ASSESSING THE EFFECTS OF SPATIAL TEMPORAL LAND USE ON VEGETATION HEALTH IN KARAMOJA RANGELAND, NORTHEASTERN UGANDA

BY

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21/U/GMAG/14061/PE

A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF MASTER OF ARTS IN GEOGRAPHY OF KYAMBOGO UNIVERSITY

OCTOBER, 2024

DECLARATION

I **AWOR JENNIFER OWILLI** declare that this dissertation report titled ***ASSESSING THE EFFECTS OF LAND USE ON VEGETATION HEALTH IN KARAMOJA RANGELAND, NORTHEASTERN UGANDA***" has never been submitted or presented to any university or institution of higher learning for any award.

Signature………………………………

Date…………………………………

APPROVAL

We the undersigned certify that this research entitled Assessment of the "***ASSESSING THE EFFECTS OF LAND USE ON VEGETATION HEALTH IN KARAMOJA RANGELAND, NORTHEASTERN UGANDA"*** *has* been conducted and compiled under our guidance and supervision, and is now ready for submission to the Directorate of Research and Graduate Training with our approval.

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DEDICATION

This work is dedicated to my son Victor Marklyn Obin and daughter Prossy Vella Acheng for the moral support and love that acted as the hypnotherapy during the crisis amidst this journey.

ACKNOWLEDGEMENT

I am grateful to my supervisors, Turyabanawe G. Loy (PhD) and Turyahabwe Remigio (PhD), for the academic guidance and mentorship they have wholeheartedly rendered to me while doing this work. Special thanks to the Department of Geography and Social Studies for the support, guidance, and advice.

My sincere thanks to Gertrude Akello, Paul Gudoyi Makoba, and Calvin Esagu Osege for their guidance and encouragement during this study, and to Mumpe K, Godfrey, and colleagues in the Master's cohort of 2021/2022 for their good coordination and academic support.

Special thanks to all the Resident District Commissioners (RDCs) and Chairpersons of Local Council V of the seven selected districts of Karamoja for the classified information. Chief Administrative Officers (CAOs) are responsible for permitting access to the technical staff and the technical staff for the rich and informative data. The field research assistants Samuel Abura (Napak), Lotipua Alex (Kaabong), Adeun Emmanuel (Napak), Akol John Bosco (Moroto) and all teams in the seven districts for without you, this study would not have been possible.

The household heads and the people of Karamoja unreservedly gave information that this study depended on for its completion, as did everyone who took part in the study in any way.

I extend my hearty appreciation to my blood family and the larger family of friends for the complete support they have rendered me during this academic journey.

Above all, I thank God for life, provision, knowledge and sustenance upon me that made this humanly almost impossible journey to become a reality.

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LIST OF ACRONYMS

EFA	Education for all
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographical Information System
IUCN	International Union for Conservation of Nature
LULC	Land Use Land Cover
RLULC	Rangeland Use Land Cover
MSAVI	Modified Soil Adjusted Vegetation Index
NDVI	Normalized Difference Vegetation Index
NEMA	National Environmet Management Authority
SAVI	Soil Adjusted Vegetation Indices
STATA	Statistics and Data
UBOS	Uganda Bureau of Statistics
UPE	Universal Primary Education
USAID	United States Aid for International Development
USGS	United States Geological Survey
UWA	Uganda Wildlife Authority

ABSTRACT

Rangelands globally are naturally managed ecological units grazed in their natural or semi-natural form. In Uganda, Pastoralism is the main livelihood activity in the Karamoja rangeland, albeit with unknown spatial quantities of cover changes and declined productivity due to environmental and anthropogenic factors. This study, therefore, aimed at (i) examining the spatiotemporal extent, trend and transitions of changes in rangeland use between 2002 and 2022, (ii) assessing the spatiotemporal variations in rangelands productivity of standing biomass between 2002 and 2022, and (iii) examining the dominant factors underlying rangeland degradation in Karamoja region. A cross-sectional and longitudinal design and mixed methods approach was adopted in this study to assess the spatiotemporal rangeland use changes and productivity in the Karamoja region, Northeastern Uganda. To examine the rangeland, use change, the study used satellite data from the USGS Earth Explorer for 2002, 2012, and 2022 series. Variation in rangeland productivity was computed using image analysis in ArcGis 10.8 and SAVI tools. In addition, 264 household interviews were conducted and analysis was conducted using a chi-square test to derive the drivers of rangeland productivity. Also, content analysis was employed to extract meaningful narratives from the 20 key informants. Results revealed that woodland, bushland, and bare ground declined in spatial extent by 38%, 9%, and 2%, respectively, by 2022. Meanwhile, grassland, cropland, and built-up increased by 20%, 12% and 2%, respectively by 2022. Maximum SAVI results of 0.660954, 0.567067, and and0.501258 in 2002, 2012 and 2022, respectively and minimum values of -0.299879 and 0.064051, and and0.0607339 in 2002, 2012, and 2022, respectively, revealed that vegetation health had been degenerating over the study years. Annual mean SAVI values of 0.15, 0.26, and 0.22 in 2002, 2012 and 2022, respectively, revealed that 2012 stood out with higher productivity compared to 2022 and 2002. The crop zone had robust vegetation compared to depleted zones of pastoral and agro-pastoralist over the study time. The perceived drivers of rangeland productivity also varied significantly across the zones with x^2 *(264) =8, P=0.05.* From this study, it is clear, therefore, that Karamoja rangelands have undergone a lot of cover and use changes between 2002 and 2022, mainly as a result of human activities. The government should develop and enforce rangeland conservation policies and invest in community-based education to raise awareness of the dangers of rangeland use/cover changes on the productivity of vegetation. The community should implement rangeland sustainable practices to enhance conservation and restoration of the ecosystems, especially in the agro-pastoral ecological zones that grapple with severe vegetation depletion.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Rangelands globally are naturally managed ecological units that are largely grazed in their natural and semi-natural form (Zerga, 2015). They are ecosystems characterized by native grasses, grass-like plants, bushes of varying degrees, alpine communities, steppes, few trees, semi-desert and desert climate (WOCAT, 2019). In Africa, rangelands are mainly covered by semi-arid and arid lands (Lulekal et al., 2018). Rangelands provide numerous ecosystem services, including supporting services like (soil formation, nutrients cycling, and photosynthesis); provisioning services like (food, fuel wood, fibre, water, and curative plants); regulating services such as (climate stabilization, water and air purification, and erosion control) and non-material like (recreational services, cognitive development, spiritual fulfilment) among many (Claessens et al., 2008; Lulekal et al., 2018; WOCAT, 2019)Rangeland ecosystems are important to the human race as they provide habitats for various species of animals and plants that are economically beneficial to different communities.

Rangelands cover approximately 25% of the world's total land surface (Bolo et al., 2019; Liebig et al., 2006; Zerga, 2015). In Africa, the coverage is estimated at 66% of the total land surface and for East Africa, rangeland coverage varied from country to country, for example, 65% in Ethiopia, 74% in Tanzania, about 80% in Kenya, and 44% in Uganda (Bolo et al., 2019). The Karamoja region hosts about 33 per cent of Uganda's rangelands (Press, 2016).

The global spatial variations in rangelands are accounted for by ununiformed climatic conditions, especially relating to severity and length of drought, onset, distribution and cessation of rainfall coupled with temperature variations (Bolo et al., 2019; Senda et al, 2020). This is confirmed by (Al-Bukhari et al., 2018), who reported that about two-thirds of the global rangelands are already degraded as a result of man's interaction with the natural environment. This, therefore, means that if no corrective or preventive measures are taken to arrest the situation, the low productivity of the already degraded ecosystem will be objectified.

Rangeland use causes either a gradual or rapid conversion from one form of cover to another due to man's activities carried out on a particular piece of land in a given time (Fenetahun & Yong-dong, 2020). Man's use of the rangelands is believed to be as old as man although the magnitude and effects are much felt currently than in the past (Hassan et al., 2016). The constantly multileveled changing rangeland use is attributed to the ever-increasing global human population. This has affected environmental conditions with cumulative and specific negative effects on ecosystem functionalities(Kumar, 2019; Teshome et al., 2022). Therefore, the nature of rangeland use directly affects the quality of the ecosystem, which can be manifested by the rate of its productivity of both crops and vegetation cover (Alem, 2022; Bekele, 2019; Maitima et al., 2009).

Rangeland productivity is the ability and or potential of the ecosystem to yield both crops and standing biomass depending on its biological, physical, and chemical status within an ecosystem (Kuule et al., 2022; Senda et al, 2020; Yang et al., 2020). The productivity of the rangelands, unfortunately, has been worryingly, progressively declining in the past three decades, for example; in 1990, the world's productivity loss of major food crops was at US$43 billion, which later rose to about US4450 billion in 2013 (Nkonya et al., 2016). Meanwhile, in sub-Saharan Africa, the decline was up to about 50% (Mirzabaev, 2016), and about 25% loss of livestock in countries that practice crop-livestock systems (Senda et al, 2020). Given the above pattern, it's predicted that in sub-Saharan Africa, the situation will likely become almost irreversible and or five times more expensive to correct in the next three decades than now (Mirzabaev, 2016). Rangeland productivity is not uniform across the globe in terms of coverage and time (Senda et al, 2020), this is because of the unique conditions experienced in various rangelands (which include location, climatic variations, population factors, and practices). This has resulted in huge inconsistencies in forage supply due to increasing rangeland use types. This has presented a major setback in both livestock and food crops productivity (Godde et al., 2020).

Drivers of rangeland degradation are, therefore, a complex subject since a number of factors are in most cases interwoven as one may lead to another, thus triggering a chain of reactions (Gupta, 2019; Megerssa & Bekere, 2019). Rangeland, degradation refers to a state of prolonged loss of ecosystems services (Nkonya et al., 2016). Rangeland degradation is the sustained decrease in the economic and biological output of land (Chude & Odunze, 2016). An interplay of both natural and anthropogenic factors (like overgrazing, climate change, bush encroachment, population pressure, a decline in traditional resource management, conversion to other land uses, and unsupportive government policies) are responsible for rangeland degradation (Dika et al., 2022; Kedu, 2021; Liu et al., 2021). The productivity levels depend on the drivers and the local factors (like geographical location and socioeconomic context) of the individual regions across the earth (Mohammed Mussa, 2016).

In Uganda, rangeland use and cover are greatly affected by unsustainable usage of the environment (NEMA, 2019). This is due to both physical and human-induced factors such as climate variability, poor methods of cultivation, over-harvesting of rangeland resources, insufficient land conservation policies coupled with limited information probably because of the very thin or weak extension services (Karamage et al., 2017; NEMA, 2019).

The rangeland resource of Karamoja has, for the last 3 to 4 decades, been faced with a lot of dynamics in land use cover changes, including expansion of arable farms at the expense of pasture land, and more semi and permanent structures. As these kept on changing, the resources progressively showed signs of decrease in the ecosystem, such as loss of vegetation, low quantities and quality of pasture, very poor harvests of food crops and low animal yields, implying ecosystem failure. These, therefore, called for interventions to arrest the situation early enough. Therefore, the current study aimed at establishing the effects of rangeland use/cover changes on productivity trends and its underlying factors in the Karamoja region (Egeru, Okia, et al., 2014; Nalule, 2010; NEMA, 2019).

1.2 Statement of the problem

Rangeland use and productivity remain the main determinants of livelihoods in Karamoja, northeastern Uganda (ACTED-Uganda, 2016; Aleper et al., 2017). However, in the last three decades, the region has witnessed environmental degradation and a decline in productivity manifested by reduced vegetation cover and health and low crop yields in the area, which are attributed to factors such as resettlements, agricultural expansion, charcoal burning, overgrazing, and climate variability (Aleper et al., 2017). The livelihoods of these local communities, which are greatly dependent on natural resources, are gradually under threat due to environmental degradation and declining productivity in the region. However, the rate and magnitude of this degradation remain largely unknown, potentially exacerbating pre-existing vulnerabilities such as water and pasture shortages, livestock-related conflicts, food insecurity, malnutrition, and associated mortality. Despite the government's interventions through sedentarization and agro-pastoralism programs, the situation has persisted. Previous studies have concentrated on climate change and policy impacts on pastoralists (Lulekal et al., 2018; Byakagaba et al., 2018) and Trees and Livelihood in Karamoja (Egeru, Okia., 2014). Even the most recent study (Samuels et al., 2023), which stressed the perceptions and opportunities that are highly tagged to the rangeland cover in the area, also missed out on rangeland use and its effects on rangeland health. Therefore, this study aimed to investigate and document the effect of spatio-temporal rangeland use and productivity and the associated dominant drivers underlying productivity in the region. This may inform decisions to develop and enforce rangeland conservation policies that will enhance the ability of rangelands to sustain livelihoods.

1.3 Objectives of the study

1.3.1 General Objective

To examine the spatio-temporal changes in land use, its effects on productivity and the dominant drivers underlying the degradation of Karamoja rangeland, Northeastern Uganda, for better and effective management.

1.3.2 Specific objectives

1. To examine the extent, trend and transitions of spatiotemporal changes in rangeland use between 2002 and 2022 in Karamoja
2. To assess the spatiotemporal variations in rangeland productivity between 2002 and 2022 in Karamoja
3. To examine the most dominant drivers of rangeland degradation in Karamoja

1.3.3 Research Questions

1) What are the extent, trend and transitions of spatiotemporal changes in rangeland use between 2002 and 2022 in Karamoja?
2) What are the spatiotemporal variations in rangeland productivity between 2002 and 2022 in Karamoja?
3) What are the most dominant drivers of rangeland degradation in Karamoja?

1.4 Significance of the Study

The trend of rangeland use/cover change results may guide the government to inform her policy decisions, sustainable development objectives, improving and redesigning livelihoods of the pastoral communities through programs like Parish Development Models may benefit from this study results and any future programs, climate change resilience is enhanced, check and reduce disaster risks and submission to international obligations.

This study's findings may be used by development partners to make targeted interventions, build the capacity of the local community, a basis for policy advocacy, and fund programs aimed at further investigations and monitoring and evaluating the status of the ecosystem.

Pastoral communities may use the study findings to directly improve their livelihoods, ensure food security, put in efforts to conserve biodiversity, resolve resource-related conflicts, Livestock production infrastructure developments and their cultural identity. This enhances the communities’ stewardship and rangeland management capacities of the resources for the good of the present and future generations.

Future researchers elsewhere undertaking similar related studies get guided by this study as it demonstrated the potential of geospatial techniques in undertaking landscape assessments

1.5 Scope of the Study

The study was carried out in seven selected districts of the Karamoja region, northeastern Uganda: Kaabong, Kotido, Abim, Moroto, Napak, Nakapiripirit, and Amudat.

Assessment was restricted to land cover areal changes and general vegetation health. Variation in rangeland productivity assessment was restricted only to standing biomass (above ground) and significant drivers underlying productivity in the Karamoja region, where field profiling of socio-economic data was done.

Field data collection was conducted in October and November 2023, when the rain cessation and onset of the dry season in the Karamoja region occurred. This provided an opportunity to observe the transition in vegetation health between the two seasons. Spatial data sets were sourced for the years 2002, 2012, and 2022.

The study established the rangeland use/cover change implications for human livelihood, that is, the severity of vegetation destruction and/or alteration and its impacts on agro-pastoral livelihoods.

1.6 Justification of the study

Rangelands signify a large portion of the earth's surface and are home to millions of people, plants and animals. They are important for the numerous ecosystem services. The ecosystem is under immense threats from both physical and human factors, given the millions of lives that derive their livelihoods from the ecosystem coupled with its vulnerable state due to climate variability and extreme weather conditions pointing towards the ruin of the ecosystem. This study's findings may provide region-specific, full-bodied data on rangeland use/cover changes and the resultant variations in productivity, as well as expose the dominant underlying drivers of the changes. This may form a basis for informed policies, management and therapeutic resolutions that incorporate the local knowledge and perceptions for feasible and culturally appropriate decisions. Lastly, it may provide insights into mitigation strategies on the hostile impacts of unsustainable rangeland use/cover.

1.7 Conceptual Framework

From the conceptual framework in Figure 1.1 below, it is postulated that rangeland components in terms of vegetation cover will change either positively, implying a healthy rangeland ecosystem or negatively, implying a degraded rangeland and, therefore, low productivity. A degraded/healthy rangeland ecosystem is affected by both physical and anthropogenic variables. Rangeland vegetation can be used to assess overall rangeland productivity.

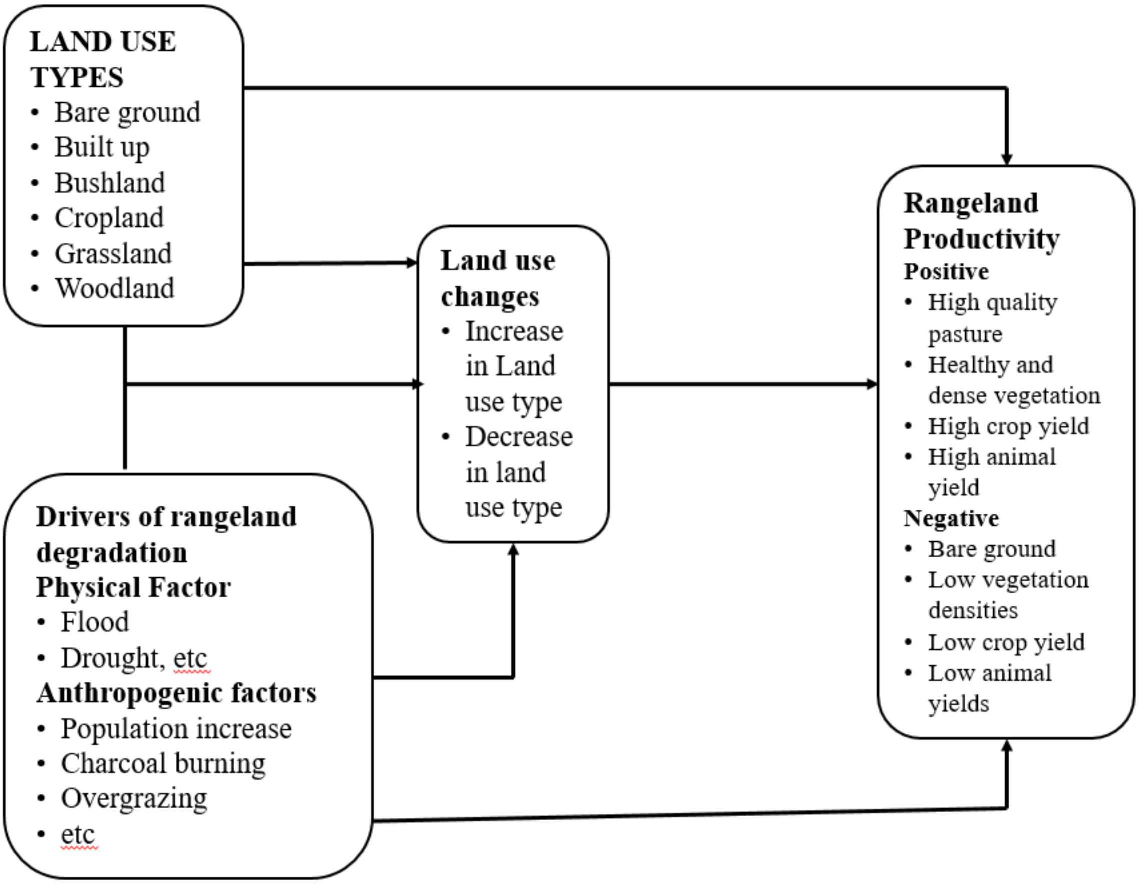

Figure 1. 1: Conceptual framework. Source: (Author)

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews related literature on rangeland use changes, their effects on land productivity, and the factors underlying rangeland productivity. The documents reviewed include journal articles, textbooks, bulletins, expert opinions, and others sourced electronically from online libraries.

2.2 The spatio-temporal changes in rangeland use.

Land use is described as man's activities on land to acquire resources that satisfy his/her economic and cultural needs, for example, agriculture, settlement, recreation, wildlife management, and urbanisation of woodland, bare ground, bushland and grassland (Horning, 2004; Kumar, 2019). Land use change is described as a gradual or rapid conversion from one form of activity to another in a given time, which in most cases poses a major challenge in sustainably managing the rangelands (Fenetahun & Yong-dong, 2020).

Land use changes on rangeland that resulted from man's interaction with the natural environment to get basic needs and livelihood is as old as man, although the magnitude and effects are much felt currently than in the past (Hassan et al., 2016). The negative effects of rangeland use hinder the normal functioning of an ecosystem (Hassan et al., 2016; Teshome et al., 2022). Therefore, the nature of land use changes directly affected the ecosystem's productivity rate. Unsustainable rangeland use translated into low yields of crops and vegetation cover in any given landscape, rangelands inclusive (Alem, 2022; Bekele, 2019; Maitima et al., 2009).

The constantly multileveled land use changes on the rangeland have affected humans and environmental conditions with both cumulative and specific effects on ecosystem function (Teshome et al., 2022). Out of the various rangeland use changes, development and agricultural functions presented numerous potential effects (Kumar, 2019). Borrelli et al. (2017) asserted that the ever-increasing population in the world was responsible for the land use changes on the face of the earth. For example, agriculture, grazing, mining, and settlement among many not forgetting the unsustainable use of the environment like commercial charcoal burning has led to degraded vegetation and loss of habitat (Borrelli et al., 2017b; Girmay, Wondwossen et al., 2017; Teshome et al., 2022). Land quality, as well as its productivity, are compromised, thereby resulting in a shortage of food, forage, energy, and water (Wondwossen. Tibetan Plateau and Pu County) in China have experienced negative effects of land use changes that have seen a decline in crop and animal production, indicating degraded land (Duan et al., 2022; Huang et al., 2023). Developing economies like Southeast Asia, South America, and Sub-Saharan Africa are predicted to experience the lowest levels of productivity due to severe soil erosion because of the great expansion in the cropland (Borrelli et al., 2017b).

In sub-Saharan Africa, meaningful biodiversity preservation has almost become impossible in the face of emerging competing land use changes in the dry lands (Karaya et al., 2021). This has seen policymakers and other stakeholders stuck in coming out with comprehensive solutions to the challenge (Borrelli et al., 2017a; Karaya et al., 2021). By 2020, 92.77% of grasslands were converted to farmlands and 15.7% into built-up areas. As farmlands and built-up areas expand at annual rates of 9.32% and 6.22%, respectively, grassland and woodland reduce at 5.52% and 2.47%, respectively, with subsistence farming being the dominant land use type at 53.16% (Bunyangha et al., 2021; Karaya et al., 2021). This pattern of changes from other forms of land use to subsistence farming remained unsafe, thus a decline in amounts of standing biomass in the ecosystem (Mathewos et al., 2022). As the people struggle to survive, coupled with compliance to sedentarization policy by cattle keepers in Uganda, rangeland cover changes became inevitable (Al, 2020; Kironchi et al., 2018). Studies conducted by Mwanjalolo (2014) agrees that grassland has been noticeably reduced by conversion into other forms of land cover, like cropland, which increased by tenfolds between the years 2000 and 2013; 59.3% of grassland was converted to bushlands, and 35.8% of cropland was converted to thickets and shrubs, but grassland remained the most dominant form of land cover.

Biodiversity within the tropical catchments got degraded and, in extreme cases was lost as a result of land use changes, for example, the forest cover, fertile soil, and water itself endangering the lives that depended on them (Akello et al., 2016). Land use changes can singly be responsible for water insecurity and quality issues because of mineral loading and high sediment yields due to soil erosion, though the effects may be adverse if they acted together with climate change (Akello et al., 2016; Gabiri et al., 2020).

In a bid to increase land productivity and restore degraded land resulting from land use changes, trees can be planted because of the roles they perform in soils, for example, breaking the speed of wind storms, effects of raindrops and generally improving the quality of the soil (Egeru, Okia, et al., 2014). Natural restoration of the ecosystem is preferred to artificial planting of trees because the natural ones are better at maintaining stability and controlling soil and water loss, among others (Egeru, Okia, et al., 2014; Hai et al., 2007).

Studies conducted on land use changes and their effects on the environment in northern Uganda account for only 03% of the total studies done in the country; it is very clear that very few studies have been conducted in Karamoja to ascertain how the changes influence rangeland productivity (Alem, 2022; Egeru, Wasonga, et al., 2014; Luwa et al., 2021). There is little literature on the effects of rangeland use changes on its productivity in the national database (Ebanyat et al., 2010; Karamage et al., 2017; Karaya et al., 2021). This study is, therefore, necessary to provide information that aids in targeting environmentally friendly interventions to minimize undesirable impacts.

Remotely sensed data, the use of GIS tools, ground-based observation, and local knowledge are essential in analysing LULC, landscape composition and ecological processes (Hesselbarth et al., 2019; Otunga et al., 2014). Several studies on rangeland monitoring have found rapid conversion of ecological regions to other land use types like agricultural and built-up areas, among many pressing demands (Otunga et al., 2018). However, where changes are rapid and unrecorded, earth observations from space provide objective information on human landscape use (Ruelland et al. 2010). Remote sensing further plays a pivotal role in guiding grazing management by providing information in support of analysis, modelling, and forecasting for decision support (Hesselbarth et al., 2019).

2.3 Spatio-temporal variation in rangeland productivity

Rangeland productivity is the soil's ability and or potential to produce crops and standing biomass depending on its biological, physical, and chemical status within an ecosystem (Kuule et al., 2022; Senda et al., 2020; Yang et al., 2020). For purposes of this study, productivity is the ability of an area to sustain plant life in a given period. This ability, therefore, underscores the rangeland's health and sustainability. Productivity refers to energy output, biomass and monetary values per unit area (Muller et al, 2012). The productivity trend of the rangelands unfortunately, has been worryingly, progressively declining in the past three decades, for example; in 1990, the world's productivity loss of major food crops like maize, rice, and wheat was to US$43 billion which later rose to about US4450 billion in 2013 (Nkonya et al., 2016). Meanwhile, in sub-Saharan Africa, the decline was up to about 50% (Mirzabaev, 2016), and about 25% loss of livestock in countries that practice crop-livestock systems (Senda et al, 2020). Given the above trend, it's predicted that in Sub-Saharan Africa, the situation may become almost irreversible and or five times more expensive to correct in the next three decades than now (Mirzabaev, 2016). Rangeland productivity is not uniform across the globe in terms of coverage and time (Senda et al., 2020); this is because of the unique conditions experienced in various rangelands (which include location, climatic variations, population factors, and practices). This has resulted in huge inconsistencies in forage supply due to increasing rangeland use/cover change accelerated productivity levels (Godde et al., 2020).

Globally, about 73% of the total rangelands are facing a significant decline in their standing biomass because of climate change and variability, thus a decline in livestock productivity which endangers the livelihood of millions of people who depend on the ecosystem services (Godde et al., 2020). Europe like the rest of the globe experiences a land productivity decline as indicated; 1.5% decline, 5.6% with early warning signs, 7.9% stressed, and 85.1% unaffected across all member states of the European Union due to the growing population pressure on land (Cherlet et al., 2013). Relatively low productivity of corn and pasture is experienced in California central Valley of the United States of America (ie about 10%-20% of the expected yields) faced with water deficit-related productivity because of low precipitation and high evapotranspiration (Yang et al., 2020).

In Africa, rangeland productivity status is determined by human factors that majorly degrade the protective cover types and compromise the quality of the soils, hence lowering the productivity of the ecosystem (Bernard et al., 2022). In the high plateau of Morocco rangeland, productivity has remained low even with the availability of native plants and animals due to overstocking hence poor quality vegetation (Mahyou et al., 2016). In Libya, the pastoralist's survival is worrying because of the reduced rangeland ability to provide goods and services (for example fodder scarcity). These are preceded by an adversely changing vegetation cover both in quantity and quality in the past 40 years as a result of degrading human activities (Al-Bukhari et al., 2018). The reduced rangeland productivity had a big implication on food security. About 20% productivity loss of the cropland in African rangelands has been realized in the last four decades as a result of unsustainable farming systems carried out by the pastoral communities. If nothing is done to combat the occurrence, then the worst food shortage is expected in the near future (Muchena et al., 2005).

Climate variability has greatly facilitated the fluctuations in rangeland forage productivity in that there is plenty of forage in rainy seasons and abject scarcity during drought, which results in a degraded rangeland cover in the long run. This has posed a management challenge to the stakeholders in Zimbabwe who almost have no immediate remedy (Senda et al, 2020). Boorana rangelands and Bale lowland eco-region of Ethiopia have reportedly experienced a steady decline in their general productivity over the past four decades. This was because of high animal mortality rates during dry seasons and general rangeland poor conditions (Dika et al., 2022; Kedu, 2021).

In central Uganda (Nakaseke), the rangeland productivity pattern is determined by rainfall variability hence the seasonal pattern of wet and dry season variations (Mbolanyi et al., 2014; Wynants et al., 2019). While the Karamoja region is facing many negative impacts of unstable rangeland productivity like high livestock mortality rate, famine, and resource-related conflicts, there are little or no preventive measures, alternative options, and restoration programs (Mohammed Mussa, 2016), and yet renewal of even one centimetre of land is almost impossible within a human lifetime (Cherlet et al., 2013; Godde et al., 2020).

2.4 Drivers of rangeland degradation

Rangeland, degradation refers to a state of prolonged loss of ecosystem services (Nkonya et al., 2016). Rangeland degradation is the sustained decrease in the economic and biological output of land (Chude & Odunze, 2016). Drivers of rangeland degradation are, therefore, a complex subject since a number of factors are, in most cases, interwoven as one may lead to another, thus triggering a chain of reactions (Gupta, 2019; Megerssa & Bekere, 2019). An interplay of both natural and anthropogenic factors is responsible for the rangeland degradation condition globally (Dika et al., 2022). The factors include; overgrazing, climate change, bush encroachment, population pressure, a decline in traditional resource management, conversion to other land uses, and unsupportive government policies (Dika et al., 2022; Kedu, 2021; Liu et al., 2021). The severity of the degradation depends on the drivers and the local factors (for example, geographical location and socioeconomic context) of the individual regions across the earth (Mohammed Mussa, 2016). The major drivers of rangeland degradation include overgrazing, climate change, bush encroachment, population pressure, a decline in traditional resource management, conversion to other land uses and unsupportive government policies (Bolo et al., 2019; Dika et al., 2022; Mohammed Mussa, 2016). In the lowland districts of Ethiopia, findings revealed that multiple factors jointly caused the degradation of the rangeland at different levels. For example about 26% by population pressure, about 50% by climate change and variability and about 26% by the existing unsupportive land use policies (Kedu, 2021).

Overgrazing mostly by domestic animals is one of the major causes of rangeland degradation. This is a state in which livestock consume vegetation faster than it can naturally regenerate leading to scarcity in plant coverage, and eventual soil erosion (Angerer et al., 2019). Overgrazing is true in Southern Caldenal rangeland, central Italy where pastoralists believe that the more animals one has, the wealthier the person is (Angerer et al., 2019). About 20% of Iranian rangeland has been greatly destroyed because of overstocking and overgrazing. Instead of accommodating about 37 million livestock units which is its rightful carrying capacity, it has about 83 million units about 2 times more than its acceptable capacity (Savari, 2023).

On the African continent, the Southeastern rangeland of Al Jabal Alakhder in Libya suffered from an overstocking problem and an alarming rate of degradation. Over 7.5 million animals were kept instead of the recommended 2.5 million, thus exceeding its carrying capacity three times. (Al-Bukhari et al., 2018).

Climate change affects the structure and function of rangelands. Increase in temperatures and evapotranspiration, altered precipitation patterns and amounts, increased frequencies of extreme weather events like floods, drought, and stormy rainfalls, disrupt ecosystem services and result in degradation (Bolo et al., 2019; Jamsranjav et al., 2018; Mohammed Mussa, 2016). The resultant acute water deficit decimates the quantity and quality of the forage that will be available (Jamsranjav et al., 2018).

Inversion of non-native and unpalatable plant species, for example, Prosopis Juliflora, and Acacia family (like Acacia Melifera, Acacia Senegal, and Acacia Seyal), is yet a very serious factor of rangeland degradation. Invasive species and bush encroachment refers to a multiplication of the plant type in an area that it did not occupy previously (Mohammed Mussa, 2016). Non-native and unpalatable plant species inversion most times lead to altered ecosystem functions reducing the grazing value of the land and management costs at the same time (Bolo et al., 2019; Jamsranjav et al., 2018). The Ethiopian Boorana rangelands have registered a steady increase in its coverage by the woody unpalatable species over the past three decades below by about 40% in 1986, 52% in 2006 and more than 63% in 2009 (Mohammed Mussa, 2016). This means a faster rate of degradation is expected if the factors responsible for its spread, like wildfires and overgrazing, are not regulated (Mohammed Mussa, 2016).

Weakened Traditional institution capacities to enforce norms, values and beliefs in the sustainable management of rangelands by policies like commercial agriculture and value addition on the produce, sedentarization and its related urban development is a factor that is worth mentioning (Bolo et al., 2019). The breakdown in traditional structures of governance has led to the confinement of pastoralists to only some parts of the rangeland thus overstocking and degrading the rangeland (Mohammed Mussa, 2016).

Land use land cover change which is man's activities on land to acquire resources that satisfy his/her economic and cultural needs (Kumar, 2019), results in continuous alteration of activities on the earth's surface in a given time. These in most cases pose a major challenge in sustainably managing land (Fenetahun & Yong-dong, 2020).

In the Heihe River Basin of China, studies conducted reveal that only land use change accounts for about 81.3% of land degradation with climate change and other factors accounting for the remaining 18'7% (Zhao et al., 2018). In Islamabad, Pakistan, forests were cleared off to create space for built-ups. This has led to the degradation of the quality of habitats and the loss of biodiversity (Hassan et al., 2016).

In Sub-Saharan Africa, stakeholders are faced with a biodiversity preservation dilemma in the face of emerging land use changes in dry lands (Borrelli et al., 2017a; Karaya et al., 2021). It has been reported that about 92.77% of grasslands are converted to farmlands and 15.7% into built-up areas. As farmlands and built-up areas expand at annual rates of 9.32% and 6.22%, respectively, grassland, woodland and wetland decline at 5.52%, 2.47% and 0.63%, respectively, with subsistence farming being the dominant land use type, 53.16% (Bunyangha et al., 2021; Karaya et al., 2021). This pattern of changes from other forms of land use to subsistence farming remains very dangerous to the increase of soil erosion (Mathewos et al., 2022). Developing economies like Southeast Asia, South America and Sub-Saharan Africa are predicted to experience the highest soil erosion rates because of the great expansion in the cropland, which is associated with more soil erosion (Borrelli et al., 2017b). The land use change may enhance the vulnerability of land to soil erosion, a major cause of degradation because the protective role played by vegetation cover is lost, and soils are exposed to agents of erosion. This, therefore, calls for interventions to avert the imminent disaster to fall the population if the problem is not solved (Bolo et al., 2019).

In Uganda Gabiri et al., (2020) believed that land use changes and climate change can each singly be responsible for water insecurity, though the effects may be adverse if they acted together. Therefore, the biodiversity within the catchment gets degraded and, in extreme cases lost for example the forest cover, fertile soil and water itself endangering the lives that depended on them (Akello et al., 2016).

Karamoja rangeland like any other has not escaped the negative impacts of land use change either as people try to find solutions to the prevalent challenges like hunger, inadequate pasture for livestock, and water scarcity (Al, 2020; Kironchi et al., 2018). Moreover, the possibility of the situation worsening cannot be ruled out as indicative factors like an increase in population and climate change still stand (Obubu et al., 2022). When land use/cover change and other actors negatively affect the environment, it translates directly to people's welfare (Kironchi et al., 2018).

2.5 Research Gaps Identified in the Literature

The most measured parameters of LULC changes are LULC trend, and its effects on; water quality, soil erosion and drainage among many (Alem, 2022; Dibaba et al., 2020; Gabiri et al., 2020). However, these studies have not examined the effects of rangeland use/cover changes on productivity. This study therefore considered the nature of Land use changes and its effects on rangeland productivity of standing biomass and the dominant underlying drivers to form a basis for appropriate and sustainable management practices backed by relevant policies

Land productivity of standing biomass has been measured in many ways, such as NDVI (Normalized Difference Vegetation Index), MSR (Modified Simple Ratio), EVI (Enhanced Vegetation Index) and many others by different researchers(Al-Bukhari et al., 2018; Bernard et al., 2022; Bolo et al., 2019). However, the above methods have limitations in measuring vegetation indices in semi-arid areas characterized by bare grounds and low vegetation coverage. This study, therefore, considered the use of SAVI (Soil Adjusted Vegetation Index) as the most suitable method for the Karamoja rangelands due to its ability to enhance the reflectance of green in areas with low vegetation coverage given its semi-arid condition. The study area will be segmented according to the dominant activity in an area giving rise to agroecological zones, and results will be compared accordingly.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter describes the study area, the research design, study population, sample size, sampling techniques, data collection, and data analysis methods.

3.2 Description of the study area

A description is given for the physical aspects of the study area, including location, climate, topography, drainage, vegetation and geology, and soils. Other geographical aspects covered include population, ethnicity, and land use activities in the study area.

3.2.1 Location

Karamoja region is located within latitudes 1°50' N and 3°50' N, and longitudes 33°50'E and 35°25'E (see Figure 3.1). It’s also estimated to cover about 27,528 square kilometres, accounting for about 10.1% of Uganda’s land area (K. Profile, 2016; Nalule, 2010; Osaliye et al, 2020).The study was conducted in seven out of the nine districts of Karamoja (namely Abim, Amudat, Kaabong, Moroto, Nakapiripirit, and Napak). The region borders Kenya to the East, South Sudan to the North, and to the south, are the districts of Kumi, Sironko, and Kapchorwa, while to the west are districts of Kitgum, Pader, Otuke, Agago, Amuria, and Katakwi(Egeru, Wasonga, et al., 2014; Profile, 2016).

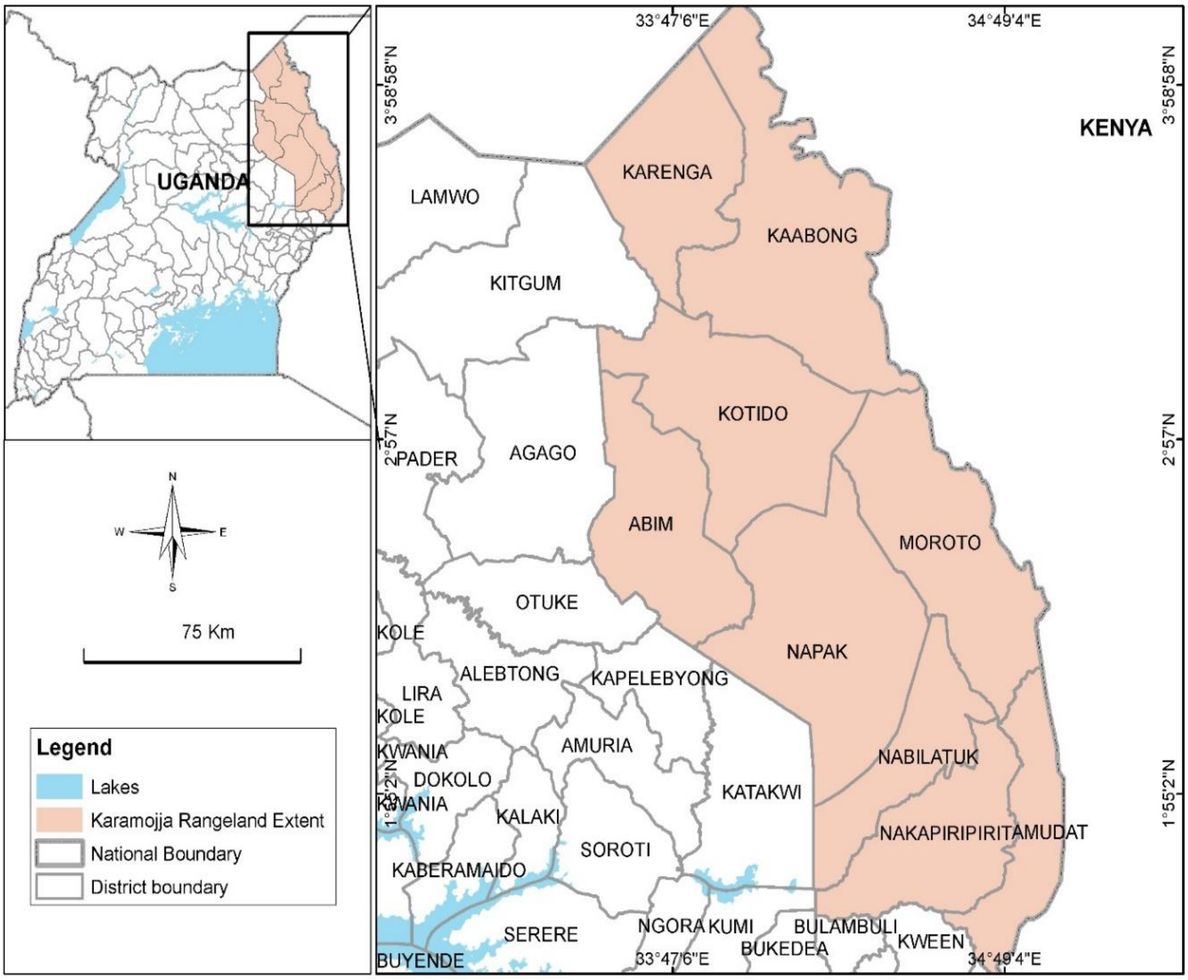

Figure 3. 1: Location of study area

3.2.2 Climate

Karamoja is a semi-arid region characterized by unpredictable rainfall and high temperatures (ACTED-Uganda, 2016; Egeru, Wasonga, et al., 2014). The region receives rainfall amounts ranging between 300mm in the pastoral region and 800-1200mm in the agricultural southwestern part of the region, which is unevenly distributed (NEMA, 2016), with average annual temperatures ranging between 16-24^0 C (USAID, 2017). There is only one rainy season between April and November with more frequent drought occurrences in the past three decades, pointing towards climate change and variability effects (Aleper et al., 2017). This type of climate leads to high evaporation rates, depriving the soil of moisture, meaning plants' growth and survival are limited, depriving the soil protection from agents of degradation, therefore lowering the fertility of the soils and leading to low productivity (NEMA, 2019; Osaliye et al., 2020).

3.2.3 Relief

The topography of the study area is characterized by volcanic mountains which include Kadam in Nakapiripirit, Napak in the Napak district, Moroto in the Moroto district, and residual hills covering much of the rolling plains to the west and northern parts of the region(K. Profile, 2016; Osaliye et al, 2020). The Karamoja rangelands are marked by a rugged landscape, encompassing plains, plateaus, and mountainous areas (Wright & Wimberly, 2013). The mountainous type of relief in the study area is most times associated with high soil erosion. When the top soils are washed and carried downstream, the eroded landscape will be degraded and in extreme cases abandoned (USAID, 2017).

3.2.4 Drainage

Several ephemeral streams and rivers emerge from the hills and mountains on the east of Karamoja and flow towards the south and west(Osaliye et al, 2020). These streams flow through deeply incised valleys over the hills and mountains through sand-filled valleys in the lower sections and become an important source of water, especially during the rainfall season and dry up during the long dry spell. During the short rainy season, the rivers/streams often burst their banks and cause flooding in the lower sections (Egeru et al., 2015). The seasonality of the streams and rivers in the region of Karamoja leads to inadequate water for the animals, especially during the long dry spell, which is most times characterized by migrations and trekking for long distances by animals. This negatively affects the physical health of animals by lowering their body mass and low yields of milk (Aleper et al., 2017).

3.2.5 Vegetation

The vegetation cover in Karamoja is made up of wooded and grassland savanna mainly in the south but translates into semi-arid vegetation in the northwestern direction. The grasslands are interrupted by isolated woodlands on the slopes and tops of mountains herbaceous and woody species are thus a common sight in the area (Egeru et al., 2015). The woody vegetation is classified as tropical deciduous vegetation. The savanna vegetation is mainly ideal for livestock keeping, though the woody vegetation is mostly infested with vectors like ticks and tsetse flies, especially in the Western part of the region. This has led to high frequencies of occurrences of animal diseases and high mortality rates. This has led to many people now turning to the environment for charcoal burning, and crop growing leading to detrimental patterns of LULC changes hence low levels of productivity in the rangelands (Aleper et al., 2017; Egeru, Okia, et al., 2014).

3.2.6 Geology and Soils

Soils comprising of sands, loamy sands of low water holding capacity, and black cracking cotton clays-vertisols from the Precambrian basement complex dominate the area (Gilbert et al., n.d.)The pre-Cambrian metamorphic rocks are evident in some areas of the catchment too These rocks are of the amphibolite metamorphic facies except for small areas of granulites, which are relics of earlier metamorphism (Westerhof et al., 2014). Some parts of the study area are characterized by planosols, calcic vertisols, and others by Hapllccalclsols, all of which have relatively low productivity levels (NEMA, 2019).

3.2.7 Land use activities

Approximately 54% of the land area is under wildlife conservation. The Uganda Wildlife Authority (UWA) established and manages Kidepo National Park to the north and three-game reserves include the Matheniko, Bokora and Pian-Upe (Osaliye et al., 2020). The remaining 46% of the land which is available to the people of Karamoja is being used mainly for pastoralism the drier east (Amudat, Moroto, Kotido and Kaabong districts), agro-pastoralism in the centre of the region (namely Nabilatuk, Napak, and parts of Nakapiripirit district and crops (the wetter part of south and western Karamoja in Namalu, Iriri, Abim and Karenga supports the growth of crops like maize, millet, sunflower, sweet potatoes, beans, and sim-sim(Egeru, Okia, et al., 2014; Nalule, 2010). The three ecological zoning were based on the environmental conditions, rainfall totals received and dominant activity in an area (Egeru, Okia, et al., 2014).

The study area falls under the pastoral and annual cropping agricultural system (NEMA, 2016). The region also hosts major mining centers for marble stones, gold, and sand. Mining of marble, gold, and limestone also takes place within the region (Rugadya & Kamusiime, 2013). The various land uses in the region have greatly changed due to the policies of sedentarization and agro-pastoralism, which were both aimed at enabling people to cope with the prevailing harsh and unstable environmental conditions in the region(Osaliye et al., 2020). These well-intended alternative means of livelihood have unfortunately become mechanisms of massive clearance of vegetation in the name of opening up farmlands and overgrazing the small remaining portions meant for grazing, thus lowering quantities and quality of standing biomass produced and supported by the ecosystem (Aleper et al., 2017).

3.2.8 Population and Ethnicity

Karamoja's population in 2021 was projected to be about 1.2 million people see Table 3.1 covering a total land area of about 27,900 square kilometres (approximately 48 persons per square kilometre) with a projection of about 1.4 million by 2022, according to UBOS (2023). The sub-region is one of the most ethnically diverse parts of eastern Africa, comprising the Jie, Dodoth, Ngikarimojong, and Tepeth, who speak generally Ngakarimojong dialect, though with minor differences. Minority ethnic groups also exist, like the Nyangia and the Ik from Karenga, Ethur from Abim, whose language is regarded as a Luo dialect (Leb-Thur), and the Pokot, who are found in the Amudat district.

Table 3. 1: Population of Karamoja by UBOScensus and projection till 2021

sn	Districts	Census Population		UBOS Projections (2015 to 2021)						
		2002	2014	2015	2016	2017	2018	2019	2020	2021
1	Abim	51,803	107,966	113,400	120,700	128,200	136,200	144,600	153,500	162,900
2	Amudat	63,572	105,769	109,400	114,200	119,100	124,300	129,400	134,900	140,400
3	Kaabong	141,568	167,879	110,800	113,800	116,900	119,500	122,500	125,400	198,500
4	Karenga	61,190	51,533	60,400	61,800	63,300	65,200	66,800	68,500	
5	Kotido	122,541	181,050	184,300	188,700	193,200	197,600	202,100	206,500	210,900
6	Moroto	77,243	103,432	105,400	108,000	110,600	113,200	115,800	118,500	121,200
7	Nabilatuk	38,723	68,409	71,100	74,500	78,100	81,900	85,700	89,700	93,800
8	Nakapiripirit	52,199	88,281	91,400	95,500	99,700	104,200	108,700	113,300	118,100
9	Napak	112,697	142,224	144,300	147,100	150,000	152,700	155,500	158,300	161,000
	Total	721,536	1,016,543	990,500	1,024,300	1,059,100	1,094,800	1,131,100	1,168,600	1,206,800

Source: UBOS, (2023).

3.3 Research Design

The research design encompassed both cross-sectional and longitudinal approaches to gather primary and secondary data respectively. In a cross-sectional study design, phenomena were examined based on single-event data, while in a longitudinal study design, phenomena with the help of remote sensing and GIS techniques were observed over a period of time (2002-2022) to discern trends and patterns. By integrating both quantitative and qualitative methods, the study was able to triangulate findings, enhancing the validity and reliability of the research outcomes. The quantitative data provided statistical support and generalizable trends, while the qualitative data offered depth and context, enriching the interpretation of results and providing a more holistic understanding of the research phenomenon. Overall, the mixed approach facilitated a comprehensive exploration of the research topic, allowing for a nuanced analysis that captured both the breadth and depth of the subject matter.

3.4 Sampling Design

For data collection purposes, the study adopted both simple random and purposive sampling methods. The study was conducted in only 7 out of 9 districts of Karamoja region. The districts of study include Abim, Kotido, Kaabong, Napak, Moroto, Nakakpiripirit and Amudat. The districts of the study were purposively sampled in such a way that all three ecological zones (namely crop, Agro-pastoral and Pastoral) were represented adequately. For the household questionnaires and key informants interviews respectively, across the selected districts. This simple random sampling ensured that each household within the chosen districts had an equal opportunity to participate in the study, thereby minimizing biases and increasing the representativeness and statistical efficiency of the sample. By using purposive sampling, the research questions were directed to the most relevant respondents, and therefore, very rich and appropriate data for the objective was collected. These two methods were aimed at enhancing the external validity of findings and enabling broader conclusions about the population of interest, which resulted in minimized variability and increased precision of results.

3.5. Sample size and sampling framework

A sample size of 384 household surveys was targeted for household interviews. This number was arrived at using a formula by Morgan and Kreijcie (1970), and the 2021 projected household number for the Karamoja region is shown in Appendix iii.

This helped to generate the 55 household numbers of respondents per district for a random survey during data collection. The equation used to generate the sample size is expressed as follows;

$$s=X^2 NP(1-P) \div d^2 (N-1) +X^2 P(1-P) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where;

s= required sample size.

X^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (0.05 = 3.841).

N = the population size (Total household size for 2021 i.e 218,500).

P = the population proportion (assumed to be 0.50 since this would provide the maximum sample size.

d= the degree of accuracy expressed as proportion (0.05).

To arrive at the 54 households per district for the questionnaire survey, I used a multi-stage random sampling method, which involved selecting three sub-counties per district that are non-urbanized, three parishes per sub-county, three villages per parish and two households per village. At the household level, the household head was targeted. For key informants' interviews, 24 technical staff were targeted. These included the seven district veterinary officers, seven district natural resource officers, seven district environment officers from each district, and three district agricultural officers, each representing a district from one of the three ecological zones.

3.6 Data Collection

3.6.1 Primary data collection methods and tools

i. **Questionnaire**

To assess the most significant drivers of productivity, primary data were collected from households and rangeland resources managers in selected Karamoja rangeland districts. The quantitative data was collected through the questionnaires administered in about 384 households that were randomly selected across the seven selected districts. Trained research assistants with at least a minimum education level of Uganda Certificate of Education (UCE) and a maximum of a University Bachelor's Degree administered the household questionnaires to randomly sampled household heads. The native research assistants were used during the collection of data because of their abilities to interpret the questions in the local language for clarity purposes in case of an illiterate respondent. Due to the armed raids then in the region, some sub-counties in districts like Moroto, Nakapiripirit, Kaabong and Kotido were completely accessible for data collection teams, leading to a low response rate and only 264 (68%) out of 384 targeted numbers were used for analysis after data cleaning. The questionnaire tool comprised both open and closed-ended questions as depicted in (appendix i). The semi-structured questionnaire tool was designed following the research themes, including (a) Agriculture production and other activities on the range land and (b) the state of the rangeland's resources.

ii. Interviews

To establish qualitative data, a total of 24 key informants were purposively selected and interviewed from the 7 selected districts. The researcher conducted the key informants' interviews with 22 out of the 24 targeted technical staff in the seven selected districts. The interview guide used during the interview sessions consisted of a list of questions aligned with the research themes and objectives (see Appendix II). The key informants' selection was based on their expertise and knowledge on the status of the rangelands which is the core of this study. Through key informants' interviews, these themes revealed insights into the diverse range of activities and practices occurring on the rangelands, the current condition and management of rangeland resources.

3.6.2 Secondary data

Data about spatio-temporal land use/cover changes was obtained from secondary data sources, mainly three satellite images, documents and reports.

a) Satellite imagery

Land use/cover change and vegetation indices data were sourced from servers of USGS explorer https://earthexplorer.usgs.gov/serving as secondary data. Notably, all images selected for analysis represented the dry seasons with cloud cover ranging between 0 and 5 of their respective years since classification is centred on observable bands. This was established by checking the Metadata of each satellite image before downloading. Landsat 5 TM (30*30) images for 2002 and 2012, along with Landsat 8 OLI scenes for 2022, were obtained and utilized to generate rangeland use change and rangeland productivity (SAVI) data within an ArcGIS environment. This dataset served as input for analyzing trends and patterns of rangeland use changes and productivity. The significance of satellite imagery data lies in its ability to provide valuable insights into rangeland use change analyses by capturing characteristics of land cover and use classes across space and time (Bekele et al., 2019). Specifically, RGB and infrared bands were targeted for LULC classification, offering optimal resolutions for vegetation and surface cover mapping while being freely accessible. To enhance the accuracy of LULC classification, ground truthing data were collected for the targeted cover classes. This involved gathering 50 GPS points per class per ecological zone within the study area using a handheld Garmin GPS Map 64s device. Additionally, Google Earth Pro was utilized to supplement field data collection efforts, ensuring comprehensive and precise classification of satellite images.

b) Documents and reports

District reports such as the Area-specific population and housing reports by UBOS and projection reports (UBOS, 2021) were used to obtain population data in the selected districts. Secondary data sources offered valuable insights into strengthening the research gap, the research themes of agriculture production and other activities on the rangeland, and the state of rangeland resources. For the theme of agriculture production and other activities on the rangeland, secondary data included academic literature exploring the impact of agricultural practices on rangeland ecosystems. This literature covered grazing management strategies, crop cultivation methods in semi-arid environments, and the interplay between agriculture and biodiversity conservation. Additionally, reports from agricultural organizations or governmental agencies provided data on crop yields, livestock production statistics, and trends in land use changes related to agricultural expansion or intensification.

Secondary data sources, including scientific studies assessing vegetation cover, soil erosion rates, and water availability, were used to establish the state of rangeland resources. These studies utilized remote sensing data, such as satellite imagery or aerial surveys, to monitor changes in rangeland ecosystems over time. Furthermore, reports from environmental organizations or land management agencies offered insights into the health and sustainability of rangeland ecosystems, including assessments of habitat fragmentation, invasive species impacts, and ecosystem services provided by rangelands.

Secondary data consisted of scholarly articles examining the socio-economic factors underlying the productivity of land in pastoralist communities. These articles explored issues such as charcoal burning, poverty, limited awareness, conflict dynamics, cultural traditions related to livestock ownership, and enforcement of the available environmental policies. Additionally, reports from humanitarian organizations or security agencies provided data on the frequency and severity of cattle raiding incidents, as well as the humanitarian impacts on affected communities.

3.7.1 Data Analysis

The downloaded satellite images were preprocessed by extracting bands from the zipped image downloaded, clipping, and setting bands. They were processed by performing unsupervised classification using Iso-Cluster, an algorithm using ArcGIS, which is also used by several scholars, such as Alipur et al. (2016) and Congedo & Taylor. The classification procedure yielded rangeland cover/ use classes for the two decades.

Table 3. 2: Descriptive Characteristic of land cover types in Karamoja

Land use/cover type	Description
Bare ground	Land consisting of exposed soils, very short grasses, seasonal riverbeds, low vegetation cover of only up to 10%, active erosion spots, burnt land surface, and marram and stone quarries (Opedes et al., 2022a).
Built-up	Include settlements (nuclear, linear, commercial, Homesteads and industrial), transport and communication routes, pavements, and compounds (Opedes et al., 2022b).
Bushland	Land with shrubs ranging between 2-6 m in height, dominated by Acacia perfecta, *A nilotica* mixed with *Euphorbia prostate*. Bushland concentrations vary with the level of disturbances across the region
Cropland	Open land under cultivation or where crops were harvested, with sorghum, maize, and cucumber (ngadekela and ngakobokob), in the local language, being the main crops.
Grassland	Natural savannah grassland is mainly found in the east and the central broad valleys of the Karamooja region
Woodland	Land with deciduous trees of average height ranging between 2-12m that form an open canopy with grass in between (Egeru, Wasonga, et al., 2014).

Source: Egeru et al., 2014

3.7.2 Image Accuracy Assessment

A total of 200 points were generated and randomly spread within the study area boundary, which were exported as a kml file and later imported into Google Earth to compare with the actual ground to obtain the user and producer accuracy matrices and the Kappa values

Overall accuracy = 1/N ∑ xii

Where x is cell values, xii is the total number of observations in row I and column I, N is the number of classes, and N= the number of samples.

Kappa coefficient

Kc= N ∑ xii − ∑ (xit×xti N2) r i=1 r i=1 ∑ (xit × xti r i=1)

Where Kc is the kappa coefficient, N is the l number of samples, xii is the total of the correctly classified pixel, r is the number of rows in the matrix, xit and xti, are the marginal totals of row i and column i respectively.

In a bid to assess rangeland spatial-temporal variability in productivity, vegetation indices were used. Specifically, the Soil Adjusted Vegetation Indices (SAVI) was used due to its ability to counteract the effect of soil brightness which is prevalent in the Karamoja rangelands due to the environmental and climatic characteristics (Venancio et al., 2019). The SAVI values were extracted from Landsat 5 and 8 Near-infrared and Red Bands in ArcGIS 10.8 environment. Landsat bands were preferred in this study because previous studies have considered coarse resolution MODIS 250m data and other vegetation indices. SAVI was computed using the formula;

$$SAVI = \frac{NIR - RED}{NIR + RED + L}(1 + L) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. equation\ (i)$$

Where; NIR is the Near Infrared;

RED is the RED bands and

L is the soil adjustment factor typically set 0.5.

The SAVI values were segregated according to years and agroecological zones of the Karamoja rangeland.

In addition, to test the variability in rangeland health over space and time, ANOVA was conducted using R software. This statistical technique compares the means of a continuous variable against a categorical variable. Regarding this study, SAVI values were grouped according to years (2002, 2012, and 2022) but also according to the agro-ecological zones (pastoral, agro-pastoral, and crop). The test statistics were analyzed at a 0.05 level of significance.

Data on objective three, which evaluated the underlying drivers of rangeland productivity, was gathered using a questionnaire survey and key informant interviews. These methods enabled the collection of primary socio-economic data from households and rangeland resources managers on the drivers of rangeland productivity. Descriptive statistics, such as case and percentages, multiple response analysis, and bivariate inferential statistics involving non-parametric techniques like the Chi-square test, were employed. Cramer's V statistical analysis was used to determine the strength of the association between rangeland productivity and the drivers. These analyses established the significance of independent variables (range LULC changes) in influencing rangeland productivity.

Table 3. 3: A Summary of Methodology

Objectives	**Data Source**	**Method**	**Analysis**
1. To examine the spatio-temporal trends in rangeland degradation in the Karamoja region, Eastern Uganda, between 2002 and 2022.	LULC (2002, 2012, 2022) Landsat 4-5 and Landsat 8 were downloaded from the United (USGS) Geoportal (http://glovis.usgs.gov/web-link).	• Iso cluster and Max at 30*30m resolution.	• Discriminate analysis, change detection. • Descriptive and Inferential statistics (ANOVA).
2.To assess the spatiotemporal variations in rangeland productivity in the Karamoja region of Eastern Uganda between 2002 and 2022	Near-infrared and Red bands from Landsat 4-5 and Landsat 8 were downloaded from the United (USGS) Geoportal (http://glovis.usgs.gov/web-link).	• Vegetation biomass estimation • Extraction of SAVI using R MODIS package 250m resolutions.	• Descriptive statistics from SAVI values, variance, standard deviation • Least significant difference-significance of variance • Post hoc ANOVA –test on SAVI statistics
3.To evaluate the significant drivers of rangeland degradation in the Karamoja region, Eastern Uganda	Household survey-socio-economic data	• Questionnaire. • Key informant interviews	• Descriptive statistics- Multiple response analysis • Inferential statistics – Non–Non-parametric - Chi-s test for strength of association • Cramer's V statistics analysis-significance of independent variables

3.8 Study Limitations

In this study, anticipated limitations, such as limited access due to unfavourable terrain and insecurity in the region, hampered the even distribution of locations for representative data points. This challenge was overcome by the use of remote sensing techniques to select spatial data, such as various land covers and land use types.

The suspicious and uncooperating local communities that would lead to giving wrong information to strangers were overcome by training the literate natives as research assistants who participated in the data collection process.

The production of the rangeland use classification map had a major challenge because both maximum likelihood (supervised classification) and Iso cluster (unsupervised classification) algorithms sensed built-up and bare ground as being the same class type, causing the built-up class to appear where bare ground is dominant and vice versa, probably because of the soil noise emitted by the bare ground. This challenge was minimized by conducting an accuracy analysis that gave moderate to strong accuracy levels, hence the subsequent use of the map.

3.9 Ethical Considerations

3.9.1 Informed Consent

Before conducting the interviews, informed consent was sought from all participants who took part in the study. These included the district political leaders, community leaders, especially the Regional Internal Security Officer (RISO), Local council V chairpersons, Resident District Commissioners, Chief Administrative Officers, Technical staff, Research assistants, Heads of households, and Opinion leaders. The purpose of the study and methods used were explained to the participants before seeking their consent to participate in the study.

3.9.2 Confidentiality and Anonymity

All personal and sensitive information gathered during the research was kept confidential. The tools used were anonymized to protect participants' identities, especially when presenting results.

3.9.3 Cultural Sensitivity

The traditions, local customs, and cultural practices of the communities were respected and community engagement was done in a manner that acknowledged their cultural heritage and values.

3.9.4 Transparency in Communication

Open and transparent communication was maintained with all stakeholders throughout the research process. Participants were informed about the study's progress and likely benefits. They were also provided with opportunities to ask questions and express concerns, which were addressed respectfully.

3.9.5 Data Integrity

The use of reliable and valid data collection and analysis methods ensured the integrity and accuracy of all the data collected during the study. Findings have also been reported accurately and honestly, avoiding any form of data misrepresentation.

3.9.6 Compliance with Legal and Institutional Requirements

All relevant legal and institutional requirements were adhered to, including obtaining necessary permits and approvals for conducting the research study.

CHAPTER FOUR

PRESENTATION OF RESULTS

4.1 Introduction

In this chapter, analyzed data are presented, interpreted, and discussed as guided by the main and study-specific objectives: to examine the spatiotemporal trend of rangeland use/cover changes, to assess the spatiotemporal rangeland productivity, and to examine the dominant factors underlying rangeland degradation.

4.1.1: To examine the extent, trend and transitions of spatiotemporal changes in rangeland land use between 2002 and 2022 in Karamoja rangeland, Northeastern Uganda

The researcher established the extent of spatiotemporal land use changes in Karamoja rangeland between 2002 and 2022. Using GIS and remote sensing, various land use types in km2 across the study period were established, and the findings are visually presented in Figure 4.1. Results showed spatial coverages of land use types (bare ground, built-up, bushland, cropland, grassland and woodland) and their changes from 2002, 2012 to 2022. Results indicated that in 2002, woodland concentrated in areas such as Karenga district (northwestern), (extreme northeastern part of Kaabong district, most parts of Abim district, western Napak district, western Nakapiripirit and on mountains such as Mt Mororto, Mt Kadam, Mountain Napak, Mt Morungole in Ik land, and Zulia within Kidepo Valley National Park. But portrayed less concentration in 2012 and 2022, with the exception of mountainous areas such as Mt Moroto in the east, Mt Zulia in the north and Mt Kadam in the south. Cropland and grassland concentration were notably increasing in places formerly covered by woodland from 2012 through 2022. Built-up concentration was higher in 2022 compared to the previous years. There was a considerable concentration of bushland in 2012, but there was a low concentration by 2022. Built-up concentration became much less by 2022.

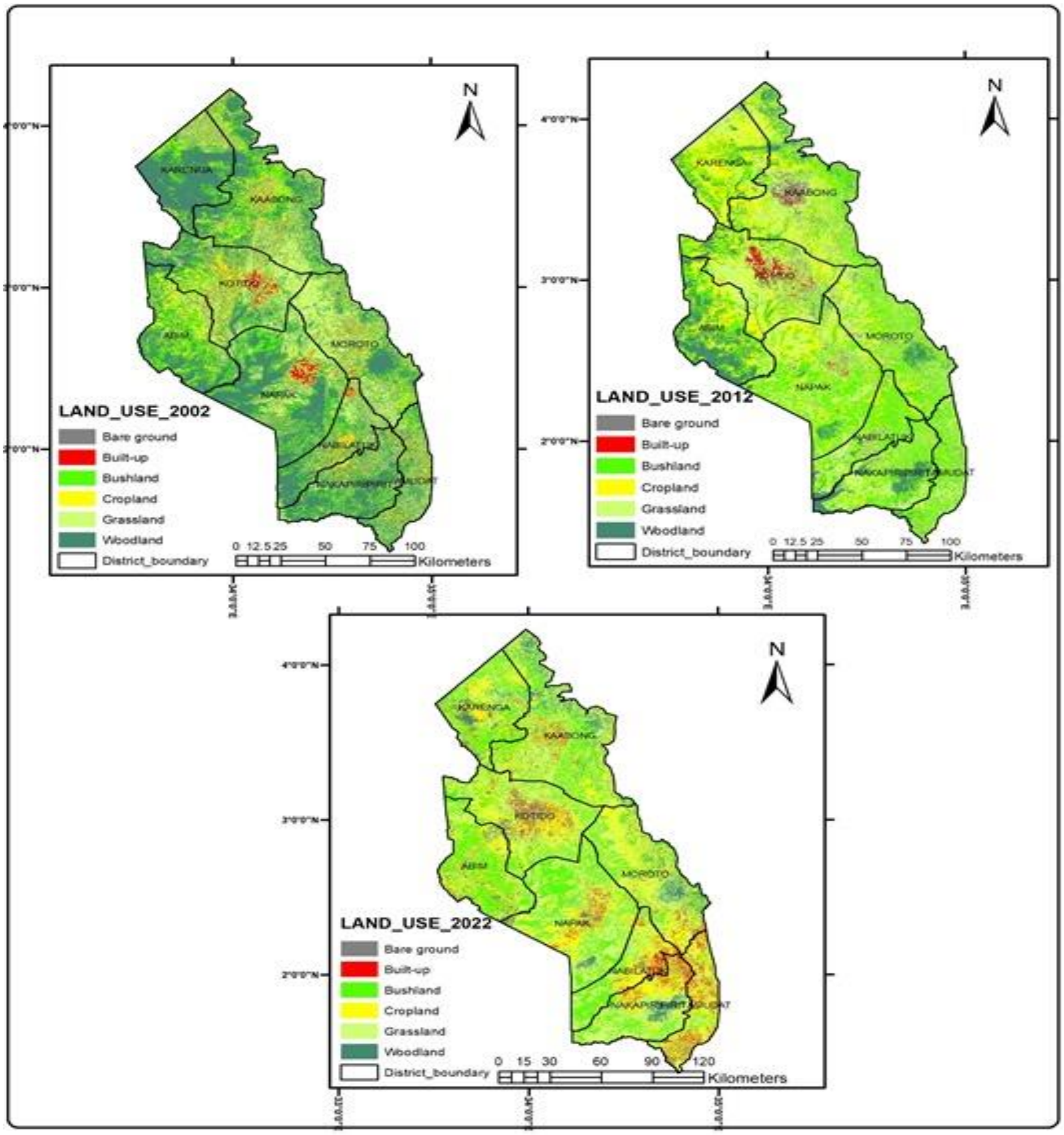

Figure 4. 1: Land use change 2002 – 2022

The extent of changes in land use coverage in the study area across the study period results are presented in Table 4.2 below.

In 2002, woodland, grassland, and bushland were the predominant natural vegetation cover types, covering 12637 km2 (46%), 5912 km2 (21%), and 4693 km2 (17%), respectively. However, woodland underwent a drastic reduction to 2953 km^2 (11%) in 2012 and further decreased to 2087 km^2 (8%) in 2022. Meanwhile, grassland expanded to 9668 km^2 (35%) and

11219 km^2 (41%) in 2012 and 2022 respectively. Bushland increased to 8776 km^2 (32%) in 2012 and decreased to 6437 km^2 (23%) in 2022.

On the other hand, cropland and built-up areas, reflecting human influence, experienced continuous expansion throughout the study period. Cropland expanded from 2951 km^2 (11%) to 4666 km^2 (17%) in 2012 and 6274 km^2 (23%) in 2022, while built-up areas grew from 274 km^2 (1%) in 2002 to 924 km^2 (3%) in 2022. Bare ground spatial coverage marginally increased from 1039 km^2 (1%) in 2002 to 1201 km^2 (1%) and registered a significant drop to 565 km^2 (-2%) in 2022.

An analysis of the accuracy of the classification results shows that percentage accuracies were 85%, 85%, and 83% for 2002, 2012, and 2022, respectively. Kappa was 78%, 80%, and 76% in 2002, 2012, and 2022, respectively. These values indicate a substantial agreement with the total accuracy values, which authenticated further analysis and transition detection.

Table 4. 1: Land use extent between 2002 and 2022 and its accuracy assessment

Land Use Type		Quantities of land use types						Quantified changes in land use types in the rangeland			
		2002		2012		2022		2002-2012		2012-2022	
								Area (km^2)	%	Area (km^2)	%
		Area (km^2)	%	Area (km^2)	%	Area (km^2)	%				
Analyzed classes	Bare ground	1039	4	1201	4	565	2	162	1	-636	-2
	Built-up	274	1	242	1	924	3	-31	0	682	2
	Bushland	4693	17	8776	32	6437	23	4084	15	-2340	-9
	Cropland	2951	11	4666	17	6274	23	1715	6	1608	6
	Grassland	5912	21	9668	35	11219	41	3756	14	1550	6
	Woodland	12637	46	2953	11	2087	8	-9685	-35	-865	-3
Accuracy assessment	Total accuracy	85%		85%		83%					
	Kappa coefficient	78%		80%		76%					

4.1.2 Trend of rangeland Use Changes

The study analyzed the trend of six land use types in Karamoja rangeland in 2002, 2012, and 2022. The line of best fit was used to present the effect of time (R^2 values) on the trend of land use changes across all classes, and the results are presented in Figure 4.2 below.

Results showed that overall, the trend lines for all the land use classes indicate relatively constant changes over the study years even when they differ in slope directions. Bushland, grassland, cropland, and built–up land use types had positive slopes, and bare ground and woodland presented negative slopes over the study years since some had positive and others had negative directions.

Cropland increased the most, from 2951 km^2 in 2002 to about 6274 km^2 in 2022. Built-up increased from 274 km^2 in 2002 to 924 km^2 in 2022, and grassland increased from 5912 km^2 in 2002 to 11219 km2 in 2022. This has made them have a very sharp (R^2) and upward fit line trend. Bareground decreased from 1039 km^2 in 2002 to 565 km^2 in 2022, and woodland decreased from 12637 km^2 in 2002 to 2087 km^2 in 2022. This made them have a sharp decreasing slope.

Cropland and grassland had a very steady pattern of increase over the study period, indicating expansion resulting from conversion from other land use types. Bare ground and woodland by pattern declined steadily, indicating their conversion into other class types over the study period.

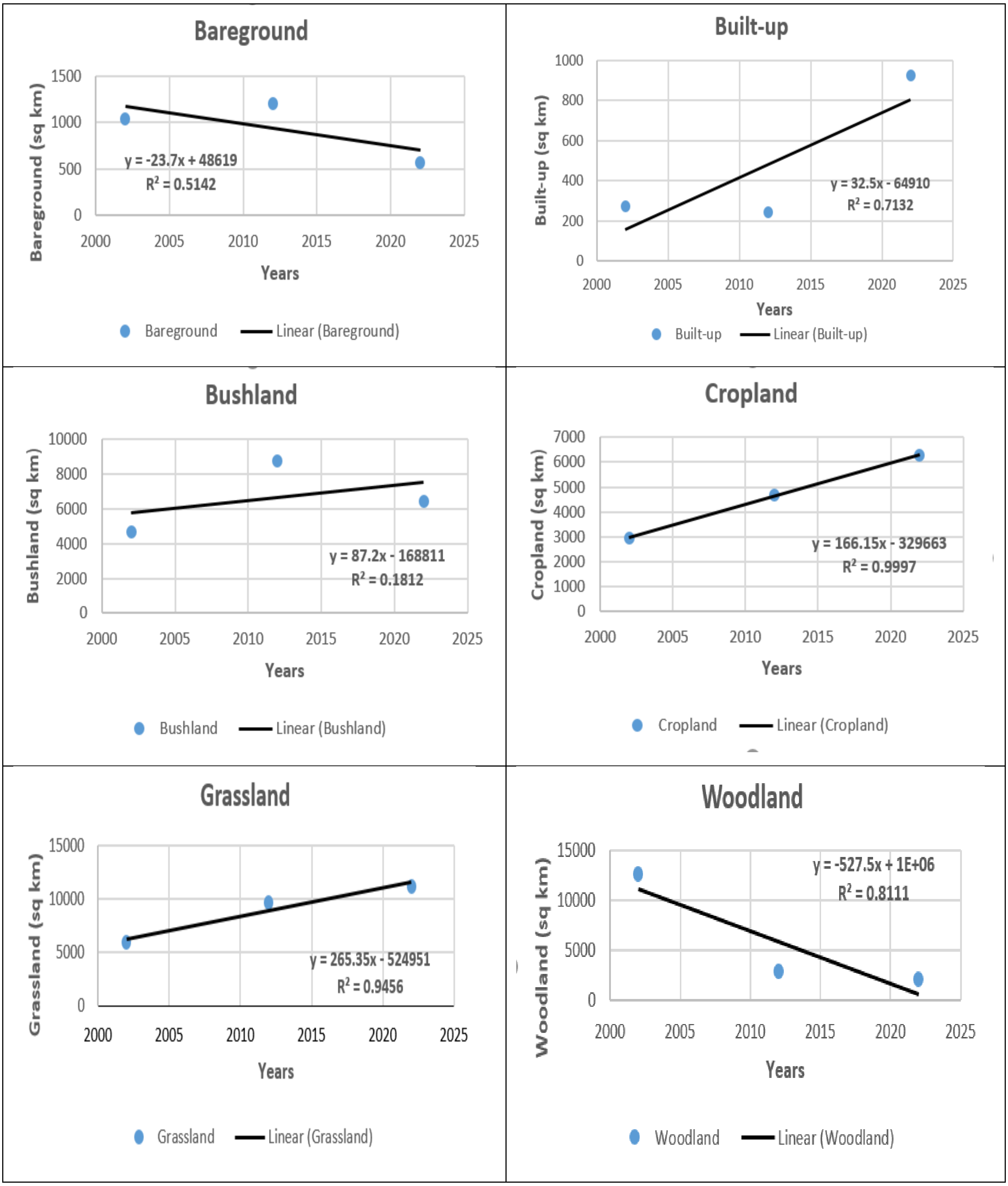

Figure 4. 2: Trend of grassland use changes

4.1.3 Transition grassland use changes

Transition shows sources of losses and gains. It gives a breakdown of the quantities or coverage gained from other land use types and or the quantities lost to other land use types over the study period of 2002, 2012 and 2022. These are presented in Tables 4.2, 4.3 and 4.4. Net gains/losses and specific gains/losses were used for presentation and interpretation purposes

The findings presented in Table 4.2 below show the Land use transitions from 2002 to 2012. Land use classes underwent substantial transitions with all of them having less than 50% remaining stable between the study periods. Bushland and grassland registered net gains of 54.5% and 139.5%, respectively, while bare land, built-up, cropland and woodland registered net losses of -51.4%, -65.2%, -12.6% and -64.1%, respectively. Specifically, bare land retained only 9.8% of the initial land in 2002 while the largest area was converted to grassland (47.8%) and bushland (23.7%). On the other hand, it gained 17.5% of built-up areas and 11.1% of cropland. In the built-up class, 29.8% of the initial area in 2002 remained unchanged in 2012. However, 44.8% was converted to grassland, 17.5% to bare land and the remaining shared out to the remaining land use/cover type. In contrast, built-up gained mainly from cropland (4%) and the rest were less than 1%. The transitions in bushland were dominated by conversions to grassland (31.8%), cropland (21%) and woodland (11.5%). At the same time, bushland gained 34.5% of woodland, 30.4% of grassland and 23.7% of bare land and the rest were under 1% with only 34.3% remaining stable. Cropland was highly unstable such that only 15.1% of the area in 2002 remained unchanged in 2012 while 41.2% was converted to grassland, 25.1% to bushland and 11.1% to bare land. And the losses to build up and woodland were below 1%. On the other hand, gains came from bushland (20.9%), bare land (17.1%), grassland (16.7%), woodland (16.4) and only 1.1%0 from built-up.

Grassland retained up to 44.6% of its initial land coverage in 2002 but lost 30.4% to bushland, 16.7% to cropland, and 5% and 2% to bare land and woodland, respectively. On the other hand, it registered major gains of 47.8%, 44.8% 41.2%, 31.8% and 29.3% from bare land, built-up. Cropland, bushland and woodland respectively. Only 17% of the initial land of 2002 remained intact to woodland while it lost 34.5% to bushland, 29.3% to grassland, 16.4% to cropland, 2% to bare land, and 0.2% to built-up. Contrary, its main gain was from bushland, with the rest having less than 1% gains.

Table 4. 2: Rangeland use/cover types Transition between 2002 and 2012

Land cover change (percentage)		2012						
		Bare ground	**Built-up**	**Bushland**	**Cropland**	**Grassland**	**Woodland**	**Total loss**
2002	Bare ground	**0.097645**	0.005364	0.236945	0.171078	0.477950	0.011018	0.902356
	Built-up	0.174587	**0.297968**	0.064904	0.011744	0.448320	0.002477	0.702032
	Bushland	0.014957	0.000650	**0.342711**	0.209071	0.317806	0.114804	0.657288
	Cropland	0.111443	0.040259	0.251065	**0.150898**	0.411832	0.034503	0.849102
	Grassland	0.057638	0.001198	0.303566	0.166601	**0.445900**	0.025098	0.554101
	Woodland	0.024840	0.002211	0.345382	0.163816	0.293013	**0.170739**	0.829262
Total gain		0.388465	0.049682	1.201862	0.722949	1.948921	0.1879	
Net gain/loss		**-0.51389**	**-0.65235**	**0.544578**	**-0.126153**	**1.39482**	**-0.641362**	

Table 4.3 below presents results on both gains and losses in all six land use classes in Karamoja rangelands from 2012 to 2022. Only cropland and grassland had positive net gains of 46.1% and 102.6%, respectively, in the study period. Conversely, built-up had -72.9%, woodland had 54.6%, Bare ground had -35.2% and finally bushland with -0.5%. Bare ground retained only 6% of its initial land coverage of 2012 by 2022. This huge loss was because of the losses it incurred to the grassland at 34.5%, cropland at 34.3%, 11.3% to bushland, built-up at 8%, and wood at 4%. Built-up just retained only 8.9% of its initial land coverage in 2012 as it lost 54% of its coverage to bare ground, cropland took away 29%, grassland got 6.7%, woodland got as little as 1.2%, and lastly, bushland took away 0.3%. At the same time, gains were made too, such as 8.6% from bare ground, 3.9% from grassland, 3.8% from bushland, 1.5% from cropland and finally, 0.5% from woodland, bushland in 2022 retained 23.8% of its initial land in 2012.

Even when it gained from other land use/cover types such as28.2% from woodland, 26.8% gain was made from cropland, 22.1% was gained from grassland, 11.3% from bare ground and 0.3% from built-up, losses were equally made for example 41.4% of the loss was made to grassland, cropland as well took 23.5%, 3.8% went to built-up, woodland took away 6% from woodland and lastly 1.4% went to bare ground. 23.1% of the original land in 2012 to cropland was unchanged by 2022. The other coverage was lost to other cover/use types for example, grassland alone took away as big coverage as 41.1%, followed by bushland with 23.7%, woodland took 6.9%, built-up got away with 1.5% of the land coverage and finally bare ground took 0.5%. However, cropland made some gains too from the other use/cover types, such as 34.2% from bare ground, 29% from built-up, 23.7% from grassland, 23.5% from bushland and 12.4% from woodland. By 2022, grassland had retained 43.1% of its original land in 2012.

Grassland got losses from other use/cover types. For example, 23.7% were lost to cropland, 22% went to bushland, 5.1% went to woodland, 3.9% went to built-up, and 2% was taken by bare ground. At the same time, grassland gains of 41.4% from bushland, 41.1% from cropland, 35.8%from woodland, 34.5% from bare ground and 6.7% came from built-up. Woodland retained 23.8% of its original land by 2012 though it registered minimal gains from other rangeland cover/use types. For example, the highest gain it made was 6.9% from cropland, followed by 6% from bushland, 5.1% from grassland4.8% from bare ground and lastly 1.2% from built-up. At the same time, woodland registered losses from 35.8% to grassland, 28.2 to bushland, 12.4% to cropland, 0.5% to built-up and 0.2% to bare ground.

Table 4. 3: Rangeland use Transition between 2012 and 2022

Rangeland use change (Percentage)		**2022**						
		Bare ground	**Built-up**	**Bushland**	**Cropland**	**Grassland**	**Woodland**	**Total loss**
2012	Bare ground	**0.066016**	0.085942	0.112592	0.342543	0.344934	0.047974	0.933985
	Built-up	0.539509	**0.087521**	0.003306	0.290546	0.067076	0.012042	0.912479
	Bushland	0.014497	0.037532	**0.237832**	0.235288	0.414195	0.060656	0.892641
	Cropland	0.005134	0.015324	0.268198	**0.231228**	0.411315	0.068801	0.768772
	Grassland	0.020066	0.039294	0.220499	0.237327	**0.431271**	0.051543	0.568729
	Woodland	0.002277	0.005521	0.282420	0.123886	0.357666	**0.228230**	0.786744
Total gain		0.581483	0.183613	0.887015	1.22959	1.595186	0.241016	
Net gain/loss		**-0.352502**	**-0.728866**	**-0.005626**	**0.460818**	**1.026457**	**-0.545728**	

Table 4.4 detailed transition results of the Land use types in two decades that is 2002-2022. Overall, results show total transitions of all the land use types, which are both positive: 119% for built-up, followed by 100.1% for cropland, 61.3% for bushland and negative -65% for grassland, -64.7% bare ground and -60.7%. Land coverage that remained unchanged by 2022 for each rangeland use/cover type is 2.7% for bare ground, 33.4% for built-up, and 28.2% for bushland. 1.4% remained under cropland, 2.9% for grassland, and lastly, 0.3% was retained under woodland. Other details were losses to other rangeland use types and gains from the same.

Table 4. 4: Rangeland use/cover Transition between 2002 and 2022

Land cover change (Percentage)		2022						
		Semi-desert grassland	**Built-up**	**Shrubs/ Bushes**	**Cropland**	**Savanna Grassland**	**Savanna Woodland**	**Total loss**
2002	**Bare ground**	**0.027862**	0.407460	0.188077	0.260814	0.103630	0.012157	0.972138
	Built-up	0.070630	**0.333579**	0.323426	0.156710	0.050618	0.065038	0.666422
	Bushland	0.050301	0.407997	**0.281599**	0.182287	0.063199	0.014617	0.718401
	Cropland	0.157252	0.175573	0.352672	**0.013740**	0.019847	0.280916	0.98626
	Grassland	0.032838	0.441085	0.276969	0.203715	**0.029421**	0.015973	0.97058
	Woodland	0.014378	0.425438	0.190507	0.282857	0.083410	**0.003410**	0.99659
Total gain		0.325399	1.857553	1.331651	1.086383	0.320704	0.388701	
Net gain/loss		**-0.646739**	**1.191131**	**0.61325**	**0.100123**	**-0.649876**	**-0.607889**	

4.2. The spatio-temporal variations on rangeland productivity between 2002 and 2022 in Karamoja region, Northeastern Uganda

Spatiotemporal rangeland productivity was evaluated using the Soil Adjusted Vegetation Index (SAVI) to measure above-ground productivity across the region, and results are visually presented in Figure 4.3

Findings illustrated that areas with healthy vegetation, depicted by deep green, were identified in Karenga, Abim, and the western and northern parts of the Kaabong district, the western part of Nabilatuk and Nakapiripirit districts, and the extreme southern Amudat towards the Elgon system. Moderate levels of green were observed in the western parts of Napak, Kotido, and eastern Nakapiripirit districts. At the same time, areas with brown were found in the eastern parts of Kaabong, Kotido, and Napak districts and the greater Moroto and Amudat regions in 2002. These depleted areas expanded to include Karenga, the northern parts of Kaabong, and Abim districts by 2012. 2022 showed an even more widespread and pronounced brown colour, indicating a higher degradation level than in previous years. In the (legend of Figure 4.3), 2002, the SAVI values were recorded as a maximum of 0.661 and a minimum of -0.299, followed by a 2012 maximum of 0.567 and a minimum of -0.064, and finally, in 2022, a maximum of 0.501 and minimum of 0.0601. Results show that the maximum SAVI values progressively declined throughout the study period 2002-2022. This means that vegetation health had been degenerating over the study years.

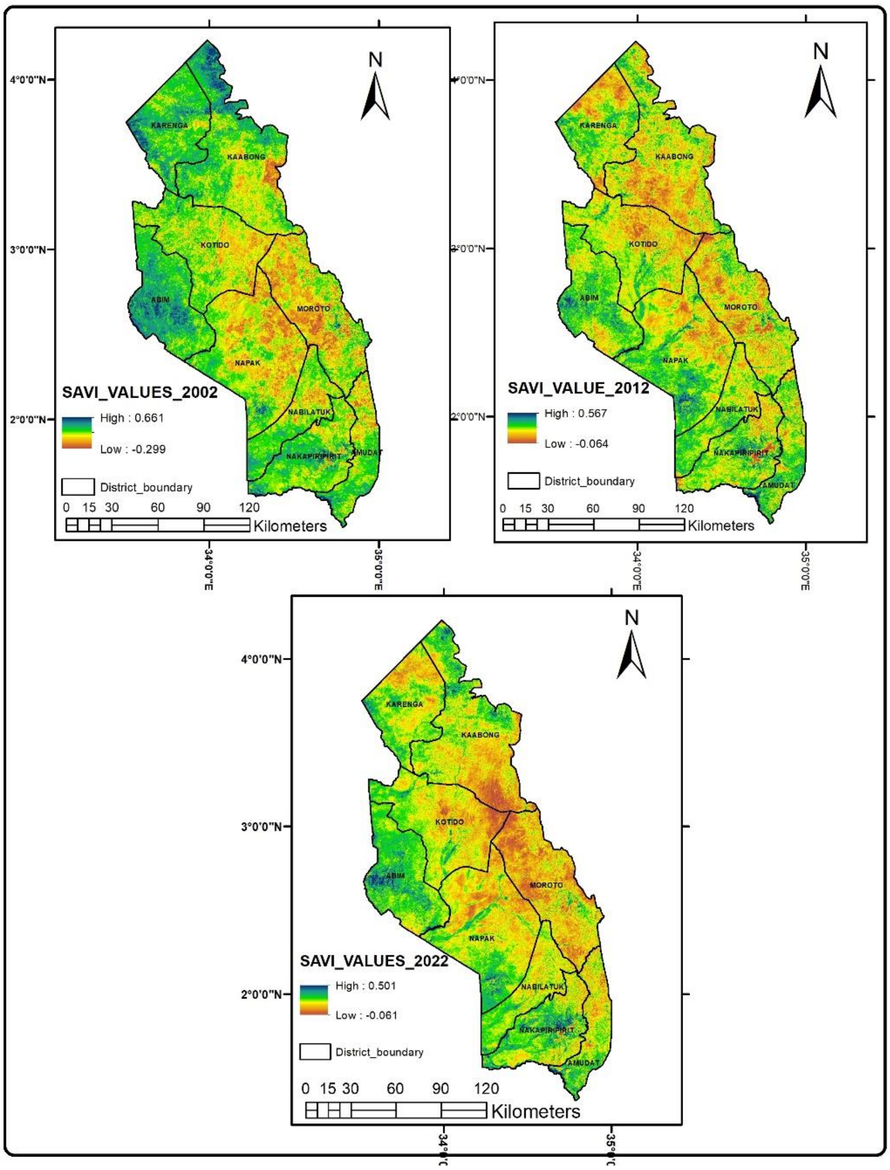

Figure 4. 3: Soil Adjusted Vegetation Index Maps 2002-2022 showing rangeland vegetation health

SAVI values were used to analyse vegetation distribution and density across ecological zones over the study period for comparison purposes. The three ecological zones (**refer to Figure 4.4**) were defined by dominant activity in the areas and climatic characteristics (rainfall totals received).

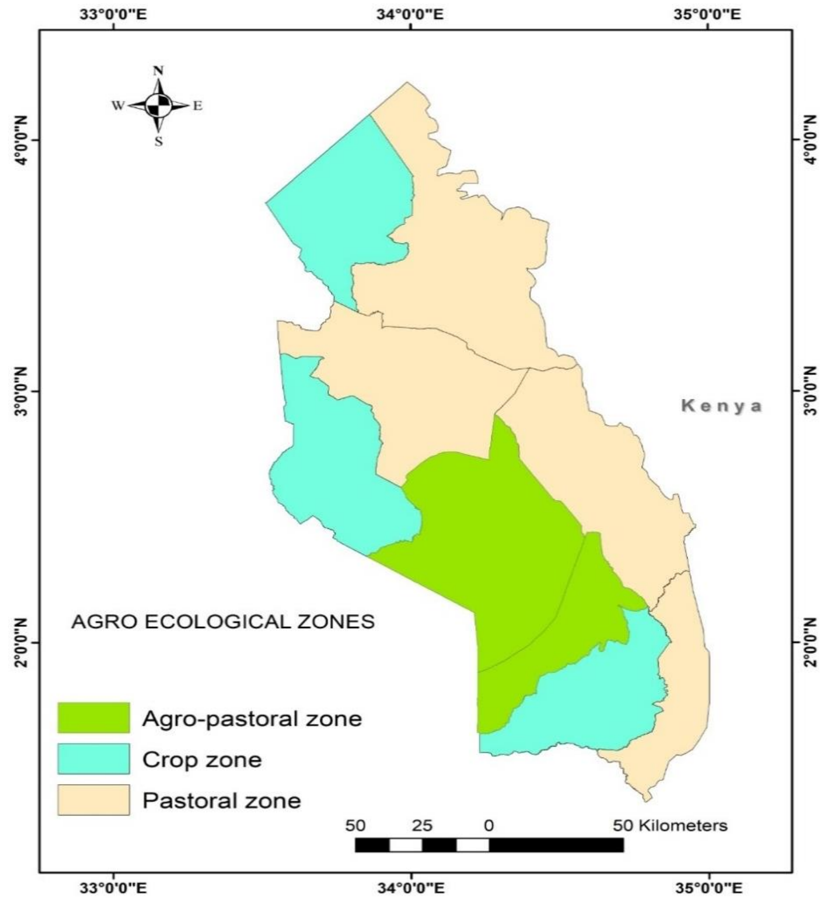

Figure 4. 4: The Map of Karamoja showing the Agro-Ecological Zones.

4.2.1 Descriptive Statistics of SAVI Values under Ecological Zones in Karamoja

The detailed description of the analysis is presented in Table 4.6. The findings, detailed in Table 4.6, indicated that 241 observations were made in the Agro-pastoral zone out of 1000 SAVI point observations randomly conducted in the whole Karamoja region.

The following results was obtained;

In 2002, the minimum SAVI value was -0.16, the maximum was 0.34, the median was 0.11, the range was 0.49, the mean was 0.11, the variance was 1, and the Standard deviation was 0.08.

In 2012, minimum 0.18, maximum 0.37, median 0.27, range 0.19, mean 0.27, variance of 1 and standard deviation of 0.04

In 2022, a minimum of 0.15, maximum of 0.34, median of 0.22, range of 0.19, mean of 0.22, variance of 1 and standard deviation of 0.03.

Findings revealed that in the Agro-pastoral zone, the lowest SAVI value, -0.16, was recorded in 2002. The highest value, 0.37, was recorded in 2012. The lowest mean value of 0.11 was recorded in 2002, and the highest value of 0.27 was registered in 2012.

The highest range value, 0.49, was recorded in 2002 and 0.19 in 2012 and 2022.

In the crop zone, findings were as follows: in 2002, the minimum was 0.02, maximum 0.44, median 0.21, range 0.42, mean 21, variance one and standard deviation of 0.07. In 2012, the minimum value was at 0.17, maximum 0.39, median 0.21, range 0.22, mean 0.27, variance of 1 and standard deviation value was 0.04. Finally, in 2022, the minimum SAVI value was 0.17, maximum 0.39, median 0.24, range value of 0.21, mean value of 0.24, variance at one and standard deviation value of 0.04. Therefore, the SAVI values in the crop zone indicated that the lowest value, 0.02, was recorded in 2002, with the highest of 0.44, also registered in 2002. The lowest mean value of 0.21 was recorded in 2002, and the highest of 0.27 was recorded in 2012. The highest range value of 0.42 was recorded in 2012, with the lowest value of 0.21 being in 2022

Findings in the Pastoral zone were as follows,

In 2002, minimum SAVI values were recorded at 0.19, maximum 0.41, median 0.14, range of 0.22, mean value of 0.13, variance of 1 and standard deviation of 0.09.

In 2012, the minimum value was 0.13, the maximum was 0.38, the median was 0.25, the range was 0.25, the mean was 0.25, the variance was 1, and the standard deviation was 0.04.

Finally, in 2022, the minimum value was 0.12, the maximum value was 0.33, the median was 0.21, the range was 0.21, the mean value was 0.21, the variance was 1, and the standard deviation was 0.03.

The lowest SAVI value in the Pastoral zone was 0.12 in 2022, and the highest value was 0.41 in 2002.

The lowest mean value was 0.13, recorded in 2002, and the highest was 0.25, recorded in 2012. The highest range value of 0.21 was recorded in 2022, and the highest range value of 0.25 was recorded in 2012.

For all the agro-ecological zones combined, the mean values were given as follows;

In 2002, the minimum value was 0.19, the maximum was 0.44, the median value was 0.15, the range was 0.63, the mean value was 0.15, the variance was 1, and the standard deviation was 0.09.

In 2012, the minimum value was 0.13, the maximum value was 0.39, the median value was 0.26, the range value was 0.26, the mean was 0.26, the variance was 1, and the standard deviation was 0.04.

Finally, in 2022, the minimum value was 0.12, the maximum was 0.39, the median was 0.22, the range was 0.27, the mean was 0.22, the variance was 1, and the standard deviation was 0.04 0.

The overall average mean SAVI values for all the ecological zones combined are as follows;

The lowest value, 0.12, was recorded in 2022, and the highest value, 0.44, was recorded in 2002.

The highest average range value, 0.63, was registered in 2002, and the lowest average value, 0.26, was recorded in 2012.

The lowest average mean in the zone was 0.15 in 2002, and the highest mean value of 0.26 was recorded in 2012. This means that productivity was higher in 2012 compared to other years.

Table 4. 5: Descriptive Statistics of SAVI Values by Ecological Zone.

Agro-Pastoral Zone	**SAVI 2002**	**SAVI 2012**	**SAVI 2022**
No. of observations	241	241	241
Minimum	-0.16	0.18	0.15
Maximum	0.34	0.37	0.34
Median	0.11	0.27	0.22
Range	0.49	0.19	0.19
Mean	0.11	0.27	0.22
Variance	1	1	1
Standard deviation (n-1)	0.08	0.04	0.03
Crop zone	**SAVI 2002**	**SAVI 2012**	**SAVI 2022**
No. of observations	277	277	277
Minimum	0.02	0.17	0.17
Maximum	0.44	0.39	0.39
Median	0.21	0.21	0.24
Range	0.42	0.22	0.21
Mean	0.21	0.27	0.24
Variance	1	1	1
Standard deviation (n-1)	0.07	0.04	0.04
Pastoral zone	**SAVI 2002**	**SAVI 2012**	**SAVI 2022**
No. of observations	482	482	482
Minimum	-0.19	0.13	0.12
Maximum	0.41	0.38	0.33
Median	0.14	0.25	0.21
Range	0.22	0.25	0.21
Mean	0.13	0.25	0.21
Variance	1	1	1
Standard deviation (n-1)	0.09	0.04	0.03
All Zones	**SAVI 2002**	**SAVI 2012**	**SAVI 2022**
No. of observations	1000	1000	1000
Minimum	-0.19	0.13	0.12
Maximum	0.44	0.39	0.39
Median	0.15	0.26	0.22
Range	0.63	0.26	0.27
Mean	0.15	0.26	0.22
Variance	1	1	1
Standard deviation (n-1)	0.09	0.04	0.04

4.2.2 Comparison of the vegetation health across the three ecological zones

The least significant test to establish the significance of variances in productivity across the ecological zines was conducted over 2002, 2012, and 2022.

Results presented in Table 4.6 revealed that SAVI values were higher in the crop zone across all the study years: 0.21, 0.29, and 0.26 in 2002, 2012, and 2022, respectively. This means that productivity was highest in the crop zone, followed by the pastoral zone with 0.13, 0.29, and 0.23 and lastly, the agro-pastoral zone with 0.11, 0.29, and 0.24 in 2002, 2012, and 2022, respectively.

Table 4. 6: Least Significant Difference Test

Ecological zones	2002	2012	2022
Crop zone	0.21	0.29	0.26
Pastoral zone	0.13	0.27	0.23
Agro-pastoral zone	0.11	0.29	0.24

4.3. To examine the most dominant drivers of rangeland degradation in the Karamoja region, Northeastern Uganda

The study established the factors underlying Karamoja rangeland's degradation, and the findings are presented in Table 4.7 according to their levels of dominance. Data was obtained from 264 (68%) households in seven selected districts (Abim, Amudat, Kaabong, Kotido, Moroto, Nakapiripirit and Napak) out of nine districts of Karamoja that participated in the exercise. The perceived drivers to underpin rangeland degradation also varied significantly across the zones. Responses from that ecological zone are presented as follows:

From the crop zone, responses reveal that charcoal burning scored highest 68 (10%), followed by overgrazing 53 (7.8%), then drought 49 (7.2%), followed by population increase 42 (6.2%), enforcement of rangeland regulations 41 (6.0%), followed by wildfires 39 (5.7%), limited awareness on rangeland conservation came next with 38 (5.6%), overharvesting of rangeland resources followed with 37 (5.4%), then poverty 36 (5.3%), next was invasion of alien species 35 (5.1%), followed by overstocking 33 (4.8%), then constructions of roads with 31 (4.6%), followed by political interference got 28 (4.1%), land tenure system followed next with 26 (3.8), agricultural expansion got 25 responses (3.7%), then urbanisation and flooding got the same number of responses 24 (3.5%), infrastructural developments followed with20 (2.9%), dumping of solid wastes and industrial effluents 19 (2.8%) and lastly mining 13 (1.9%)

From Agro-pastoral zone, results indicated that charcoal burning still came top of the list with 40 (8.7%), followed by agricultural land expansion, then wildfires, overstocking and overgrazing followed with 38 (8.3%), poverty got 36 (7.9%), enforcement of rangeland regulation 35 (7.6%), population increase 34 (7.4%), floods and construction of roads 32 (7.0%), drought 31 (6.8%), land tenure system 24 (5.2%), mining 13 (2.8%), invasion of alien species 12 (2.6%), infrastructural development 09 (2.0%), limited awareness on rangeland conservation was next 04 (0.9%), dumping of solid wastes followed with 02 (0.4%), and lastly was political interference with 1 response (0.2%)

From Pastoral zone, results showed that overgrazing ranked highest with 73 (12.0%), followed by charcoal burning with 72 (11.8%), third in line was drought with 60 (9.9%), overstocking with 59 (9.7%), followed by population increase got 46 (7.6%), poverty 45 (7.4%), this was followed by agricultural land expansion with 44 (7.2%), next was mining 35 (5.8%) next was overharvesting rangeland resources which had 26 (4.3%), flooding was next with 21 responses (3.5%), construction of roads and wildfires came out with 20 (3.3%), next was limited knowledge with 18 responses (3.0%), dumping of solid wastes and infrastructural developments eg industries got 14 (2.3%), political interference got 12 responses (2.0%), followed by land tenure system which got 11 responses (1.8%), enforcement of rangeland regulation had 9 (1.5%), invasion of alien species got 7 responses (1.2%) and lastly came urbanization with 02 responses (0.3%).

The summation of all responses from the three ecological zones per driver gave an overall ranking of each driver underlying rangeland degradation as follows; charcoal burning was ranked highest with 180 responses across ecological zones (10.3%), followed by overgrazing with 164 (9.4%), this was followed by drought with a total of 140 (8.0%), next was overstocking which got 130 (7.4%), population increase was next in the line with 122 (7.0%), followed by poverty with 117 (6.7%), then agricultural land expansion followed with 108 (6.2%), next was wildfires with 97 (5.6), enforcement of rangeland regulations followed with 85 (4.9%), next was construction of roads with 83 (4.8%), flooding followed suit with 77 (4.4%), overharvesting of rangeland resources was 63 (3.6%), land tenure system and mining followed with 61 (3.5%), limited awareness on rangeland conservation was next with 60

(3.4%), invasion of alien species followed with 54 (3.1%), infrastructural development e.g., industries followed with 43 (2.5%), political interference was subsequent with 41 (2.3%), dumping of solid wastes followed with 35 responses (2.0%) and lastly was urbanization with 26 responses (1.5%).

Overall findings revealed significant drivers responsible for the low productivity across all ecological zones in the study area based on the frequency of responses. Charcoal burning, with a frequency of 180 (10.3%), was ranked the highest, followed by overgrazing at 164 (9.4%) and drought at 140 (8.0%). Other drivers with significant contributions were population increase, poverty, expansion of agriculture, wildfires, weak enforcement of the rangeland regulation, flooding and road construction. The drivers underlying rangeland degradation that were found to be less significant included urbanization with a frequency of 26 (1.5%), dumping of solid waste, 35 (2.0%), political interference, 41 (2.3%), and industrial development, 43 (2.5%).

Using the P-value, all drivers except mining, with a P-value of .133, were found to be statistically significant to rangeland degradation because their P-values ranged from .000 to .011, which is less than the threshold of 0.05.

Cramer's V statistical analysis was used to determine the strength of the association between rangeland degradation and the drivers. The findings indicate that most drivers had moderate to strong associations represented by Cramer’s V of 0.3-< 0.5. However, drought, mining, dumping of solid wastes, industrial development and overgrazing were found to have a low association (0.1-< 0.3) with rangeland degradation. Wildfires had a powerful association (> 0.586), while weak enforcement of rangeland regulation did not have any association.

Table 4. 7: Responses of members of households on underlying drivers of rangeland degradation (number of households=264)

SN	Underlying drivers	Crop zone		Agro pastoral zone		Pastoral zone		Total		Pearson Chi-Square	P-value	Cramer's V
		N	%	N	%	N	%	N	%	X^2	Sig.	
1	Charcoal burning	68	10	40	8.7	72	11.8	180	10.3	43.648	.000	.413
2	Over grazing	53	7.8	38	8.3	73	12.0	164	9.4	21.274	.000	.288
3	Drought	49	7.2	31	6.8	60	9.9	140	8.0	15.091[a]	.001	.243
4	Over stocking	33	4.8	38	8.3	59	9.7	130	7.4	34.945	.000	.369
5	Population increases	42	6.2	34	7.4	46	7.6	122	7.0	31.840	.000	.353
6	Poverty	36	5.3	36	7.9	45	7.4	117	6.7	38.008	.000	.385
7	Agricultural land expansion	25	3.7	39	8.5	44	7.2	108	6.2	56.097	.000	.468
8	Wildfires	39	5.7	38	8.3	20	3.3	97	5.6	87.789	.000	.586
9	Weak enforcement of rangeland regulations	41	6.0	35	7.6	9	1.5	85	4.9	106.091	.000	.000
10	Construction of roads	31	4.6	32	7.0	20	3.3	83	4.8	60.115[a]	.000	.485
11	Flooding	24	3.5	32	7.0	21	3.5	77	4.4	58.719[a]	.000	.479
12	Over harvesting of rangeland resources like firewood and poles	37	5.4			26	4.3	63	3.6	36.629[a]	.000	.378
13	Land tenure	26	3.8	24	5.2	11	1.8	61	3.5	49.367	.000	.439
14	Mining	13	1.9	13	2.8	35	5.8	61	3.5	4.041[a]	.133	.126
15	Limited awareness of rangeland conservation	38	5.6	4	.9	18	3.0	60	3.4	38.946	.000	.390
16	Invasion of alien species	35	5.1	12	2.6	7	1.2	54	3.1	47.994[a]	.000	.433
17	Infrastructural developments e.g., industries	20	2.9	9	2.0	14	2.3	43	2.5	8.997[a]	.011	.187
18	Political interference	28	4.1	1	.2	12	2.0	41	2.3	33.016	.000	.000
19	Dumping of solid waste and industrial effluents	19	2.8	2	.4	14	2.3	35	2.0	11.211[a]	.004	.209
20	Urbanisation	24	3.5			2	.3	26	1.5	51.288	.000	.448

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 15.54.
N is the number of responses on each underlying driver
NB. Divers with P value less or equal to 0.05 are significant drivers.

Source: Field

4.3.1 Charcoal burning

Charcoal burning received the highest responses and was therefore taken as the number one factor influencing rangeland cover degradation in the area, especially in the pastoral zone, where seventy respondents attested to it. The key informant interview further revealed that charcoal burning was one of the major factors underlying degradation patterns**.**

> "*… The current low level of vegetation (especially trees and bushes) coverage in the district is due to charcoal burning not grazing. The district has lost many animals to the current cattle raids that started around 2018 and has affected the whole region, Napak district inclusive. The most affected sub-counties are Matany, Lopei, Lotome, Lokopo and Ngoleriet. The problem with this practice is that some of the trees being destroyed are leguminous fodder trees (source of proteins) for the animals….".***Key informant, 2023.**

The key informant's narrative highlighted the district's low vegetation coverage primarily due to charcoal burning as depicted in Figure 4.8, exacerbated by significant cattle raids since 2018, impacting not only the district but also Napak district, particularly affecting sub-counties like Matany, Lopei, Lotome, Lokopo, and Ngoleriet, with the additional concern of the destruction of leguminous fodder trees crucial for animal protein sources, emphasizing the interconnected environmental, social, and economic challenges.

Plate 1: Researcher conducting key informant interview.

Plate 2: Research assistant administering household questionnaires

Source: Field 2023

In addition, another key informant interview with an environment officer emphasised that some parts of the district are completely barren, with only tree stumps, stone heaps without grass, big gullies, and rills.

> "*… said "after most farmers in the district losing their animals to cattle raids coupled with very long dry spells that have resulted in most times in very poor harvests or nothing completely, the people have unstoppably turned to the environment by mercilessly destroying trees for commercial charcoal production to survive the painful bite of hunger in the recent years with 2022 and 2023 being the worst".* **Key informant, 2023**

A combination of factors, including cattle rustling, drought, soil degradation, and famine, underpinned the high levels of charcoal burning in Karamoja. Prolonged dry spells led to crop failure and serious hunger among households, leaving people with no other option apart from burning charcoal, thus cutting down the trees.

Plate 3: Charcoal burning in Napak district **Plate 4: Charcoal burning in Abim district**

Source: Field, 2023

"… To save themselves from starvation, trees have suffered destruction for Charcoal burning. For the first time in 40 years, Kaabong district has had serious famine due to failed crops in the previous season and yet the animals that used to save people from this kind of shock were all raided with very few left…." **Key informant, 2023**

"the widespread charcoal burning in the district and the all-region for me is an indicator of a degraded soil, hence the low productivity of both food and pasture… however, we have passed a number of resolutions, and one among them is no cutting of trees which was very rampant, natural resource office to form a committee on rangeland management and come out with the district tree planting guide…", **Key informant, 2023**

The above narrative highlights the correlation between widespread charcoal burning and degraded soil, evidenced by low productivity in food crops and pasture lands, while also noting community resolutions such as prohibiting tree cutting, establishing a rangeland management committee, and developing a district tree planting guide, all aimed at addressing environmental degradation and promoting sustainable rangeland productivity. This reflected a community's awareness of the environmental challenges they face and their commitment to implementing solutions through policy interventions, committee formations, and sustainable practices such as tree planting and rangeland management

Plate 5: Trees cleared for charcoal burning in

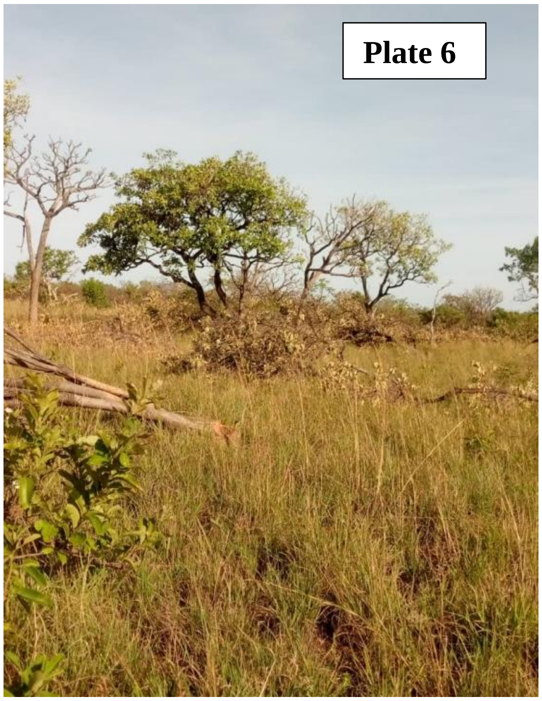

Plate 6: **Trees cut for charcoal in Namalu**

4.3.2 Over grazing

Overgrazing was the second most dominant underlying driver affecting rangeland degradation, with response frequency as high as 164 (representing 9.4%) due to overstocking in some areas; respondents to a tune of 130, representing 7.4%, perceived it as one of the reasons for rangeland degradation. There are selectively overgrazed areas which have high livestock concentrations, like in protected kraals, within the communities and watering points, especially around the valley tanks, due to the insecurity that had ravaged the region, especially from 2018 to date (2023 October-November when this data was being collected).

The examples of these overgrazed water areas depicted in Figures 8 and 9 in the region were Rupa Kobebe (the biggest in the whole region) found in Moroto district at the border with Kotido, where the Jie of Kotido, Turkana of Kenya and the Matheniko of Moroto water their animals from, Lokomaebu valley tank in Kotido sub-county in Kotido District, Longoromith valley tank (biggest) in Lobongya sub-county, Lokithelarengan valley tank in Kasile South and Longoritopoth valley tank in Lolelia Main, Timu, all in Kaabong District, Akado valley tank, Gulopopno, Arookojoland Kiruin Abim District, Areck valley tank in Nakicumet Parish and Kopedur in Lorengecora sub-county in Napaak District, Lokatapan, Namalu in Nakapiripirit District and Koicom (1.3 million cubic liters), Kosike in Amudat district. The overgrazed grazing land is those not far away from the protected kraals, settlements and even within the towns; this was true with Kaabong, Kotido, Abim and Nakapiripirit towns.

Plate 7: Grazing area at Nakichumet

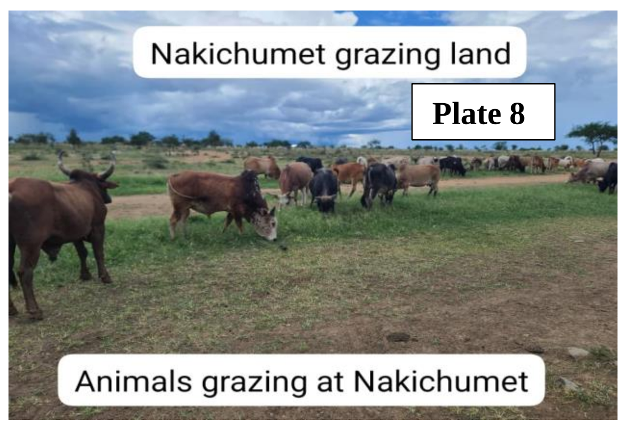

Plate 8: Namalu grazing land in Nakapiripirit district

Plate 9: Grazing land in Kiru Town Council, Abim District

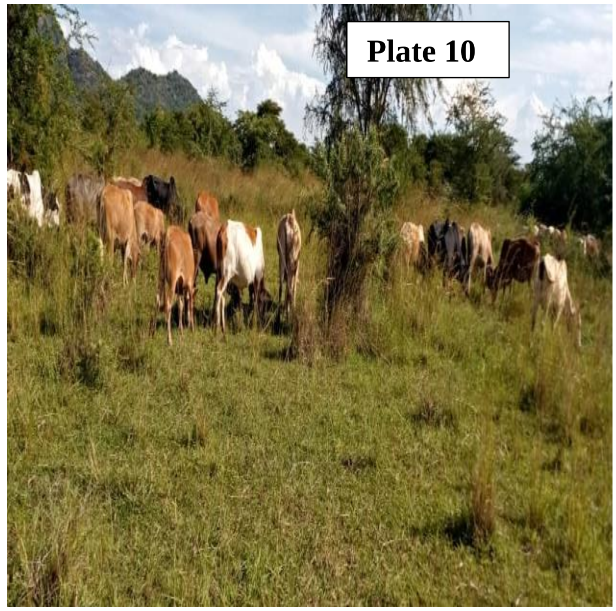

Plate 10: Timu grazing land in Kaabong district

Source: Field, 2023

The overgrazed areas have also been exposed to severe erosion and land degradation in case of rainfall, as shown in plates 4.7-4.10, thus worsening the rate of rangeland degradation, particularly around water points. Overgrazing depleted vegetation, caused soil erosion, and led to biodiversity loss, ultimately reducing rangeland productivity. The concentration of livestock around water points worsened the situation, intensifying grazing pressure in those areas. Additionally, insecurity exacerbated the problem by limiting livestock mobility and confining them to specific areas, resulting in localised overgrazing. Interventions such as rotational grazing, proper land management practices, and community-based natural resource management initiatives were implemented to address this trend and improve rangeland health. These efforts aimed to reduce grazing pressure around water points, promote sustainable livestock management practices, and enhance security measures to enable livestock mobility and reduce localized overgrazing.

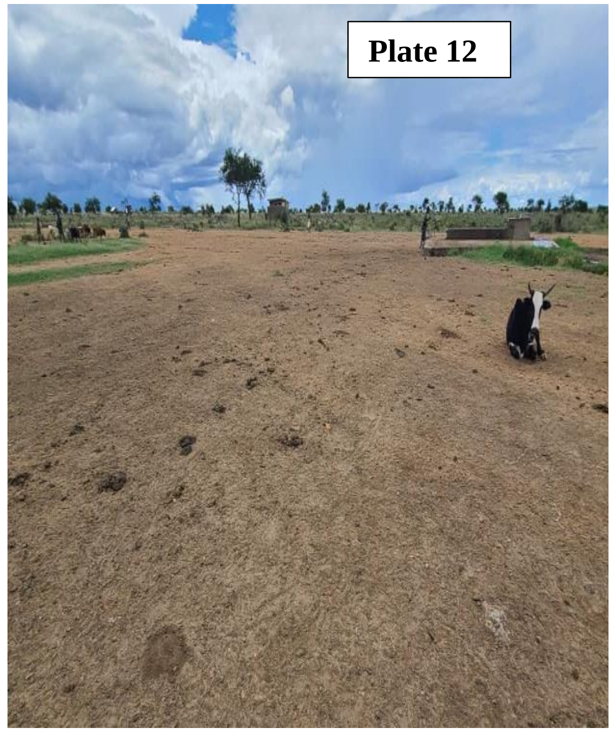

Plate 11: Rupaloreng in Karamoja

Plate 12: Degraded rangeland covers due to overgrazing Nakichimet

Source: Field, 2023

4.3.3 Agricultural Land Expansion

Agricultural expansion was also reported as one of the factors that influenced rangeland degradation, with 108 representing 6.2% of the total responses. The results revealed that the biggest degrading factor to the rangeland is bad agricultural practices like opening up very large chunks of land by completely clearing down trees and burning grass, leaving the land bare and prone to erosion, burning off the crop stalks that should have decomposed to better the soil for both crop and pasture, growing of the same crops on the same piece of the land season after season, especially cereals like sorghum, maize and to a small extent bull rush form the main crops grown in most pastoral districts. In contrast, the crop-zoned districts grow other additional crops like simsim, groundnuts, cassava, sweet potatoes, and others alongside the main cereal crops.

Recently, sedentarisation and agro-pastoralism programs have increased the need for fresh land for growing crops, further destroying vegetation and negatively impacting its health. Many non-governmental organizations in the region, like Mercy Corps and Feed the Hungry, are encouraging crop rotation as a way of soil conservation. The large chunks of land opened are most often abandoned in case of crop failure. This agricultural expansion was highly reported during a key informant interview in Napak district.

> *"In KangoleChini, a place called Lomuriangalepan (the name means the place of star grass which gives fresh milk) has currently changed into cropland by an investor who has opened up about 5200 hectares of land and is growing Seso 3 type of sorghum which the breweries use for making beers".* **Key informant, 2023.**

Furthermore, in Kotido District Local Government, it was revealed that similar practices championed rangeland degradation; she had this to say

> *"The unexplainable opening up of very large chunks of land for agriculture in the district is being driven by people from the nearby districts of Abim, Agago, Kitgum Lira Otuke, and Soroti who come and hire the land from the Jie people to grow mainly groundnuts which yield well when the rain is sufficient".* **Key informant, 2023**

4.3.4 Overharvesting of rangeland resources

Overharvesting rangeland resources like tree stems and firewood is one factor fastening rangeland degradation in Karamoja. To secure their animals from raiders and enemies, pastoralists cut down trees to build kraals houses and dead fences around their homes called the "Manyaatas." See the illustration on plates 13-15. The key informant interviews further emphasized this.

"…. a lot of young trees are destroyed for dead fencing of the Kraals ngawioyi and around the homesteads (akurao) and (ngalodoi) for joining, poles (nagkalio) for construction. The common trees used for this construction are from river banks like; Omaniman, Nasinyonoit in Morulinga, part of Lokok-Lokore catchment…" **Key informant, 2023**

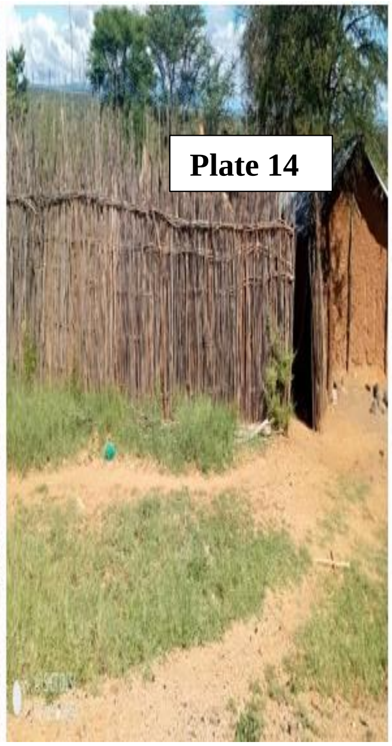

Plate 13: Harvesting rangeland resources for construction purposes; Animal kraal in Namalu (Nakapiripirit)

Plate 14: Home dead fencing in Nadunget (Moroto)

Plate 15: Poles for roofing and walling the houses (Napak)

Source: Field, 2023

4.3.5 Political insecurity

These insecurities from both within and from neighbouring districts of Karamoja and across the international borders of Kenya and in the region were factors that respondent pointed out to underlie Karamoja rangeland productivity and loss. They noted that cross-border raids were a form of insecurity that saw armed raiders from South Sudan, Turkana, and the Pokot of Kenya coming into the region with both their animals and guns. The animals become too many for the existing resources hence causing unnecessary competition that most times ended up in major conflicts, but also a source of illegal firearms to the Karimojong through the "black-market (exchange arms with animals). In the process, large numbers of animals are lost to raids but also those remaining become less yielding due to low or no feeding resources. The low political will to gazette the rangelands and ensure the existing environmental policies are enforced is viewed as an aspect of political interference.

4.3.6 High poverty levels among households

Poverty emerged as one of the key factors identified by household members in the study area, a finding corroborated by key informants. According to the district environment officer for Kotido District Local Government, over 80% of the population in Kotido and the wider region remains below the poverty line due to various factors such as climate variability, low education levels, and high unemployment rates. These circumstances drive them to seek livelihoods primarily through cutting down trees and bushes for commercialized wood fuel and charcoal burning and burning vegetation to open up hunting grounds for wild game for food and sale. Additionally, minor factors impacting rangeland productivity in the Karamoja region include mining, flooding, road construction, solid waste dumping, industrial effluents, industrial development, limited awareness, and a poor land tenure system.

4.4 Socio-demographic characteristics of the sampled households

Table 4.8 shows the demographic details of the people who took part in the survey. The survey involved 264 participants in the study area. Among them, 142 were females (55.5%) and 114 were males (44.5%). Regarding household roles, among the 114 males in the study, 102 were fathers, 8 were sons, and 4 were grandfathers. Meanwhile, out of the 142 females who participated, 127 were mothers, 5 were daughters, and 10 were grandmothers. This indicates a balanced representation of male and female perspectives in the collected data. Therefore, the information gathered is reliable for drawing conclusions and making decisions regarding the region.

The average age of respondents was 40 years, with a standard deviation of 13 years. This means the youngest respondent was 27 years old, while the oldest was 79. It indicates that individuals from all age groups are involved in production processes, with the most energetic group (around 40 years old) forming most of the workforce in activities such as burning charcoal, grazing animals, and managing rangelands through controlled fires. Regarding marital status, the majority of respondents, 246 (92%), were married, while 5 (1.8%) were single, 1 (0.3%) were separated, and 15 (5.9%) were widowed. This suggests that a significant portion of the population is settled in families, leading to inevitable population growth due to the childbearing age of the majority and the resulting pressure on existing resources.

In terms of household positions, 102 (40%) were fathers, 127 (50%) were mothers, 8 were sons, 5 were daughters, and 14 (3.8%) were grandparents. This indicates that the information was gathered from adults who hold decision-making positions within the family, particularly concerning tasks division, economic activities, and rangeland management practices. Regarding education level, findings revealed that 177 (67%) had never received formal education, 52 (19.7%) had primary education, 18 (6.8%) had completed Ordinary level, 4 (1.5%) had completed Advanced level, 4 (1.5%) had received specialized training, and 9 (3.4%) had other educational backgrounds. With most of the population being illiterate, there may be challenges in adapting to new changes, limited knowledge of sustainable rangeland management, inefficient resource management skills, limited access to information and extension services, and little to no capacity for adaptive management involving ecosystem monitoring. The average number of children per family, 4.69, as shown in the table, reflects the population increase and the subsequent rise in resource usage and demand.

Table 4. 8: Demographic characteristics of the respondents (N=264)

Variables	Description	Statistics
Household position	Father	102 (40.3%)
	Mother	127 (49.8%)
	Son	8 (3.2%)
	Daughter	5 (2.0%)
	Grandfather	4 (1.2%)
	Grandmother	10 (3.6%)
Marital status	Married	246 (91.5%)
	Single	5 (2.0%)
	Separated/divorced	1 (0.4%)
	Widowed	15 (6.0%)
Education level	No formal education	157 (63.3%)
	Primary/elementary	56 (22.6%)
	Ordinary (O) level	18 (7.3%)
	Advanced (A) level	4 (1.6%)
	Specialized/Vocational training	4 (1.6%)
	Graduate (Diploma/Degree)	9 (3.6%)
Gender	Female	142 (55.5%)
	Male	114 (44.5%)

Source: Field, 2023

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 Introduction

In this section, the main study outcomes are presented and analyzed in relation to previous studies, guided by the study objectives.

5.1.1 The extent, trend and transitions of spatiotemporal changes in rangeland use between 2002 and 2022 in Karamoja region, Northeastern Uganda

This persistent increase in grassland coverage could have been attributed to massive transitions from other land uses into grassland. For example, cropland is among the land covers that transited more into grassland, with 41% in 2012 and 2022. The reason is frequent occurrences of drought in the region that have led to continuous crop failure and discouraged farmers from continuing with the activity, hence the formerly opened land for agriculture regenerating into grassland. The study findings above agree with the findings by (ACTED-Uganda, 2016), who reported that the increasing importance attached to agriculture was losing out due to the constant failure of crops every year, making it a non-viable venture. About 70% of crop failure is attributed to irregular patterns of rainfall (Egeru, Okia, et al., 2014) much of bare ground, built-up, and bushland also transitioned into grassland by 47%, 44%, 31% in 2012, 34%, 3.9%, and 41% in 2022, respectively. A study by Samuels et al. (2023) in Karamoja could be attributed to changes in rainfall, stocking rate, and kraaling in rangeland conditions.

However, reports from the field also attributed the trend to the relocation of former occupants of the built-up places shifting to their traditional homesteads together with their livestock that had overgrazed and caused the community grazing land to become bare. Consequently, the abandoned settlements and bare lands were regenerated into grassland by 2012. This is in line with the findings of Nalule (2010), who noted that those ‘forcefully evacuated’ from towns and ‘cattle raid victims’ relocated to the ‘voluntary’ camps to start crop farming. The bushland also gave way to grassland as a result of the herdsmen starting to graze animals in the bushes that had grown during the insecurity period in the region. Overall, grassland became a dominant land cover type by 2012, according to the study findings, with the most significant spatial extent of 9668 km^2, representing 35% of the total land extent of the Karamoja region. This is in line with the earlier findings by (Mwanjalolo, 2014), who reported that grassland was still the dominant cover type in the Karamoja region by 2013, with the trend continuing up to 2022 when it finally topped the coverage with a total percentage of 41%.

Built-up, on the other hand, increased in 2022 from the transitions of other land uses and cover types by 18.3% in the current study. This increase is because of the recent creation of many administrative units like new districts, town councils, sub-counties, and parishes between 2010 and 2020 by the government of Uganda. This has seen seven districts being curved out of the previous two districts (Moroto and Kotido) that formerly formed Karamoja now having nine districts in total. The increasing trend of built-up places in the current study agrees with the trend revealed by the study conducted by Bunyangha et al. (2021) and Karaya et al. (2021) of built-up increasing by 15.7%, with a variation of 2.6% lower than the current study findings. Given the time difference with the current study, the variations can be genuine.

The extensive coverage of woodland (46%) in 2002 is attributed to the insecurity related to cattle rustling in the area in the previous years. ACTED-Uganda, (2016); and Egeru et al., (2014), have also reported that in the previous three and a half decades Karamoja region experienced civil unrest because of the presence of small firearms in possession of the local community. However, after the 2001 disarmament program by the government, peace was experienced, and this enabled the people to engage in extensive farming activities that led to massive clearing of natural vegetation cover, especially woodland. Woodland rapidly got destroyed because it was believed that areas with luxuriant trees were fertile and, therefore, crops would do better there. This is in line with (Egeru, Okia, et al., 2014) who acknowledged earlier study findings that reported deforestation as a significant factor causing major changes in the vegetation and pasture landscape in the region. Consequently, the clearing of woodland vegetation led to the massive conversion of woodland by 82.9% into other land uses and covers like bushland by 34%, grassland by 29%, and cropland by 16% in 2012, yet woodland only gained 18% from other land uses and covers in the same period. This study's findings are in agreement with (Mwanjalolo, 2014), whose findings revealed that between 1986 and 2013, woodland lost over 80% of its spatial coverage to other land use/cover types in Karamoja rangelands.

Bushland registered the highest increase (15%) than any other land use/cover type in the region by 2012, making it second to grassland. The reason on the ground was that much woodland was destroyed during grazing since some of the trees like *Alilii, Olwedho* which form most of the wooded trees found in Abim, western Napak around Acukudu, Nyar-kidi, Lobanya in Kotido and parts of Karenga are most times cut down for animals to feed on causing the modification of the woodland into bushland. These study findings align with the report by IUCN (2016), which indicated that the farming approaches were characterized by the "clearcutting" of trees, causing the loss of valuable species used as feeds by animals. Further still, when cropland was abandoned due to crop failures resulting from weather variability, the previously cut trees regenerated into bushes before maturing into trees after many years. This is in line with (Egeru, Okia, et al., 2014), who reported that woodland transitioned to bushland by over 30% between 1986 and 2013, probably due to the perception that soils under woodland are cool.

Cropland progressively increased in spatial coverage across the study years 2002, 2012, and 2022 with 17% and 23% in 2012 and 2022 respectively. This trend was attributed to the effect of the cattle raids that had hit the region badly, leaving many people without animals and, therefore, crop farming becoming the most available option for them to survive. This was augmented by the government's project of sedentarization and supplying of farming inputs. These findings are in agreement with the study findings by Nakalembe, (2017) who reported an increase in crop farming by three folds from 2000 to 2011. This finding was further supported by Al, (2020), who reported on the increment in small-scale croplands over the past three to four decades at the expense of woodland and bushland**.**

5.1.2 The spatiotemporal variations on rangelands productivity between 2002 and 2022 in Karamoja region, Northeastern Uganda

This study established that there is generally low vegetation coverage in the Karamoja region, evidenced by the low vegetation indices (SAVI values) with maximum values of 0.44, 0.39 and 0.39 for 2002, 2012 and 2022, respectively, with minimum values of -0.19, 0.13 and 0.12 for 2002, 2012 and 2022 respectively. Even the highest value of 0.44 in the region is below the vegetation index average. The low values imply low densities and unhealthy vegetation and, eventually, a low level of an ecosystem to produce adequate standing biomass. This low vegetation cover in the region is attributed to the semi-arid climatic condition experienced in the area, which is characterized by low, unevenly distributed rainfall received, coupled with the recent high frequencies of prolonged drought causing low plant coverage. These study findings complement those of (Bernard et al., 2022), who noted that the lowest production of standing biomass in Uganda was registered in the Karamoja region, which experiences a semi-arid climate and other factors. This assertion confirms that there is a relationship between a place's climate and the amount of standing biomass in an ecosystem. Senda et al. (2020) too agree with the fact that climate variability has further lowered the productivity levels of rangelands in semi-arid areas Egeru, Wasonga, et al., (2014), also agreed with the study findings by reporting that rainfall irregularities and drought, which are associated with variations in climatic and weather conditions in the Karamoja region, are responsible for close to 70% of crop failure and insufficient pasture availability. Aleper et al. (2017) it should be noted that weather conditions determine the availability of pasture, and so even when the region had a high livestock population, the productivity was low as a result of poor pasture and water, leading to long-distance trekking by the animals, which physically wore them off.

The study findings indicated that the Productivity of standing biomass is not uniform across all ecological zones as well as over the years of the current study; the crop zone had the highest average SAVI values of 0.21, 0.29 and 0.26 in 2002, 2012 and 2022 respectively compared to agro-pastoral with 0.13, 0.27 and 0.23 and 0.11, 0.29 and 0.24 for pastoral zone in 2002, 2012 and 2022 respectively. This pattern is attributed to the crop zone being found on the region's green belt that receives higher rainfall totals compared to the other two zones, making it greener to depict healthier vegetation indices than agro-pastoral and pastoral zones. These field results are in line with the study finding by (Senda et al., 2020), who said rangeland productivity is not uniform across the globe in terms of coverage and time, which he attributed to the unique conditions experienced in various rangelands (which include; location, climatic variations, population factors and practices). The varying conditions experienced in the rangelands have resulted in huge inconsistencies in forage supply attributed to rangeland use/cover change that quickened degradation levels (Godde et al., 2020); this presents a major setback in both livestock and food crop productivity.

On a global scale, (Godde et al., 2020) reported that about 73% of the total rangelands face a significant decline in their standing biomass because of the distinctive conditions globally; thus, a decline in livestock productivity endangers the livelihood of millions of people who depend on ecosystem services. Cherlet et al. (2013) asserted that Europe, like the rest of the globe, experiences a land productivity decline across all member states due to the growing population pressure on land. Relatively low productivity of corn and pasture is experienced in lower Mississippi and California central Valley of the United States of America (i.e. about 10%-20% of the expected yields) faced with water deficit-related degradation because of low precipitation and high evapotranspiration (Yang et al., 2020). This points to the need to control the population of both people and animals, climate change adaptation strategies, and irrigation in the areas facing water deficit to reduce the alarming decline of rangeland productivity (Yang et al., 2020).

5.1.3 The most dominant drivers of rangeland degradation in Karamoja region, Northeastern Uganda

The dominant factors underlying rangeland degradation in Karamoja findings reveal that several factors jointly contribute to the region's widespread vegetation depletion. Charcoal burning, overgrazing, wildfires, and drought patterns were highlighted as primary factors in the degradation status of the region. Both household heads and Key informants attributed this trend to the challenging living conditions in the region, including economic setbacks such as animal loss due to raids and crop failures from drought. As a survival strategy, people turn on the environment to burn charcoal and cut trees for commercial wood fuel, driven by the ready market in significant towns both within and outside the region and unsustainable hunting for wild game, further degrading the already compromised rangeland. The survival of the local people, who are largely dependent on the natural environment for their daily living, is in great danger if the destruction of the environment continues at this rate unchecked. These findings align with studies by Aleper et al. (2017) and Mercy Corps (2016), highlighting charcoal burning as a detrimental response to environmental challenges.

Cropland expansion and sedentarization emerged as significant factors affecting rangeland degradation in Karamoja, displacing pastoralism as the dominant activity and reducing available grazing land. This transformation has led to overstocking and overgrazing of remaining rangelands. The disarmament initiative in 2001 initially brought about a period of peace, encouraging sedentary lifestyles and crop cultivation. However, this transition has adversely impacted animal yields due to reduced rangeland availability, as noted by Aleper et al. (2017). (IUCN, 2016) highlighted that clearing vegetation for crop cultivation and sedentary living contributes to ecological degradation.

This study established the prevalence of Political interference, notably Turkana and the Dinka of South Sudan practising cross-border raids from neighbouring countries of Western Kenya and counter-raids from the Karamojongs of Uganda. This has resulted in insecurity in the region, leading to the loss of lives and animals and worsening the high poverty levels very high in the region. Likewise, ACTED-Uganda (2016) identified armed raids from communities in South Sudan, Turkana, and Pokot of Kenya as significant sources of conflict, corroborating the study's findings. IUCN (2016) also highlighted the lack of political will to gazette rangelands and enforce environmental policies as contributing to poor rangeland conditions. High poverty levels in Karamoja significantly impact rangeland productivity, as evidenced by the study's findings and supported by IUCN (2016) and Mercy Corps (2016). Limited livelihood alternatives drive indiscriminate resource exploitation, such as tree cutting for charcoal burning, further degrading rangelands. The disparity between regional and national poverty indices exacerbates environmental degradation as impoverished communities turn to natural resources for survival.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. Introduction

This chapter presents the conclusion and possible way forward on areas of concern that require the attention of stakeholders.

6.2. Conclusion

The study concluded that there had been significant and rapid changes in rangeland use types over the study period mainly due to shifts from one type of use, especially pastoralism, to crop cultivation and charcoal burning, which are detrimental to the natural cover, with woodland mainly being sacrificed, and bushland following suit. For example, much of the woodland was cleared, evidenced by a sharp reduction in its coverage that is from 12637 km^2 in 2002 to 2953 km^2 and 2087 km^2in 2012 and 2022, respectively, with bushland coverage declining too between 2012 (8776 km^2) and 2022(6437 km^2) as other land use types such as grassland and cropland increased across the study years. This decline gives emphasis to the impact of human activities on rangeland ecosystems, pointing to the need for sustainable land management practices to mitigate further deforestation and land degradation.

The study concluded that Karamoja rangeland productivity is highly related to rangeland use pattern. This is because the vegetation indices fluctuated following the region's land use pattern. For example, as built-up areas increased, productivity lowered drastically, indicating the dynamic influences of such land use on the productive capacity of the area affected. Therefore, areas with high productivity were mainly identified as basically in the crop zone, while areas of concern showed notable expansions of depleted zones over time. These findings stress the need for ongoing monitoring and adaptive management strategies to ensure the sustainability of rangeland ecosystems and enhanced productivity in all three ecological zones.

The study concluded that the factors underlying rangeland degradation were not uniform across all ecological zones. This underscores the need for comprehensive region-specific management strategies to address rangeland ecosystems' multifaceted challenges.

6.3 Recommendation

The government should develop and enforce land use policies that prioritize the conservation of rangeland ecosystems, ensure sustainable management practices, and prevent further land degradation.

Invest in community-based education and outreach programs to raise awareness about the importance of rangeland conservation and sustainable land management practices.

The local community should implement sustainable land management practices, such as agroforestry and rotational grazing, to mitigate further deforestation and land degradation and preserve valuable woodland areas.

Enhance community-led initiatives for reforestation and bushland conservation efforts, promoting the restoration of degraded ecosystems and biodiversity, especially in the agro-pastoral ecological zones that grapple with severe rangeland degradation.

6.4 Areas for further studies

The government, local communities and or able individual well-wishers can fund studies on

Longitudinal studies will investigate the long-term impacts of human activities and climate change on rangeland productivity and explore potential adaptation strategies for mitigating negative effects.

Explore the socio-economic drivers behind land use changes and their implications for rangeland ecosystems, integrating interdisciplinary approaches to develop comprehensive management strategies.

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Appendices

Appendix I: Questionnaire tool

HOUSEHOLD QUESTIONNAIRE

INTRODUCTION AND CONSENT

My name is …………………………….. from Kyambogo University. We are conducting a study on **Spatio-Temporal Variability in Rangeland degradation and drivers in the Karamoja Sub-region of Northeastern Uganda.** You have been randomly selected to participate in this survey and your participation is completely voluntary but very important. The information collected will solely be used for academic purposes and your private information will be kept confidential.

A: IDENTIFICATION AND LOCATION

A.1 Date…………………………………………

Location

A.2 Ecological Zone	**A.3 District**	**A.4 Sub county**	**A.5 Parish**	**A.6 Village**
1. Crop 2. Mixed crop and livestock 3. Pastoral	1. Abim 2. Amudat 3. Kaabong 4. Kotido 5. Moroto 6. Nakapiripiriti 7. Napak	1. ………….. 2. ………….. 3. ………….. 4. …………..	1. ………… 2. ………… 3. ………… 4. …………	1. …………. 2. …………. 3. …………. 4. ………….

A.7 Coordinates: Latitude……………………
Longitude………………………..Elevation……………

B. DEMOGRAPHIC CHARACTERISTICS OF HOUSEHOLDS

B1. What is your household Position?

1. Father
2. Mother
3. Son
4. Daughter
5. Grandchild
6. Grandfather
7. Grandmother
8. Others

B2. What is the composition of the family? (Members who have lived here in the past 3 months).

Category	**Males**	**Females**
Children (Below 18 years)		
Youth (18-35 years)		
Adult (Above 35 years)		

B3. Sex of the respondent

1. Female	2. Male

B4. Age of respondent (Age in complete years) ……………………….

B5. Marital status of household representative

1. Married	2. Single	3. Separated/divorced	4. Widowed

B6. What is your level of education?

1. No formal education
2. Primary/elementary
3. Ordinary (O) level
4. Advanced (A) level

5. Specialized/Vocational training
6. Graduate (Diploma/Degree)
7. Post-graduate (Masters/PhD)
8. Others (Specify)…………

B7. How many years have you lived in this village?

………………………………………………..

SECTION ONE: AGRICULTURAL PRODUCTION AND OTHER ACTIVITIES ON THE RANGELAND

1.1 List and rank the activities you carry out on land (***Multiple responses***)

Livelihood source	**1=yes, 2=no**	**If yes, give rank (starting with the most important (1, 2, 3, 4 ..)**
1. Crop farming		
2. Livestock farming		
3. Fish farming		
4. Fishing		
5. Charcoal burning		
6. Formal employment		
7. Business/trading		
8. Timber harvesting		
9. Casual labor		
10. Bee keeping		
11. Soap making		
12. Others (specify)		

1.2 How much land is allocated to each of the following activities?

Land use	**Land size (in acres) by type of ownership**			
	Privately owned	**Rented**	**Communally owned**	**TOTAL**
Crop production				
Grazing				
Under trees				
Aquaculture				
Fallow				
Abandoned				
TOTAL				

1.3 For land under crop farming, what is your mode of production?

1. Subsistence farming

2. Commercial farming

3. Both subsistence and commercial

1.4 For land under livestock, which livestock production system do you practice? **(Multiple responses)**

1. Communal/pastoral system

2. Agropastoral system

3. Tethering system

4. Extensive system (Here, mixed herds of cattle, sheep and goats are kept)

5. Fenced dairy farming system

6. Zero grazing

7. Mixed farming system (It involves both crop and livestock production)

1.5 List the crops you cultivated in the last 12 months and mention how much you harvested, consumed and sold.

	Crop	**Total area cultivated crop (acres)**	**Total harvested (Kg)**	**Quantity consumed at home (kg)**	**Quantity sold (kg)**
1	Maize				
2	Sorghum				
3	Millet				
4	Beans				
5	Sunflower				
6	Simsim				
7	Ground nuts				
8	Rice				
9	Sweet potatoes				
10	Cassava				
11	Fruit trees				
12	Vegetables				
13	Peas				
14	Cotton				
15	Irish potatoes				
16	Others (specify)				

1.6 Which of the following are the benefits of growing the above crops? (***Multiple Responses***)

1. Improved incomes
2. Improved diet of family members
3. Crop residues for manure

4. Improved standards of living
5. Community togetherness
6. Source of employment
7. Others (specify)

1.7 Which of the following have been the challenges to crop cultivation? (***Multiple Responses***)

1. Pests and diseases
2. Price fluctuations
3. Poor road networks
4. Limited markets
5. Unreliable rainfall
6. Theft/raids
7. Flooding
8. Bush fires
9. Counterfeit inputs (seeds, pesticides etc.)
10. Low soil fertility
11. Limited access to credit facilities
12. Others (specify)

1.8. What have been the impacts of the above challenges? (***Multiple Responses***)

1. Reduced yields
2. Reduced incomes
3. De-incentive to grow improved varieties
4. Wilting and drying of crops
5. Food insecurity
6. Malnutrition
7. Others (specify)

1.9 For land under livestock rearing, what animals have you owned in the last 12 months? (***Multiple responses***)

	Livestock	Number owned	Number sold/used in kind	Number consumed
1	Cattle			
2	Goat			
3	Sheep			
4	Pig			
5	Rabbit			
6	Donkey			
7	Chicken			
8	Turkey			
9	Ducks			
10	Camels			
12	Others (specify)			

1.10 What are the benefits of rearing livestock? (***Multiple Responses***)

1. Improved incomes
2. Improved diet of family members
3. Source of manure
4. Improved standards of living
5. Community togetherness
6. Source of employment
7. Social prestige
8. Form of saving
9. Others (specify)

1.11 What are the challenges to livestock rearing? (***Multiple Responses***)

1. Pests, parasites and diseases
2. Price fluctuations

3. Poor road networks
4. Limited markets
5. Cattle rustling/raids/theft
6. Inadequate pastures
7. Inadequate drinking water
8. Bush fires
9. Counterfeit inputs (feeds, acaricides etc.)
10. Others (specify) ……..

1.12 How much money did you spend on agricultural inputs for crops in the last 12 months?

Input	**Amount spent (UGX)**
Seed	
Fertilizer	
Agricultural chemicals	
Labor	
Animal mature	
Tractor hire	
Ox-plough hire	
Others (specify)	
TOTAL	

1.13 How much money did you spend on agricultural inputs for livestock and livestock products in the last 12 months?

Input	**Amount spent (UGX)**
Feeds	
Treatment/vaccination	
Labor	
Utensils	
Others (specify)	
Total	

SECTION TWO: STATE OF THE RANGELAND RESOURCES

2.1 Do you have access to rangelands in this village?

1. Yes
2. No

2.2 If yes, which of the following benefit(s) does your household or community get from the nearby rangelands? (***Multiple responses***).

1. Absorbs pollutants from the atmosphere
2. Aesthetic services (recreation and tourism)
3. Climate regulation (formation of rains)
4. Cultural/Religious importance
5. Firewood
6. Food (e.g., fruits, nuts, mushrooms, and spices)
7. Habitat for wildlife and a range of biodiversity
8. Herbal medicine
9. Hunting of animals
10. Important in soil formation
11. Pastures for livestock
12. Poles for construction
13. Reduces soil erosion
14. Reduces the impact of extreme climate change events like drought and strong winds
15. Others (specify)

2.3 What is the state of these rangelands?

1. Intact
2. Degraded

2.4 If degraded, what have been the driver(s) of rangeland degradation? (***Multiple responses***).

1. Agricultural expansion
2. Charcoal burning
3. Drought
4. Mining
5. Flooding
6. Construction of roads
7. Dumping of solid waste and industrial effluents
8. Infrastructural developments e.g., industries
9. Invasion of alien species
10. Limited awareness of communities
11. Over grazing
12. Over harvesting of rangeland resources like firewood and poles
13. Over stocking
14. Political interferences
15. Population increase
16. Poverty
17. Unclear land tenure
18. Urbanization
19. Weak enforcement of rangeland regulations
20. Wildfires
21. Others (specify)

2.5 Which of the following have been the impact(s) of rangeland degradation? (***Multiple responses***)

1. Decline/loss of rangeland biodiversity
2. Drought
3. Flooding
4. Human-wildlife conflicts
5. Increased pests and diseases

6. Invasion of alien species
7. Loss of habitat for some animals
8. Reduced amount of rainfall
9. Reduced firewood and herbal medicine
10. Reduction of rangeland size
11. Soil erosion
12. Others (specify)

2.6 What have been the impact(s) of climate change on rangelands in this village? (***Multiple responses***)

1. Decline/loss of rangeland biodiversity
2. Drought
3. Drying of rangeland vegetation
4. Emergence of invasive species
5. Flooding
6. Carbon loss from the soils
7. Reduced rangeland productivity
8. Shift in suitable habitat range for some trees
9. Wildfires
10. Others (specify)

2.7 Of the following, what has been done to conserve and restore rangelands? (***Multiple responses***)

1. Cancellation of land titles in rangelands
2. Demarcation of the boundary of rangelands
3. Development and implementation of rangeland management plans
4. Enforcement of the rangeland policy and environmental bye-laws
5. Eviction of people farming and settling in rangelands
6. Establishing a good relationship between local communities and the local government
7. Provision of alternative livelihoods to people farming in rangelands
8. Regulation of human activities such as charcoal burning in rangelands

9. Planting of improved pastures
10. Sensitization of people about the benefits of rangeland
11. Upscaling of afforestation programs
12. Others (specify)

2.8 How do you assess the health of rangelands? Are there any specific indicators or methods you use for this assessment?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

THANK YOU FOR YOUR TIME AND COOPERATION!!

Appendix II: Interview guide tool

KEY INFORMANTS INTERVIEW GUIDE

INTRODUCTION & CONSENT

My name is …………………………….. from Kyambogo University. We are conducting a study on '**Spatio-Temporal Variability in Rangeland Health and Productivity in the Karamoja Sub-region of North-eastern Uganda'**. You have been purposely selected to participate, and your participation is voluntary but very important to achieving the objectives of the study. Please note that the information you provide will be solely used for academic purposes and treated with utmost confidentiality.

Section 1: Identification

1. Enumerator name?
2. Date?
3. Start time?
4. How long have you been involved in rangeland management in this region?
5. Can you provide a brief overview of your experience and expertise in rangeland management?

Section 2: Rangeland Health Assessment

1. In your observation, have you noticed any changes in the health of rangelands over the past few years? If yes, could you describe the changes you have observed?
2. What indicators do you use to assess the health of rangelands in the region?
3. How do you think changes in rangeland health might impact the availability of grazing resources for cattle herders in different areas?

Section 3: Factors Affecting Rangeland Health

1. What are the key factors that influence the health of rangelands in this region? (e.g., rainfall patterns, temperature fluctuations, intensity of cattle herding, livestock density, Invasive species, conversion of rangelands for other purposes, etc.)

Section 4: Cattle Raids and Land Use Patterns

1. Do you have any records about cattle raid/rustling events (i.e., specific date, month & year; No. of Cattle raided; Location of raid -Village, Parish-sub-County – district; No. of Cattle

recovered; Raid destination/ place of recovery (if any) and; Recorded Death? (Kindly share a copy of the recorded events)

2. Do you believe there are any connections between cattle raids and specific rangeland conditions? For example, do cattle raids occur more frequently in areas with depleted grazing resources?
3. Have you noticed any changes in cattle raid patterns over time, and do you think these changes are related to fluctuations in rangeland health?
4. Are there any particular seasons or periods when cattle raids tend to occur more?

Section 5: Livelihoods and Conflict Resolution

1. How do cattle raids impact the livelihoods of cattle herders and the overall pastoral community in the region?
2. What are the existing conflict resolution mechanisms or strategies employed by the pastoral community to address issues related to cattle raids?

Section 6: Future Perspectives

1. How can improved rangeland management and monitoring contribute to reducing conflicts over grazing resources and mitigating cattle raids?
2. What do you think are the key challenges in promoting sustainable rangeland management and reducing cattle raids in the region?

Appendix III: Field introductory letter

KYAMBOGO UNIVERSITY

P. O. BOX 1 KYAMBOGO

FACULTY OF ARTS AND SOCIAL SCIENCES

DEPARTMENT OF GEOGRAPHY

6th October, 2023

TO WHOM IT MAY CONCERN

AWOR JENNIFER OWILLI

21/U/GMAG/14061/PE

This is to introduce to you the above named student who is pursuing a Master of Arts in Geography degree course at Kyambogo University. She is in her second and final year and she is supposed to conduct a research study entitled **"Spatio-Temporal Variability in Rangland Health and Cattle Raide in Karamoja Sub-region of Northeastern Uganda"**. Her research is under the supervision of Dr. Turyabanawe Loy Gumisiriza and Dr. Turyahabwe Remigio.

Any assistance accorded to her will be highly appreciated.

Thank you.

DEPARTMENT OF GEOGRAPHY KYAMBOGO UNIVERSITY 06 OCT 2023 P.O. BOX 1 KYAMBOGO

Dr. Turyabanawe Loy Gumisiriza

RESEARCH COORDINATOR

Appendix IV:The 2021 projected household number for the Karamoja region that guided the sample size calculation

Sn	Districts	2015	2016	2017	2018	2019	2020	2021
1	Abim	19,200	20,600	22,200	23,800	25,700	27,700	29,800
2	Kaabong	19,300	19,800	20,300	20,800	21,300	21,800	22,400
3	Amudat	16,400	17,300	18,200	19,100	20,100	21,200	22,500
4	Kotido	27,400	28,200	29,100	30,000	31,000	32,000	33,100
5	Nakapiripirit	16,500	17,400	18,200	19,200	20,200	21,300	22,500
6	Nabilatuk	10,500	11,100	11,800	12,500	13,300	14,000	15,000
7	Karenga	10,600	10,800	11,100	11,400	11,700	12,000	12,300
8	Napak	28,100	28,900	29,700	30,400	31,300	32,200	33,100
9	Moroto	23,000	23,700	24,500	25,300	26,000	26,900	27,800
	Total	**171,000**	**177,800**	**185,100**	**192,500**	**200,600**	**209,100**	**218,500**

Source: UBOS, (2023)

Appendix V: Accuracy assessment metrices

MATRIX_02)1

OID	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	Total	U_Accuracy	Kappa
0	C_1	83	0	0	0	8	6	97	0.85567	0
1	C_2	1	15	0	0	2	0	18	0.833333	0
2	C_3	0	0	3	0	1	0	4	0.75	0
3	C_4	0	0	0	2	0	0	2	1	0
4	C_5	6	0	0	0	37	0	43	0.860465	0
5	C_6	4	0	0	0	2	30	36	0.833333	0
6	Total	94	15	3	2	50	36	200	0	0
7	P_Accuracy	0.882979	1	1	1	0.74	0.833333	0	0.85	0
8	Kappa	0	0	0	0	0	0	0	0	0.779006

MATRIX_12_1

OID	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	Total	U_Accuracy	Kappa
0	C_1	50	4	0	3	0	6	63	0.793651	0
1	C_2	0	55	1	1	0	4	61	0.901639	0
2	C_3	0	4	10	0	0	0	14	0.714286	0
3	C_4	1	1	0	26	0	2	30	0.866667	0
4	C_5	0	1	0	0	3	0	4	0.75	0
5	C_6	2	1	0	0	0	25	28	0.892857	0
6	Total	53	66	11	30	3	37	200	0	0
7	P_Accuracy	0.943396	0.833333	0.909091	0.866667	1	0.675676	0	0.845	0
8	Kappa	0	0	0	0	0	0	0	0	0.796941

MATRIX_22_1

OID	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	Total	U_Accuracy	Kappa
0	C_1	2	0	0	1	0	0	3	0.666667	0
1	C_2	0	67	3	1	1	1	73	0.917808	0
2	C_3	0	5	45	10	0	0	60	0.75	0
3	C_4	0	3	3	36	1	3	46	0.782609	0
4	C_5	0	2	0	1	11	0	14	0.785714	0
5	C_6	0	0	0	0	0	4	4	1	0
6	Total	2	77	51	49	13	8	200	0	0
7	P_Accuracy	1	0.87013	0.882353	0.734694	0.846154	0.5	0	0.825	0
8	Kappa	0	0	0	0	0	0	0	0	0.757324

Appendix VI: Post Hoc ANNOVA Test

PSOT HOC ANOVA TEST

	2002	**2012**	**2022**
Zone	**mean±sd**	**mean±sd**	**mean±sd**
Agro-Pastoral Zone	0.11±0.08[c]	0.27±0.04[a]	0.22±0.03[b]
Crop-Zone	0.21±0.07[a]	0.27±0.04[a]	0.24±0.04[a]
Pastoral zone	0.13±0.09[b]	0.25±0.04[b]	0.21±0.03[c]

Note: Different letters imply statistically significant difference at 5%

Appendix VII: Some of the field photos

Young trees used for construction of, b) Dead fencing homesteads a) kraals and c) houses.

Plate 16 **Plate 17** **Plate 18**

Figure 1: woods/sticks used in constructing the fences of the Manyattas by majorly women

Source: Field 2023

Plate19

Plate 20

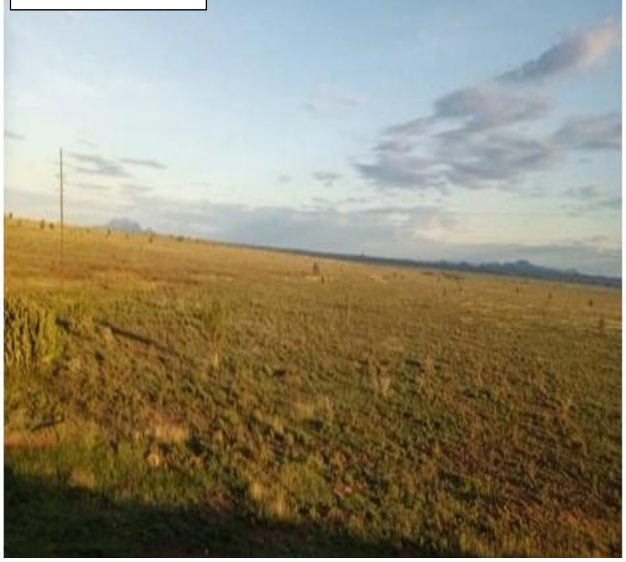

Plate 21

Lomuriangalepan in Napak district where an investors is growing Seso 3 sorghum on a commercial level of 5200 hectares of land (plates 19, 20 and 21)

Source: Field 2023

Plate 22),Nadunget grazing ground-Moroto, **Plate 23),**Kopedur-Lorengecora water point-Napak and **Plate 24),** River Lomacariwareth water point-Kaabong

Source: Field 2023