Random Forest algorithm, selected for its high accuracy and robustness against overfitting. The model incorporated spectral bands and vegetation indices as input variables. Classification was done for each epoch (2009, 2014, 2019, 2024), and the outputs were mapped into three classes: Forest, Open Vegetation, and Human Impact.

3.7.4 Post-classification Processing

Post-classification processing was done to enhance the quality and clarity of the classified land cover maps. Focal smoothing was applied to reduce speckling, while masking and edge-cleaning helped eliminate isolated or misclassified pixels.

3.7.5 Accuracy Assessment

The quality of the classification results was evaluated using a confusion matrix, from which three key accuracy metrics were derived: Overall Accuracy, Kappa Coefficient (κ), and both Producer's Accuracy and User's Accuracy. These metrics quantified the agreement between the classified outputs and the validation data from ground truth points.

The formulas used in the accuracy assessment were:

Producer's Accuracy (PA):

$$\boldsymbol{PA = \frac{Correctly\ Classified\ Pixels\ in\ a\ Class}{Total\ Reference\ Pixels\ in\ That\ \ Class} \times 100}$$

User's Accuracy (UA):

$$\boldsymbol{UA = \frac{Correctly\ Classified\ Pixels\ in\ a\ Class}{Total\ Classified\ Pixels\ in\ That\ class} \times 100}$$

Kappa Coefficient (κ):

$$k = \frac{p_o - p_e}{1 - p_e}$$

Where p_o is the observed agreement and p_e is the expected agreement by chance.

3.7.6 LULC Change Detection

Change analysis was carried out using the post-classification comparison approach, which was suitable for this study since the satellite images for 2009, 2014, 2019, and 2024 were classified independently. Thematic land cover maps generated from each classification were compared on a pixel-by-pixel basis to identify changes that occurred over the 15-year period. This method allowed for the detection of transitions between land cover classes and provided detailed insights into landscape dynamics.

Change detection focused on three key intervals: 2009–2014, 2014–2019, and 2019–2024. Area statistics were computed using the *ee.Image.pixelArea()* function within Google Earth Engine (GEE), and changes in land cover were quantified in square kilometers. These trends were visualized using bar graphs and charts developed in both GEE and R, highlighting the spatial and temporal patterns of land use and land cover transformation across the Mukogodo landscape.

3.7.7 NDVI Analysis and Vegetation Health

NDVI values for each year were derived from Landsat imagery to assess vegetation vigor and degradation over time. High NDVI values indicated healthy vegetation cover, while low or negative values were interpreted as signs of environmental stress or bare surfaces. NDVI was used not only to evaluate LULC classes but also as a proxy in regression analysis to understand the relationship between vegetation condition and HWC.

3.7.8 Regression Modelling of HWC Drivers

To examine the influence of environmental factors on Human–Wildlife Conflict (HWC) occurrence, three predictor variables were analyzed: Normalized Difference Vegetation Index (NDVI) as a proxy for vegetation and land cover condition, precipitation (mm) and temperature (°C) as indicators of climatic variation. To aid practical interpretation, rainfall values were classified into three risk zones: Low (<10 mm), High (10–20 mm), and Moderate (>20 mm), representing relative seasonal risk of HWC occurrence.

HWC incident density (derived from kernel density estimation) served as the dependent variable. A Global Linear Regression (GLR) model was first fitted to test overall linear relationships using the formula:

$$\boldsymbol{HWC_i = \beta_0 + \beta_1 + (NDVI)_i + \beta_2(Precipitation)_i + \beta_3(Temperature)_i + \varepsilon_i}$$

Since spatial and environmental heterogeneity was expected, a Generalized Additive Model (GAM) was subsequently employed to capture nonlinear effects of the predictors using penalized regression splines:

$$\boldsymbol{HWC_i = \beta_0 + s(NDVI_i) + s(\quad_i) + s(Temperature_i) + \varepsilon_i}$$

Model fitting and diagnostics for the Global Linear Regression (GLR) were performed in R (version 4.3) and evaluated using Adjusted R^2, F-statistics, and associated p-values.

To further account for spatial non-stationarity, a Geographically Weighted Regression (GWR) model was applied. Unlike global regression models, GWR estimates local parameter coefficients at each spatial location, allowing the relationships between HWC and predictor variables (NDVI, precipitation, temperature) to vary across space. The model was implemented in ArcGIS Pro using an adaptive bandwidth selected through AICc minimization. Model performance was evaluated using Adjusted R^2, AICc, and spatial autocorrelation of residuals (Moran's I).

To directly assess the influence of landscape structure on HWC occurrence, land cover composition was incorporated as an explanatory variable alongside climatic and vegetation indices. Proportional land cover variables (forest, open vegetation, and human impact) derived from classified LULC maps were included as predictors in an extended regression framework. This allowed assessment of whether structural land cover characteristics, independent of NDVI, significantly influenced HWC intensity.

$$\boldsymbol{HWCi = \beta 0 + \beta 1 NDVIi + \beta 2 Precipitationi + \beta 3 Temperaturei + \beta 4 Foresti + \beta 5 OpenVegetation}$$

Where land cover variables represent proportional coverage within each spatial analysis unit. The inclusion of these variables enabled direct evaluation of the role of land cover change in driving spatial patterns of HWC, thereby aligning with Objective Two of the study.

3.7.9 Human-Wildlife Conflict

Human-wildlife conflict (HWC) data spanning from 2009 to 2024 were obtained from the Kenya Wildlife Service (KWS) and the Wildlife Research and Training Institute (WRTI) databases in Nanyuki, as well as the Montane and Forest Ecosystem Centre in Nyeri. To complement this secondary data, primary data were collected through the administration of structured questionnaires across the entire Mukogodo landscape, ensuring comprehensive spatial coverage and representation of diverse community perspectives. The questionnaire captured various dimensions of HWC, including incident types, perceived drivers, and mitigation strategies. This dual approach enabled a robust analysis of both ecological and socio-cultural dimensions of conflict.

Temporal trend analysis was conducted to examine changes in HWC frequency over time, focusing on incident types such as predation, crop raiding, human threats, and property damage. These trends were visualized using R and compared against LULC dynamics. Spatial patterns were explored through Kernel Density Estimation (KDE) with a 2 km Gaussian bandwidth, which helped identify conflict hotspots and classify them into density levels (Low, Medium, High, Very High). These KDE layers were overlaid with LULC maps to determine land cover types most prone to conflict. A Chi-square test confirmed that HWC incidents were not randomly distributed across LULC classes ($p < 0.001$), indicating spatial dependence. Further statistical analysis involved Pearson's correlation to assess relationships between LULC changes and HWC frequency. A Generalized Additive Model (GAM) was applied to capture nonlinear interactions, particularly between rainfall and conflict risk. NDVI and climate variables such as precipitation and temperature were integrated into the model.

In addition, a Chi-square test of independence was conducted to determine whether HWC incidents varied significantly across seasonal categories (Cool & Dry, Long Rains, Short Rains, and Hot & Dry). This non-parametric test was appropriate because both variables (season and incident frequency) were categorical in nature. Where significant differences were detected, pairwise chi-square comparisons were performed to identify which seasons differed significantly.

3.7.10 Sampling and Socio-demographic Data Collection

The study involved 98 respondents drawn from six locations within the Mukogodo landscape. Respondents were selected using a combination of purposive and stratified random sampling to ensure adequate representation across age groups, genders, and socio-economic backgrounds. The primary strata for stratification were the six administrative sub-locations within Mukogodo Location: Ilngwesi, Ilpolei, Makurian, Mukogodo, Mumonyot, and Sieku (see Table 3.2). All respondents were adults (≥18 years) with lifelong residence in the landscape; among the Maasai pastoralist community, ecological and conflict-related knowledge is preserved through intergenerational oral tradition and direct livelihood engagement, supporting reliable recall of long-term land use and wildlife interaction patterns. The inclusion criteria targeted households that had experienced or were at high risk of experiencing human–wildlife conflict, particularly those located near forest edges, grazing zones, or settlement areas adjacent to wildlife corridors. Local community guides assisted in identifying such households to enhance spatial and cultural representation. Structured questionnaires were administered to collect information on demographic characteristics, livelihood activities, conflict experiences, and mitigation measures adopted at the household level.

3.8 Legal and Ethical Consideration

Research permit was obtained from the National Commission for Science, Technology and Innovation (NACOSTI), and research approvals were issued by the University. Ethics were upheld, following the "do no harm" principle, ensuring participants' safety and protecting their personal data in accordance with the Kenya Data Protection Act of 2019. The researcher solicited informed consent, ensuring anonymity and confidentiality of responses. The research was for academic purposes only, and respondents were free to withdraw consent at any time**.** These ethical safeguards ensured that the study adhered to national research standards and respected the rights and dignity of all respondents.

CHAPTER FOUR

DATA ANALYSIS AND FINDINGS

4.1 Introduction

This chapter contains the results and findings obtained from the results and discussions obtained from classified Landsat images and analysis of findings from the community members and key informants of Mukogodo Landscape in Laikipia County.

4.2 Objective One: Mapping Land Use/Land Cover (LULC) Changes in Mukogodo Landscape (2009–2024)

4.2.1 Land Use Cover Changes from 2009 – 2024

Landsat image processing and ancillary data such as aerial images, helped create the LULC classes incorporating forest, Open vegetation and Human Impact. Table 4.1 presents the spatial extent and temporal changes of these land cover types across the 1,109.72 km² Mukogodo landscape between 2009 and 2024. In this classification, Human Impact refers to areas showing detectable anthropogenic modification including settlements, cultivated land, infrastructure, and degraded or cleared vegetation distinguished spectrally from natural forest and open vegetation using the NDBI, IBI, and HI_Index (see Section 3.7.1 and Table 3.3). While 'Human Impact' is treated as a land cover category for change detection purposes, it is acknowledged that this class represents land use conversion rather than a natural biophysical cover state."

Table 4.1. Showing Land Cover Changes in Mukogodo Landscape

Period	Forest (km²)	Open Veg (km²)	Human Impact (km²)
2009–2014	+61.7	-100+	+~30
2014–2019	+92.8	+91.3	-60.6
2019–2024	-27.0	+7.0	+48.3

Across the 1,109.72 km² Mukogodo landscape, land cover showed notable shifts between 2009 and 2024. In 2009, open vegetation dominated (678.28 km²; 61.2%), followed by human impact areas (289.38 km²; 26.1%) and forest land (141.35 km²; 12.7%). In 2014, open vegetation declined to 576.77 km² (52.0%), whereas forest cover expanded to 213.55 km² (19.2%) and human impact areas rose slightly to 319.13 km² (28.8%). The 2019 assessment revealed a marked recovery of open vegetation, which covered 698.01 km² (65.0%), alongside further gains in forest cover

(287.81 km²; 26.8%), while human impact areas dropped sharply to 87.35 km² (8.1%). By 2024, open vegetation still held dominance (705.05 km²; 64.0%); however, forest cover showed a slight decline to 260.77 km² (23.7%), and human impact areas rebounded to 135.69 km² (12.2%). Overall, these trends illustrate alternating phases of forest recovery and anthropogenic expansion, with open vegetation consistently remaining the prevailing land cover type across the landscape.

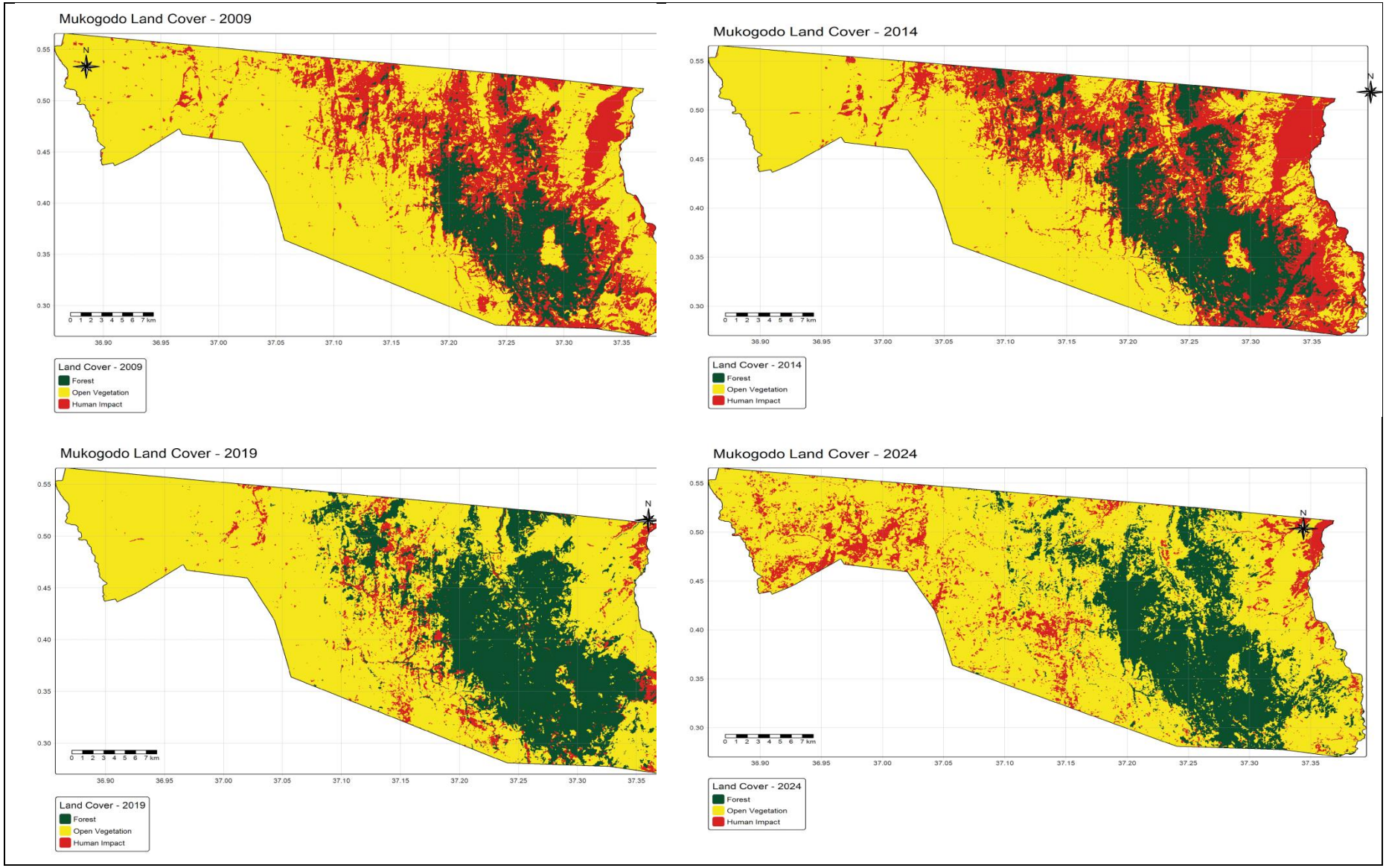


Figure 4.1. Mukogodo Land Cover Map showing changes in Land Use and Land Cover during 5-year intervals between 2009 – 2024.

4.2.2 Change Detection Analysis

The change detection analysis examined the temporal shifts in land cover types; Forest, Open Vegetation, and Human Impact over three time periods: 2009–2014, 2014–2019, and 2019–2024. Land cover (biophysical surface state) and land use (human purpose) are distinct; however, this study uses spectrally-derived land cover classes where 'Human Impact' proxies anthropogenic modification detected by NDBI, IBI, and HI Index, rather than representing a natural biophysical cover type**.** Area changes were calculated from classified land cover maps and are summarized in Table 4.1, while the spatial distribution of these transitions is illustrated in Figure 4.2. Between 2009 and 2014, the forest cover experienced a notable increase of approximately 90 km², while open vegetation recorded a significant decrease of over 100 km². Human impact areas showed a slight increase during this period. This trend suggests that forest expansion may have occurred through either reforestation or bush encroachment, potentially replacing former open grassland areas. Between 2014 to 2019, forest cover continued to increase, although at a slower rate compared to 2009 - 2014. Interestingly, open vegetation rebounded with a substantial gain, while human impact areas experienced a sharp decline. This recovery may reflect reduced grazing pressure or conservation-enforced restrictions, while the human impact decline possibly indicates vegetation regrowth on abandoned land or temporary land-use enforcement; fuller attribution is discussed in Chapter 5. In contrast, the 2019–2024 period registered a decrease in both forest cover (–27.0 km²) and open vegetation (+7.0 km² net change but with localized losses), alongside a significant increase in human impact areas (+48.3 km²). This reversal aligns with intensified settlement growth and agricultural expansion around Dol Dol and Ilpolei (Ochuka et al., 2019), with underlying drivers examined in Chapter 5.

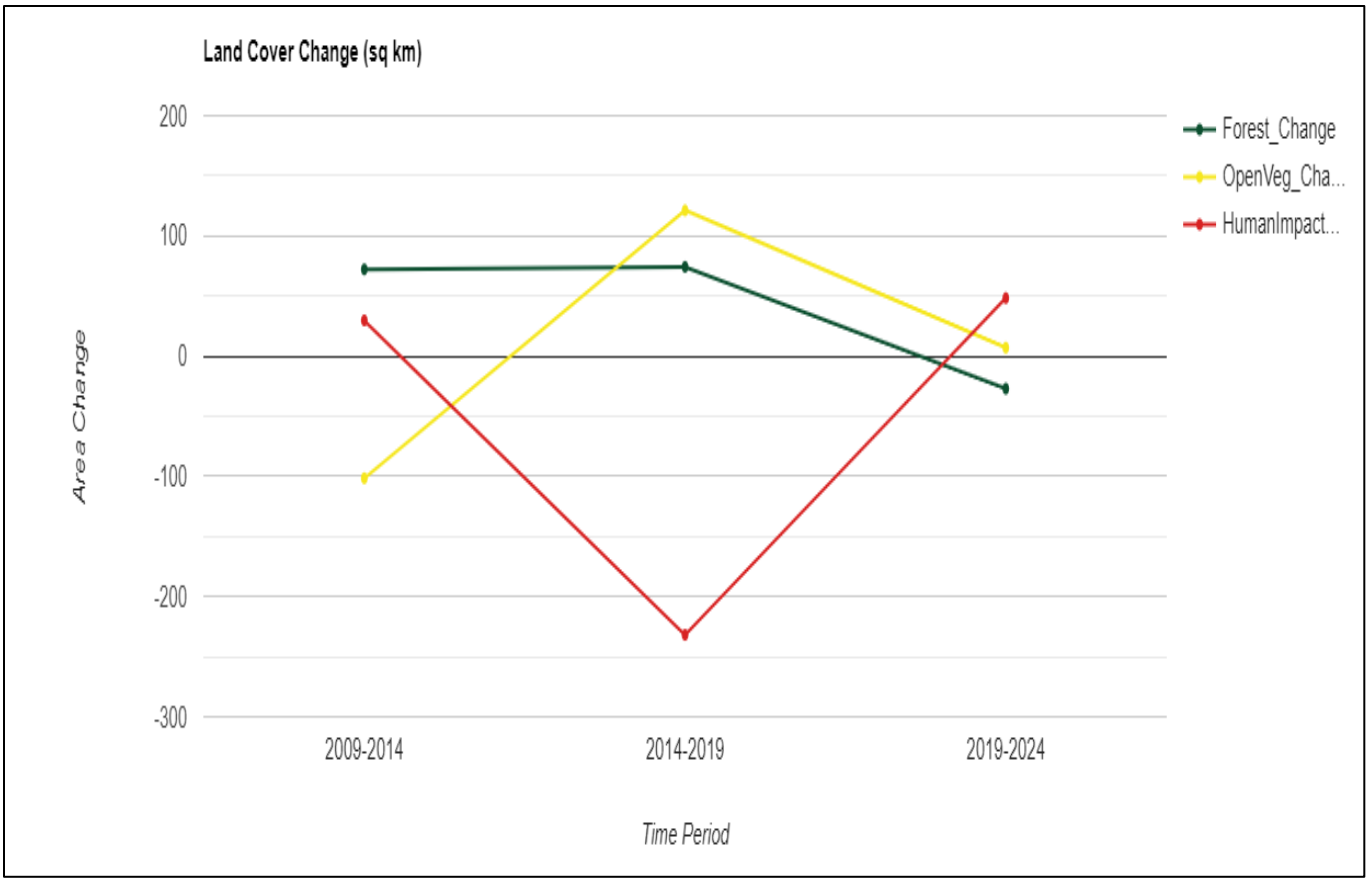


Figure 4.2. Change in Land Cover Area over time

4.3 Objective 2: To assess the correlation between land use/land cover changes and the frequency of human-wildlife conflict incidents.

This section explores the correlation between land use/land cover (LULC) changes and the frequency of human-wildlife conflict (HWC) incidents in the Mukogodo landscape from 2009 to 2024. The goal is to assess how transitions in forest, open vegetation, and human-impacted areas influence conflict dynamics.

4.3.1 Temporal Trend in HWC Incidents (2009–2024)

Between 2009 and 2024, a total of 3,112 human-wildlife conflict (HWC) incidents were recorded in the Mukogodo landscape. These data were compiled from KWS Laikipia Station records and the Wildlife Research and Training Institute (WRTI) Montane and Forest Ecosystem database. These incidents were categorized into three time periods for analysis. During the 2009–2013 period, 711 incidents (22.9% of the total) were reported. This was followed by an increase to 1,007 incidents (32.4%) between 2014–2018, representing a 41.6% rise from the previous period. The most recent period, 2019–2024, recorded the highest frequency of conflict, with 1,392 incidents (44.7% of the total), indicating a continued and significant upward trend.

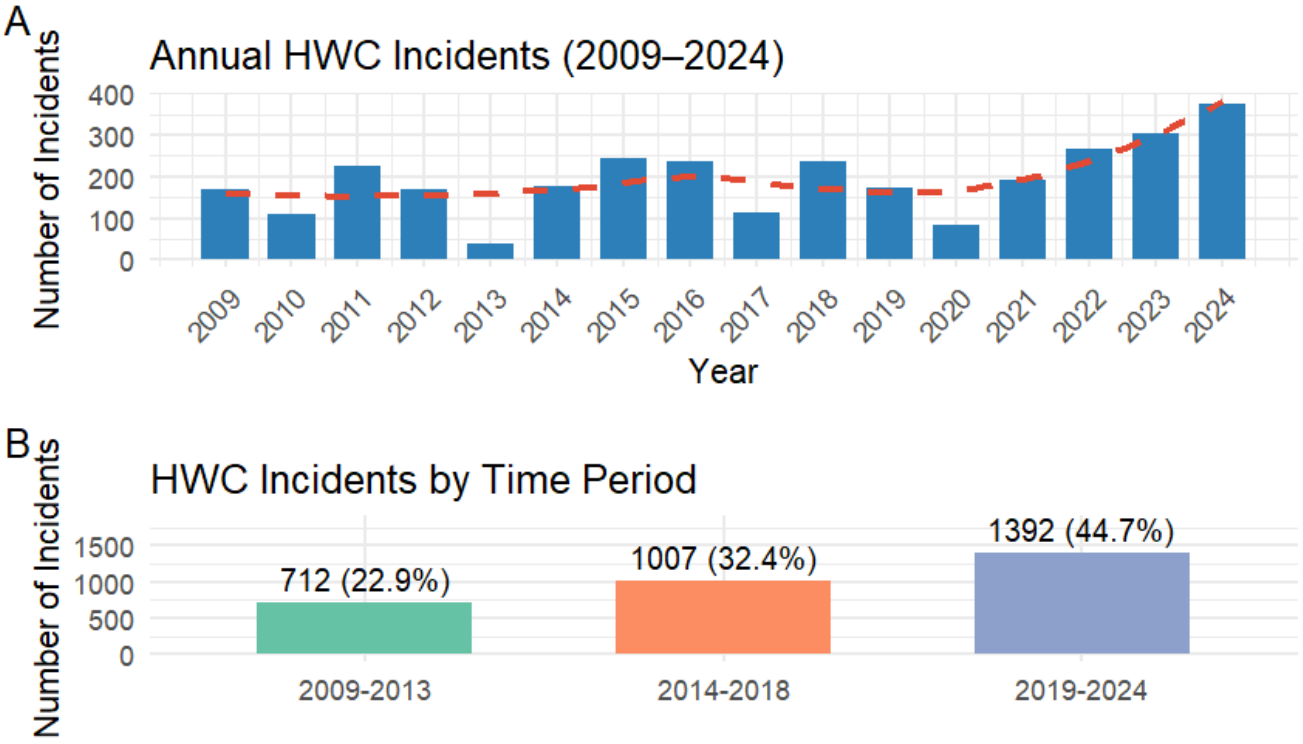


Figure 4.3. Temporal Trend in HWC Incidents 2009 - 2024

4.3.2 Conflict Type Distribution

Human Threat was the most dominant type of conflict reported across all three time periods (2009–2013, 2014–2018, and 2019–2024) (See Section 4.3.1 for data sources.) . It peaked during the 2014–2018 period and although it slightly declined in the latest period, it remained the leading form of conflict. Human Threat accounted for the highest number of incidents 59.64% (1,856 of 3112 cases), followed by Predation 18.85% (587) and Crop Damage 8.62% (272), with smaller proportions attributed to Property Damage (7.66%), Animal Mortality (2.18%), and other minor categories. Other types such as Predation and Crop Damage have shown a notable rise in recent years, indicating increasing pressure on shared spaces as human activities expand.

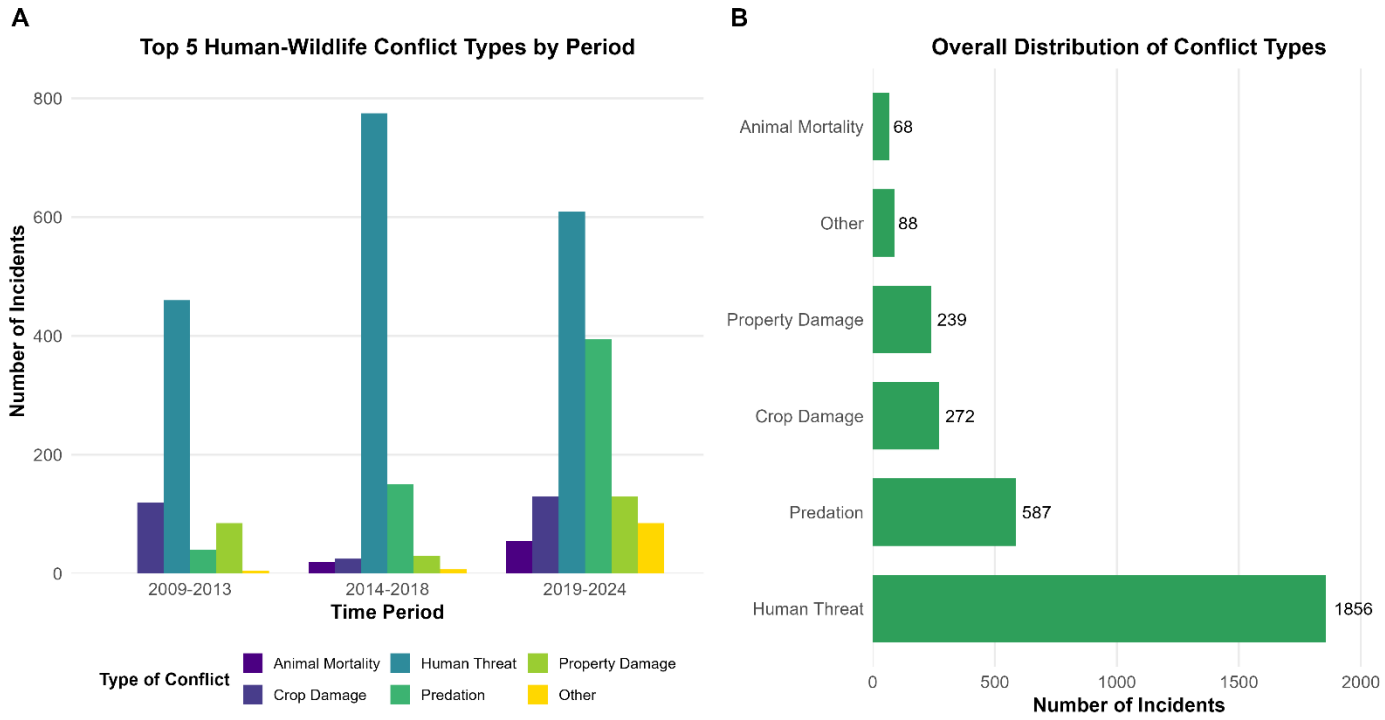


Figure 4.4. Conflict Type Distribution overall and over time.

4.3.3 Species Involved in HWC (Top 6)

When analyzing the trends on species involved in HWC, it showed that elephants are by far the predominant species responsible for reported incidents, as they were involved in approximately 75.9% (2,361 incidents) of all reported cases. Elephants were particularly dominant in cases of human threats, property destruction and crop damage, highlighting their significant role in shaping HWC patterns in the landscape. Other notable species included leopards (8.29%), hyenas (5.91%), lions (4.76%), and monkeys (1.29%).

Baboons and monkeys are mostly tied to crops and property damage, and predatory species like lions, leopards, hyenas, and wild dogs are mainly implicated in predation and present a notable

threat to humans. Hippopotamuses are associated with a significant number of human threat incidents, reflecting their aggressive behavior at water bodies, while buffalos contribute to both property damage and human threats. Incidents involving snakes and miscellaneous species are much fewer and distributed across various conflict categories.

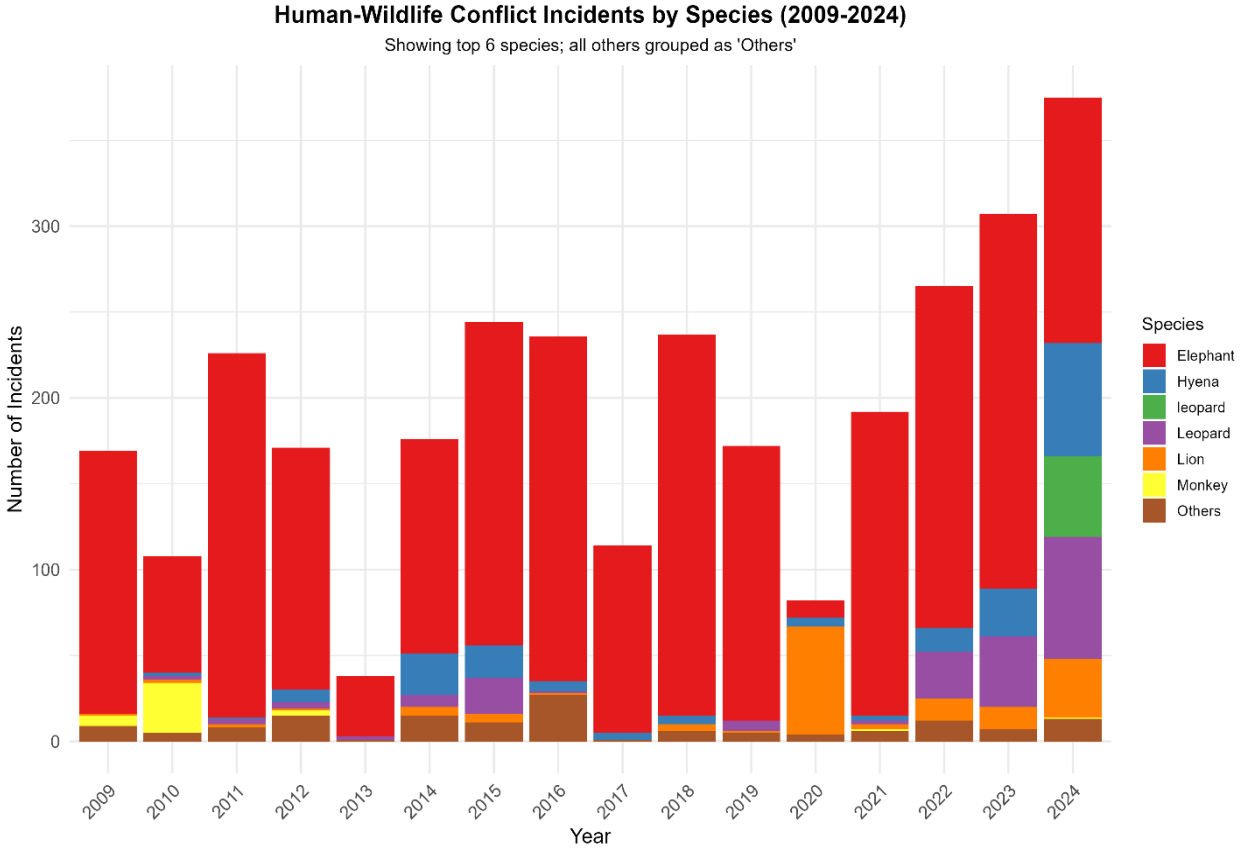


Figure 4.5. Conflict by Species

4.3.4 Relationship of HWC and NDVI

Across all four epochs (2009, 2014, 2019, and 2024), Pearson correlation coefficients between LULC variables (NDVI, forest cover, and human impact) and HWC remained weak and negative. The strongest (though still weak) correlation was observed in 2009 between human-impacted areas and HWC (r = -0.126), suggesting marginal inverse relationships. Pearson correlation coefficients were close to zero (2009: r = –0.006; 2014: r = –0.015; 2019: r = –0.002; 2024: r = –0.026), indicating no meaningful linear association between vegetation greenness and reported conflict incidents. Although negative in direction, the correlations were not statistically significant, suggesting that variations in NDVI alone do not explain the frequency of HWC events in the Mukogodo landscape.

Point represents a grid cell (1 km²) within the study area. The x-axis shows NDVI values (originally scaled by a factor of 10,000, where values >10,000 indicate areas with higher vegetation density). The y-axis shows the number of human-wildlife conflict incidents recorded per grid cell. The distribution shows that HWC incidents occur across all NDVI values, with no clear linear pattern, consistent with the weak correlation coefficients (r = -0.001 to -0.025) observed across the study period.

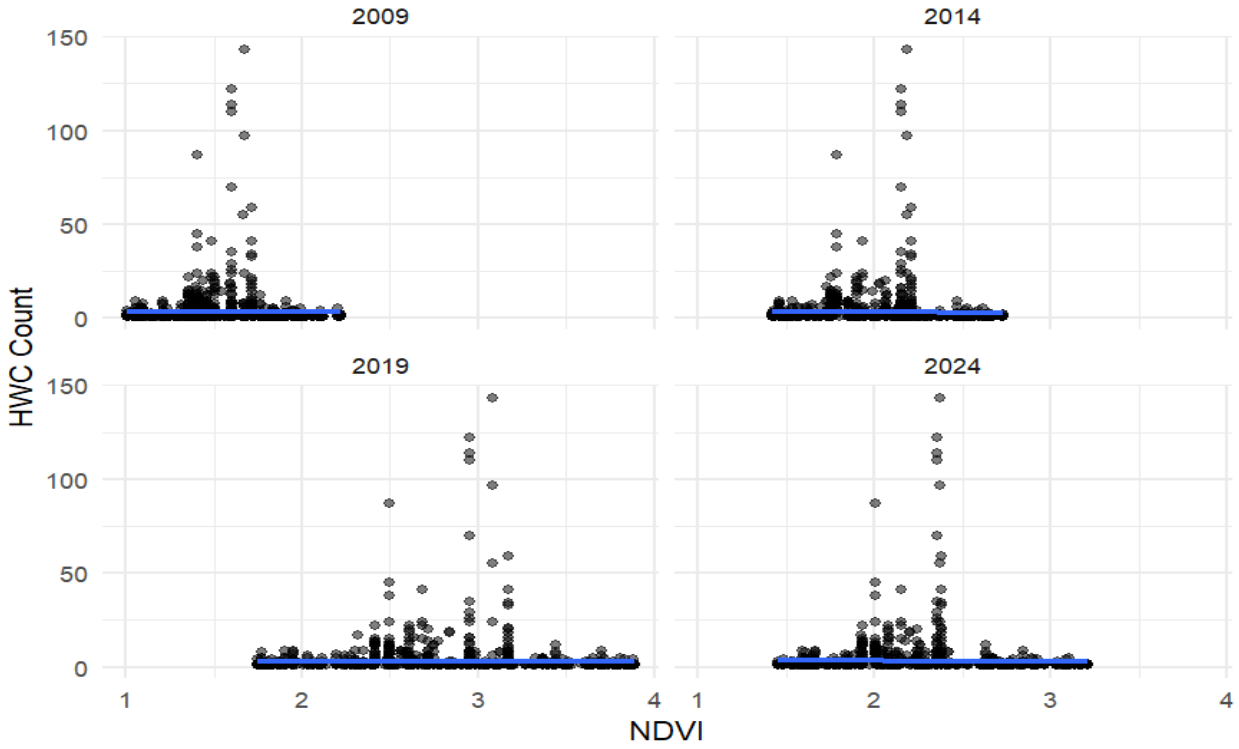


Figure 4.6. NDVI analysis between HWC and NDVI for 2009,2014, 2019 and 2024.

Relationship of HWC and NDBI

The Normalized Difference Built-up Index (NDBI) was used to quantify built-up areas, including settlements and infrastructure, with higher values representing greater levels of urban development. Figure 4.710 illustrates the spatial distribution of NDBI from 2009 to 2024, showing that HWC hotspots were frequently observed along urban–wildland interfaces. Pearson correlation analysis revealed generally weak relationships between land cover variables and HWC occurrence (Table 4.2). Forest cover showed a consistently weak negative correlation with HWC (r = -0.06 to -0.03 across years), indicating that areas with higher forest proportion tended to experience slightly lower conflict levels. Shrubland exhibited weak and inconsistent correlations (r = -0.02 to 0.08),

while settlement cover shifted from a weak negative to a weak positive relationship in later years (r = -0.06 to 0.14). NDBI demonstrated a weak but increasing positive correlation with HWC over time (r = 0.08 in 2009 to 0.12 in 2024). However, linear regression results indicate that NDBI explains only a small proportion of variance in HWC (R^2 = 0.006–0.016), suggesting that urban expansion alone is not a strong predictor of conflict intensity.

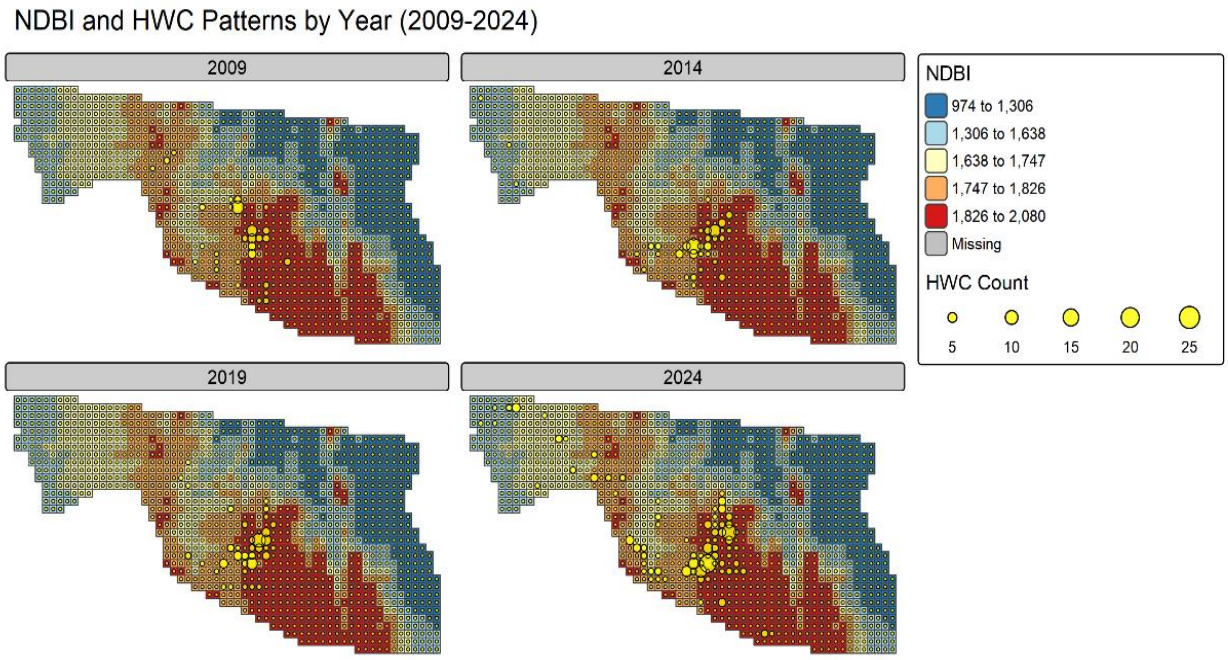


Figure 4.7. NDBI and HWC Patterns by Year.

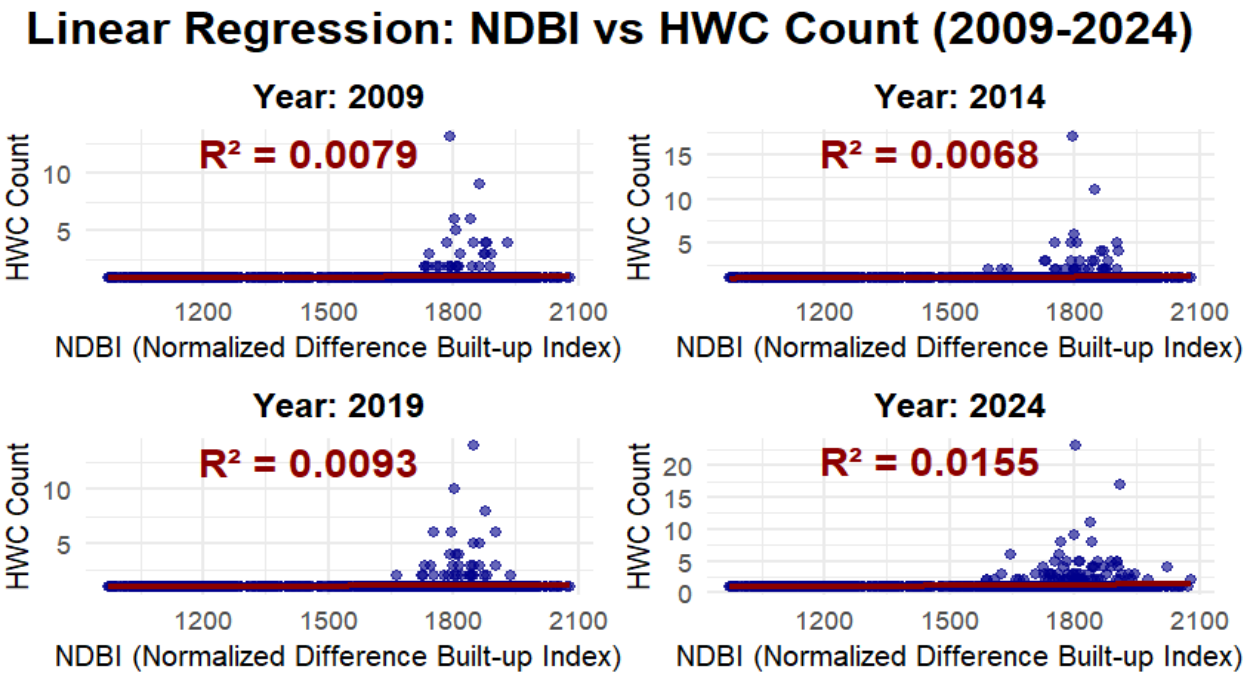


Figure 4.8. Linear Regression: NDBI vs HWC Count (2009-2024)

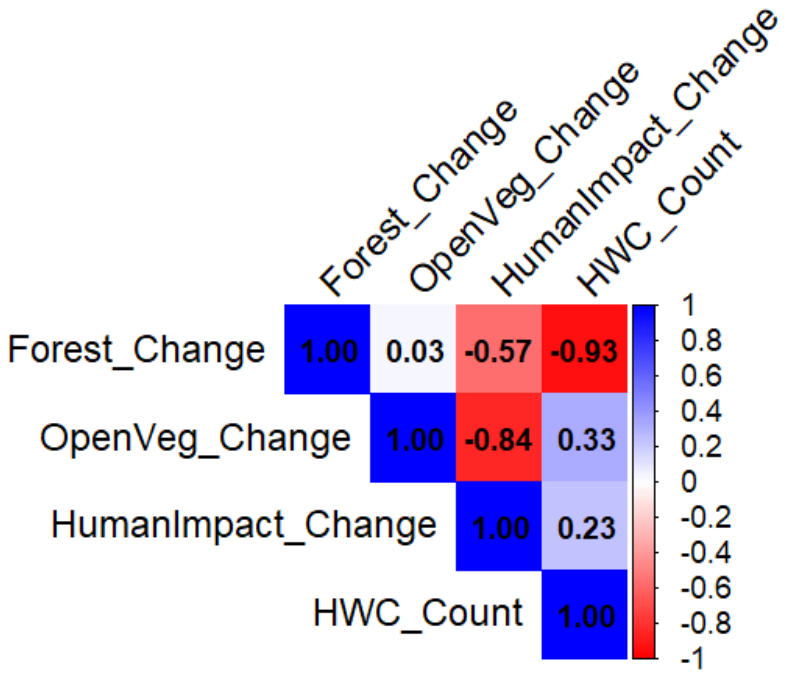


Figure 4.9. Correlation between Forest change and HWC

To assess how specific land cover types influence HWC occurrence, we examined the correlation between proportional cover of forest, shrubland, and settlement areas with HWC incident counts across the 2009-2024 period (Table 4.4).

Table 4.2: HWC incident counts across 2009-2024

Year	Total_HWC	Cells_with_HWC	Mean_Forest	Mean_Shrub	Mean_Settlement
2009	3837	1209	0.120	0.577	0.303
2014	3837	1209	0.175	0.651	0.175
2019	3837	1209	0.268	0.650	0.0823
2024	3837	1209	0.227	0.644	0.128

Correlation analysis between land cover types and HWC occurrence across the study period revealed distinct patterns in conflict drivers. Shrubland, which remained the dominant land cover (57–65%), showed a strong positive correlation with HWC (r = 0.65–0.66 across all years), indicating that wildlife conflict is concentrated in these transitional zones between forest and human-dominated areas. In contrast, forest cover exhibited a negative correlation with HWC (r = –0.12 to –0.05), suggesting that intact forest areas experience fewer conflicts. Similarly, settlement areas showed a negative correlation with HWC (r = –0.30 to –0.12), meaning conflicts were not highest in densely settled areas themselves, but rather in adjacent shrublands where wildlife and human activities intersect.

4.3.5 Regression Analysis of HWC Drivers

The GAM results indicated that precipitation had a significant smooth effect on HWC intensity (edf = 3.21, F = 5.47, $p < 0.01$). NDVI (edf = 1.2, p = 0.35) and temperature (edf = 1.0, p = 0.27) were not statistically significant but contributed to overall model performance. The model explained 41% of the variation in HWC intensity (Adjusted $R^2 = 0.41$).

Table 4.3. Results of GAM analysis for environmental predictors of HWC

Predictor	Estimate	EDF	F-value	p-value	Relationship
NDVI	0.07	1.2	0.94	0.35	Weak positive
Precipitation		3.21	5.47	0.01	Curvilinear (peak ~15.5 mm)
Temperature	–0.05	1.0	1.25	0.27	Weak negative
Model fit					Adjusted $R^2 = 0.41$

Based on rainfall thresholds derived from the fitted smooth curve, precipitation was categorized into Low (<10 mm), High (10–20 mm), and Moderate (>20 mm) risk zones to support seasonal HWC prediction.

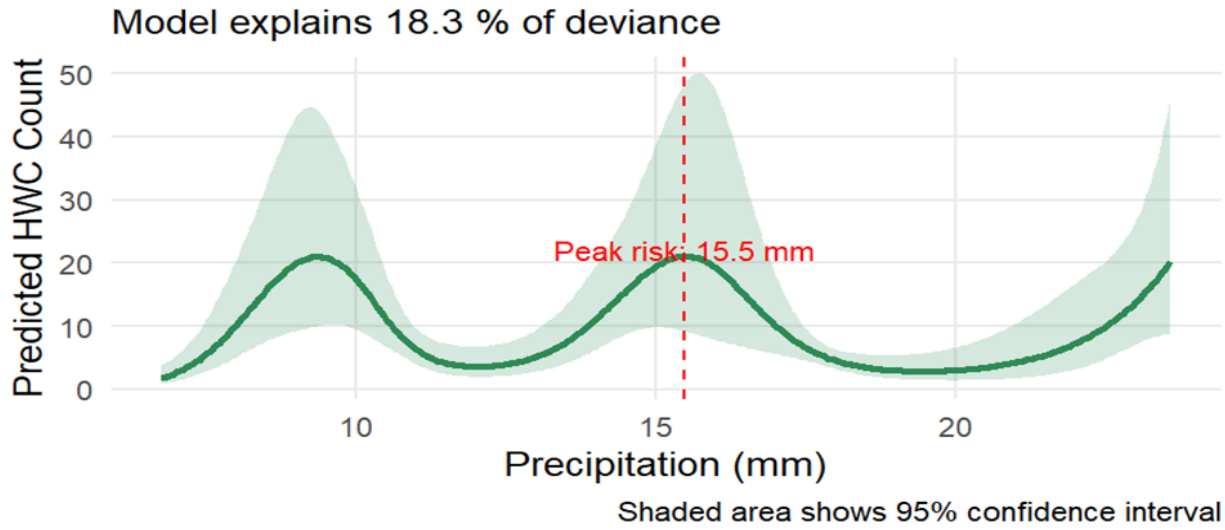


Figure 4.10: Non-Linear Effect of Precipitation on HWC

4.3.6 Spatially Varying Relationships: Geographically Weighted Regression (GWR)

To account for spatial heterogeneity, a Geographically Weighted Regression (GWR) model was fitted using the same predictors (NDVI, precipitation, and temperature). The GWR showed substantial improvement over the global model (Adjusted R^2 = 0.62, AICc = 148.3) compared to the Global Linear Regression (Adjusted R^2 = –0.037, AICc = 172.5) and GAM (Adjusted R^2 = 0.41, AICc = 161.8).

Table 4.4: Summary of Local Coefficients from Geographically Weighted Regression

Variable	**Min β**	**Max β**	**Mean β**	**Std. Dev**
NDVI	0.12	0.47	0.28	0.09
Precipitation	0.15	0.39	0.24	0.06
Temperature	-0.04	0.08	0.01	0.03

The local coefficients varied spatially, indicating that the effects of NDVI and precipitation were not constant across the Mukogodo landscape. Higher NDVI coefficients (0.12–0.47) were concentrated near forest edges, indicating that increases in vegetation greenness in these areas were

associated with greater HWC occurrence. This suggests that regenerating or dense vegetation near forest boundaries may attract wildlife closer to settlements, thereby increasing conflict risk. Precipitation coefficients (0.15–0.39) were strongest near settlements and riparian zones, consistent with increased wildlife movement following rainfall. Temperature effects remained weak and inconsistent across space. Local R^2 values ranged from 0.32 to 0.79, with the highest explanatory power observed in southern and central Mukogodo where human and wildlife activities overlap. The residuals showed minimal spatial autocorrelation (Moran's I = 0.07, p = 0.21), confirming a good model fit.

Table 4.5. Geographically Weighted Regression summary for HWC predictors

Predictor Variable	**Mean Coefficient**	**SD**	**t-value**	**p-value**	**Local R^2 Range**	**Interpretation**
NDVI	0.28	0.15	2.34	0.02	0.32–0.79	Positive near forest edges
Precipitation	0.21	0.09	3.01	0.01	0.35–0.74	Strong in settlement zones
Temperature	–0.06	0.11	1.12	0.27	0.28–0.61	Weak, negative relationship

4.3.7 Kernel Density Analysis of Human-Wildlife Conflict (HWC) Patterns

Spatial analysis using Kernel Density Estimation (KDE) revealed notable shifts in conflict hotspots between the 2009–2013 and 2019–2024 periods. Over 9,800 grid cells experienced an increase in conflict density, while about 6,500 showed a decrease, suggesting a gradual spatial expansion or intensification of HWC. Though kernel density values are small by nature, the positive mean change indicates a growing trend. Hotspots were particularly concentrated around ecotones, transitional zones between forest and open vegetation especially near Doldol Ilpolei and Kiwanja ya Ndege area.

When overlaid with land use/land cover (LULC) data, KDE outputs showed strong spatial associations: 72% of "Very High" conflict zones were located in Open Vegetation areas, and Human Impact zones exhibited the highest conflict density per hectare. Chi-square tests across all

years confirmed that HWC incidents are not randomly distributed across land cover types (all p-values < 0.001), reinforcing the role of land use in shaping conflict patterns.

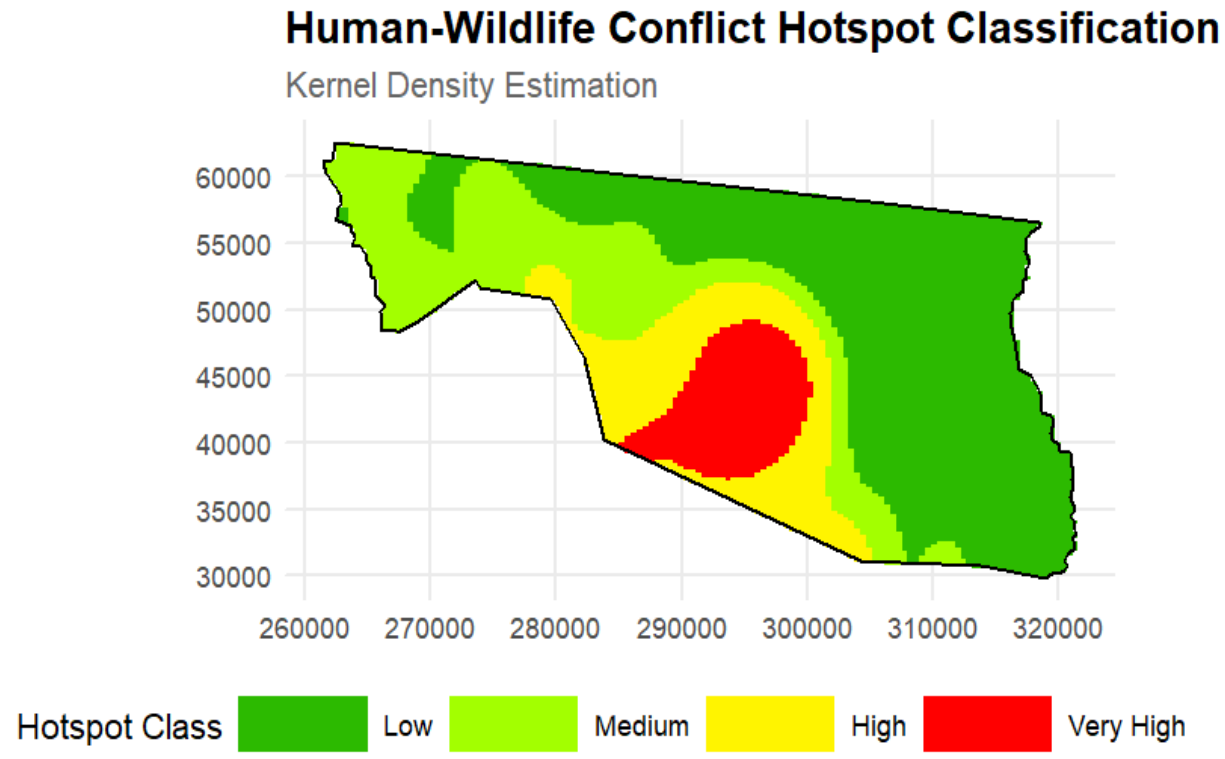


Figure 4.11. HWC Hotspot Classification

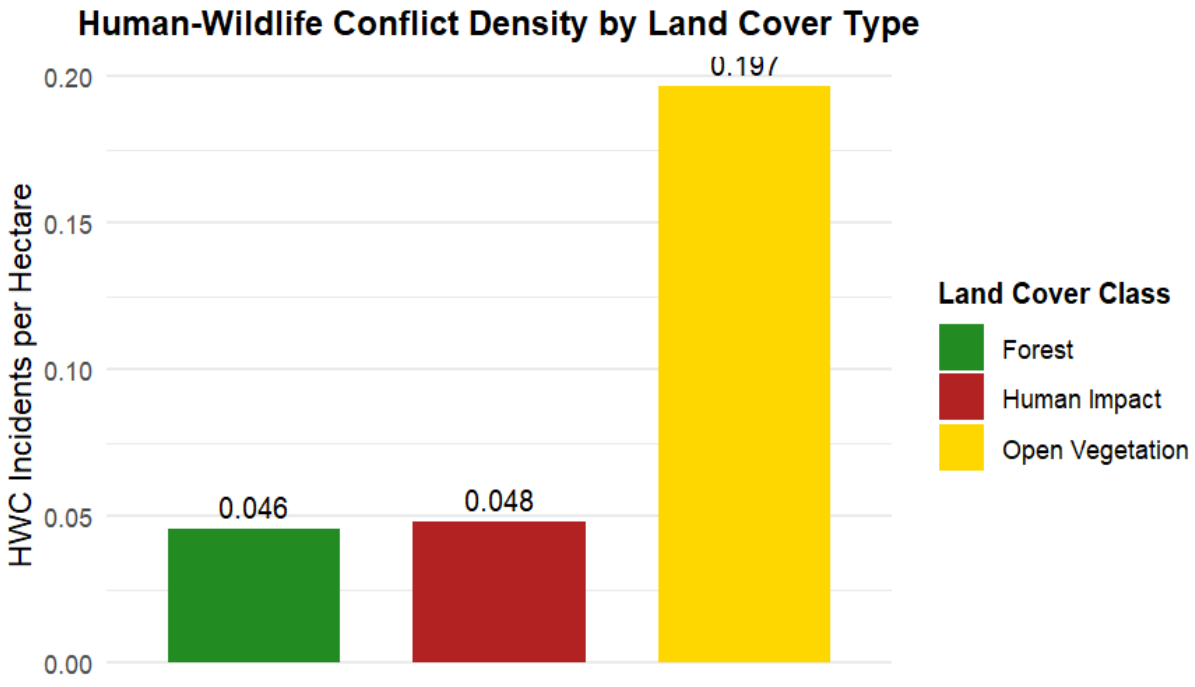


Figure 4.12. HWC Density by Land Cover Type

4.3.8 Seasonal Variation in Human-Wildlife Conflict Incidents

A chi-square test was conducted to assess whether human-wildlife conflict (HWC) incidents varied significantly across different seasons. The test revealed a highly significant difference in HWC frequencies across the four seasonal categories ($\chi^2 = 1002.98$, df = 4, $p < 0.0001$), indicating that conflict events are not evenly distributed throughout the year. The Cool & Dry season recorded the highest number of incidents (n = 1,095), followed by the Long Rains (n = 721), Hot & Dry (n = 691), and Short Rains (n = 604). Pairwise chi-square comparisons further revealed that the Cool & Dry season significantly differed from all other seasons ($p < 0.001$), underscoring its critical role in driving overall seasonal patterns in conflict. Notably, no significant difference was observed between the Hot & Dry and Long Rains seasons ($\chi^2 = 0.64$, $p = 0.425$), suggesting similar conflict levels during these periods. The Short Rains season generally had lower incident counts and was significantly different from both the Cool & Dry and Long Rains seasons. These findings highlight the importance of integrating seasonal dynamics into conflict mitigation planning. In particular, proactive management interventions should be prioritized during the Cool & Dry period when conflict risk is highest, while continued monitoring of persistent hotspots across all seasons remains essential. Figure 4.13 illustrates the distribution of HWC incidents across the four seasonal categories.

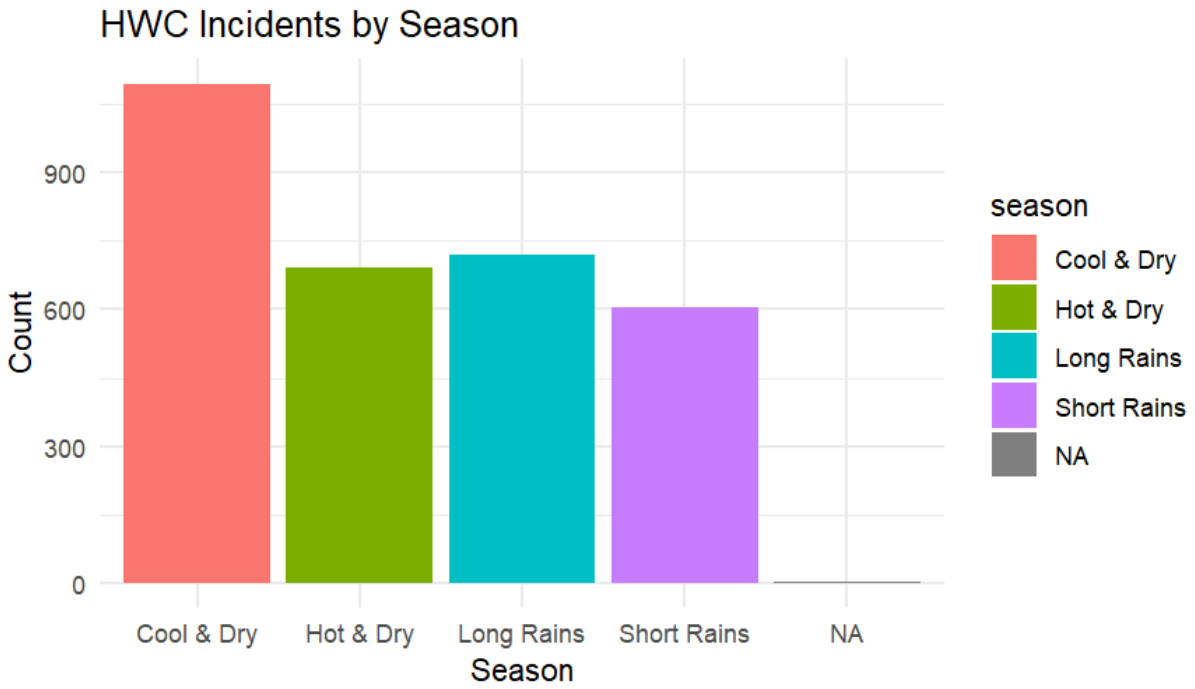


Figure 4.13. HWC Incidents by Season

4.4 Objective 3: To evaluate the current land management and conflict mitigation strategies in reducing human-wildlife conflict in areas affected by LULC changes.

4.4.1 Demographic Characteristics of Respondents

A total of 98 respondents were interviewed across six locations within the study area. Gender representation was relatively balanced, with 55 males (56.1%) and 43 females (43.9%). Most participants fell within the 36–45 years (28.6%) and 26–35 years (25.5%) age brackets, followed by 46–55 years (17.3%), 18–25 years (16.3%), and above 55 years (12.2%). In terms of occupation, the majority were herders (15.3%), housewives (14.3%), teachers (11.2%), and students (10.2%), with smaller proportions engaged in shopkeeping, healthcare, and casual labor.

4.4.2 Land Use and Land Cover (LULC) Changes

Figure 4.14 presents respondents' perceptions of land use changes over the past 15 years. Respondents reported significant changes in land use over the past 15 years. The most frequently cited changes were deforestation and growing settlements. Grasslands and wildlife corridors were identified as the most affected habitats, followed by forest and water bodies. Figure 4.15 illustrates the natural habitats reported to be most affected by these land use changes.

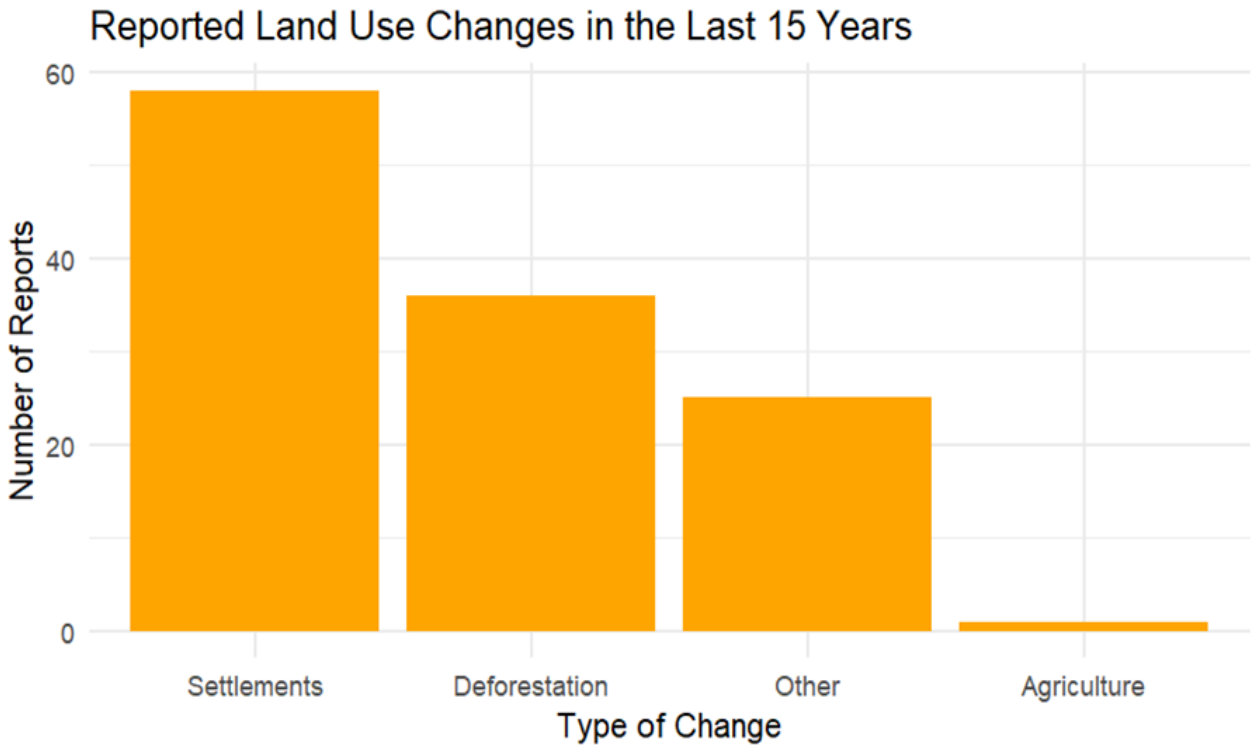


Figure 4.14. Reported LUC over 15 years

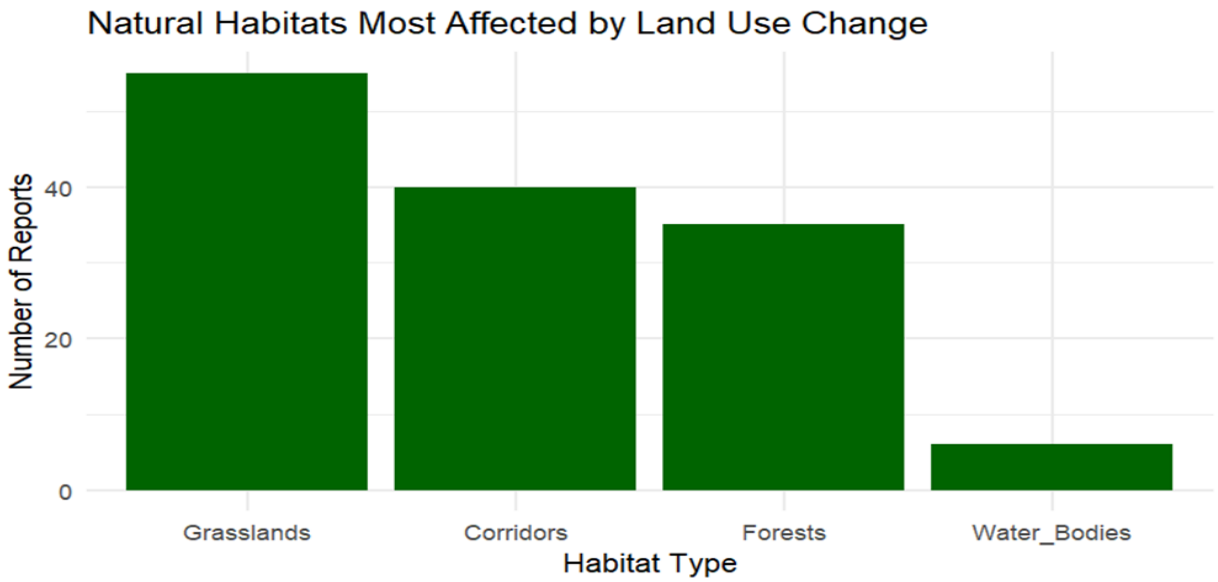


Figure 4.15. Natural Habitat most affected by LUC

4.4.3 Types and Frequency of Human-Wildlife Conflict

The study identified and quantified various types of human-wildlife conflict experienced by the local community. The primary conflict types included crop raiding, livestock predation, property damage, and concerns for human safety. Among these, livestock predation was the most frequently reported conflict, followed by human safety, property damage, and crop raiding (Table 4.5 below).

Table 4.6. Conflict Type

Conflict Type	Crop Raiding	Livestock Predation	Property Damage	Human Safety
Count	5	53	36	49

4.4.4 Species Involved in Conflicts

Elephants, lions, and hyenas were the key species cited in conflicts. Elephants were primarily involved in crop damage and property destruction, while lions and hyenas were associated with livestock predation. Other species like leopards and snakes were also mentioned but less frequently. These patterns were consistent with the secondary HWC dataset obtained from the KWS and WRTI, which also identified elephants and carnivores (particularly lions and hyenas) as the leading conflict species across the 2009–2024 period.

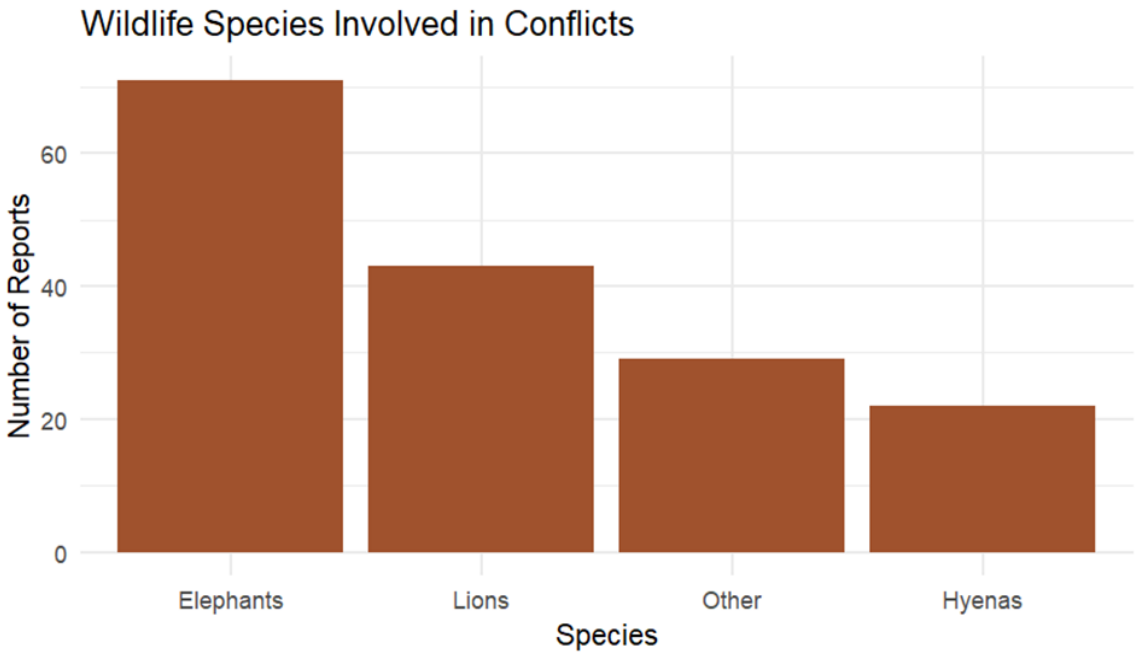


Figure 4.16. Species involved in Conflicts

4.4.5 Community Perceptions and Attitudes

When asked about existing mitigation strategies, most respondents acknowledged their presence, although the perceived effectiveness was mixed. A considerable number of respondents expressed willingness to participate in conservation initiatives, though some doubted whether current land use practices adequately support wildlife conservation.

4.4.6 Relationships Between Socio-demographic and Perceptual Factors and HWC Patterns

Chi-square tests showed a significant association between residence location and conflict frequency ($\chi^2 = 68.089$, df = 48, $p = 0.0297$), indicating that conflict incidence varied across villages. A near-significant relationship was observed between behavior change in wildlife and conflict frequency ($p = 0.0577$). A strong significant association was found between belief that land use supports conservation and willingness to participate in conservation programs ($\chi^2 = 16.3$, $p < 0.001$).

Key informant interviews (KIIs) revealed that HWC in the Mukogodo Ecosystem is intensifying due to a combination of ecological and socio-economic pressures. A total of 12 KIIs were conducted, with two informants drawn from each of the six study locations. The composition

of the informants included local community leaders (primarily village elders), Kenya Wildlife Service (KWS) officers, conservancy workers, and rangers, who were selected based on their knowledge and direct experience with conservation and conflict issues in the landscape.

Respondents highlighted encroachment into wildlife habitats, blocking of migration routes, and poaching as major threats, compounded by climate change, which is making the area hotter and drier while reducing the availability of critical resources such as water, pasture, and woody plants. Wildlife-related threats to people were reported to include crop raiding, destruction of property, livestock predation, and risks of injury or death. The key drivers fueling these conflicts were identified as human population growth, limited socio-economic opportunities, the rising costs of wildlife conservation borne by local communities, and the worsening impacts of climate change. While key informants identified multiple mitigation measures currently in place, including electric fencing, predator-proof bomas, compensation schemes, and community ranger patrols. Systematic evaluation of their effectiveness was limited by the absence of longitudinal outcome data. Informants consistently reported that fencing reduced crop raiding in targeted zones but was undermined by poor maintenance and exclusion of non-fenced settlements. Compensation was described as chronically delayed and insufficient to cover losses, eroding community trust. These perceptions align with the household survey findings (Section 4.4.5), where respondents expressed limited confidence in existing strategies. The effectiveness of land management interventions such as grazing rotations, settlement zoning, or corridor enforcement could not be independently verified due to the lack of enforcement records and baseline spatial data. Consequently, this study relies on perceived effectiveness rather than measured impact, a limitation that informs the recommendation for improved monitoring frameworks (Chapter 5.5).

CHAPTER FIVE

DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents a reflection on the study's key findings, drawing conclusions and offering practical recommendations based on the observed relationship between LULC changes and Human-Wildlife Conflict in the Mukogodo landscape. It also highlights areas for future research and policy action to support sustainable coexistence.

5.2 Discussion

The study sought to map and predict land use and land cover change dynamics in human and wild animal dominated Mukogodo Landscape in Laikipia county, a region where people and wildlife coexist within the same space. According to the results of this study it is evident that LULC in Mukogodo Landscape has changed over the years, influencing both ecological integrity and human livelihoods. This study also evidently shows that local people perceive human wildlife conflict as a problematic issue. Thus, we can say that there exists a human wildlife conflict in the entire Mukogodo landscape and human threat, livestock, predation, crop damage and property destruction were found as some of the consequences due to wildlife and loss of wildlife due to retaliatory killing also exists. These findings affirm that HWC is not only present but constitutes a significant challenge across the Mukogodo landscape. Addressing this challenge is central to ensuring both biodiversity conservation and the sustainable development of rural communities that depend heavily on livestock, agriculture, and natural resources for their livelihoods. All these aspects are discussed in the following topics.

5.2.1 Land Use and Land Cover Changes in Mukogodo Landscape (2009–2024)

The land use and land cover changes have significant environmental and socio-ecological implications for sustainable wildlife land use planning. These changes demonstrate alternating cycles of vegetation recovery and anthropogenic expansion, ultimately reflecting the complex socio-ecological pressures shaping this rangeland ecosystem.

Between 2009 and 2014, forest cover expanded by approximately 61.7 km², largely at the expense of open vegetation, which declined by over 100 km². This trend may be attributed to bush

encroachment, a well-documented phenomenon in savanna ecosystems where suppressed fire regimes, grazing pressures, and climate variability promote woody vegetation growth at the expense of open grasslands (Roques et al., 2001). Alternatively, community-based conservation initiatives in parts of Laikipia may have supported localized reforestation or natural regeneration efforts (Lima Johnnie Loreng, 2023).

The 2014–2019 period recorded further forest expansion (+92.8 km²) and a rebound in open vegetation (+91.3 km²), while human impact areas declined sharply (–60.6 km²). This unusual pattern suggests either the reclamation of abandoned or previously disturbed areas by vegetation or the effect of effective land use regulations during this interval. It also highlights the resilience of rangeland ecosystems, which can recover vegetation cover when human pressure is reduced (Tuffa, 2022).

In contrast, the 2019–2024 period marked a reversal of these gains. Both forest (–27.0 km²) and open vegetation (+7.0 km² net but showing localized declines) contracted, while human impact areas expanded significantly (+48.3 km²). This surge in human impact likely reflects intensified anthropogenic activities, including settlement growth, agricultural expansion, and infrastructure development (Ochuka et al., 2019). These changes reflect broader trends in the rangelands, where increasing population density and livelihood diversification have sped up land conversion and fragmentation (Reid et al., 2004).

The dominance of open vegetation throughout all epochs (averaging 60–65% of land cover) highlights the rangeland character of Mukogodo. However, the expansion of human impact zones threatens to fragment these rangelands and undermine ecological connectivity, especially for wide-ranging species such as elephants and lions. Similar trends have been noted in Amboseli and Tsavo landscapes, where habitat conversion has been strongly correlated with increased human wildlife tensions (Okello et al., 2014; Western et al., 2019). Land use change will not only affect the species in M ukogodo area but species from Samburu and other areas, especially those that have large home ranges as well as influence their migration by blocking migratory corridors. Elephants are known to migrate yearly from Northern Kenya to Mt Kenya national Park through Laikipia county, which is currently in the process of development (Kuria et al., 2024). With this kind of migration and urban development local communities within this area are experiencing

intensified human wildlife conflicts occasioned by blockage of this elephant migratory corridor (Kioko & Seno, 2011). The LULC changes in Mukogodo reflect a dual trajectory: natural vegetation recovery in some periods, but intensifying human-driven land use in recent years. This suggests that without strategic land use planning, anthropogenic pressures will increasingly dominate, with severe implications for biodiversity conservation.

5.2.2 Correlation Between LULC Changes and Human-Wildlife Conflict

Species-level analysis revealed that elephants were overwhelmingly responsible for conflict incidents (75.9%). Their dominance in human threats, property destruction, and crop damage reflects both their ecological needs and their mobility across the fragmented Mukogodo landscape. This trend aligns with findings from broader studies in Kenya and Tanzania, where elephants are the main species involved in human-wildlife conflict because of their extensive movement patterns and dependence on corridors that are progressively obstructed by human activities (Okello et al., 2014). Carnivores such as leopards, hyenas, and lions were important contributors to livestock predation, while primates (baboons and monkeys) were primarily linked to crop and property damage. Hippopotamuses and buffalos also emerged as growing threats in recent years, highlighting the diversification of conflict species as human activity extends into riparian zones and grazing areas.

The upward trajectory of conflict, from 711 incidents (2009–2013) to 1,392 incidents (2019–2024), indicates that HWC is intensifying over time. This continuous increase indicates intensifying interactions between humans and wildlife, driven by both ecological and anthropogenic pressures. On the other hand, increasing wildlife abundance as a result of conservation efforts from KWS and the establishment of several community conservancies within the landscape could also lead to competition between wildlife and humans. Habitat disturbance, lack of natural prey and distribution and abundance of the species are considered as the main reasons for the great loss of livestock in the study area. Similar upward trends have been reported in other rangeland ecosystems of East Africa, where human settlement growth and habitat fragmentation have heightened contact between people and wildlife (Okello et al., 2014; Nyhus, 2016).

The predominance of human threat incidents, which accounted for nearly 60% of all reported cases, emphasizes the seriousness of safety concerns within the community. While the peak occurred during the 2014–2018 period, human threats remained consistently high across all epochs, suggesting persistent tensions. Other forms of conflict, including predation and crop damage, showed notable increases in recent years, reflecting growing competition for land and resources. Another frequent form of human-elephant conflict involved injuries and fatalities among people. Although records show these events were rare, their sensitive nature means even a single occurrence is significant. Deaths and injuries provoke deep and lasting hostility towards elephants and wildlife overall, largely because of human social bonds and support networks. When injury and death generate fear and insecurity, even a small number of cases can undermine the positive relationships and benefits that local communities gain from wildlife conservation (Roy et al., 2025).These results align with findings from Laikipia and Samburu, where expanding settlements and agricultural land use have amplified incidences of livestock predation and crop raiding (Georgiadis et al., 2007; Graham et al., 2010). Land cover changes also influence the animal's movement, e.g., obstruction of routes with the corridor. Most wildlife species are endangered due to loss of habitat, poaching, and human wildlife conflict. The land cover changes trigger the loss of wide ranges of wildlife or elephant habitat and damages of human belongings, e.g., household, trees, and agricultural - fields, even social death.

Spatial analysis further confirmed that conflict incidents are not randomly distributed but clustered in hotspots. The significant Moran's I value (0.617, $p < 0.001$) indicates strong spatial autocorrelation, meaning that certain areas consistently experience higher conflict. Kernel Density Estimation (KDE) revealed that hotspots were concentrated in ecotones, especially around Doldol, Ilpolei and Kiwanja ya Ndege areas, with over 70% of "Very High" conflict zones occurring in open vegetation areas. Importantly, human impact zones recorded the highest conflict density per hectare, reinforcing the conclusion that LULC changes strongly shape conflict patterns. These findings support previous studies that emphasize the role of land conversion and settlement expansion in creating conflict-prone edges between human and wildlife habitats (Long et al., 2020).

The statistical correlations provide further insights into these dynamics. The strong negative correlation between forest cover and HWC ($r = –0.93$) highlights that forest loss

significantly increases conflict. As forests decline, elephants and carnivores are forced into open or human-dominated areas, heightening encounters with people. In contrast, the weak positive correlations of HWC with open vegetation (r = 0.33) and human impact (r = 0.23) suggest that conflict is more likely to occur in transitional landscapes where human activities overlap with wildlife ranges. These patterns underscore the importance of preserving forested habitats and mitigating degradation of open rangelands.

Environmental drivers also emerged as critical. The Generalized Additive Model (GAM) indicated that conflict risk peaks around 15.5 mm of rainfall, confirming that seasonal rainfall thresholds influence wildlife movements. The Cool & Dry season recorded the highest number of incidents (n = 1,095), likely due to resource scarcity that pushes wildlife toward settlements. This seasonal pattern is consistent with studies in Amboseli and Tsavo, which show that elephants and carnivores intensify interactions with humans during dry periods (Nyhus, 2016). The use of Geographically Weighted Regression (GWR) further revealed that rainfall and NDVI effects are spatially heterogeneous, with stronger impacts near settlement–forest edges. This spatial variation demonstrates that conflict dynamics cannot be explained by uniform models but require localized strategies.

5.2.3 Evaluation of Current Land Management and Conflict Mitigation Strategies

The survey results revealed that local communities in the Mukogodo landscape are acutely aware of the land use and land cover (LULC) changes occurring in their environment. Respondents consistently cited deforestation and settlement expansion as the most significant transformations over the past 15 years, with grasslands and wildlife corridors identified as the most affected habitats. These perceptions align with the satellite-based analysis presented earlier in this study, which showed a marked increase in human-impacted areas since 2019. The recognition of wildlife corridors as vulnerable emphasizes community awareness of habitat fragmentation, which has been documented as a major driver of human-wildlife conflict (Western et al., 2015).

When asked about types of conflict, the community identified livestock predation as the most frequently experienced challenge, followed closely by human safety, property damage, and crop raiding. These results correspond with broader patterns observed in pastoral landscapes across Laikipia and Samburu, where carnivores such as lions and hyenas are responsible for substantial

livestock losses (Frank, 2016). KWS records, however, indicated that human threat was the most dominant category of conflict, largely linked to elephants, which were also implicated in crop damage and property destruction (Kioko et al., 2008; Graham et al., 2010). This difference between household reports and official records highlights the importance of integrating multiple data sources for a more complete understanding of conflict dynamics. Elephants were also frequently cited, particularly for crop damage and property destruction, which is consistent with their dominant role in HWC incidents in the region (Kioko et al., 2008; Graham et al., 2010). The overlap between species-specific ecological requirements and expanding human land use highlights the persistent pressure on both pastoralist livelihoods and wildlife populations.

The species-specific findings highlight that elephants, lions, and hyenas are the most problematic wildlife in the region. Elephants were particularly associated with threats, crop damage, and property destruction, while lions and hyenas were mainly responsible for livestock predation. Other species such as leopards, snakes, monkeys, and baboons were also involved but less frequently, often linked to smaller-scale crops and property damage. Notably, the study revealed that some households experience direct stress from wildlife, with elephants occasionally entering homesteads, underscoring the severity of conflict impacts on community well-being.

Community perceptions of mitigation strategies revealed mixed views on their effectiveness. While most respondents acknowledged the presence of interventions such as compensation schemes, predator-proof bomas, and patrols, many questioned their adequacy in addressing the growing scale of conflicts. This reflects a common challenge in HWC management across East Africa, where strategies are often undermined by inconsistent implementation, insufficient funding, or limited community involvement (Dickman, 2010; Barua et al., 2013). Encouragingly, however, a considerable proportion of respondents expressed willingness to participate in conservation initiatives, provided that land use practices are aligned with wildlife conservation. This finding underscores the potential of co-management and incentive-based conservation models, such as eco-tourism, carbon credits, and Payment for Ecosystem Services (PES), which have shown promise in nearby conservancies (Greiner et al., 2013).

The statistical analysis further strengthens these insights. The significant association between residence location and conflict frequency suggests that HWC is unevenly distributed

across villages, with certain settlements being more exposed due to proximity to forest edges, water points, or open vegetation corridors. This supports the spatial clustering of conflict identified in the kernel density analysis and indicates the need for localized, village-specific mitigation strategies. The absence of a significant relationship between age and perception of strategy effectiveness suggests that attitudes toward mitigation are shaped less by generational differences and more by direct experiences with conflict.

Of particular importance is the strong significant association between belief that land use supports conservation and willingness to participate in conservation programs. This implies that communities are more likely to engage in wildlife-friendly land management when they perceive tangible benefits or synergies between conservation and livelihoods. Such findings emphasize the necessity of designing land management interventions that integrate pastoral production, settlement planning, and biodiversity conservation, rather than treating them as competing land uses.

5.2.4 Opinions of Key Informant and Local Leadership and Researcher

Encroachment on wildlife habitats that lead to blocking immigration routes, poaching and competition for critical resources are increasing in the Mukogodo Ecosystem. This is aggravated by the impacts and effects of climate change that is making the area hotter and drier and therefore affecting abundance and availability of critical resources such as water, pasture, woody plant resources and general space by both wildlife and people. Threats that wildlife pose to people included crop raiding, injury and death to people, destruction of property, environmental destruction and degradation, injury and death to livestock, and general insecurity to people.

Key informants identified drivers that fuel human wildlife conflicts, generally ranging from; increasing human population, lack of economic incentives from conservation and increased cost of wildlife conservation to local community, to lack of socio-economic opportunities and impacts of climate change.

5.2.5 Implications for Management and Conservation

The increasing trend of HWC coupled with expanding human impact areas signals urgent need for integrated land use planning and conflict mitigation strategies in Mukogodo. Maintaining

and restoring natural habitats and corridors can help reduce overlap and competition between humans and wildlife while supporting biodiversity conservation. Simultaneously, community-based participatory approaches are vital to incorporate local knowledge, address human safety concerns, and foster coexistence.

5.3 Summary of Main Findings

The study established that changes in LULC within the Mukogodo landscape have had a profound impact on the patterns and prevalence of hum HWC between 2009 and 2024. The findings indicate a marked decline in forest cover and grasslands, accompanied by a steady expansion of settlements. These shifts have contributed to habitat degradation, fragmentation, and heightened competition over scarce resources such as water and pasture.

Spatial analysis revealed that incidents of HWC were predominantly concentrated around settlement clusters, cultivated areas, and regions bordering degraded ecosystems. Kernel density estimations further identified emerging conflict hotspots in zones undergoing rapid land transformation. Climate variability, especially recurrent droughts, was found to intensify these tensions, forcing both wildlife and local communities to compete for dwindling natural resources.

Insights from key informant interviews highlighted the role of human encroachment, poaching, and obstruction of migratory corridors in escalating conflict dynamics. Moreover, the absence of coherent land use planning frameworks has hindered the development of sustainable strategies for peaceful coexistence between humans and wildlife in the region.

5.4 Conclusion

This study set out to assess the relationship between LULC changes and HWC in the Mukogodo landscape, Laikipia County. First, the analysis revealed that LULC has undergone significant shifts between 2009 and 2024, with alternating periods of vegetation recovery and anthropogenic expansion. Forest cover expanded in earlier years, partly due to natural regeneration and conservation efforts, but has declined in recent years as human impact areas increased by nearly 50 km². Open vegetation remained dominant across all periods, reflecting the rangeland character of the landscape, but was increasingly fragmented by settlement expansion, agricultural

activities, and infrastructure development. These findings confirm that anthropogenic land conversion is the primary driver of habitat change in Mukogodo.

Second, the study established a strong correlation between LULC changes and the frequency and intensity of HWC incidents. A total of 3,112 incidents were recorded between 2009 and 2024, with conflict frequency rising consistently over time. Elephants, lions, and hyenas were identified as the main conflict species, responsible for crop raiding, livestock predation, and property destruction. Statistical results confirmed that forest loss was strongly associated with higher conflict rates, while settlement growth and agricultural expansion significantly increased human–wildlife interactions. Spatial analysis showed that conflict hotspots were concentrated near ecotones, settlement–forest edges, and open vegetation areas, emphasizing that habitat fragmentation and resource competition are central to escalating conflicts.

Finally, the study evaluated the effectiveness of current land management and conflict mitigation strategies. While existing measures such as fencing, predator-proof enclosures, and water provisioning have reduced conflict in some areas, their overall effectiveness remains limited, particularly in regions with high settlement density and poorly managed wildlife corridors. Communities expressed willingness to participate in conservation, suggesting strong potential for participatory approaches. However, sustained conflict reduction will require scaling up targeted strategies such as strengthening wildlife corridors, regulating settlement expansion, improving compensation mechanisms, and enhancing community engagement in conservation decision-making. Overall, the findings highlight that unless sustainable land management practices are implemented, intensifying anthropogenic pressures will continue to exacerbate human–wildlife conflict in the Mukogodo landscape.

5.5 Recommendations

Being a dispersal area, the Mukogodo landscape requires scientifically informed land use planning and the careful selection of suitable land use options to balance human needs with conservation goals. Such planning should adopt an ecosystem-based approach aimed at establishing a “Zone of Interaction’’ that simultaneously caters to local community livelihoods and the ecological needs of wildlife. This will help counteract potential land resource degradation while mitigating human–wildlife conflicts. Protecting and monitoring migratory corridors,

particularly those used by elephants, and safeguarding critical catchments of rivers and streams will be vital in maintaining ecological integrity while accommodating a growing human population. To this end, conflict mitigation infrastructure such as electric and predator-proof fencing should be expanded in strategic hotspots, with an emphasis on community ownership and regular maintenance.

At the same time, habitat restoration efforts should focus on rehabilitating degraded grasslands and forests while enhancing landscape connectivity through the opening and securing of wildlife corridors. Strengthening community engagement is equally important, given the demonstrated willingness of residents to participate in conservation; this requires awareness creation, co-management arrangements, and the development of conflict-reporting systems that empower local custodians of the land.

Livelihood diversification should be promoted to reduce household dependence on crops and livestock that are vulnerable to conflict, while policy and institutional frameworks for compensation, monitoring, and rapid response need to be reinforced in line with national conservation policies.

Finally, building community knowledge on the links between land use dynamics and wildlife conflict will facilitate participatory planning, while longitudinal research and monitoring that combine community surveys with remote sensing will be essential to evaluate the effectiveness of interventions and to project future human–wildlife conflict scenarios in the face of ongoing land use change.

5.6 Areas of Further Research

While this study has provided valuable insights into the correlation between LULC changes and HWC in the Mukogodo landscape, several avenues remain open for further exploration. Future research should investigate the long-term ecological consequences of habitat fragmentation on wildlife migration patterns, particularly for wide-ranging species such as elephants and lions. Integrating telemetry data from GPS-collared animals could offer deeper understanding of movement disruptions caused by land conversion and blocked corridors. Additionally, assessing the socio-economic resilience of communities affected by HWC, especially in relation to

compensation schemes, livelihood diversification, and conservation incentives like Payment for Ecosystem Services (PES) could inform scalable coexistence strategies. Predictive modeling using machine learning and climate projections may also help anticipate future conflict hotspots under varying land use and climate scenarios.

Moreover, there is a need to examine the policy and governance landscape, including how wildlife conservation laws, land tenure systems, and land subdivision practices influence both LULC dynamics and HWC outcomes. Evaluating the cumulative impacts of HWC alongside other stressors such as climate change, invasive species, and human population growth would provide a more holistic view of ecosystem pressures. Further research should also assess the long-term ecological and social effectiveness of mitigation structures like predator-proof bomas, electric fencing, and wildlife corridors. Lastly, understanding community perceptions and tolerance levels toward wildlife over time is crucial, as these attitudes significantly shape the success of conservation interventions and conflict resolution efforts.

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APPENDICES

Appendix 1 – Questionnaires
Questionnaire for Assessing Land Use and Human-Wildlife Conflict

Community Members Questionnaire

Section 1: Demographic Information

Name (optional): _____

Age: [ ] 18-25 [ ] 26-35 [ ] 36-45 [ ] 46-55 [ ] Above 55

Gender: [ ] Male [ ] Female

Occupation: _____

Residence location: _____

How long have you been living in this area?

- ☐ Less than 1 year
- ☐ 1-5 years
- ☐ 6-10 years
- ☐ More than 10 years

Section 2: Land Use and Land Cover Changes

6. How has the land use in your area changed in the last 15 years?
    - ☐ Increased agriculture
    - ☐ Deforestation
    - ☐ Increased settlements
    - ☐ Other (please specify): _____
7. What types of natural habitats have been most affected by these changes?

- ☐ Forests
- ☐ Grasslands

- ☐ Water bodies
- ☐ Wildlife corridors

8. Have you noticed changes in wildlife movement or behavior due to these changes?

- ☐ Yes (specify): _____
- ☐ No

Section 3: Human-Wildlife Conflict

9. What types of human-wildlife conflicts have you experienced? (Select all that apply)
    - ☐ Crop raiding
    - ☐ Livestock predation
    - ☐ Property damage
    - ☐ Threats to human safety
10. How frequently do these conflicts occur?

- ☐ Daily
- ☐ Weekly
- ☐ Monthly
- ☐ Rarely

11. What wildlife species are involved in these conflicts?

- ☐ Elephants
- ☐ Lions
- ☐ Hyenas
- ☐ Other (specify): _____

Section 4: Mitigation Strategies

12. Are there current strategies in place to reduce human-wildlife conflict in your area?

- ☐ Yes (specify): _____
- ☐ No

13. How effective do you think these strategies are?

- ☐ Very effective
- ☐ Somewhat effective
- ☐ Not effective

14. What additional measures do you recommend to address these conflicts?

Section 5: Perception and Attitudes

15. Do you believe land-use practices in the area support wildlife conservation?

- ☐ Yes
- ☐ No

16. How willing are you to participate in conservation programs?

- ☐ Very willing
- ☐ Somewhat willing
- ☐ Not willing

Appendix 2 – Key Informant Interview

Section 1: Background Information

1. Name (optional): _____
2. Position/Title: _____
3. Organization/Institution: _____
4. How long have you been working in this area/region? _____

Section 2: Land Use and Land Cover Changes

5. In your professional view, what have been the key drivers of land-use changes in this area over the last decade?

---

6. What types of natural habitats have been most impacted by these changes?
    - Forests
    - Grasslands
    - Water bodies
    - Wildlife corridors
    - Other (specify): _____
7. What do you consider to be the primary consequences of land-use changes on wildlife populations and ecosystems in this region?

Section 3: Human-Wildlife Conflict

8. What are the most significant human-wildlife conflicts in this area, and what are their underlying causes?

---

9. How have wildlife movement patterns or behaviors changed due to these conflicts?

---

10. Which wildlife species are most commonly involved in conflicts?
    - Elephants
    - Lions
    - Hyenas
    - Other (specify): _____

11. What socio-economic impacts have human-wildlife conflicts had on local communities?

Section 4: Policy and Mitigation Strategies

12. What policies are currently in place to address human-wildlife conflict, and how effective have they been?

---

13. What challenges or gaps exist in implementing these policies?

---

14. What partnerships or collaborations exist to mitigate human-wildlife conflicts and manage land use in this area?

---

15. Are there any community-based initiatives aimed at reducing conflicts or promoting coexistence? If so, please describe them.

Section 5: Recommendations and Future Perspectives

16. In your opinion, what additional measures or strategies are needed to effectively address human-wildlife conflicts and improve land-use management?

---

17. What role do you see for local communities, conservation organizations, and government institutions in these efforts?

---

18. Do you think current land-use practices in this area support sustainable wildlife conservation? Why or why not?

Appendix 3 – ANU Letter Authorizing the Research

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16th April 2025

TO WHOM IT MAY CONCERN

RE: RESEARCH PERMIT: PERES LARE

Peres Lare Reg. No. (110062775) is a Bonafide postgraduate student at Africa Nazarene University pursuing a master's degree in Environment and Natural Resource Management. This program entails Coursework and Thesis. She has successfully completed her coursework and defended her thesis proposal entitled:

"Evaluating the impact of Land Use/Landcover change on Human-Wildlife Conflict in Mukogodo Landscape, Laikipia County, Kenya."

Any assistance accorded to her to facilitate data collection and complete her thesis will be highly appreciated.

Sincerely.

Prof. Orpha K. Ongiti
Dean, Postgraduate Studies & Director, Institute of Research

Appendix 4 – NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **349728**

Date of Issue: **28/April/2025**

RESEARCH LICENSE



This is to Certify that Ms.. PERES AKINYI LARE of Africa Nazarene University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Laikipia on the topic: Evaluating of the Impact of Land Use/Land Cover Change on Human-Wildlife Conflict in Mukogodo Landscape, Laikipia County, Kenya for the period ending : 28/April/2026.

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Appendix 5 – Map of Study Area

