ASSESSMENT OF FORAGE DYNAMICS UNDER VARIABLE CLIMATE IN KARAMOJA SUB-REGION OF UGANDA

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Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Doctor of Philosophy in Dryland Resources Management of the University of Nairobi

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DECLARATION

I **Egeru Anthony** do solemnly declare that this thesis and its content thereof is my original piece of work and it has never been submitted to any institution of higher learning for research leading to any academic award. I therefore take personal responsibility for the content of this work.

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Date…………………………………………

With the approval of my supervisors here undersigned, I submit this thesis to the Board of Postgraduate Studies of the University of Nairobi for the award of degree of Doctor of Philosophy in Dryland Resources Management of the University of Nairobi.

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DEDICATION

This work is dedicated to my Grand parents Mzee Justin E. Egeru and Faith Norah Apila Egeru. Firstly, Grand mother, you did not have any formal education but your tireless effort and resolve for education has seen the Egeru family shoulder on to greater heights. On the occasion of my departure from the village in 1997 to seek for a better secondary school, your send-off message was "*Never stop working hard, as always*"; I was only 14 years then but that message leaveth in me to this day and has delivered this harvest. It is only unfortunate that you are nolonger in position to stand on your feet to celebrate with the traditional dance tunes of 'Emali' due to the stroke but God was gracious enough that you are able to sing your favourite hymnal song "*Praise to the Lord, the Almighty*". Secondly, Mzee Egeru you embody a spirit of resilience in pursuit of formal education. Although you did not reach the apex of formal education, you set a foundation for the generation a head of you; that is now the generation reeping from these earlier efforts. I have visited Sir Samuel Baker Secondary School in Gulu; I can only imagine what a horrendous journey it was for you in the 1950s to reach this place using a bicyle as the only means through the bushes of Teso, Lango and finally Acholi sub-region. Thank you for the foundation and inspiration!

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ACRONYMS

AgMIP	Agricultural Model Intercomparison and Improvement Project
AOGCM	Atmosphere Ocean General Circulation Models
AVHRR	Advanced Very High Resolution Radiometer
BCSD	Bias Correction Spatial Disaggregation
CAADP	Comprehensive Africa Agriculture Development Programme
CAHW	Community Animal Health Workers
CDI	Combined Drought Index Calculator
CFSR	Climate Forecast System Reanalysis
CGCM	Coupled Atmosphere General Circulation Models
CMIP	Coupled Model Intercomparison Project
DFID	Department for International Development
EAC	East African Community
ENSO	El Niño Southern Oscillation
EVI	Enhanced Vegetation Index
FAO	Food and Agricultural Organisation of the United Nations
FEWS NET	Famine Early Warning Systems Network
FGD	Focus Group Discussion
GCM	General Circulation Models
GDP	Gross Domestic Product
GLAM	Global Agriculture Monitoring Project
GoU	Government of Uganda
GPS	Global Positioning System
IGAD	Intergovernmental Authority on Development
IIED	International Institute for Environment and Development
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
KALIP	Karamoja Livelihoods Programme
LAI	Leaf Area Index
LANDSAT	Land Remote Sensing Satellite System
LRD	Land Reform Decree

MAAIF	Ministry of Agriculture, Animal Husbandry and Fisheries
MERRA	Modern Era-Retrospective Analysis for Research and Applications
MODIS	Moderate Resolution Imaging Spectro-radiomter
MoDP	Ministry of Disaster Preparedness
MWE	Ministry of Water and Environment
NAPA	National Adaptation Programmes of Action
NASA	National Aeronautics and Space Administration
NCEP	National Centres for Environmental Prediction
NDP	National Development Plan
NDVI	Normalized Difference Vegetation Index
NEMA	National Environmental Management Authority
NGO	Non-Governmental Organisation
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
OPM	Office of the Prime Minister
OXFAM	Oxford Committee for Famine Relief
PEAP	Poverty Eradication Action Plan (PEAP)
PMA	Plan for Modernization of Agriculture
RCM	Regional Climate Models
RCP	Representative Concentration Pathways
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
SAVI	Soil Adjusted Vegetation Index
UBOS	Uganda Bureau of Statistics
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UPDF	Uganda Peoples Defense Force
USAID	United States Agency for International Development
USGS	Unites States Geological Survey
WMO	World Meteorological Organisation

ABSTRACT

Livestock herding is an important undertaking in rangeland areas of East Africa. These regions are characterized by climate variability that affects the availability of key livestock production resources especially forage and water. This study sought to assess the dynamics of forage under variable climate conditions of Karamoja sub-region. The study adopted a mixed methods approach utilising both primary and secondary data obtained through herbaceous biomass survey, cross-sectional survey, key informant interviews, focus group discussions, remote sensing and archived climate data. Data was analysed using descriptive statistics, correlations, standard soil processing procedures, analysis of variance (ANOVA), Ordinary least squares (OLS) and Log-linear regression, and statisitical downscaling using the delta method.

The results showed that there is a spatio-temporal variability of forage production leading to the existence of heterogeneity that supports transhumant livestock herding in the sub-region. The sub-region has a high diversity of herbaceous forage species (65) whose abundance is dominated by a few species (9), these include: *Hyparrhenia rufa, Sporobolus stafianus, Chloris pychnothrix, Setaria sphacealata, Pennisetum unisetum, Aristida adscensiones*, *Hyparrhenia diplandra* and *Panicum maximum* that vary across space and time. The pastoralists and agro-pastoralists possessed detailed knowledge of forage species type, location, growth periods and forms, perceived quality and preferences by livestock species. However, land use and land cover change orchestrated by a tenfold increase in croplands and a 10% increase in woody vegetation cover over the last decade (2000-2013) is threatening forage resources particularly in the grasslands.

Land use and cover type, and seasonality ($P \leq 0.05$) were identified to singinificantly influence forage dynamics in the sub-region. Further, the perceived determinants of forage dynamics included: length of residence by livestock keepers at a location, frequency of grazing, number of kraals in a location, presence of governing rules, and presence of conflicts, knowledge of pasture locations, restricted movement and ease of access to grazing areas ($P \leq 0.05$). The results also showed that soil nutrients such as: N, P, K, and SOM significantly influenced forage dynamics ($P \leq 0.05$). In addition, development interventions inform of piospheres had a significant influence on forage dynamics by influencing species composition and abundance leading to the observance of increaser and decreaser forage species around the piosphere zones.

The results of climate analysis showed that the sub-region's climate is highly variable (Coefficient of variation > 35.0%) with spatio-temporal oddities in rainfall and temperature. Over the historical time step (1979-2009), there was a progressive rise in minimum, maximum and mean temperature by 0.9°C, 1.6°C and 1.3°C respectively. In the same period, there were more dry months (< 1.0 threshold) from 1979 to 1994 than between 1995 to 2009, with wetness intensity (>2.5 threshold) increasingly common after the year 2000. It is projected that rainfall will increase in total however the increase will be non-significant and inter and intra-annual variability will remain pronounced. A significant increase in minimum temperature will be expected such that by mid-century (2040-2069) it will have increased by 1.8°C (RCP 4.5) and 2.1°C (RCP 8.5) and by 2.2°C (RCP 4.5) and 4.0°C (RCP8.5) during end-century (2070-2099). The projected patterns in rainfall and temperature are expected to lead to a relatively high but variable forage production under both RCP 4.5 and RCP 8.5. Continued increase in temperature to RCP 8.5 level will be expected to induce a significant decline in forage production; thus indicating that higher temperatures in the future compared to the present level will become a limiting factor to vegetation production in the sub-region. Given the above findings, it is vital to; undertake community based land use planning so as to better manage land use transformations occurring in the sub-region. It is also essential that any efforts geared towards rangeland resources and biodiversity management in the sub-region should tap into the detailed cultural knowledge of the pastoral communities in Karamoja. In addition there is need to continuously monitor socio-ecological conditions perceived to influence forage dynamics as they have potential of creating 'artificial forage shortages'. In-light of observed and projected climate variability and change; there is need to use location specific and sub-regional climate information for timely adjustment to extreme climate events and early warning in the sub-region.

Key words: *Grazing, pastoralists, pro-active planning, remote sensing, variability*

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

1.1.1 Importace of livestock in semi-arid areas of Africa

Semi-arid lands make upto 43% of Africa's land area and are home to an estimated 268 million people (De Jode, 2009). These areas are primarily used for livestock production, mainly through pastoralism. In Sub-Saharan Africa alone, an estimated 25 million pastoralists and 240 million agro-pastoralists depend on livestock as their primary source of income (AU-IBAR, 2012). Livestock also contributes significantly to the economies of the region, for example; the livestock sector ranks second to coffee in foreign exchange revenue in Ethiopia, pastoral livestock contributes up to USD 800 million in Kenya and its share contribution is estimated at 3.2% larger than the GDP derived from cash crops or fishing in Uganda (Behnke and Nakiraya, 2012). Further, between 70-90% of livestock reared in the Sahelian countries of Burkina Faso, Chad, Mali, Mauritania and Niger is based on transhumant herding in the drylands with over 35% estimated share contribution to agricultural GDP (Kamuanga et al., 2008; Ickowitz et al., 2012) .

In most pastoral communities in Africa, livestock is a store of wealth, provides draught power, organic fertilizer and agents of environmental change (Upton, 2004). Further, livestock constitute capital assets; produced in the past and contributing to the future product output. Thus, investment in or acquisition of livestock involves saving or borrowing, justified by the expected future return to capital (Upton, 2004). Pastoral groups in Africa seem to have mastered this economic principal over several centuries and applied it judiously. In addition, livestock is an important insurance against vulnerability and covariant risk[1] of variable climatic conditions that often predispose households and communities to loss of income and food insecurity in semi-arid areas of Africa (Kamuanga et al., 2008).

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[1] Covariant risk describes both meso-shocks that affect specific groups of households within a region and macro-shocks that affect all households in a region. Pastoralists face covariant risk of drought (Rass, 2006). In addition, at different levels depending on individual adaptative capacity, micros-shocks, also referred to as idiosyncratic; affecting specific individuals or households are a common occurrence in semi-arid areas

The predominance of pastoralism in semi-arid areas of Africa is evolutionary because it is a system that has managed to exploit the variability in climate patterns that lead to heterogeneity in forage resources common in these areas (Nori et al., 2008; Teague et al., 2013). Where other land use systems have failed and are failing in the face of global climate change, mobile livestock herding is still generating national and regional economic and environmental benefits in the drylands (Nori et al., 2008; Nassef et al., 2009). In countries such as; Namibia, Botswana, and South Africa, many pastoralists are now fencing for heterogeneity, as opposed to homogeneity, due to the poor performance of livestock grazing in the latter relative to the former (Teague et al., 2013). However, the drylands are reknown for their fragility. This means that resources that support livestock production especially water and pastures are in delicate balance. This calls for monitoring of the dynamics of these resources as well as the general health of the rangeland ecosystems.

1.1.2 The Livestock Sector in Uganda: Historical perspective, challenges and opportunities

The livestock sector in Uganda has been that of despondence; that which has sought to alienate the traditional livestock keepers. During the colonial times, indigenous livestock keepers were perceived as major threats to the integrity of the environment. They were blamed for land degradation (Mugerwa, 1992). Strict measures were subsequently undertaken by the British through the Cattle Grazing Act 1945 to limit the number of cattle that could be grazed in a particular location. The Special Regions Act, 1958 was used to declare certain areas as prohibited and closed to livestock and humans without a permit (Iyodu, 2009). These legislations were strictly implemented to the detriment of livestock based communities and most which have not been repealed todate.

Other efforts involved the establishment of ranches. In the 1960s, several tracts of land were confiscated from the 'cattle corridor' (a strip of land running diagonally from southwestern to northeastern Uganda, Figure 1.1; Stark, 2011) for ranch development. Several pastoralist communities were thus dispossessed of land for example; Singo (34 ranches), Bunyoro (37 ranches), Buruli (27 ranches), Ankole (50 ranches) Mbarara, and Masaka (59 ranches) (Rugadya, 2009). These efforts had limited success in transforming livestock development among pastoral communities because they were based on a wrong premise that pastoralists were degrading the environment. However, these efforts caused a major shift in land tenure and livestock resources (forage and water) access and utilisation balance in the country (Kirk et al., 1999).

In the Karamoja sub-region, a different form of dispossession occurred; most of the land was earmarked for conservation efforts. According to Rugadya et al. (2010) in the 1960s the Kidepo National Park covering 1,442 sq km was established followed by three controlled hunting areas of Napak covering 196 sq km, North Karamoja protected area covering 10,820 sq km and South Karamoja protected area covering 7,882 sq km were established. These targeted conversions of land in the sub-region did not end soon enough; thus in 1964, a further three game (wildlife) reserves of Matheniko (1,573 sq km), Bokora (2,145 sq km) and Pian-Upe (2,152 sq km) were established. Consequently, by 1965 a total of 26,204 sq km (94.6%) of Karamoja's land was under protected areas (Rugadya et al., 2010). In an attempt to mitigate this historical injustice, the Government of Uganda degazetted some 54% of the protected lands in early 2000s. But, to date, some 40.8% of land in Karamoja remains under protected areas (Rugadya et al., 2010).

Livestock numbers in Uganda have fluctuated. Despite a 0.3% indicative growth in cattle numbers (1980-1990), a 30% decline in cattle population was observed between 1985 and 1990 (Holden et al., 1996). This was partly attributed to disease outbreaks and collapse of veterinary service delivery systems (Holden et al., 1996). The growth pattern of cattle numbers is however experiencing a positive trend. For example, in the period 1990-2000; cattle population increased by 2.0% (FAO, 2005). By 2008, some 70.8% of all households in Uganda owned some sort of livestock or another (MAAIF-UBOS, 2009). However, several constraints abound among the livestock keeping communities. Some of the constraints relate to the historical injustices that I have already alluded too above. Others are natural conditions such as climate variability and change that affect water and pasture availability (MAAIF, 2005). Not forgetting disease out breaks and failures in veterinary service delivery systems (Holden et al., 1996). Poor livestock breeds (Ellis and Bahiigwa, 2003), limited investment into the sector (Ashley and Nyanyeenya, 2002) and limited understanding of the distribution of livestock. Political instability and civil unrest such as: in parts of Teso, Lango and Acholi (Turner, 2005), cattle rustling and poor quality of pastures and feeds for livestock (Powell, 2010; Republic of Uganda, 2010).

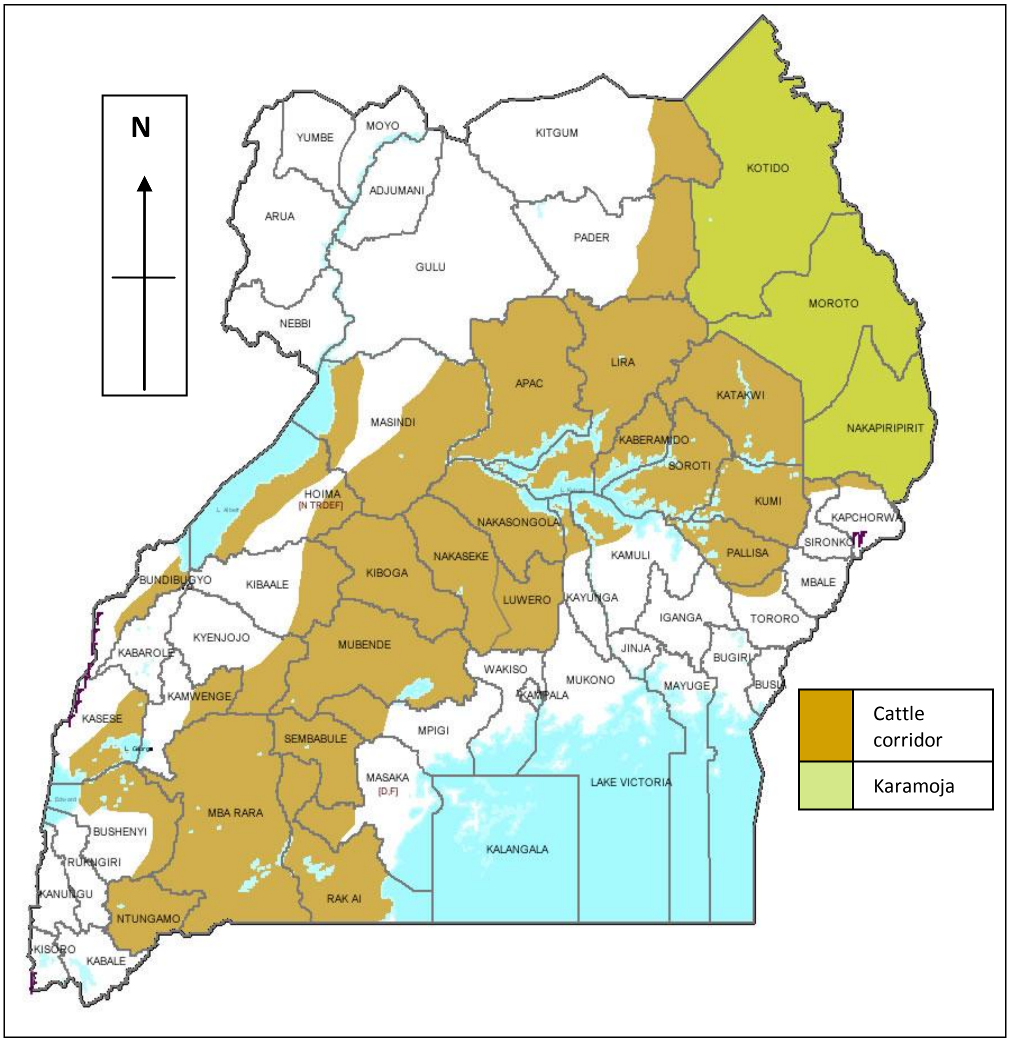

Figure 1.1: The cattle corridor of Uganda (Source: Stark, 2011)

The National Development Plan recognizes inadequate livestock nutrition manisfested through low productive pastures a key constraint to livestock sector's growth (Republic of Uganda, 2010). However, no deliberate efforts have so far been undertaken to develop adequate and good quality forage resources. Empahsis has been put on water with six strategic action points. Further, the water, land and feeds policies are not pro-poor because they do not propose policy instruments that take into account the needs and constraints of the livestock-dependent poor (Pica-Ciamarra and Robinson, 2008). In addition, extension service delivery system in the livestock sector is fundamentally weak (World Bank, 2011).

However, a spectrum of opportunities does exist in Uganda's livestock sector. Livestock has been recognized by the National Development Plan (NDP) as an important sector. Its share contribution to GDP is estimated at 9% per annum. The NDP anticipates achieving a 5.5% growth rate in the livestock sector by 2015 as strategies for achieving expected targets (Republic of Uganda, 2010). It identifies increasing the provision of water for livestock in the cattle corridor from 36% to 50% and outside the cattle corridor from 21% to 30% by the year 2015 (Republic of Uganda, 2010b). Several other policy documents such as Poverty Eradication Action Plan (PEAP), Plan for Modernization of Agriculture (PMA) and the Livestock Sector Development Strategy (LSD) (Pica-Ciamarra and Robinson, 2008); and the Livestock Feeds Policy (MAAIF, 2005) indicate avenues for developing the livestock sector but most of these actions are yet to be put in practice! Further, there is a rapidly growing demand for livestock products locally and regionally. The current production levels can only satisfy half the domestic and regional demand. Opportunities still exist in the regional export market that is growing in South Sudan and Democratic Republic of Congo (MAAIF-UBOS, 2009).

Uganda's rapidly growing population expected to triple by 2050 presents another opportunity for the livestock sector. Carlin (2011) shows three scenario situations of Uganda's population growth. First, if women continue to have six children as at present, Uganda will have 144 million by 2050; if the average number of children drops to about 2.35 then Uganda will have 105 million; if fertility declined further to about 1.85 children, then Uganda will have 94 million people by 2050. Either way, Uganda's population will still double thus, exerting demand for livestock products. At present, the per capita milk and meat consumption are estimated at 50 litres compared to the espxected average of 200 litres such demand deficits are a crucial opportunity. Therefore, inorder to increase livestock production an understanding of present and future patterns of livestock production resources is vital.

1.1.3 Pastoralism and rangeland management in Uganda

Rangelands compose 44% of Uganda's landscape (NEMA, 2006). They predominantly occur in the cattle corridor that runs from southwestern to northeastern parts of the country (Figure 1.1). High temperatures, low to medium but variable rainfall regimes, low vegetation cover density and fragile soils characterise Uganda's drylands (Mugerwa, 2001). These areas equally have high productivity potential but are at the sametime fragile landscapes (Adeel et al., 2008). They are the second most fragile landscapes after mountainous landscapes (NEMA, 2007).

Pastoralists and agro-pastoralists inhabitating these areas through historical time mastered how to deal with variable livestock resources orchestrated by variability in rainfall regimes. They did so through opportunistic management of forage resources (Anderson and Johnson, 1988). Uganda's rangelands support up to 90% of the total livestock population providing upto 85% of the livestock products such as milk, meat, hides and skins (Sabiiti et al., 2003). However, these areas are faced with unprecedented and recurrent drought conditions (Sabiiti et al., 2003). Consequently, there is a decline in production of these locations with regard to pasture for livestock and sustainable biodiversity; a situation that in part is negatively impacting on the livelihoods of pastoral communities (Sabiiti et al., 2003; Zziwa et al., 2012).

Since colonial and post-independence times, rangeland management in Uganda has sought to curb pastoralists and particularly those in Karamoja into 'a modern people'; who respect authority, pay taxes and live a settled life (Mamdani, 1982; Gartrell, 1988). Colonial administration and post-independence governments instituted several laws for example; the Cattle Grazing Act 1945; the National Parks Ordinance 1952, the Special Regions Act 1958, with a perspective of developing pastoralism (Mamdani, 1982; Gartrell, 1988). However, most of these investments and laws had limited success if any to write about. Although some authors attribute failure of these programmes on ecological and climatic characteristics of rangelands (Mugerwa, 2001) most of it had to deal with the spirit with which the programmes were conceived, designed and implemented. This is because pastoralism was largely viewed as retrogressive and a backward practice (Sabiiti and Mugasi, 2004).

Futher, the need to transform the socio-economic institutions governing rangelands under pastoralism to equate them with institutions governing other farming systems constituted one of the failures (Mugerwa, 2001). It was further complicated by the various land tenure regimes that cut across the cattle corridor (Mugerwa, 1992); a confusion introduced by the British colonial administration itself. In Karamoja for example, detoriation of the environment came about during and as a result of colonial rule and particular forms of exploitation that later followed. This included the alienation of grazing land; the conversion of hunting into "poaching"; and "de-stocking" of cattle under the the guise of addressing the resulting over-grazing; this was simply adding insult to an existing injury (Mamdani, 1982). The Karamojong had also previously lost several tracts of land (1,500-2,000 squares miles) from the Chemerongit hills to the Kamyangareng river that was transferred to Kenya between 1920 and 1940 (Mamdani, 1982).

All these actions affected livestock resources availability; particularly grazing grounds as land area was shrinking. The situation was later compounded by the 1975 Land Reform Decree that accelerated individual acquisition of land in pastoral areas. This is because the decree lifted the basic protection enshrined in the Public Lands Act 1969 that protected customary land tenants.

With the 1975 Land Reform Decree (LRD) all land under customary tenure was held under sufferance (Mugerwa, 1992). To date, Uganda does not have a comprehensive rangeland management policy. However, several legislations provide bits and pieces for the management of rangelands in Uganda. These include: the 1995 Constitution of Uganda, Land Act 1998; Uganda Wildlife Act 1996; National Environment Statute 1995; Wetlands Act 1995; and Local Government Act 1997. The absence of a comprehensive rangeland management policy has led to profliferation of several actions that have become detrimental to the successful existence of pastoralism in the rangelands of Uganda. Access to land resources has progressively reduced, as successive individual, private and government agency actions, alienated grazing areas for the establishment of national parks, wildlife reserves, protected areas, government or military schemes and/or individual ranches (Republic of Uganda, 2013). In view of the increasing constrained access to pastoral resources, the 10th European Development Fund (EDF) Karamoja Livelihoods Programme (KALIP) recommended that a full study be undertaken of pasture dynamics by season and location in Karamoja sub-region (Anderson and Robinson 2009). It is this that provided a foundation to the current study.

1.1.4 Climate variability and change in Uganda

Climate change, a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (UNFCC, 1992); is already a reality in Uganda (Wasige, 2009). Uganda is also vulnerable to climate change as most of its agriculture is rain-fed; agriculture is the backbone of the economy, and the livelihoods of many people depend upon it (Republic of Uganda, 2007). Variability in rainfall may be reflected in the productivity of agricultural systems and pronounced variability may result in adverse impacts on productivity (Mubiru et al., 2012). The country is already facing the impacts of climate change and variability; and is hampering the achievement of development goals (Republic of Uganda, 2013).

It is expected that climate change will increase the frequency and intensity of extreme weather events such as droughts, floods, landslides and heat waves. Over the past few years, the magnitude of the problem is descernable for example, the frequency of extreme events such as droughts increased. These had debeilitating impacts on the availability of pastures and livestock in most pastoral areas of the country (Republic of Uganda, 2007).

The cattle corridor of Uganda (Figure 1.1) is the most affected region in the country (Kaggawa et al., 2009). The sub-region has experienced differing climatic change and variability conditions including variation in seasons, and increasing dry spells within the rainy season (Nimusiima et al., 2013). Global climate change models show that Uganda will generally have an increase in average temperatures by up to 1.5°C in the next 20 years and up to 4.3°C by 2080s. Similarly, changes in rainfall patterns and total annual rainfall amounts are also expected. It is also expected that rainfall will increase over much of the country by 10–20 percent. However, a decrease in rainfall is anticipated over the semi-arid cattle corridor (MWE, 2013). Generally, the current climate change and variability information available in terms of analysis and empirical studies is at national scale from coarse Global Circulation Models (GCMs). There is little focus at local level; even those that are available have focused on high potential areas with emphasis on high value crops such as coffee (Jassogne et al., 2013), tea (Seitz and Nyangena, 2009) and food crops such as maize (Wasige, 2009). Limited attention has been given to the analysis of the impact climate change has on livestock resources such as forage despite the recognition that climate change affects pastoralists; leading to reduced productivity and escalation of climate induced migration (Muhanguzi et al., 2012; Mubiru et al., 2012; MWE, 2013).

1.2 Statement of the Problem

Pastoral communities occupy rangelands with harsh climatic and ecological conditions (Republic of Uganda, 2013); this has meant that pastoral livestock herding for a long time has been the basic and viable production system in areas such as Karamoja (Mkutu, 2009). The viability of this production system has come under scrutiny in the face of unprecedented climate change and variability. This is because climate change and variability disrupts water and forage dynamics, productivity and availability. It also introduces new disease patterns (Mwang`ombe et al., 2011) modify animal diets and compromise the ability of smallholders to manage feed deficits (Calvosa et al., 2009). Further, climate change and variability has pushed cultivators into pastoral areas that were once grazing lands causing increased severity of competition for grazing and water resources. It has also contrained pastoral mobility, a key ingredient in managing the low net productivity, risk and unpredictability in the rangelands (Republic of Uganda, 2013).

However, there is a dearth of information on the dynamics of forage resources by location and season under the variable and changing climate conditions in Karamoja sub-region. In addition, information on the type and abundance of forage species available in the sub-region remain scanty. Yet, increasing challenges in the availability of livestock production resources in the sub-region have been reported (Anderson and Robinson, 2009). Thus, in view of these pressing challenges, the 10th European Development Fund (EDF) Karamoja Livelihoods Programme (KALIP) recommended that a full study be undertaken of pasture dynamics by season and location in Karamoja sub-region (Anderson and Robinson, 2009). This study sought to bridge these gaps. Further, the study sought to bridge the lack of climate change and variability intensity evidence in Karamoja. This is because climate change evidence in the sub-region has largely been drawn from the subjective testimony of people living in the region rather than from empirical meteorlogical data (Stark, 2011).

Further, no traceable effort has been committed to down-scaling and projecting the sub-region's climate; the current climate adaptation options prescribed for the sub-region are based on the global and national level projection information that provide a generalized conclusion for the semi-arid areas of Uganda (MWE, 2013; Friss-Hansen et al., 2013; Tumushabe et al., 2013; GoU, 2013). Thus, it is vital to undertake sub-regional level projections of climate change and variability and analyse their impact on potential forage resources production. Generating climate characteristics is important in guiding strategic and tactical decision-making as well as in defining the direction of change along the weather-climate continuum for planning adaptation strategies (Mubiru et al., 2012). This study sought to assess the dynamics of forage on spatio-temporal scale, identify the determinants of forage dynamics and determine the influence of climate change and variability on future forage production in Karamoja sub-region.

1.3 Justification

The challenge climate variability and change poses to pastoralists and agro-pastoralists is one among the four broad groups of challenges; the others being political and economic marginalization, inappropriate development policies, and increasing resource competition (Oxfam, 2008). As the sub-region grapples with some of these challenges knowingly and unknowingly; climate variability and change continues to further weaken the region's ability to provide for itself by affecting the dynamics of livestock production resources especially water and forage. It is also notable that climate variability makes cropped agriculture a high risk undertaking with significant chances of complete failure within and between years. Yet evidence available suggests that livestock provides more food security than growing crops in many semi-arid areas; and that the food crisis in these regions is essentially a livestock crisis (Kratli et al., 2013). In Karamoja, Akabwai and Ateyo (2007) reported that approximately 70% of households in the "food secure" category owned livestock or poultry, as opposed to less than 60% of "food insecure" households.

The uniqueness of this current study is that; it provided an opportunity of exploring in part some of the other challenges along the spectrum. This study provided an understanding of pastoralism and agro-pastoralism as practiced in Karamoja in a situation of climate variability and change in the future (mid-century 2040-2069; and end century 2070-2099). In light of the study's interest; spatial and temporal forage dynamics were assessed; determinants of forage dynamics were examined; the status of piospheres (waterholes and protected kraals) and their influence on forage species abundance were equally analysed.

The study's utilization of remote sensing and geographic information systems and climate down-scaling and modeling were paramount in providing spatio-temporal information relevant to planners and resource managers. According to Mubiru et al. (2012) given the implication of long-term projections for climate change, generating climate characteristics is not only important in guiding strategic and tactical decision-making, but it also helps to define the direction of change along the weather-climate continuum for planning adaptation strategies (Mubiru et al 2012). Thus, the information generated is helpful in guiding the design of appropriate interventions in livestock production, sustainable management of natural resources that support livestock production, anticipatory adaptation planning as well as conflict management in the sub-region.

The scenarios generated are also important for impact, vulnerability and adaptation planning and further aid in National Communications as espoused under the Articles 4.1 of the United Nations Framework Convention on Climate Change (UNFCC) that commits parties (Uganda is a signatory) to formulating, cooperating on, and implementing measures to facilitate adequate adaptation to climate change (UN, 1992; Smit and Pilifosova, 2003). In addition, the generated information is vital to a cross-section of Public institutions such as Office of the Prime Minister (OPM), Ministry of Disaster Preparedness (MoDP) and National Emergency Coordination and Operations Centre (NECOC); civil society organizations, Non-Governmental Organizations-NGOs and Community Based Organization-CBOs as well as the academic community.

1.4 Objectives of the study

This study broadly sought to assess the dynamics of forage and its determinants in the variable climate conditions of Karamoja sub-region, Uganda. The study specifically sought to:

1. Determine the spatio-temporal dynamics of forage in Karamoja sub-region
2. Determine the drivers of forage dynamics in Karamoja sub-region
3. Project forage production in Karamoja sub-region in the context of a changing climate

1.5 Research questions

1. What is the seasonal distribution of forage by land use/cover in Karamoja sub-region?
2. What are the determinants of forage dynamics in Karamoja sub-region?
3. What will be the trend of climate and climate change induced forage production during the mid-century and end-century in Karamoja sub- region?

1.6 Limitations of the study

The household survey was conducted during the long dry season; thus two challenges arose; firstly, there was anticipation for relief food aid. The community was willing to participate in anticipation of being included among the potential beneficiaries for food aid. Respondents therefore tended to veer-off to discuss their crop production failure and food needs. Secondly, it emerged that one researcher had previously conducted a survey and provided 'tokens' of appreciation to the respondents inform of money. The respondents had a similar expectation this time round. In one area at Katikekile sub-county in Moroto district; the enumerators were harassed. It took the intervention of the local council administration to move with the enumerators from one household to the other. Similarly, in one of the Focus group discussions in Nakiloro in Moroto district the demand for financial rewards was very high in the agenda because on the eve of our meeting, one of the non-governmental organisations operating in the sub-region had provided the elders with a good 'token' of appreciation for their participation. Meanwhile, in the piospheres and protected kraals, the community was generally in need of livestock drugs. In addition, the results of this study, particularly the drivers of forage dynamics as perceived by the community may only be applicable to areas with a similar geo-political set up such as Karamoja.

1.7 Organisation of the thesis

The structure and linakges between the theoretical and empirical chapters constituting this thesis include: part I (chapters 1, 2 and 3) that presents the theoretical basis and methodological approaches leading to the research. Part II consists of the empirical chapters (4, 5, and 6) that detail the linkages in the assessment of forage dynamics in variable climate conditions as applied in this study. Part III, consists of the conclusions and recommendations that emanates from the analysis and discussions of the three results chapters. This thesis has led to two peer reviewed research papers developed from part of the results of Chapter four and Chapter six; these papers include:

Egeru, A., Wasonga, O., Kyagulanyi, J., Majaliwa, M.G.J., MacOpiyo, L., and Mburu, J., **(2014).** Spatio-temporal dynamics of forage and land cover changes in Karamoja sub-region, Uganda. *Pastoralism: Research, Policy and Practice Journal*, 2014, 4:6. http://www.pastoralismjournal.com/content/4/1/6

Egeru, A., Osaliya, R., MacOpiyo, L., Mburu, J., Wasonga, O., Barasa, B., Said, M., Aleper, D., and Majaliwa, MGJ. **(2014).** Assessing the spatio-temporal climate variability in semi-Arid Karamoja sub-region in north eastern Uganda. *International Journal of Environmental Studies*, 71(4), 490-509. http://dx.doi.org/10.1080/00207233.2014.919729

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CHAPTER TWO

LITERATURE REVIEW

2.1 Forage dynamics in semi-arid areas

Discussions on forage dynamics in semi-arid areas cannot be separated from the discourse surrounding rangeland ecologist's search for an appropriate paradigm to interpret and manage vegetation dynamics (Briske et al., 2003). In its very essence, an agreement on the common definition of vegetation dynamics has eluded vegetation scientists for a considerable period of time with an increased re-examination of the conceptual basis of vegetation dynamics. The general meaning of vegetation dynamics in itself has generated considerable literature, which in essence reflects the confusion in the subject matter. Accordingly, in an attempt to alleviate these controversies, Glenn-Lewin et al. (1992) considered vegetation as population-based phenomena on a time and space scale.

Conventional range science and management has largely been dominated equilibrium-based ecological paradigms of the Clementsian model of vegetation change which forms the basis for range condition model of vegetation dynamics (Fernandez-Gimenez and Allen-Diaz, 1999). Under the range condition model, plant and herbivore interactions are coupled; thus, as herbivore numbers increase, plant biomass and cover subsequently decline and species composition shifts from the dominance by perennial grasses towards dominance by unpalatable forbs and weedy annuals (see Figure 2.1).

On the other hand, when grazing is decreased and/or removed, biomass and cover are predicted to increase and species composition shifts back towards late-successional stages (Fernandez-Gimenez and Allen-Diaz, 1999). Thus, under the equilibrium model, vegetation composition, cover and productivity are a function of livestock density feedback and to the alternate (Vetter, 2005). It is generally argued that the explanations in range condition model were overly simplified and could result into ineffective and/or destructive management practices and environmental policy particularly in semi-arid lands (Sullivan, 2009). Even after the incorporation of rainfall, the range condition model only adequately explained vegetation changes in humid areas. In such areas, rainfall is high with regular occurrence thus successional tendency of plants occurs in continuum from pioneer through sub-climax to climax states (Rothauge, 2000).

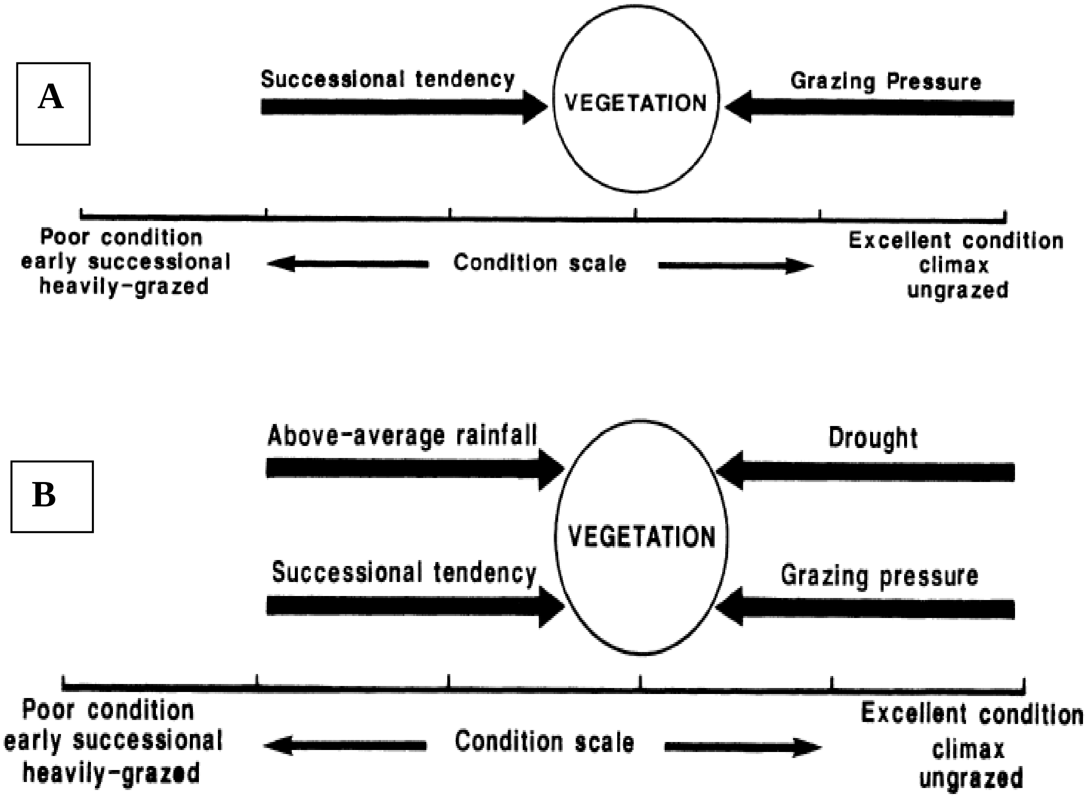


Figure 2. 1: General scheme of the range succession model

Note that in (b) rainfall variability has been incorporated into the range succession model (Source: Westoby et al., 1989).

Semi-arid and arid ecosystems are unique because they contain multiple complex pathways. The stochastic forcings in these areas present ecologists with questions of why complex ecosystems do in fact exist (De Agelis and Waterhouse, 1987). The inability of the range condition model to address this complexity led to the quest for an alternative approach that correctly explains the observed dynamics in rangeland ecosystems. The ecological community was not short in proposing alternative explanations to rangeland dynamics. Westoby et al. (1989) put forward the state and transition model and threshold model (Laycock, 1991). All these models were fundamentally derived from the non-equilibrium model view point. They described semi-stable vegetation states, predicting the circumstances that trigger transitions to specific different states, and modeling these changes. Further, they emphasized the non-linearity of vegetation responses to grazing and other environmental perturbations (Fernandez-Gimenez and Allen-Diaz, 1999). While developing the state and transition model, Westoby et al. (1989) summarised mechanisms that are found on rangelands and are known to produce complex ecosystem dynamics to include:

- Demographic inertia, a situation in which some plants may require a rare event for establishment to occur, but once this has occurred, the resulting cohort can persist for a long time;
- Grazing catastrophe, a condition in which grazer intake and plant net growth and reproduction respond to plant abundance according to nonlinear functions. These functions are shaped in such a way as to suggest that plant abundance may vary discontinuously and irreversibly in response to changes in stocking rate;
- Priority in competition, a situation where alternative stable states may result when the outcome of competition depends on the initial abundances of the competitors;
- Fire positive feedback, often some vegetation components such as; grasses, promote fire and are also themselves promoted by fire. Woody plant populations may be competitively superior once established, but sensitive to fire in the seedling stage; and
- A vegetation change that triggers a persisting change in soil conditions (surface erosion) may not be reversible on a time-scale relevant to management.

The work of Ellis and Swift in Turkana Kenya, spanning over a decade led to a suggestion of the non-equilibrium persistent (NEP) model of rangeland dynamics (Ellis and Swift, 1988). They posit that density independent and abiotic factors rather than density dependent and biological interactions are dominant in many rangeland ecosystems. Despite high variability in inter-annual and inter-seasonal productivity and fluctuating livestock populations, these ecosystems and pastoralists they support persists (Fernandez-Gimenez and Allen-Diaz, 1999). Five characteristics for non-equilibrium rangeland ecosystems were suggested by Ellis and Swift (1988) to include: (i) plant-herbivore interactions are loosely coupled; (ii) herbivore populations are controlled by density-independent factors; (iii) carrying capacity is too dynamic for close animal population tracking; and (iv) plant biomass is abiotically controlled; and (v) competition among plant species is not an important force in structuring communities. These perspectives changed the discourse of rangeland-livestock dynamics in Africa with several studies later on testing the applicability of this model; for example, in Zimbabwe and Ethiopia by Scoones

(1993) and Coppock (1993) respectively. Ellis and Galvin (1994) suggested a 33% coefficient of variation (CV) as an indicator for areas where non-equilibrium dynamics may exist.

However, there has never been an agreement among ecologists on the thresholds for non-equilibrium systems for example; Shepherd and Caughley (1987) used 30% CV cut-off, Briske et al. (2003) used < 300 mm while Coppock (1993) used < 400 mm as a threshold indicative of non-equilibrium systems. It is clear that there is not yet a concrete agreeable position on the explanation of rangeland vegetation dynamics. The current study area's coefficient of variation is unknown; however the rainfall total (~300-900 mm) is within to above average threshold indicated by Briske et al. (2003) and Coppock (1993). This study is generally focused at identifying factors that influence forage dynamics in the semi-arid Karamoja sub-region. In this regard, vegetation dynamics as used in this study refers to oscilations and patterns of pasture productivity in space and time associated with climate parameters in the sub-region particularly rainfall and temperature, abiotic environment such as soils, biotic interactions such as livestock grazing and number, and disturbance history through actions such as frequent burning. In the next sub-section, the factors that influence forage dynamics are reviewed. Some of these conditions have already been identified in the foregoing discussion on the search for an explanation for rangeland vegetation dynamics.

2.2 Factors influencing forage dynamics in semi-arid areas

Climate as a determinant of forage dynamics is perhaps the most well-known influencing livestock production in rangeland areas. Livestock production in rangelands relies on primary production dynamics. As such, climate has a considerable influence on the structure and functioning of rangeland ecosystems. This influence is driven by rainfall dynamics; particularly seasonality (Easdale and Aguiar, 2012). Climate variability has the potential to generate two vital characteristics of forage dynamics that are particularly important in livestock management i.e. average forage production and temporal variability which may either be deterministic in nature (such as seasonality) or stochastic (Easdale and Aguiar, 2012). Climate variability creates oscillations in forage availability and quality depending on rainfall oscillations. In most dryland ecosystems, herbaceous biomass increases during wet months and decreases during dry months

(Nyamukanza et al., 2008); the same occurs in the drylands of Uganda and most African savannah ecosystems.

The situation is not any different in most of the dryland areas such as those in the Horn of Africa; where pastoralists grapple with seasonality (Angassa and Oba, 2007). In the Sahel belt, a similar trend of forage dynamics persists. Several other studies have alluded to the fact that precipitation variability is a much more important determinant of vegetation growth than grazing in semi-arid ecosystems (Fernandez-Gimenez and Allen-Diaz, 1999); this ultimately determines available forage at a location. And in pastoral communities such as those in Eastern Africa; grazing patterns resonate with rainfall seasonality and thus with forage spatial and temporal distribution (Behnke et al., 2011). In fact rainfall seasonality affects forage dynamics, livestock production and the livelihoods of the people (Kathleen et al., 2004).

Management practices such as animal management, use of fire, grazing intensity, length of patch rest, seasonal movements (frequency, timing, site and distance), rules of forage access and use and institutions such as council of elders and government have been identified to have an influence on forage resources patterns (Admasu et al., 2010). However, most of the studies that have in one way or the other identified these management practices as having influence on forage resources have not gone in length to elucidate the margin of influence. They have only remained at observational and associative level with respect to various pastoral lands.

Animal management through livestock grazing for example has been known to have a profound impact on vegetation. Vegetation change induced by grazing is well articulated (Alemyehu, 2004). Credible evidence suggests that unpalatable plants increase at the expense of more palatable species. At the same time, community structure gets altered when improper grazing continues for a long period. This has an implication on livestock production, forage quantity and quality. Although studies have pointed out the effect of grazing management on forage, much emphasis has been put on forage quality; limited attention has been put to relating these patterns of grazing to forage dynamics; this kind of information remains conspicuously missing from most of these studies.

The role of fire in savannah ecosystems is well articulated by several studies (van de Vijver, 1999; van Langevelde et al., 2003). It is not in the interest of this review to articulate the various theories underpinning fire as a determinant of savannah ecosystems but rather to look at how fire tends to influence forage dynamics in dryland areas. Butz (2009) recognizes the limited research on traditional fire practices. Traditionally, pastoral Maasai of northern Tanzania and Kenya have used fire as a land management tool for pasture regeneration (Butz, 2009).

Several reasons are provided for burning including aomong others; reducing fire hazard (Mapaure and Campbell, 2002); controlling bush encroachment and ticks (Dirbaba, 2008); and fire is used to regenerate rangelands (Ruiz-Mirazo et al., 2012). Mwongomo (2003) also pointed to the fact that in the areas of the Serengeti National Park; early burns are associated with inducing production of re-growth that generally favors grazers and ensure the availability of forage supplies so as to sustain migratory herds in dry season refuge areas. According to Pausas et al. (2008) fire can cause profound changes in vegetation types. Further, changes in floristic composition as well as in savannah health can be anticipated (Butz, 2009). However, few studies (Sachro et al., 2005) have attempted to examine the effect of fire on forage dynamics and species patterns. According to Shombe (2007) the biomass of nearly all live compartments and mass of dead compartments is higher on non-burnt than on burnt grasslands, thus emphasis the proposition that fire one of the determinants of vegetation dynamics in dryland ecosystems.

Land use and land cover change has become pronounced in pastoral lands over the past two decades. The loss in access to land for pastoralists has been greater than almost any other resource users which have seriously compromised their livelihood option (Huntsinger et al., 2010). This trend in land use and land cover change represents a growing concern in most of the pastoral regions because it is affecting the grazing resource base. The shifts in land use are largely externally driven and have set in motion a myriad of other challenges including: restricted mobility of pastoral herds, reductions in grazing lands and increased conflicts, especially between farming and pastoral communities (Nelson, 2012). The consequence of diminishing grazing lands is exemplified by livestock losses and exit of pastoralists from the practice among the Rufa’a Al Hoi ethnic group of the Blue Nile State in Sudan (Ahmed, 2009). Similar trends have been reported in Burkina Faso among the Fulani pastoral community. In Eastern Africa, land use and land cover change dynamics are evident in privatisation of pastoral land and sedentarisation in pastoral communities constraining grazing resources availability

(Lesorogol, 2005). Land use change tirggers vegetation changes by influencing species composition and the inversion of grazing lands by woody vegetation species (Lesorogol, 2005).

In Uganda, livestock keepers in Kaliro district have experienced shortage in forage owing to conversion of communal grazing lands into cropped agriculture (Tabuti and Lye, 2009). In Karamoja, the trend in land use and land cover changes overtime are not known, there has not been a sub-regional quantification of land use and land cover change. However, work by Majaliwa et al. (2009) in Moroto district (one of the districts in the sub-region) indicated that deforestation was the most significant biophysical change occurring in the district. A dearth of information on the influence of land use and land cover change on forage dynamics in the sub-region remains glaring.

2.3 Piospheric influence on forage composition and abundance

Proximity to water, topography and the availability of food have been identified as key determinants of foraging decisions at landscape level (Senft et al., 1987). These foraging decisions certainly have impacts on biological diversity because herbivore foraging affects various aspects of vegetation dynamics (Landman et al., 2012). In arid and semi-arid ecosystems, where standing surface water is an uncommon occurrence; the introduction of artificial watering sources has significant ecological effects (Brooks et al., 2006). This is because these artificial watering surfaces, introduce focused grazing and activity patterns around the watering sources. It is these activity patterns that introduce the disturbance gradient called ‘a piosphere’ with the interactions being centered on the piosphere such as watering points (Lange, 1969).

Piosphere influence resulting from activity gradients have been largely studied with a focus on large herbivores such as elephants (Landman et al., 2012). Distance dependent effects including: declines in perennial plant cover and species richness as well as structural diversity of perennial plant classes have been observed (Brooks et al., 2006). Further, their influence on soil nutrients (Stumpp et al., 2005); concentric and landscape degradation (James et al., 1999); soil compaction and erosion (Mugerwa et al., 2014); and variation in biomass defoliation and trampling (Shahriary et al., 2012) have also been reported. In addition, variation in forage species composition with increased presence of unpalatable perennial shrubs beyond the zone of extreme degradation and a decrease in the abundance of palatable native perennial grasses due to selective grazing have been documented (James et al., 1999

Indicsriminate location of piospheres in the grazing lands and particularly; that which leads to decrease in distance between piospheres has considerable influence on forage dynamics. This is because trampling around the piosphere leads to vegetation loss; and the influence of these dams on the herbaceous cover is often apparent over seven kilometres from the watering point (Thrash et al., 1991). Thus, where watering points are located too close to one another, there will be an overlap of their piospheres and overall reduction in the forage potential of the grassland (de Leeuw et al., 2001). Futher, evidence available suggests that piospheres lead to instability in the dynamics of the system as a whole. According to Verlinden et al. (1998) in livestock scenarios, crowding of watering points, feed troughs among others; results in the loss of forage abundance and pasture quality.

The development of piospheres in semi-arid Karamoja cluster (a grouping that includes; the Turkana of Kenya, Toposa of Sudan and Nyangtome of Ethiopia) is a result of different trajectories. Firstly, the proliferation of small arms in the sub-region changed the dynamics of pastoral management decisions that were often related to pasture, water and herd reconstitution after a drought (Mkutu, 2007). Small-arms influenced livestock raiding (using semi-automatic rifles-AK47 guns) within the Karamoja cluster and this became an additional stress. Livestock raids were not unusual in the pastoral Karamoja cluster however, with small arms the practice later shifted from the traditional to commercialized raids. Power relations also shifted such that the power now rested '*in the barrel of the gun'* (Mkutu, 2010). Following this transformation, the intensity of lethality sky rocketed with deaths approaching 60 per 100,000 of the population in the Karamoja sub-region of Uganda (Bevan, 2008). The dynamics in the sub-region became too complex (Mkutu, 2010) and Karamoja was temporally '*cut-off'* from the rest of Uganda (Stites et al., 2007). Karamoja had become ungovernable, 'a state within a state' where national law enforcement was barely inapplicable; and Karamoja became to be perceived as disconnected from 'the rest of Uganda' (Kratli, 2010).

In a bid to address the rampant insecurity in the sub-region, the Government of Uganda launched a series of disarmament exercises both voluntary and forcefully in the 2000s to recover the estimated 40, 000 to 50, 000 guns in the sub-region (Stites et al., 2007). This process led to the recovery of thousands of small arms (10,000 guns recovered in the first 1 year of the exercise) (Government of Uganda, 2007). However, the balance of power shifted between the disarmed and the armed pastoralists within and without the sub-region. The disarmed communities became highly vulnerable to armed livestock raids from the 'superior clans' (those who had not yet been disarmed) (Mugerwa et al., 2014). Thus, the Government of Uganda instituted the protected kraal system to provide security and safety to pastoral herds and the disarmed pastoral communities. These protected kraals introduced the second piosphere zone category in Karamoja centered on security of the protected kraal. Consequently, all other grazing and grazing management decisions were now defined by the protected kraal. The distance covered to graze livestock depended on the military security intelligence status because the Uganda Peoples Defense Forces (UPDF) had and have (still in some areas) to escort herders to the grazing lands and watering sources.

During the same period, Government of Uganda and development partners were grappling with intermittent droughts that affected availability of water and pasture for livestock as well as food security; a situation partly cofounded by livestock raids (Stites et al., 2007). In response, several waterholes were constructed within the sub-region to tame the persistent water shortages, build peace, and encourage reconciliation and sendetarisation of pastoral communities as preconditions for achieving food security. This increased the number of waterhole piosphere zones centered on constructed temporal to permanent water sources that had hitherto been non-existent in the sub-region. The construction of these facilities was hastily undertaken with minimum consideration to other ecological resources such as forage resources and the traditional grazing calendar (Mugerwa et al., 2014). Further, the sub-region lacks a water resources development master plan as such all interventions continue to be haphazard and driven by political goals rather than sound technical reasoning.

As noted earlier that animal impacts often become concentrated around piospheres according to geometrical relationship between the available foraging area and distance to the piosphere zone. This spatial distribution of animal impacts on vegetation often becomes organized a long utilisation gradients (Chamaille-Jammes et al., 2009). Much as these studies have shown dynamic effects associated with piospheres; considerable dearth in information necessary in facilitating the management of piosphere impacts in Karamoja sub-region pertains. Information specific to the effects of piospheres created by domestic livestock is particularly important in the management of rangelands. This study therefore sought to bridge this gap by examining the influence established waterholes and protected kraals have had on forage dynamics by analyzing forage species composition and abundance as proxy indicators.

2.4 Forage assessment and monitoring in semi-arid areas

Standing crop of herbaceous biomass produced by annual grasses is an important indicator of resource availability for livestock in semi-arid areas (Wylie et al., 1991). Forage productivity assessments during the growing season can help livestock managers make decisions for adjusting stocking rate and managing pastures (Sanderson et al., 2001). Several approaches for biomass assessment are in operation but the most suitable technique depends on available budget, accuracy required, structure and composition of the vegetation, and whether species and component biomass are required (Catchpole and Wheeler, 1992). Conventional forage clipping and weighing is generally accepted as the most accurate method for determining canopy biomass of pastures for forage availability estimation (Harmoney et al., 1997). The Clipping approach in quadrats has traditionally been used as the best bet approach. Clipping at ground level is recommended for best repeatability, but clipping at a grazed-height gives a more pertinent measure of forage biomass. Clipping height is most sensitive when a greater proportion of the plant biomass occurs close to the ground such as in herbs or prostrate shrub species (Brummer et al., 1994).

Because each quadrat represents only a very small area of the entire site, many quadrats often have to be clipped to obtain a representative sample size that adequately represents the amount of biomass on the site. Therefore, clipping is very time consuming and not practical for inventory or monitoring purposes over extensive areas. In such circumstances, the utilization of estimation and indirect methods has been suggested. Some of these approaches include; the comparative yield method, double sampling method, and weight estimate method (Bonhma, 1989). However, even these earlier approaches relied on extensive field data collection for precision.

Semi-arid lands and grasslands generally occupy large tracks of land and are remotely located with diverse mix of livestock species grazing the lands. Quantification of vegetation biomass for feed inventories is often quite challenging. This restricts the potential of traditional quadrat clipping approaches to deliver timely results needed in monitoring forage dynamics in search locations. There has been an increasing advancement in the search for faster methods that require less time and labor to help producers to monitor forage dynamics in pastures on a daily and/or weekly basis. Several indirect methods have thus surfaced including among others; modified Robel pole, rising plate meter, canopy height stick, and Li-Cor LAI ZOOO leaf canopy analyzer (Harmoney et al., 1997). Other methods include; disc pasture meter (Trollope and Potgieter, 1986); forage disk meter (Karl and Nichlson, 1987); 3D quadrat, a point quadrat method, plate meter; a measure of physical volume, and visual estimation, a component of the botanical method (Redjadj et al., 2012).

Further, there is growth in the use of models based on easily obtainable variables such as plant height and cover (Axmanova et al., 2012). There is equally a growing utilisation of remote sensing technologies in the assessment and monitoring of biomass. The increased utilisation of remote sensing is owed to increased freely available remote sensing data at increased temporal and spatial scale (Moreau and Le Toan, 2003). The use of remote sensing has been discussed in the following sub-section.

2.5 Utilizing remote sensing for forage dynamics monitoring

Owing to the limitations of field data i.e. small spatial and temporal scales and variations in type and reliability; advances in remote sensing technology have changed this situation (Gobron et al., 2000). Both physical and physiological parameters of vegetation can be obtained from satellite remote sensing (Gitelson and Kaufman, 1998). Consequently, satellite imagery has become very important for ecologists for predicting regional and global changes (Pettorelli et al., 2005). Satellite imagery provides a variety of information including sea surface temperature, ocean colour, topography, phenology and amount and distribution of vegetation (Turner et al., 2003).

Spectral vegetation indices derived from satellite imagery are also important indicators of spatial and temporal variations in vegetation structure and biophysical parameters and conditions. These indices also enable the assessment and monitoring of changes in canopy biophysical properties such as vegetation fraction, leaf area index, fraction of absorbed photo-synthetically active radiation and net primary production (Tucker et al., 1985). Parameters such as phenology, amount, temporal and spatial distribution of vegetation are very important parameters in influencing animal distributions, dynamics and life forms (Vintier et al., 2011).

There are several indices that are used for vegetation monitoring and assessment; some of the earliest and most common productivity algorithms are simple band ratios (SBR) which express an index of photosynthetically active radiation (Weber et al., 2009). The vegetation indices (VI's) are equally varied, but typically leverage a ratio of reflectance in the red band of a sensor to that of the near infra-red band of the sensor. Numerous vegetation indices are in operation including: Enhanced Vegetation Index (EVI), Soil Adjusted Vegetation Index (SAVI), General Soil Adjusted Vegetation Index (GSAVI), Normalized Difference Vegetation Index (NDVI-most commonly known), Integrated Normalized Difference Vegetation Index (INDVI) and Composite Normalized Difference Vegetation Index (cNDVI). However, the NDVI remains the principal index for vegetation monitoring (Aranha et al., 2008). The development of NDVI traces its routes to the work of Jordan in 1969 in which he utilised the red and NIR regions to measure leaf area index in forest canopies. This concept was later further developed by Deering in 1978 empahsising that the low dynamic range of NIR/Red ratio over sparse vegetation could be enhanced by rationing the difference between NIR and red bands to the sum of the two bands. It is this vegetation index that was named the normalized difference vegetation index (NDVI) defined by: $\mathbf{NDVI} = (\mathbf{NIR} - \mathbf{Red})/\ (\mathbf{NIR} + \mathbf{Red})$ (Jackson and Huete, 1991).

Subsequent vegetation indices developed have been a modification of NDVI in attempt to alleviate some of the challenges encountered. One of such a vegetation index is the composite normalized difference vegetation index (cNDVI). The composite NDVI (cNDVI) describes peak photosynthetic activity over a selected time series. It is a vegetation index that was developed to alleviate the challenges of spatial heterogeneity and seasonally dynamic land cover associated with semiarid rangelands (Weber et al., 2009). What is clear is that all the subsequent vegetation indices are simple modifications of NDVI and none has replaced the principle NDVI.

Given the importance of NDVI in vegetation assessment and provision of early warning information to a wider audience, research into how to make it much more reliable has been ongoing. Pettorelli et al. (2005) distinguishes two broad categories to include: Firstly, the long-term NDVI data sets that include; firstly; (i) the coarse scale (8-16 km resolution) National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR) time-series; these can be obtained from 1981 to the present and (ii) the small-scale (few meters) Landsat Thematic Mapper (TM) data sets extending from 1984 to 2003. Landsat ETM+ that is obtainable from 1999 to the present is also in operation (USGS, 2013). Secondly, better quality, but short-term NDVI time-series that include: (i) the Moderate Resolution Imaging Spectro-radiomter (MODIS-TERRA) data set (250-1000m resolution) extending from 2000 to the present; and (ii) the Satellite I'Observation de la Terre-Vegetation (SPOT-VGT) data set (up to a few meters resolution) extending from 1998 to the present. This study utilised AVHRR, MODIS and LANDSAT.

The Moderate Imaging Spectro-radiometer (MODIS) provides products such as MODIS vegetation index (VI), NDVI, Enhanced Vegetation Index (EVI) and Leaf Area Index (LAI) are mainly used in evaluating the ecological variables (Potithep et al., 2010). MODIS provides daily vegetation dynamics with seven specifically selected, highly characterised and calibrated spectral channels in the solar spectrum. MODIS data provide a much better picture of vegetation dynamics than the previous satellite data records (Gitelson and Kaufman, 1998). However, MODIS data is limited when long term time-series analysis is needed due to its relatively short-term availability extending from 2000 to the present. MODIS data is also limited by the clouding effect that is apparently very pervasive during the wet seasons (Samanta et al., 2012). Over the tropics, nearly every MODIS run during the wet season is corrupted by cloud cover; a considerable proportion is also affected during some months of the dry seasons (Samanta et al., 2012; Meng et al., 2009).

Although MODIS data is limited in certain spectra, it to a large extent alleviates the shortcomings associated with the AVHRR NDVI data (e.g. calibration degradation, loss of orbit, lack of satisfactory atmospheric correction, broad spectral bands, saturation in dense vegetation, and insufficient validation among others). This is because MODIS instruments represent an improvement in measurements of surface vegetation conditions, spatially, spectrally, and radiometrically (Tucker et al., 2005). MODIS also complements the spectral, spatial and temporal coverage of other instruments aboard the platform such as Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), Multi-angle Imaging Spectro-Radiometer (MISR) and the Cloud and Earth's Radiant Energy System (CERES) (Justice et al., 1998).

The Land Remote Sensing Satellite System (LANDSAT) for the last four decades (Figure 2.2; USGS, 2013) has provided spectral information from the earth's surface, creating unparalleled historical archive of detailed, quality, coverage and length of earth's information (Rocchio et al., 2005). There have been seven Landsat satellites (Landsat 1; Landsat 2; Landsat 3; Landsat 4; Landsat 5; Landsat 7; and Landsat 8) launched since 1972. Landsat 6 was not successfully launched after it failed to attain maximum velocity necessary to obtain orbit (USGS, 2013). The most recent, Landsat 8 Enhanced Thematic Mapper Plus (ETM+) was launched in February, 2013. Landsat 8 will ensure continued acquisition and availability of Landsat data, which is consistent with the current standard Landsat data products (USGS, 2013).

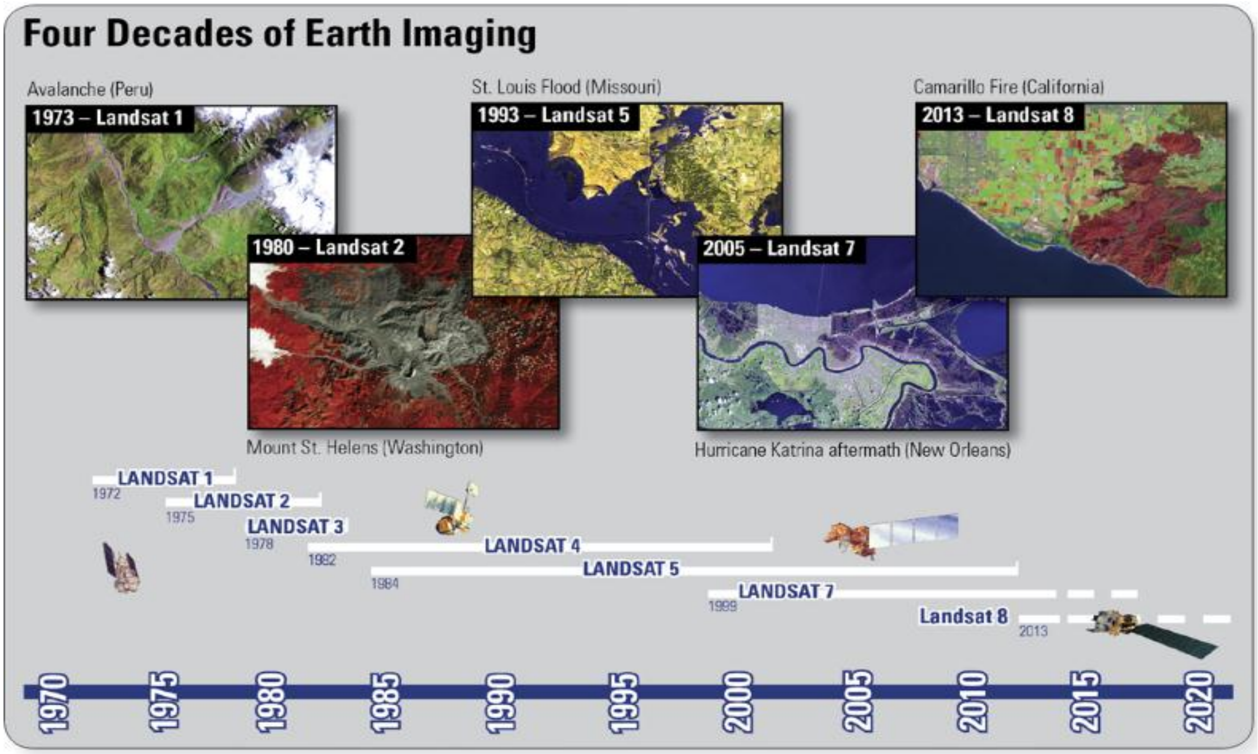


Figure 2.2: Trends in the development of Landsat and provisioning of imagery (Source: USGS, 2013)

All the seven satellites except Landsat 6 have provided millions of multispectral images of the earth's land surface. Consequently, this retrospective portrait of the earth's surface is available to be used for improved understanding of the earth's land surface. Utilizing the various band combinations different information is provided. This is because each of these bands in the wavelength is sensitive to particular aspects on the earth's land surface and with it carries a specific spatial resolution (Eldeiry and Garcia, 2008).

When the different bands are combined various colour composites are obtained (Idris, 2005). It is this ability to manipulate various bands that vegetation indices are generated to describe vegetation conditions and land cover patterns. The Normalized Difference Vegetation Index (NDVI) that is an indicator of photosynthetic biomass is derived from the TM bands 4 and 3 (NIR and Red) respectively. This defined as the ratio of their difference divided by their sum. This is possible because vegetation reflectivity is high in the NIR and relatively low in the visible. In this study, Landsat imagery for 1986, 2000 and 2013 covering Karamoja sub-region were utilised.

2.6 Climate variability and change

Climate change and variability have remained 'thorny' issues in scholarly discussions with some optimists opposed to the existence of the former. The optimists see bad weather as bad weather, not climate, and that climate is not changing. Nonetheless, the common distinction between the two is based on time-scale. Climate variability is conceptualized as variations in the climate system over short time scales such as months, years and/or decades. According to Ganopolski (2008) climate has traditionally been referred to as averaged weather conditions, such as the mean July temperature or annual precipitation. However, for many applications it is important to know not only the averaged characteristics, such as monthly averaged temperature, but also different measures of variability (statistics), like the interannual variability of the precipitation or a number of extreme weather events. Thereby, more precisely the term climate is characterized as 'the statistical description (of the climate system) in terms of the mean and variability of relevant quantities'. *Temporal evolution of the climate characteristics beyond the timescale of individual weather events is named* '*climate variability*' while *statistically significant trend of climate state on longer timescales* (decades and more) *is the 'climate change*'.

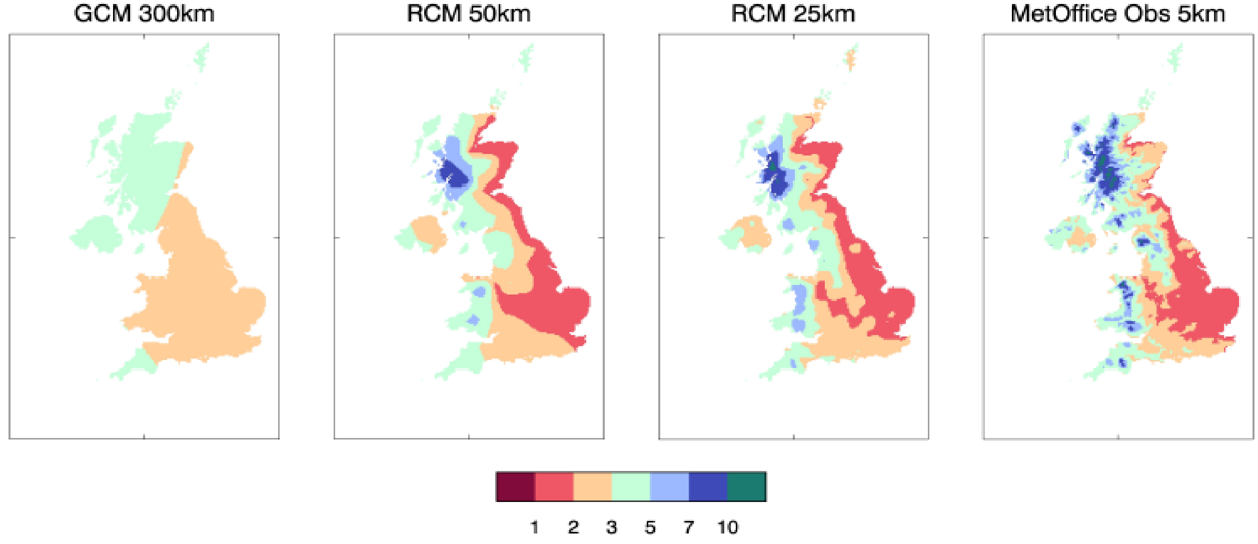
According to the World Meteorological Organisation (WMO) climate change are long term changes in average weather conditions. Conversely, the Intergovernmental Panel on Climate Change (IPCC) considers climate change as "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period. This is however different from the definition adopted by the UNFCC. According to the UNFCC, climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCC, 1992). While these differences in definition exist; the difference arises from the emphasis in time-scale, cause, effect and measure. The UNFCC encompasses all the four components while the WMO and IPCC definition emphases the time-scale and measure of the change. Climate change is generally attributed to the high concentrations of greenhouse gases in the atmosphere (IPCC, 2001).

On the other hand, climate variability refers to the spatial and temporal variation in the mean, standard deviation and occurrences of extreme events of climate (IPCC, 2001). Climate variability thus takes care of year to year variations of the climatic variables such as temperature and precipitation at different time scales (Douguedroit, 1997). It can also be understood as variations in the prevailing state of the climate on all temporal and spatial scales beyond that of individual weather events (O'Brien and Leichenko, 2000). In the same respect, climate variability means the seasonal and annual variations in temperature and rainfall patterns within and between regions or countries (UNEP, 2002). Climate Variability may be a result of natural internal processes within the climate system or due to variations in natural or anthropogenic external forcing and depend on physical processes of the climate system (Waiswa, 2003). Over the African surface, climate variability is largely driven by the prevailing patterns of sea surface temperature, atmospheric winds, regional climate fluctuations in the Indian and Atlantic Oceans, and by the El Niño Southern Oscillation (ENSO) phenomenon (Mubaya, 2010).

2.7 Downscaling climate data

Climate remains one of the most important production components to mankind especially where communities are natural condition’s dependent. Understanding the past, present and future climate is thus important for sustainable production of both natural ecosystems and economies. Over the second half of the last century mean annual temperatures in Africa were indicated to have risen by approximately half a centigrade. Some areas such as the Nile Basin countries increased by 0.2°C and 0.3°C per decade while others warmed faster over a 50 year period for example in Rwanda temperature increased by 0.7°C to 0.9°C (Eriksen et al., 2008). Further, there is evidence to the effect that global temperatures will continue to rise. Global climate change models show that Uganda will generally have an increase in average temperatures by up to 1.5°C in the next 20 years and up to 4.3°C by 2080s. Similarly, changes in rainfall patterns and total annual rainfall amounts are also expected. It is also expected that rainfall will increase over much of the country by 10–20 percent (MWE, 2013).

The general circulation models (GCMs) provide information on future climate change scenarios. The coarse spatial resolution with which GCMs are conducted makes them limited in providing information needed at regional and local level (Cavazos and Hewitson, 2005). This is because GCMs do not capture the local features needed for regional impact assessments. This makes it necessary that advanced downscaling is conducted at regional to local level to capture these conditions and provide more site specific climate relevant information. Downscaling, is simply a translation across scales (Figure 2.3; Maraun et al., 2010), is a term adopted to describe a set of techniques that relate local- and regional-scale climate variables to the larger scale atmospheric forcing (Hewitson and Crane, 1996). It also refers to the simulation of local and regional scale weather and climate predictands such as temperature, precipitation, humidity, and wind direction as a function of synoptic-scale indictors of atmospheric conditions (Linderson et al., 2004; Hayhoe, 2010). According to Hewitson and Crane (1996) downscaling was developed specifically to address present needs in global environmental change research, and the need for more detailed temporal and spatial information from Global Climate Models (GCMs).



Average UK winter precipitation (mm/day) for 1961-2000 simulated by the Hadley Centre global climate model (GCM) HadCM3 and the regional climate model (RCM) HadRM3 at 50 km and 25km resolutions, compared with gridded observations 300km.

Figure 2.3: Demonstration of downscaling from GCM to RCM level

The inability of GCMs to provide local level relevant climate information for example, at seasonal time scale (Rabbinge, 2009) yet political negotiations, policy reforms, adaptation, and land management planning require such information for effectiveness (van de Steeg et al., 2009) means that downscaling is a necessary step to derive high resolution information (Boe et al., 2007). Regional climate models (RCMs) are now addressing the inadequacy of global climate models (GCMs) to provide climate information needed for assessing impacts of climate change and variability at local to regional level (Leung et al., 2003). A regional climate model (RCM) is a downscaling tool that adds fine scale (high resolution) information to the large-scale projections of a global general circulation model (van de Steeg et al., 2009). The ability of the RCM to provide local to regional scale details arises from its ability to resolve features down to 50 km or less. In so doing, the RCMs use GCMs to provide grid-scale averages of spatio-temporal hydro-climatic state variables, as well as soil hydrology and thermodynamics and some vegetation dynamic variables (van de Steeg et al., 2009). Downscaling attempts to resolve the scale discrepancy between climate change scenarios and the resolution required for impact assessment. It is based on the assumption that large-scale weather exhibits a strong influence on local-scale weather, but in general disregards any reverse effects from local scales upon global scales (Maraun et al., 2010). According to Hewitson and Crane (1996) two general downscaling techniques exist; firstly, the process based techniques focused on nested models, and secondly, empirical techniques using one form or another of transfer function between scales. These two approaches represent what is commonly referred to as dynamical and statistical downscaling respectively. Thus:

Dynamical downscaling is a process where a regional climate model (RCM) is nested into the GCM to represent the atmospheric physics with a higher grid-box resolution within a limited area of interest. According to Hayhoe (2010) in dynamical downscaling, some higher-resolution models are dynamically nested; that is, information is exchanged in both directions between the global and the regional climate model on a regular basis throughout the simulation, allowing higher-resolution regional processes to feedback directly to global climate but most high resolution models use pre-calculated GCM output fields to update their boundary conditions every 3 or 6 hours, depending on the temporal resolution available from the GCM output. While dynamical downscaling offers potential to provide high quality climate states output, the approach is computationally demanding thus not accessible and user friendly. The approach also suffers from difficulties in the interface between the GCM and the nested model (Hewitson and Crane, 1996). There are barely any results from the Africa scientific community in report in which dynamical downscaling has been utilised. In the present state, dynamical downscaling is not feasible for the global south.

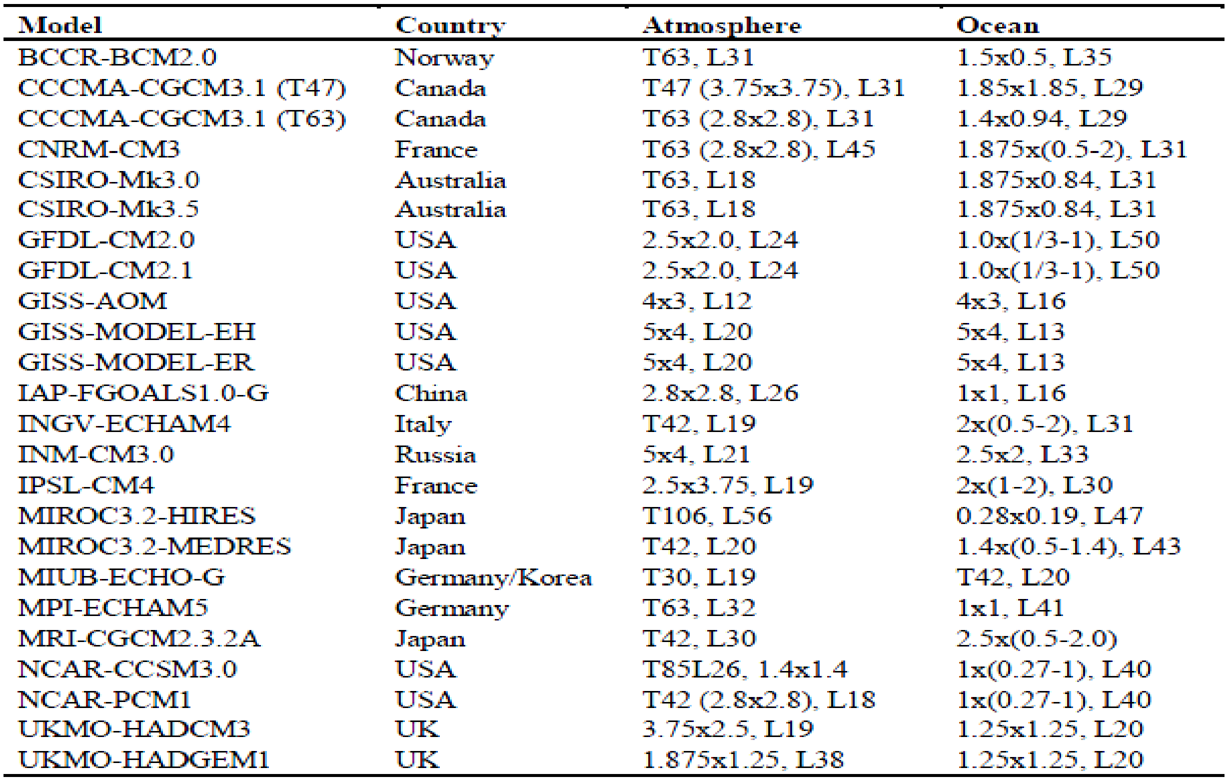
Statistical downscaling is an approach based on establishing a statistical relationship between the large (r) scale weather and the observed local-scale weather (Maraun et al., 2010). Statistical down-scaling generally involves two steps: (i) developing statistical relationships between local climate variables such as surface air temperature and precipitation with large-scale predictors such as pressure fields; and (ii) the application of such relationships to the output of the GCMs experiments to simulate local climate characteristics in the future (Hoar and Nychka, 2008). Statistical models may be developed for any variable for which long, high-quality observational series exist, though the practical value of such models depends on the existence of strong, physically meaningful and temporally stable links between large scale predictors and the predictand (Hanssen-Bauer et al., 2005). According to Kattenberg et al. (1996) statistical downscaling is particularly recommended in areas with complex topography. However, Hayhoe (2010) indicates that the cardinal principle for any statistical downscaling method is a robust record of historical instrumental data that permits calibration at the local scale. Statistical downscaling methods are flexible and rapid, capable of developing climate projections based on multiple emission scenarios and daily rather than six hour GCM simulations. Further, several GCMs simulations can be downscaled using the same computing resources required to run only a few years of regional model or dynamical downscaling (Hayhoe, 2010).

Several sub-approaches are available to aid in executing statistical downscaling which include: weather generators, weather classification schemes, and regression method (e.g. Delta method, Bias correction method, Analogue approach, Quantile mapping Bias Correction Spatial Disaggregation (BCSD) (Mearns, 2009). This study adopted the use of the delta method; firstly, because the topography of the region under study is fairly non-complex; secondly, the approach is fairly easy to implement with basic available computer applications. The delta method is based on the use of a change factor, the ratio between a mean value in the future and historical run (Ruiter, 2012). Delta method produces a smoothed (interpolated) surface of changes in climates (deltas or anomalies) and then applies this interpolated surface to the baseline climate, taking into account the possible bias due to the difference in baselines. The method assumes that changes in climates are only relevant at coarse scales and that relationships between variables are maintained towards the future (Ramirez-Villegas and Jarvis, 2010). The above assumptions could be erroneous in highly heterogeneous landscapes where topographic conditions cause considerable variations over relatively small distances. However, the current sub-region under study (Karamoja) generally consists of plains with isolated highlands spread apart over a direct distance in the range of 50-100 km.

2.8 General Circulation Models and emissions scenarios

General circulation models (GCMs) simulate past and possible future climatic changes by numerically integrating the fluid dynamical equations of motion for the atmosphere with boundary conditions that incorporate various factors influencing the climate system (Covey and Ghan, 1987). The development of these models has been an on-going step-by-step process; from stand-alone atmosphere models to coupled ocean-atmosphere models, and later to multi-sphere inter-active models (Yongqiang et al., 2004). From the 1980s, there has been a rapid development of the coupled atmosphere general circulation models (CGCMs). These developments have led to the Atmosphere Ocean General Circulation Models (AOGCMs) that have become instrumental in climate modeling. The basis of Intergovernmental Panel on Climate Change (IPCC) climate predictions are drawn from the utilisation of the AOGCMs. Presently, several GCMs are in use (Figure 2.4; Ramirez-Villegas and Jarvis, 2010) by the scientific community.

General circulation models use transient climate simulations to project future climate changes under different scenarios. A transient climate simulation is an approach of running a GCM in a period of time with continuously varying concentrations of greenhouse gases such that the climate represents a realistic mode of possible change in the real world (Boer et al., 2000). On the other hand, scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyse how driving forces may influence future emission outcomes and to assess the associated uncertainties. Scenarios provide a basis for climate change analysis, including climate modeling and the assessment of impacts, adaptation and mitigation (Nakicenovic et al., 2000). The IPCC developed a multi-model set of scenarios (A1, A2, B1, and B2) commonly referred to as the SRES (Special Report on Emissions Scenarios); they describe the relationships that evolve between the climate system and the various forcings-driving forces (IPCC, 2000).



Model	Country	Atmosphere	Ocean
BCCR-BCM2.0	Norway	T63, L31	1.5x0.5, L35
CCCMA-CGCM3.1 (T47)	Canada	T47 (3.75x3.75), L31	1.85x1.85, L29
CCCMA-CGCM3.1 (T63)	Canada	T63 (2.8x2.8), L31	1.4x0.94, L29
CNRM-CM3	France	T63 (2.8x2.8), L45	1.875x(0.5-2), L31
CSIRO-Mk3.0	Australia	T63, L18	1.875x0.84, L31
CSIRO-Mk3.5	Australia	T63, L18	1.875x0.84, L31
GFDL-CM2.0	USA	2.5x2.0, L24	1.0x(1/3-1), L50
GFDL-CM2.1	USA	2.5x2.0, L24	1.0x(1/3-1), L50
GISS-AOM	USA	4x3, L12	4x3, L16
GISS-MODEL-EH	USA	5x4, L20	5x4, L13
GISS-MODEL-ER	USA	5x4, L20	5x4, L13
IAP-FGOALS1.0-G	China	2.8x2.8, L26	1x1, L16
INGV-ECHAM4	Italy	T42, L19	2x(0.5-2), L31
INM-CM3.0	Russia	5x4, L21	2.5x2, L33
IPSL-CM4	France	2.5x3.75, L19	2x(1-2), L30
MIROC3.2-HIRES	Japan	T106, L56	0.28x0.19, L47
MIROC3.2-MEDRES	Japan	T42, L20	1.4x(0.5-1.4), L43
MIUB-ECHO-G	Germany/Korea	T30, L19	T42, L20
MPI-ECHAM5	Germany	T63, L32	1x1, L41
MRI-CGCM2.3.2A	Japan	T42, L30	2.5x(0.5-2.0)
NCAR-CCSM3.0	USA	T85L26, 1.4x1.4	1x(0.27-1), L40
NCAR-PCM1	USA	T42 (2.8x2.8), L18	1x(0.27-1), L40
UKMO-HADCM3	UK	3.75x2.5, L19	1.25x1.25, L20
UKMO-HADGEM1	UK	1.875x1.25, L38	1.25x1.25, L20

Figure 2.4: Some of the available GCMs and principal characteristics

The IPCC emissions scenarios have provided a basis for progress in climate projection and modeling with a focus on advancing the understanding of past and future climates, providing information for impact assessments, adaptation and mitigation. Coordinated coupled model experiments have continued to be undertaken and at present the fifth Coupled Model Intercomparison Project (CMIP5) has been under way in different parts of world (Rupp et al., 2013; Chen and Frauenfeld, 2014). The CMIP5 is focused at: (i) assess the mechanisms responsible for model differences in poorly understood feedbacks associated with the carbon cycle and with clouds; (ii) examine climate "predictability" and exploring the predictive capabilities of forecast systems on decadal time scales; and, 3) determine why similarly forced models produce a range of responses.

These efforts have not only remained with the prediction community but have also been applied to impact studies. The Agricultural Model Intercomparison and Improvement Project (AgMIP) is one of such initiatives that are being undertaken at global, regional and national level (Rosenzweig et al., 2013). AgMIP strives to link the climate, crop, and economic modeling communities with cutting-edge information technology to produce improved crop and economic models and the next generation of climate impact projections for the agricultural sector (Rosenzweig et al., 2012). AgMIP Regional Integrated Assessments are particularly commendable because they focus at production systems rather than specific fields (Rosenzweig et al., 2013). However, they are still largely implemented at regional and national level basis. This study undertook a sub-region based (local level) downscaling of climate and applied the result to project potential forage production in a pastoral region of Uganda. This is part of complimenting sub-regional and national level climate projection and impact studies.

2.9 Impact of climate variability and change on forage production

Projections into the future show that global drylands are expanding and will continue to expand in the 21st century (Feng and Fu, 2013). In these drylands, the total precipitation amount will generally decrease coupled with more extreme events (including droughts, storms) that are erratic and unpredictable varying from one location to another. Such climate patterns have potential to impact on production and availability of livestock resources in dryland areas. Several researchers (Hesse and Cotula, 2006; Cowie and Martin, 2009) have shown that a decline of rainfall by at least 10% will affect the quality, quantity and spatial distribution of natural pastures. This coupled with the present demographic shift within and outside the drylands, makes the likelihood of stronger competition between pastoral communities and other groups much greater-with a possibility of conflicts resulting into violent clashes.

However, downscaling of GCM outputs to finer spatial and temporal scales has received relatively little attention in East Africa (van de Steeg et al., 2009). There is also a considerable gap between the available information at seasonal time scales and the available information at climate change (2050 and beyond) time scale (Rabbinge, 2009). Generally, the information of what is likely to occur over the next 3 to 20 years is largely missing (Washington et al., 2006). Moreover, limited projections that have been conducted in the region have been applied to high value crops such as coffee, tea, and maize. In this case, considerable dearth of information on the potential impacts of climate change on forage resources at regional to local levels in pastoral areas such as Karamoja sub-region exist.

2.10 The conceptual framework used in this study

The conceptual framework indicating the interaction between the climate system and determinants of forage dynamics and the likely outcomes of this interaction in the present and future situation is presented in Figure 2.5 (personal illustration). The framework acknowledges the functionality of the global climate system interacting with the regional climate system; these have an influence on the rainfall and temperature patterns at local climate level. The local climate patterns especially in dryland areas such as in Karamoja have been documented to have a considerable influence on forage dynamics (Ellis and Swift, 1988; Ellis and Galvin, 1994; Galvin et al., 2004).

Climate has been demonstrated to influence both physical and chemical properties of soil (Varallyay, 2010) with multiple effects on plant growth. It is not in the interest of this study however to investigate the effect climate has on soil properties in Karamoja but rather develop a linkage between soil as a determinant of forage dynamics in Karamoja. These determinants do not operate in isolation of other determinants such as socio-cultural and livelihood actions (Kirwa et al., 2012), fire, grazing intensity, patch accessibility, livestock density among others in influencing forage dynamics; these act as modifiers of the range. In addition, interventions introduced into the pastoral systems such as waterholes act as piospheres of influence in forage dynamics through their influence on trampling and grazing intensity (Vetter, 2005).

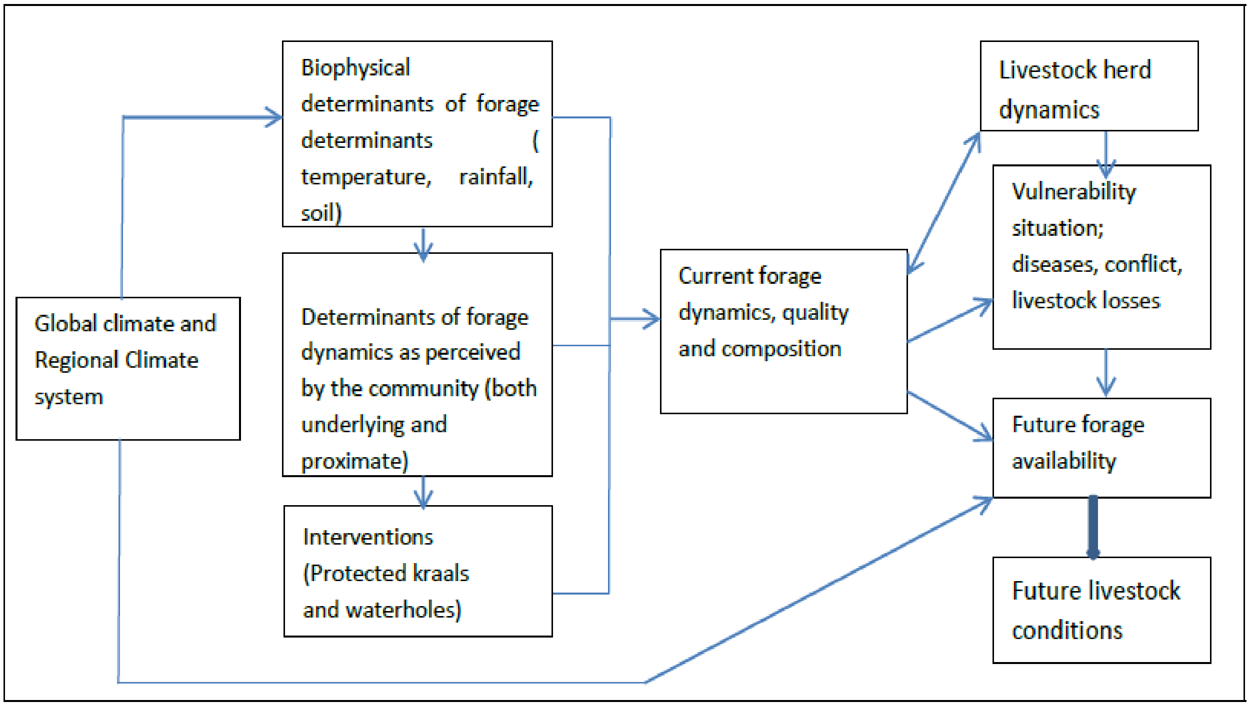


Figure 2.5: A conceptual framework indicating the interaction between the climate system, determinants of forage dynamics and the likely outcomes

The outcome of this interaction is anticipated to influence livestock herd dynamics; this study recognizes that livestock herd dynamics-forage interaction is a two way fold. Forage dynamics is noted as one of the determinants in herd and flock recruitment in pastoral systems (Nyariki et al., 2009) the others being disease and management. However, it is not in the interest of this study to investigate the determinants of herd dynamics in a pastoral production system such as Karamoja but recoganise in this framework that forage dynamics is influenced by livestock herd size and to the alternate.

The interaction is also anticipated to provide insight into the vulnerability situation and patterns especially those associated with key livestock resources; forage and water. The vulnerability dimensions particularly highlighted in this study (Chapter 11) include the the shift in seasons and the inter-annual variability. Available literature indicates that human populations can become vulnerable due to changes in environment through floods or droughts, changes in human population, climate change, diseases, and change in environmental and social policy (Galvin et al., 2004). This study did not investigate the vulnerability pathways among the Karamojong pastoralists and agro-pastoralists however the interactions herein offer pointers to vulnerability conditions given the variability in projected rainfall and rise in temperature. Further, given the oscillations in the climate system, it is anticipated that this will have impact on the future forage dynamics and availability (Wheeler and Reynolds, 2013); when the entire interaction in the variables is holistically taken, they will have a bearing on the future livestock conditions.

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of Karamoja

Karamoja, a land of 27, 200 square km is located in North Eastern Uganda between 1°.4’-4.24°N and 33°50’-35°E (Figure 3.1). The Republic of South Sudan and Kenya border the region to the north and east respectively. Internally, it borders the tribal communities of Teso, Lango and Sanbiny in the west, northwest and southwest respectively. The region has seven administration districts including: Kotido, Moroto, Abim, Kaabong, Napak, Amudat and Nakapiripirit (Figure 3.1; personal illustration, 2014).

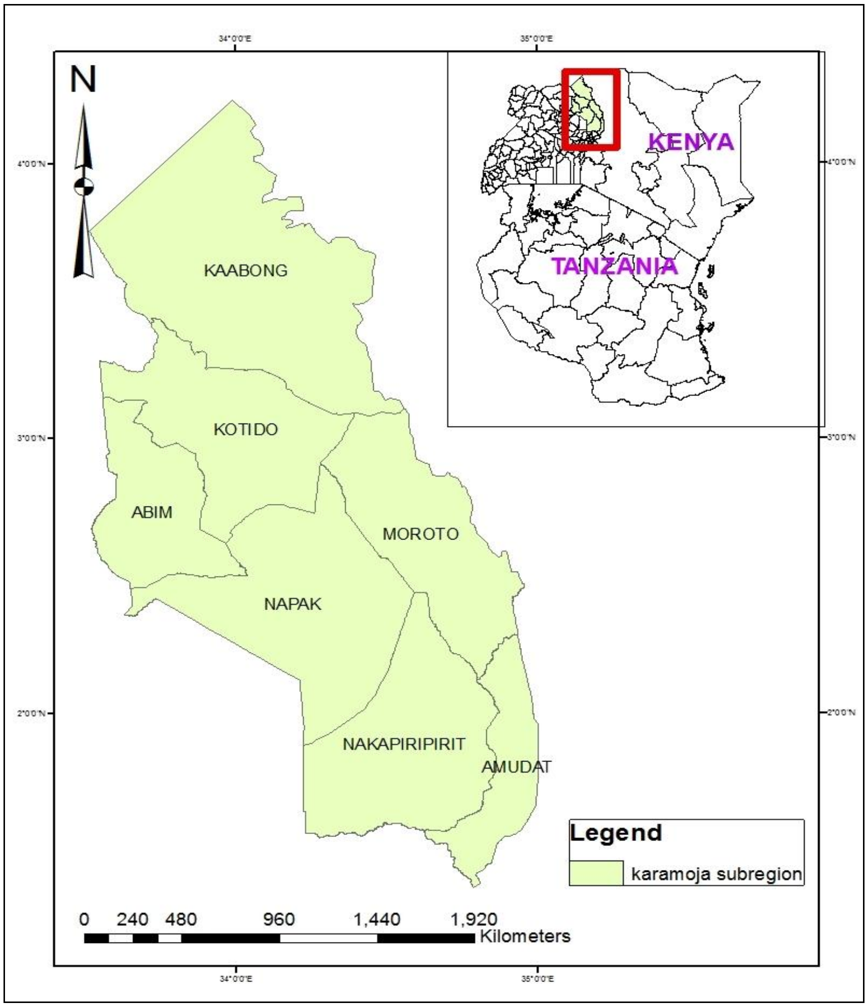

Figure 3.1: Location of Karamoja sub-region

3.2 Climate of Karamoja

Karamoja is the driest sub-region in Uganda. For many months of the year, the area is brown and dry this pattern has been unceasing (Thomas, 1943; Mubiru, 2010). Climate variability typifies Karamoja sub-region, Thomas (1943) using rainfall data from Moroto station provided a glimpse into this variability. For 19 years, a period running up to around 1943; the average rainfall was 19 cm (190 mm). However, a significant variation was experienced in the late 1930s with 1937 receiving a total average of 148 cm (1480 mm); this was a considerable rise from 48 cm (480 mm) received in 1924. Further, Weatherby (1988) indicated that rainfall patterns in Karamoja are variable with the mean mountain annual rainfall fluctuating between 40-50 inches (1016-1270 mm). The variability indices for the region between 1947 and 1976 revealed high inter-annual variability with the existence of extreme events; floods and drought (Figure 3.2; Egeru et al., 2014a).

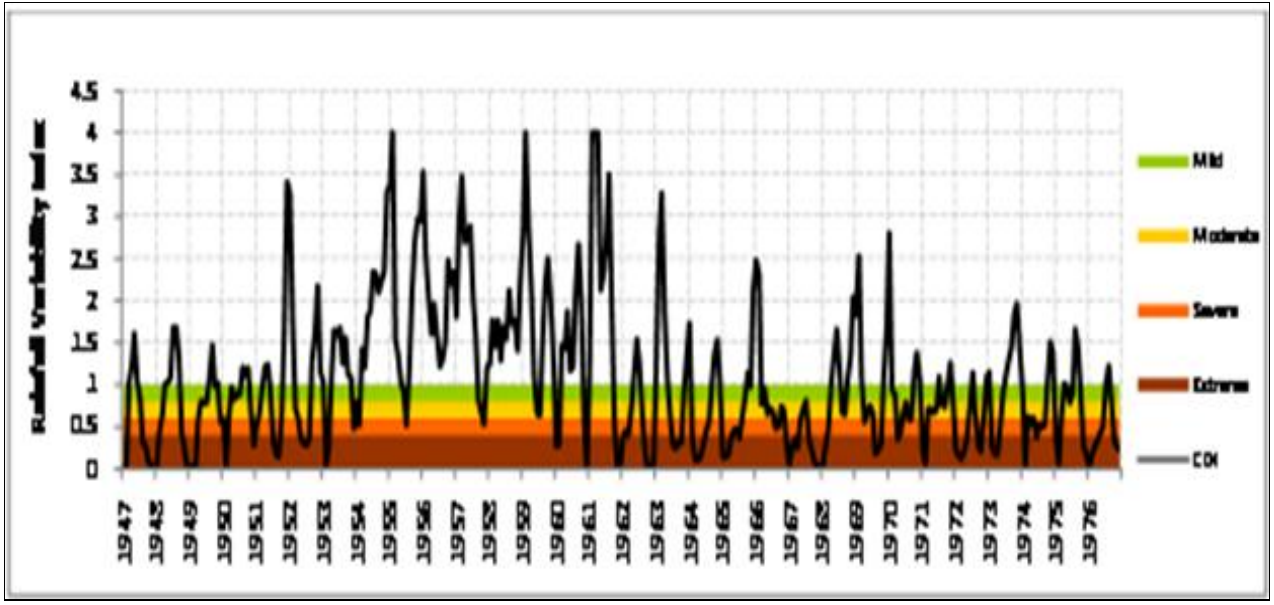

Figure 3.2: Rainfall variability index for Namalu station, Karamoja (1947-1976)

Temperatures in the sub-region are generally high averaging 28°C-33°C for minimum and maximum temperature respectively. The temperatures tend to be higher during the dry seasons especially from December to February (Grange, 2010). According to Gavigan et al. (2009) the climate records for the region during the 20th century show that patterns of air surface temperature changed mirroring those observed in the global data sets, with post WW2 cooling giving way to a strong warming in the trend since the 1960s (Figure 3.3). The sub-region also experiences very high evapotranspiration. It is estimated that on average annual potential evaporation (PET) in the sub-region is 1800-2200 mm/year, with an average even distribution of 5-7 mm every day (Ngirane-Katashaya and Kaford, 2011).

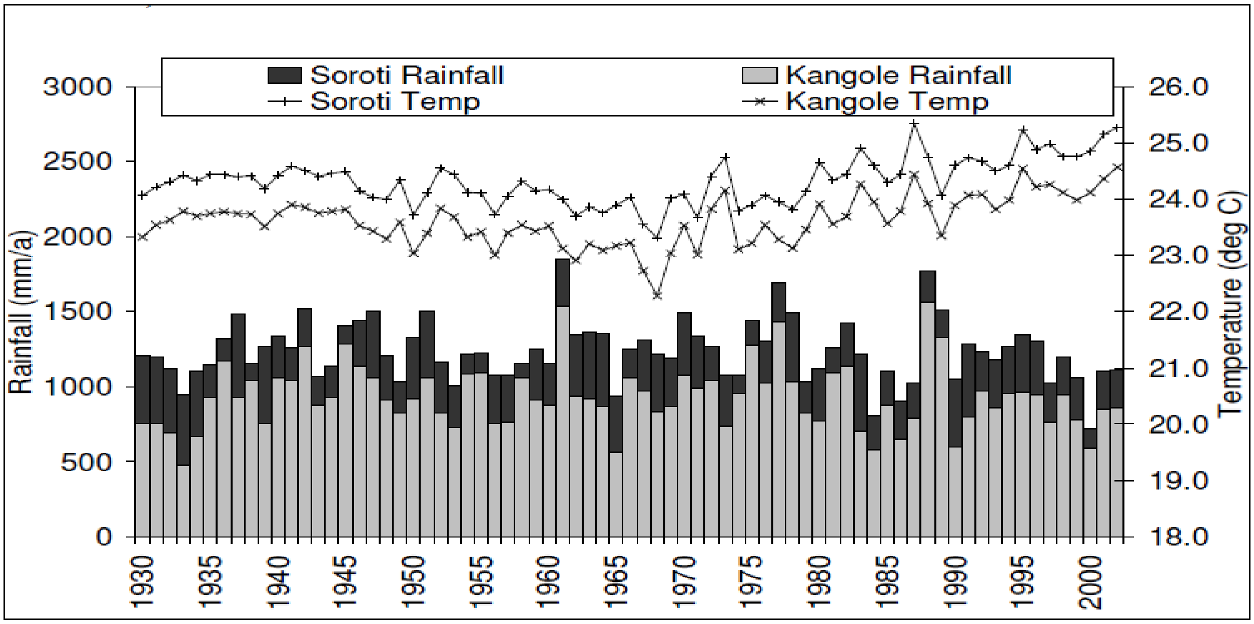

Figure 3. 3: Annual total rainfall and annual average air temperature

(Source: Gavigan et al., 2009)

3.3 Vegetation of Karamoja

The vegetation of Karamoja generally consists of open savannah grasslands, woodlands, thickets and shrublands. Accroding to Thomas (1943) Karamoja's vegetation can simply be described as consisting of *Acacia–Combretum–Terminalia* species associations, with a grass layer of *Hyparrhenia*, *Setaria*, *Themeda*, *Chrysopogon* and *Sporobolus* species. These are principally C4 grass species (Nalule, 2010). Five land use/cover types are identifiable in Karamoja sub-region, namely subsistence farm lands, woodlands, grasslands, thickets and shrublands and bushlands (Plates 3.1a, 3.1b, 3.1c and 3.1d; Egeru et al., 2014b). Table 3.1 below presents a description and characteristics of each of these land cover types.

Table 3.1: Characteristics of land cover types in Karamoja

Land use/cover type	**Location**	**Description**
Subsistence farmlands	About 1-4 kilometers away from the manyattas (homesteads). Traditionally the largest cultivations are those around Kangole (now Napak district), west of Moroto (Nadunget sub-county), around Kotido (Panyangara and Nakapelimoru), north of Toror hills (Thomas 1943). From Lorengdwat through to Southern Karamoja-Namalu area are dotted plots of croplands. Water deficits are a re-known challenge to the cropping estate.	All land is dedicated to the production of cultivated crops. In Karamoja these are principally open cultivated fields with sorghum as the main staple crop (Plate 3.1d). Trees (often thorny bushes, twigs and trees) are cleared during land opening. Once productivity has declined the farmer either clears the adjacent land and/or shifts to another location. These farmlands are often located a few meters from the manyattas to about 4 kilometers away.
Grasslands	Between the four groups of hills; Moroto, Toror, Napak-Iriiri (Plate 3.1a) and Lawor there is a land scape of open grasslands. Grasslands also occur in the open plains of Nakaale in Amudat district after Tokora to the lower areas of Namalu through the broader plains of Moruajore and Pian upe game reserve and much of Lolachat in Nakapiripirit district. This stretch of grasslands follows a northword trending through Lolachat to Iriir and to the foot slopes of Opopwa hills north of Napak district where Themeda triandra, Bracharia brizantha, and Sporobolus pyrimidalis are dominant grasses (Thomas, 1943).	Land on which composed on annual, biennial, and/or perennial self-seeding grasses. In Karamoja these are natural grasses that include: all the grass-steppes and savannas in the east, grasslands of the broad valleys in the center and open grasslands of the plains in the south and west of generally grass steppes. Grasses such as *Setaria holstii*, *Panicum meyerianum, Themeda triandra* and the legume *Clitoria ternatea* can be found in these areas (Thomas, 1943).
Thickets and shrubland	These are generally more dominant in Kotido (Plate 3.1b) district than anywhere else in the region. They also occur around Panyangara, Nakapelimoru and parts of Regen sub-county from areas of Lokadeli.	Land on which vegetation is dominated by low growing woody plants having single to multiple stems arising at or near the base (Allen et al., 2011). In Karamoja, this landscape when looked at from a distance forms whitish carpeting (especially during the dry season) of thorny trees (generally of a low height 1-3 m although the more mature trees may reach 5-6 meters) with short grasses at the base. These trees are generally Acacia species (e.g. *Acacia drepanolobium, Acacia oerfota, Acacia kirkii*) providing browse for ruminants.
Woodlands	Generally tropical savanna-woodlands occurring in the south and west (Iririr), north west in the Labwor ranges (present	Land with a plant community which, in contrast to a typical forest, contains trees that are often small, characteristically short-boled (height

	day Abim district) central region around Mount Moroto, far north to Mount Zulia area; from Nabuin (Plate 3.1d) through parts of Kamulasabala through to Acholchol in Nakapiripirit district; and areas around Moruita in Amudat district. Compared to all other districts in the sub-region woodlands in Kotido are insignificant and those that exist occur mainly along river channels and a few major shrines (respected for traditional ceremonies).	ranges 5-20 m) relative to their crown depth and forman open canopy only with the intervening area being occupied by shorter vegetation, commonly grass (Allen et al., 2011). In Karamoja, these areas are generally occupied by deciduous trees with a fair height level in the range of 5-12 m (Plate3.1d at the far background). Tree species such as: *Combretum binderianum*, and *Bauchinia thoningii* can be found in this land cover with interwoven Acacia and other plant forms including grasses that similarly occur in the grasslands.
Bushlands	Fringes of gardens, areas with a past history of grazing but with decreased grazing over the last 15 years and former abandoned kraals (old livestock bomas). One can easily observe bushland land covers around Toror mounts, Lobel in Kotido district (Plate 3.1c). In Kaabong district a wide spread beginning from around Lobunyet, to the northeast trending parts of Nakimoru, Napararo, Kamion, Oropoi, Morungole and towards Pirre. In Moroto district bushland can be observed after the Moroto River in the north east trending to Lokisile, Ilokapel and after River Acholchol and towards the airstrip in Amudat district.	Land with >15-20% bush or shrub cover and plant height ranging on average between 3-6 m. In the Karamoja case, some bush and shrub vegetation form a V shape spreading canopy (Plate 3.1c). It is dominated by *Acacia oerfota*, *Acacia mellifera*, and *Acacia nilotica*, and around Lorengdwat in Nakapiripirit district and Lokisile in Moroto district; there is a mix of *Euphorbia prostrate*, *Euphorbia candlebrum*, and *Eurpobia tirucalli*. A slight variation exists in the bushlands of southern which are relatively stable and even becoming woodlands in places while the bushlands in Moroto and parts of Kotido are relatively young with aggressive tree species of *Acacia oerfota* and *Acacia mellifera*. These were mainly identified by the key informants as formally heavily grazed areas with some having occurred in former subsistence farmlands.

Plate 3.1a: Typical grassland dominated by *Hyparrhenia rufa, Chloris pychnothrix* in Karamoja as seen from Nakicument, Napak

Plate 3.1b: A thicket and shrubland as seen in Regen sub-county, Kotido district. The landscape is dominated by grasses such as

district. . In the background are the Iriiri mountains.

Bracharia spp, *Hyparrhenia spp* grasses and thicket and shrub species such as *Commiphora campestris*, *Cadaba farinosa*, and *Acacia brevispica*

Plate 3.1c: A bushland land cover near Lomogol dam in Kotido district. (*Acacia oerfota* seen in the middle of the picture).

Plate 3.1d: A maize garden adjacent to woodland land cover in Nabuin. The woodland is at the background of the photo.

3.4 Topography, soils and geology of Karamoja

Detailed studies on the geology and soils of Karamoja were conducted by Wayland et al. (1938). The sub-region essentially consists of a plain sloping west wards. Karamoja's border with Kenya is raised and to the extreme northeast is Mt. Zulia dropping to the eastern rift valley. The region consists of basement complex dominated by undifferentiated acid and granitoid gneisses (Ngirane-Katashaya and Kaford, 2011). There are isolated higlands interspersed in the plains including: Mt. Kadam (Debasien) 3200 m; Mt. Napak (Kamalinga) 2500 m; and Mt. Moroto 3050 m. Much of the central to western Karamoja consists of carbonatites with deeply dissected agglomerates, tuffs, and silica unsaturated flows of lava overlying Precambrian basement (Smonetti et al., 1996). Several ephemeral streams and rivers rise in the hills and mountains on the east of Karamoja and flow towards the south and west. These rivers are deeply incised; sand filled and become important sources of water from time to time during the dry seasons.

3.5 Study approach

This study adopted a mixed methods approach; this was deemed necessary because the study was integrating a range of issues to understand forage dynamics construct in Karamoja sub-region.

According to Creswell (2013) mixed methods design is a research approach focusing on research questions that bring out real-life contextual understanding, multi-level perspectives, and cultural influences; employing rigorous quantitative research assessing magnitude and frequency of constructs and rigorous qualitative research exploring the meaning and understanding of constructs; utilizing multiple methods; intentionally integrating and/or combining methods to draw on the strengths of each; and framing the investigation within philosophical and theoretical positions. This study sought for breadth and depth of understanding and corroboration on spatio-temporal forage dynamics; forage species composition and abundance; drivers of forage dynamics (both proximate and underlying); the past, present and future climate trends and forage production. In a study where the use of qualitative and quantitative view points, data collection, analysis and inference techniques are involved, the use of mixed methods approach is preferred (Johnson et al., 2007).

3.6 Sampling procedure

This study utilised multi-stage sampling technique in three districts that were purposively selected to represent the three livelihood zones (pastoral, agro-pastoral and agricultural) in the sub-region (Figure 3.4). Household population for the cross-sectional survey was drawn from the 2002 Population and Housing Census (PHC) results for Uganda. Basing on $n = z^2 x p x q /e^2$ (Saxena et al., 2010); where n is the required sample size; z^2 is 1.96 at 95 percent level of significance; p is 0.84 (which is approximately 84% which accommodates the margin of households with one form of livestock or another in Karamoja sub-region as per the 2008 National Livestock Census) and q = 1-P i.e. 0.16, and e = 0.05 (which is the margin of error at 5%); this gave a sample size of 207 households.

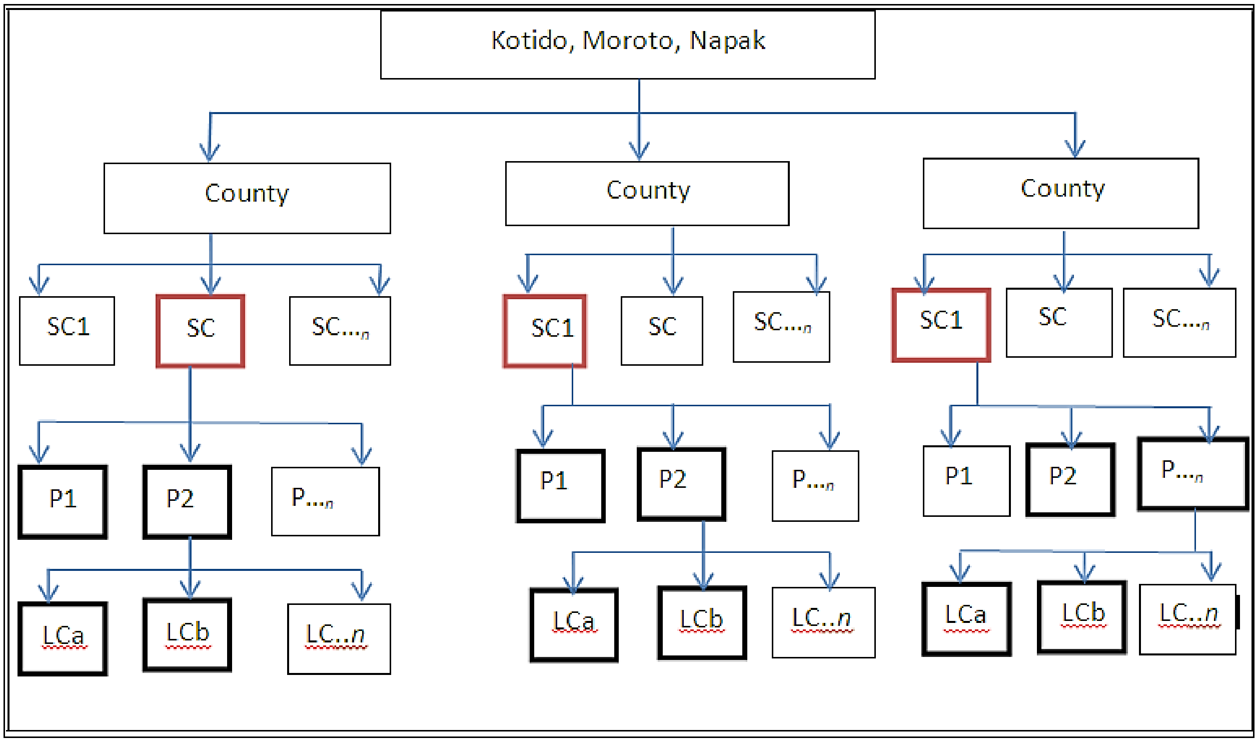

Figure 3.4: Multi-stage sampling process

Out of the 207 intended sample households, only 198 questionnaires were successfully administered; this gave an overall success return rate of 94.3% (Table 3.2). For Moroto district, the nine households were not covered because on the last day of survey, the enumerators had to leave the village before they could be cut-off by an unexpected torrential downpour.

Table 3. 2: Proportional sample size allocation

District	Number of households	% representation	Total sample size used	Total no of questionnaires returned	% return rate
Napak	21402	36	75	75	100
Moroto	15180	26	53	44	83.0
Kotido	22927	39	79	79	100
Total	59509	100	207	198	94.3

3.7 Secondary data and sources

3.7.1 Satellite imagery data

Gaining a better understanding of the ways that land cover and land use practices evolve is a primary concern for the global change research community. Changes in land cover affect ecosystems function and biodiversity (Southworth, 2004). Landsat satellite imagery play a significant role in land use and land cover change analysis; this is because they have been made available by NASA, USGS, Global Observatory for Ecosystem Services, and several other international actors. A series of landsat imagery was downloaded from the Global Observatory for Ecosystems Services (http://www.landsat.org/), USGS (http://earthexplorer.usgs.gov/) and from NASA (http://reverb.echo.nasa.gov/reverb). The use of different sources for image acquisition was necessitated by the fact that not all sources had all the images available. Thus, it became necessary to explore different providers in order to find all the needed imagery. A series (1986, 2000 and 2013) of multi-spectral and multi-temporal Landsat TM and ETM+ imageries were thus obtained. The images obtained were generally cloud-free (less than 10% cloud cover) with a 30m resolution occurring over Karamoja sub-region.

Additionally, because landscape spatial and long term temporal monitoring of vegetation conditions requires considerable availability of consistent data sets; a series of NDVI imagery to supplement the landsat imagery were obtained. In particular, to provide a consistent monthly time series remote sensing data. Thus, the NOAA AVHRR time's series NDVI (1981-2009) 8 km spatial resolution was obtained from the FEWSNET African data portal (http://earlywarning.usgs.gov/fews/africa/web/datatheme.php). Given that; on-site field assessment commenced in 2013; it was therefore necessary to extend the availability of NDVI imagery to 2013 period. To bridge this gap, Moderate Resolution Imaging Spectro-radiometer (MODIS) NDVI imagery from the Global Agriculture Monitoring (GLAM) Project (http://pekko.geog.umd.edu/usda/test) were obtained. MODIS NDVI has been found to be fitting with data from other sensors such as AVHRR, LandSAT ETM+, Spot vegetation and SeaWIFS (Tucker et al., 2005). For this study, 16 day-MODIS NDVI at 250 m spatial resolution for the period 2000-2013 were obtained; and fitted line in 2000-2009 MODIS-AVHRR data to determine the level of association. A significant correlation ($R^2 = 0.972$) was obtained between the NOAA-AVHRR and MODIS NDVI was obtained. Thus, the available MODIS NDVI was then useable with other available AVHRR NDVI data sets.

3.7.2 Climate data

East African climate data since the post-independence era of the 1970s suffers from many spatial and temporal discontinuities (Schreck and Semazzi, 2004). The situation is worse in areas, such as the current study region, that have experienced periods of civil unrest. To overcome this data problem, the National Ocean and Atmospheric Administration-NOAA (1979-2009) Global climate data provided by the National Centres for Environmental Prediction (NCEP) was obtaoned. The NCEP are part of NOAA re-analysis programmes, which model the interaction between the earth's oceans, land and atmosphere to eliminate fictitious trends caused by model and data assimilation changes in real time (Saha et al., 2006). Thus, the re-analysis provides multi-year global state-of-the-art gridded representations of atmospheric states, are generated by a constant model and a constant data assimilation system (Saha et al., 2010a).

The re-analysis climate data were generated under the Climate Forecast System Reanalysis (CFSR) project which conducts six simultaneous streams of analyses covering a 31 year period. Several quality control mechanisms on the re-analysis data have been undertaken using both historical and operational archived data as well as satellite bias correction spin-up (Saha et al., 2010a; Saha et al., 2010b). CFSR data have been shown to be reliable weather input in watershed modelling studies (Fuka et al., 2013). Therefore, based on data consistency, open availability, spatial resolution within the 30 km range, and a long term temporal resolution, the CFSR data were preferred for this study that was conducted in a remote location of Uganda where data gaps, high inconsistency in climate data, and limited spatial coverage of weather stations prevail.

The CFSR dataset consists of hourly weather forecasts generated by the National Weather Service's NCEP Global Forecast System. In this system, forecast models are reinitialized every six (6) hours using information from the global weather station network and satellite-derived products. At each level of analysis hour, the CFSR includes both the forecast data, predicted from the previous analysis hour and the data from the analysis utilised to reinitialize the forecast models (Fuka et al., 2013). The NCEP CFSR data provided a spatial coverage of sixteen (16) stations in Karamoja. The CFSR provides climate data for precipitation, wind, relative humidity, and solar radiation for each location. This study used precipitation and temperature data for the analysis of spatio-temporal climate variability in semi-arid Karamoja. Climate data were subjected to quality control; firstly, outlier detection using the Turkey fence approach for trimming outlier climate values as described in Ngongondo et al. (2011) was conducted. Secondly, a homogeneity test using the cumulative deviation approach as described in the work of Hadgu et al. (2013) was undertaken and, thirdly, as observed by Ngongondo et al. (2011), climate data for trend analysis ought to be non-persistent. Therefore, a test of randomness and persistence as described in Hadgu et al. (2013) was conducted on the data set.

Further, inorder to undertake climate downscaling for the sub-region the Modern Era-Retrospective Analysis for Research and Applications (MERRA) daily climate data covering seven locations in Karamoja sub-region was obtained. This data was provided by the Agricultural Model Intercomparison and Improvement Project (AgMIP). It is this data that provided the historical baseline climate time series data (1980-2010) consisting of minimum and maximum temperature, precipitation and solar radiation necessary for the downscaling. MERRA is a product of the National Aeronautics and Space Administration (NASA)'s Global Modelling and Assimilation Office (Rienecker et al., 2011). The data provided covers the 1979 to present and the current analysis are being performed on near-real-time level. MERRA data has under gone strict quality control mechanisms and complete descriptions of processes undertaken have been documented by Rienecker et al. (2011) and Yi et al. (2011). The decision to use MERRA data in downscaling was based on the fact that MERRA data has had quality improvements because it has benefited from observational assembly and advances made by the National Centres for Environmental Prediction (NCEP data) reanalysis, under the Climate Forecast System Reanalysis (CFSR) as well as the ECMWF Re-Analysis-ERA. Secondly, a very high correlation (R^2 = 0.81) between CFSR-NECP and MERRA climate data sets in the Karamoja sub-region was established. Thirdly, the Agricultural Model Intercomparison and Improvement Project (AgMIP) is currently using MERRA data for climate downscaling and for modelling impacts of climate change on agricultural production in East Africa. Fourthly, through AgMIP, the downscaling scripts have already been developed for the different models, time slices and emissions scenarios; it was therefore not necessary to reinvent the wheel.

3.8 Organisation of the household survey

In order to undertake the household survey, structural steps were followed before household interviews were undertaken. This was aimed at ensuring the validity and reliability of the data collected through the questionnaire as the principle instrument. Additionally, these initial steps were essential in: familiarizing with the study region, building strategic alliances with different individuals and organisations in the region, understanding power dynamics, train enumerators and refine the instrument. The process involved: reconnaissance, questionnaire preparation, training of enumerators, and pre-test of the instruments. Thus:

A preliminary visit into the region was undertaken by the researcher to develop an understanding of the sub-region. Previously, the researcher had only been to one district for a very short time on a different assignment. This knowledge was insufficient to be utilised as a basis for the current study. This visit provided the researcher opportunity to interact with the security personnel, Resident district commissioners, the zonal agricultural institute at Moroto, the district veterinary officers, and submit letters of introduction to the district offices and obtain a host organisation. The researcher was subsequently hosted by Catholic Relief Agency (CARITAS) in Kotido district and Nabuin Zonal Agricultural Research and Development Institute in Moroto. The visit also aided in planning for resources; particularly labour costs for enumeration, road network and timing of when the survey was to be conducted.

A structured questionnaire was thereafter developed prior to the main data collection period. The questionnaire was comprehensive taking into consideration all the major research questions (Appendix A). A structured questionnaire was deemed necessary because the study focused on a continuum of issues and given that the study was conducted among the pastoralists and agro-pastoralists that are generally illiterate (only 12% of the population is literate). Questions were designed with vocabulary appropriate for the target respondents and could easily be translated by the enumerators, simple sentence structures were used, ambiguity and vagueness was avoided. Before the questionnaire was utilised, it underwent expert scrutiny and judgment.

A total of fifteen enumerators were recruited to help in the data collection exercise. Five enumerators were utilised in each district. The enumerators recruited had to have completed Uganda Advanced Certificate of Education (A'level), had to have previously participated in one or more similar engagements as research assistants, had a good command of local language (Ngakikaramojong) and a good knowledge of the district. Each group of respondents had 2 day's training; divided into 1 day familirisation with the purpose of the study, research questions and interpretation of the questions. The second day was sub-divided into two parts; half day involved pre-testing the questionnaire in the morning to mid-morning. In the afternoon of the same day, all the enumerators reconvened to analyse the challenges and propositions to improve the questionnaire and/or seek further clarification. Every enumerator trained was required to complete at least four questionnaires. During the pre-test the enumerators were required to fill start time and end time so as to establish the average time required by each enumerator to complete a questionnaire. It also helped to plan for the length of time a respondent would be required to spend with the enumerator. On average, the enumerators returned with an average of 90 minutes time duration per questionnaire. As such we examined the questions that were repeated and were not at the core of the study; such questions were removed and the questionnaire restructured. The pre-test also returned a Conrach's reliability static of 88.5% indicating that the enumerators had grasped the questionnaire very well. All the pre-test questionnaires were not incorporated into the main study.

The main data collection exercise was then conducted in January to February, 2013; using face to face interviews. Face to face interviews were preferred because they permit for longer survey time once the interviewer has gained entry and initial cooperation and acceptance from the respondent (Neuman, 2012). The target respondent was the household head (who was either male or female) but in the evident that the household head was absent then a spouse was interviewed. Face to face interviews allowed the research team opportunity to clarify questions, provide adequate explanation on the purpose of the study and seek further clarification on the responses provided. A success rate of 94.3% questionnaire return rate was registered (Table 3.2). Further, given the nature of the pastoral lifestyle and settlement pattern, the research team was able to benefit from spontaneous corrections to the household head responses. Krysan et al. (1994) recommended that when dealing with lower income, less educated and minority populations face to face interviews are preferable because these categories are often less likely to positively respond and participate in non-face to face modes.

3.9 Organisation and conduct of focus group discussions

Focus group discussions were an instrumental part of this study; they provided opportunity for participatory examination of issues. Additionally, they provided opportunity for clarification and explanations to some of the spontaneous responses that emerged out of the household interviews. Focus group discussion participants were purposively selected including herders/youth, elders, and security personnel (Uganda People's defense forces and Anti-Stock Theft Unit-ASTU para-military group) (see Plates 3.2a-3.2d). On average there were seven participants per each focus group discussion. Each of these groups addressed specific to broad areas of the study focus. In order to reduce bias, a check list of guiding questions was prepared (Appendix B). The Focus group discussions were held in various parts of the districts and a summary has been provided in Table 3.3. Altogether, a total of 29 FGDs were conducted. According to Cook and Crang (1995) focus group discussions facilitate obtaining accounts of individuals as well as a means to setting up a negotiation of meanings through intra and inter-personal debates. This was particularly important in this study's case given that individual to collective experiences were instrumental in the evaluation of perceived causes of climate variability and change, influences of climate on forage dynamics and availability among other issues under discussion.

In addition to general to specific conversations and discussions, other participatory techniques including proportional pilling, and seasonal calendars were utilised in the community assessment of forage resources. Proportional pilling was particularly used to assess perceived availability of forage species during dry and wet seasons. Seasonal calendars were utilised to identify plant species relative abundance, and livestock species preferences by season. This information was particularly relevant in the documentation of native forage species abundance in the sub-region.

Table 3. 3: Number of focus group discussions by district and participant category

District	Security personnel	Youth/herders	Elders	CAHWs	Total
Napak	2	3	2	1	**8**
Moroto	3	3	3	1	**10**
Kotido	3	3	4	1	**11**
Total	**8**	**9**	**9**	**3**	**29**

Plate 3.2a: FGD with the youth/herders at Lomejan Kotido district

Plate 3.2b: FGD with the elders in Lomejan Kotido district

Plate 3.2c: FGD with CAHWs at Losilang Kotido district

Plate 3.2d: FGD with the security personnel at Lomogol dam Kotido district

3.10 Organisation and conduct of key informant interviews

Key informant interviews were conducted with purposively selected persons. Eight unit commanders; 2 in Napak, 3 in Kotido and 3 in Moroto districts; three District Veterinary Officers; 1 in each district; 1 Resident District Commissioner of Kitodo district; 1 district environment officer, and 2 NGO representatives; 1 in Kotido district and 1 from Moroto district were interviewed. In total 15 key informants were interviewed. A question guide was utilised during the interview so as to reduce bias and ambiguity as well as help structure the interview process. The data collected considered the state of forage resources, drivers of forage patterns, status of climate variability and security situation in the sub-region. This data was particularly important in helping provide explanatory notes to the perceived drivers of forage dynamics in Karamoja sub-region. Thus, this information was largely supplemental.

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CHAPTER FOUR

SPATIO-TEMPORAL DYNAMICS OF FORAGE AND LAND COVER CHANGES IN KARAMOJA SUB-REGION, UGANDA

ABSTRACT

Spatio-temporal dynamics of pastoral grazing resources influence several dynamics in the pastoral production system. Obtaining timely and reliable information on the status of these resources is critical in ensuring planning and early response in the face of climatic variability and change. This study identified herbaceous and woody forage species in different land cover types, quantified forage in different land covers, analyzed long term land use/cover change and determined the relationship between Normalized Difference Vegetation Index (NDVI) and herbaceous biomass. Results showed that the sub-region has about sixty five grass species and 110 woody species occurring in different land cover units and whose abundance varies by season. During the wet season, woodlands, grasslands and thickets and shrublands recorded a wet weight of 1342.5±104.5 kg/ha; 857.5±29.4 kg/ha and 501±43.9 kg/ha respectively. In the dry season 542.5±57.6 kg/ha, 273±6.4 kg/ha and 140±9.2 kg/ha was realized in the woodlands, grasslands and thickets and shrublands respectively. However, in the transitionary season 276 kg/ha, 512.5 kg/ha and 529.2 kg/ha was obtained in the woodlands, grasslands and thickets and shrublands accordingly. Similar trends were observed in dry matter biomass in the respective land cover type. Seasonality, land use-land cover type, and location accounted for the variations in the observed forage species and quantity. Analysis of land cover and land use change revealed a tenfold increase in croplands in the last thirteen years (2000-2013). The expansion of crop cultivation is attributed to interventions by the Government of Uganda and development partners to promote food security in the sub-region. Heightened bushland encroachment was similarly observed in the last thirteen years. The study also found a significant positive relationship between NDVI and herbaceous biomass, indicating that remote sensing offers reliable resource assessment and monitoring option for informing planning and interventions in semi-arid areas.

Key words: *Dry matter, bushland encroachment, aboveground herbaceous biomass, semi-arid, variability*

4.1 Introduction

Livestock rearing has continued to play a significant role in the economy and welfare of Uganda. About 71% of households in Uganda owned livestock in 2008 (MAAIF and UBOS, 2010). Livestock and livestock products account for over 5% of the Gross Domestic Product (GDP) and about 14% of the agricultural GDP as well as a range of valuable services and products for domestic and export markets (FAO, 2005). Among the poor livestock keepers of Uganda, livestock is hailed for its multiple benefits including: facilitating saving, providing security, asset accumulation, financing planned and uncertain expenditures, providing a diversity of products and maintenance of social capital (Ashley and Nanyeena, 2002). The "cattle-corridor" of Uganda is the most important livestock herding region in the country. This region runs diagonally across Uganda from southwestern (Ankole sub-region) to northeastern Uganda (Karamoja sub-region). Livestock herded in this region by the pastoralists and agro-pastoralists accounts for over 90% of the national livestock herd. In Karamoja, livestock is interwoven in the socio-cultural fabric of the people. Livestock influences relationships, determines self-worth and existence in a community and it is central in traditional ceremonies and rites of passage, in particular, marriage (Grade et al., 2009). Karamoja's livestock alone constitute about 10% of the national livestock herd, 20% of the national cattle herd, 16% of goats, 60% of all horses, 97% of all camels and 91% of all donkeys in Uganda (UBOS and MAAIF, 2010).

Like most of the pastoral groups in Eastern Africa such as; the Turkana of Kenya, Toposa of Sudan and the Nyangatome, Rendile and Borana of Ethiopia, the Karamojong practice transhumant livestock herding. Men, often energetic youth and their livestock move between wet and dry season grazing areas (Grade et al., 2009). During such times, women, children and elders remain behind in the manyattas (semi-permanent homesteads). It is therefore evident that the Karamojong still exercise a self-provisioning form of livestock rearing-pastoralism (Weber and Horst, 2011). This form of livestock rearing largely depends on the availability of livestock resources on the range which are managed primarily by livestock and fire (Basset and Crumney, 2003). The use of these primary management tools has enabled pastoralists to better manipulate grazing regimes and circumvent patchy vegetation. In so doing, they have been able to effect subsequent changes in land cover over time (Weber and Horst, 2011) as well as survive the harsh realities of climatic variability.

A growing concern in most of the pastoral regions is how the current trends in land use and land cover are affecting the grazing resource base. These shifts in land use are largely externally driven and have set in motion a myriad of other challenges including restricted mobility of pastoral herds, reductions in grazing lands and increased conflicts, especially those between farming and pastoral communities (Oba, 2012). The fact that changes in land use and land cover affect forage availability has implications for the viability of the pastoral livestock production and therefore livelihoods of pastoral communities in the region. The consequence of diminishing grazing lands is exemplified by livestock losses and exit of pastoralists among the Rufa'a Al Hoi ethnic group of the Blue Nile State in Sudan (Ahmed, 2009). Similar trends have been reported in Burkina Faso among the Fulani pastoral community. In Eastern Africa for example, land use and land cover change dynamics have become evident in privatisation of pastoral land and sedentarisation in pastoral communities a (Lesorogol, 2005). In Uganda, livestock keepers in Kaliro district have experienced shortage in forage (Tabuti and Lye, 2009) due to conversion of communal grazing lands for agriculture. Such processes exacerbate the vulnerability of the pastoral groups to the vagaries of nature, particularly the devastating impacts of climate variability that include livestock losses and reduced livestock productivity (Nelson, 2012).

Unlike other rangeland ecosystems in the region, minimal assessment and monitoring has been undertaken in the Karamoja sub-region of Uganda. This is particularly attributed to prolonged periods of conflict and civil unrest that have plagued the sub-region. With the return of relative peace, security and stability there has been increased promotion of sedentarisation and crop cultivation ostensibly to promote food security. As a result, the pastoralist system in Karamoja is undergoing radical changes that are negatively affecting the pastoral livestock production. The on-going conversion of rangelands to croplands has not been adequately informed by technical evidence (Republic of Uganda, 2009). Limited efforts have been channeled towards examining the extent to which the changes, particularly in the grazing landscapes, have occurred over time. Nonetheless, a few studies have attempted to provide insights into the land use and land cover changes in Karamoja sub-region. One such study conducted in Moroto district indicated that deforestation was the most significant biophysical change occurring in the district (Majaliwa et al., 2009). In addition, vegetation cover and pasture resources were reported to have undergone significant changes in the area. No study has attempted to provide a regional analysis of land use and land cover changes and how they impact on extensive livestock production system in the

Karamoja sub-region and yet pastoralism is still the main livelihood activity for the Karamojong community. Transhumance pastoral production systems transverse administrative borders and therefore their assessment require a landscape approach so as to provide decision makers with a sub-regional status of grazing resources. It is against this background that the 10th European Development Fund (EDF); Karamoja Livelihoods Programme (KALIP) recommended that a full study be undertaken of pasture availability by season and location in the sub-region (Republic of Uganda, 2009).

Sustainability of grazing and forage resources in pastoral areas requires, as prerequisite for management, the assessment and routine monitoring of spatio-temporal distribution and changes of these resources, as well as the drivers of the observed change dynamics (Feng et al., 2009). Where changes are rapid and unrecorded, earth observations from space provide objective information of human utilization of the landscape (Ruelland et al., 2010). Remote sensing further plays a pivotal role in guiding grazing management by providing information in support of analysis, modeling and forecasting for decision support (Kawamura and Akiyama, 2010). However, the relevance of satellite imagery in providing information for planning to address challenges relating to livestock grazing resources will be greater when satellite data is integrated with ground based assessments. The ground based assessments help to fill the gaps in the satellite data particularly with regard to the composition of vegetation resources (Gintzburger and Saidi, 2009). A dearth of knowledge exists regarding the current real spatial and quantitative extent of forage resources in Karamoja sub-region. Therefore this study sought to determine the spatio-temporal dynamics of forage in Karamoja sub-region. In order to fulfill this objective, the study: (i) identified herbaceous and woody forage species by season in the different land covers; (ii) quantified the extent of the land use/land cover change in Karamoja and compared land cover change rates; (iii) quantified the potential available forage in the sub-region by integrating clipped wet weight and dry matter and related this to the extent of each land cover unit; and (iv) determined the relationship between NDVI and herbaceous biomass in the sub-region.

4.2 Materials and methods

For the description of study area, climate, vegetation, topopgraphy, soils and geology refer to Chaper 3 (3.1, 3.2. 3.3 and 3.4)

4.2.1 Herbaceous forage quantification and woody species identification

Herbaceous and woody forage production in different land cover classes was quantified through ground measurements of aboveground herbaceous forage. The study study sites were jointly identified by researcher and community elders and herders. Selection of sampling plots targeted areas that were currently used for grazing. However, only the accessible sites and those secure from banditry and raiding at the time of the study were selected for sampling. Once the sites were identified, sampling plots for forage clipping, measuring 50 x 40 m with four replications, were randomly established in each of the identified grazing land covers. In all the 50 x 40 m plots, nested sub-plots (1 x 1 m) were diagonally established from which forage was clipped. All the above ground herbaceous plants grasses, grass-like species, herbaceous legumes and other forbs collectively, were clipped. In each land cover type (woodlands, grasslands and thickets and shrublands) 20 plots were utilised; 10 plots running diagonally from one corner to the other. In the woodlands, grasslands and thickets and shrublands, five additional plots of 5 x 5 m were established to estimate tree density. The clipped herbaceous forage was fresh weighed and a 0.5 kg proportion obtained for dry matter determination. Clipping was done during the dry, wet and transition season. Additionally, in each sampling plot, existing herbaceous and woody species were identified onsite by a field taxonomist. Specimen of species that could not be readily identified were collected using a plant press and taken to Makerere University for identification.

4.2.2 Perceived forage species abundance

Perceived abundance of grass and browse forage species were documented using ethnobotanical approach through focus group discussions. Fifteen (15) focus group discussions (FGDs) were conducted with elders, youth, scouts and herders. All participants were male adults between 19-75 years. In Kotido district, five focus group discussions were held in Regen, Lobel, Nakapelimoru, Kayelein and Panyangara. Five FGDs were also held in Moroto district in parts of Kobebe, Rupa, Nadunget, Mogose and Katikekile. Simlarly, five FGDs were conducted in Napak district at Lopei, Nakicumet, Lotome, Lokopo and Kangole. Each FGD that was conducted consisted of seven to twelve participants. Participants were asked to identify grass and browse forage species available in their granzing land covers using local names. They were then tasked to identify those species availabile during the dry season and the wet season and/or both. Each participant provided with 10 small stones (each stone representing 10%) and was required to proportionately pile stones to a particular forage species based on its perceived abundance during wet and dry seasons relative to other species. Further, participants were asked to provide a brief description of location characteristics of the identified species. After, the FGD assessment process, a select team of participants (identified by the FGD participants as more knowledgeable) moved with a botanist to match the identified grass and browse forage species with botanical names. The grass and browse forage plants that could not be readily identified were taken to Makerere University herbarium for identification. However, some grass and browse species identified by the participants could not readily be obtained for identification as they were remotely located.

4.2.3 Satellite data and image processing

Land use and land cover change in Karamoja was determined using 27 years' time-series multi-spectral and multi-temporal Landsat TM and ETM+ satellite imageries. The images obtained were generally cloud free (less than 10% cloud cover) with a 30 m resolution. Four scenes covering the sub-region were mosaiced (Figure 5.2; personal illustration, 2014) in ERDAS IMAGINE 9.1 with the projection set at datum WGS 1984, UTM zone 36N and Ellipsoid WGS 84. All the image sets utilised were acquired within a similar period (season) of the calendar year so as to minimize distortions associated with phenological variations between seasons. With reference to the 2009 land use/land cover map for Karamoja developed under KALIP, reconnaissance field surveys conducted from October 2012 to November 2013; Landsat TM and ETM+ images were interpreted and classified using unsupervised classification. A total of 465 ground truthing points were used to aid in the image classification and validation. Elders locally known as Ikasuko and youth, referred to as Karachuna in NgaKarimojong language with detailed knowledge of the grazing landscapes provided additional information for image validation. Imagery processing and analysis were performed in ERDAS IMAGINE 9.1 and ArcGIS 10.1.

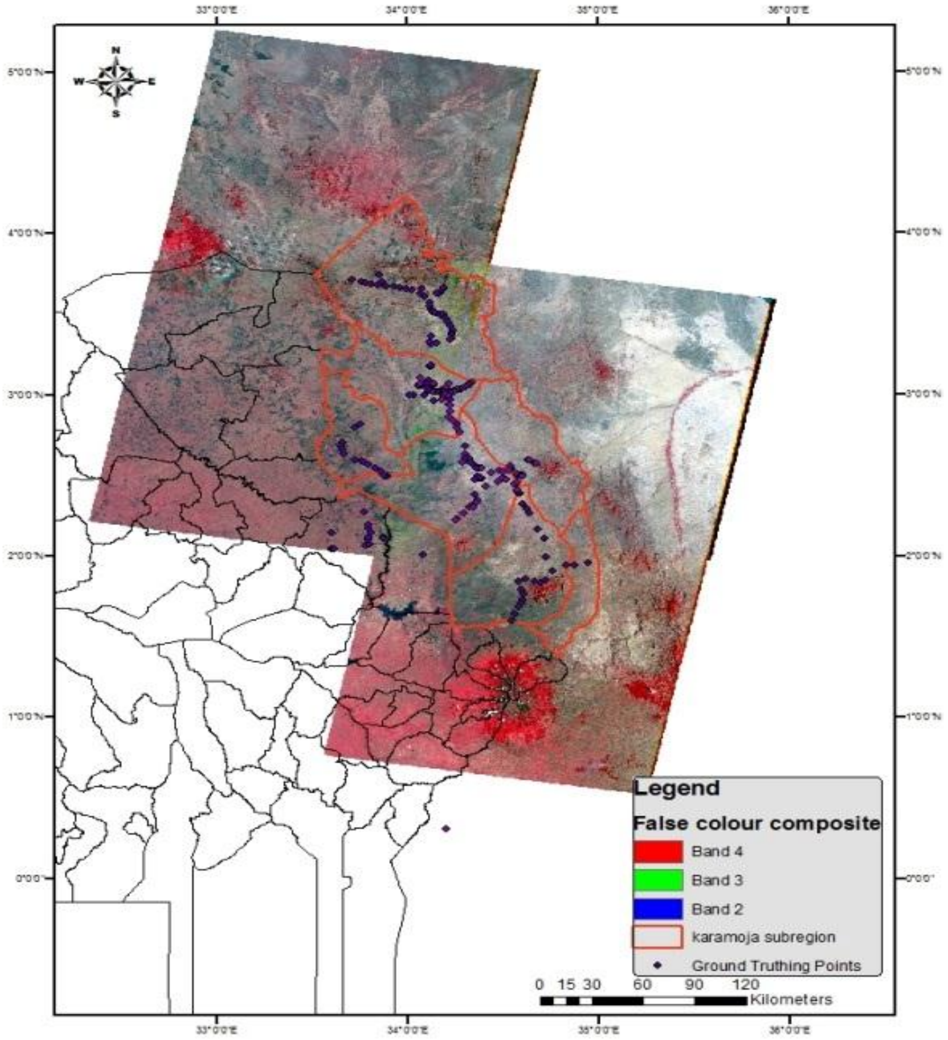


Figure 4. 1: A mosaic of image scenes covering Karamoja sub-region and ground-truthing points

4.2.4 Normalized Difference Vegetation Index data and processing

The Normalized Difference Vegetation Index data obtained from the Moderate Resolution Imaging Spectoradiometer (MODIS) was obtained from the National Aeronautics and Space Administration-NASA (http://reverb.echo.nasa.gov/reverb/). MODIS NDVI was preferred due to its consistency, uniform coverage, minimal interferences and a high temporal (16 day) resolution. MODIS NDVI imagery was pre-processed in ERDAS IMAGINE 9.1. Subsequently, NDVI values were extracted for each plot where herbaceous biomass clipping was undertaken. The extraction was performed in ArcGIS 10.1 using the extraction tool embedded the spatial analyst.

4.3 Data analysis

4.3.1 Forage species analysis and determination of herbaceous forage quantity

Data on the identified herbaceous and woody species were collated and subjected to descriptive statistical analysis using Genstat 12.1 to generate a matrix of frequency of species and life forms for the different land cover classes in study area. In order to determine the quantity of dry matter, herbaceous samples taken to the laboratory were oven dried at 60˚ C until a constant weight. Following Undersander et al. (1993) approach, dry matter was determined gravimetrically as the residue remaining after oven drying. The gravimetrical results of different sampling plots were pulled together by land cover type and averaged to obtain dry matter weight (kg/ha). Analysis of Variance (ANOVA) was conducted to identify sources of variation in forage quantity at 5% significance level. With regard to community perceptions on forage dynamics, data was thematically analysed. The proportional stones piled by the participants were transformed into percentages.

4.3.2 Determining land cover change

This study adopted Peng et al.'s (2008) approach (Equation 1) of determining land use/cover change. Land cover change matrix was computed by overlaying two land use/cover maps. Using this method, an overlay of two land cover maps A_{i*i} and B_{i*i} adheres to the map algebraic Equation 1 which is only functionally valid where land cover classes are not in excess of 10. After operationalizing the map algebraic function, a land cover change map is obtained. Thus, C_{i*j} becomes the output that represents the type of land cover variation from time A to time B with the associated spatial dispersion. In this study, there are five land covers (i.e. grasslands, woodlands, thickets and shrublands, subsistence farmlands and bushlands).

$$C_{i*j} = A_{i*j}*5 + B_{i*j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

4.3.3 Determination of land cover change rate

The rate of land cover change was computed following Peng et al. (2008), Equation 2.

$$K_1 = \frac{U_b - U_a}{U_a} * \frac{1}{T} * 100\% \quad \text{...........} \quad (2)$$

Where K_1 is land cover dynamic degree, this measures the change rate of the target land cover type; U_b and U_a are the area of the target land cover at the beginning and end of the study period respectively; and T is the study period in years. Land use and land cover change was assessed over three periods namely: 1986 and 2000 (14 years); 2000-2013 (13 years); and 1986-2013 (27 years).

4.3.4 Determining the regional forage quantity

The average weight (kg/ha) of herbaceous biomass (both dry matter and wet weight) was multiplied by the total land area (ha) of respective land cover types to obtain the relative regional quantity of herbaceous forage by land cover type and season. Although clipping was not extensively conducted in the bushlands (for security reasons) and croplands, a few sites that provided a comparison value were available. In addition, the quantity of herbaceous biomass obtained from the bushlands compared quite well with the results of Ooro Olang (1984) in southern Turkana an area bordering the study region at Amudat district. The computation of herbaceous weight in the croplands revealed that it was 5% of the thickets and shrublands standing crop during the dry season. This study assumed that during the wet season, all croplands were non-useable for livestock since they had been planted with crops.

4.3.5 Determining the relationship between herbaceous forage quantity and NDVI

The relationship between herbaceous biomass and NDVI was determined through correlation analysis. The average NDVI values were derived from the plot specific extractions using the extraction tool embedded in spatial analyst in ArcGIS. The extracted plot specific NDVI values were matched with plot specific wet weight herbaceous biomass quantity of each land cover type monitored. A generalized linear regression using XL-STAT 2013.5 statistical package was conducted.

4.4 Results

4.4.1 Herbaceous and woody forage species in Karamoja

A total of thirty three (33) grass species were observed during the wet season in the grasslands. Overall, *Hyparrhennia rufa* (13.9%); *Sporobolous stapfianus* (12.2%), *Chloris pychnothrix* (9.8%) and *Pennisetum unisetum* (9.4%) had the highest abundance during the wet season (Table 4.1). District wise, *Pennisetum unisetum* (26.3%), *Sporobolus sphacealata* (18.4%), *Aristida adscensiones* (15.1%) and *Hyparrhenia rufa* (13.2%) were the most observed grass species in Kotido district during the wet season (Table 4.1). In Moroto district, *Sporobolus stapfianus* (24.7%), *Chloris lamproparia* (22.7%), *Chloris pychnothrix* (17.3%) and *Aristida adscensiones* (12%) were the most observed species. On the other hand, *Hyparrhenia rufa* (23.9%), *Setaria sphacealata* (18.1%), *Chloris pychnothrix* (10.2%) and *Perotis pateus* (8.8%) registered a higher abundance in Napak district during the wet season (Table 4.1).

Table 4. 1: Abundance of grass species in the grasslands during the wet season

Sub-regional all Grass species	%	Napak district	%	Moroto District	%	Kotido district	%
Hyparrhenia rufa	13.9	*Hyparrhenia rufa*	23.9	*Sporobolus stapfianus*	24.7	*Pennisetum unisetum*	26.3
Sporobolus stapfianus	12.2	*Setaria sphacealata*	18.1	*Chloris lamproparia*	22.7	*Sporobolus sphacealata*	18.4
Chloris pychnothrix	9.8	*Chloris pychnothrix*	10.2	*Chloris pychnothrix*	17.3	*Aristida adscensiones*	15.1
Pennisetum unisetum	9.4	*Perotis patens*	8.8	*Aristida adscensiones*	12	*Hyparrhenia rufa*	13.2
Aristida adscensiones	8.5	*Sporobolus stapfianus*	6.2	*cynodon dactylon*	5.3	*Sporobolus stapfianus*	8.6
Setaria sphacealata	8.1	*Sporobolus primidalis*	6.2	Others (n=12)	18.2	Others(n=16)	18.5
Chloris lamproparia	6.4	Others (n = 16)	26.3				
Sporobolus sphacealata	5.3						
Others (n=26)	26.4						

Note: *All those forage species whose abundance levels were below 5% were aggreaged as others; their number in each category is represented by n*

During the dry season, the number of observed grass species in the grasslands dropped to seventeen (17); this represented a 48.5% decline. At the same time, there was a shift in relative abundance of grass species such as *Aristida adscensiones* (21.8%), *Hyparrhenia diplandra*

(16.1%), *Pennisetum sp* (15.3%) and *Chrloris pychnothrix* 13.2%; (Table 4.2). Further, there were variations within the district sites with only twelve species observed in Kotido district including: *Hyparrhennia diplandra* (35.6%), *Pennisetum* spp. (33.9%), *Hyparrhenia rufa* (16.1%) increased in abundance. Grasses such as *Sporobolus sphacealata, Aritisda adscensiones, Mellinus repens, Sprobolus festivus* and *Bracharia scalaris* that had previously been cited during the wet season could not be observed during the dry season in the monitoring sites of Kotido district.

Table 4. 2: Abundance of grass species in the grasslands during the dry season

Sub-regional level %		Kotido	%	Napak	%	Moroto	%
Aritistida adescensiones	21.8	*Hyparrhenia diplandra*	35.6	*Aritistida adescensiones*	25.9	*Aritistida adescensiones*	46.2
Hyparrhenia diplandra	16.1	*Pennisetum* spp.	33.9	*Hyparrhenia rufa*	24.7	*Cynodon nlemfuensis*	24.2
Pennisetum spp.	15.3	*Hyparrhenia rufa*	16.1	*Tragus berteronianus*	18.5	*Chloris pychnothrix*	22
Chloris pychnothrix	13.2	Others(n=9)	14.4	*Chloris pychnothrix*	14.2	Others(n=4)	7.7
Tragus berteronianus	7.8			*Perots pateus*	8		
Hyparrhenia rufa	7.3			Others (n=4)	8.7		
Cynodon nlemfuensis	5.7						
Others (n=10)	12.8						

District wise, Moroto district experienced a 58.8% decline in the number of species observed between the wet and dry season with *Aritisda adscensiones* (46.2%), *Cynodon nlemfuensis* (24.2%), *and Chloris pychnothrix* (22.0%) recording a higher abundance during the dry season. Grasses such as; *Chloris lampropria, Bracharia jubata, Pennisetum unisetum, Setaria sphacealata, Sporobolus primidalis, Setaria prunilla, Setaria kagerensis, Dactylon aegyptum, Sprobolus pellucidus* and *Digitaria nuda* that were previously observed in the wet season were not observed in the same monitoring sites in the dry season. Of the twenty one (21) grass species observed in the wet season in Napak district, only nine (9) grass species were observed in the dry season (Table 4.2); this represented a 57.1% decline. *Aritisda adscensiones* (25.9%), *Hyparrhenia rufa* (24.7%), *Tragus berteronianus* (18.5%), *Chrloris pychnothrix* (14.2%) had a high abundance during the dry season in Napak district. Grass species such as; *Bracharia platynota, Hyparrhenia filipendula, Eichnocloa haploclada, Loudeta simplex, Panicum* *maximum, Crotalaria sp, Paspalum scrobiculatum, Cynodon nlemfuensis, Bracaharia polystachion* and *Sporobolus primidalis* that were previously observed in the wet season were not observed in the dry season.

With regard to woody plant species; a considerable number were observed in the grasslands of Karamoja during both wet and dry seasons. Table 4.3 portrays the list of observed browse plants in the sub-region and in the respective districts of Kotido, Moroto and Napak during the wet season. *Triumfetta anua* (16.4%), *Indigofera erecta* (15.1%), *Asaparagus flagellasis* (9.6%), and *Ocimum canum* (7.3%) were observed with a high abundance. Similarly, *Triumfetta anua* 26.5% and 13.2% had high abundance in the Napak and Kotido districts while *Indigofera erecta* (18.9%) was the most prevalent in Moroto during the wet season. A range of other browse trees such as; *Acacia drepanolobium* (26.2%), *Lanea humilis* (21.5%), *Balanite aegyptica* (18.5%), *Acacia kirkii* (15.3%), *Acicia nilotica* (7.6%), *Acacia oreberiana* (3.1%), *Acacia xanthopholea* (1.5%) and *Commphora Africana* (1.5%) were observed with differentiated levels of abundance in the grasslands during the wet season. Generally, *Acacia drepanolobium, Acacia kirkii* and *Acacia nilotica* were the browse species with high abundance in the grasslands of Karamoja during the wet and dry seasons.

Table 4. 3: Abundance of woody species in the grasslands during the wet season

Sub-regional	%	Moroto	%	Napak	%	Kotido	%
Triumfetta anua	16.4	*Indigofera erecta*	18.9	*Triumfetta anua*	26.5	*Triumfetta anua*	13.2
Indigofera erecta	15.1	*Triumfetta anua*	13.7	*Indigofera erecta*	22.6	*Ocimum canum*	12.9
Asparagus flagellasis	9.6	*Asparagus flagellasis*	12	*Ipomea kituensis*	7.7	*Vigna membranacea*	12.1
Ocimum canum	7.3	*Cadaba farinosa*	8	*Desmodium tortuosum*	7.1	*Asparagus flagellasis*	11.2
Solanum incanum	6.4	*Grewia holstii*	6.3	*Cadaba farinosa*	7.1	*Indigofera erecta*	9.7
Vigna membranacea	6.3	*Maerua pseudopetalosa*	5.7	*Abutilon hirtum*	5.2	*Cyphosteua Serpens*	9.1
Others (n=29)	38.2	*Solanum incanum*	5.1	Others (n=13)	23.6	*Solanum incanum*	7.6
						Others (n=8)	24.2

During the dry season, *Triumfetta anua* (27.0%) and *Indigoferra erecta* (5.3%) had higher abundance. An increased presence of *Desmodium* spp (22.6%), *Grewia holstii* (7.7%), and

Maerua pseudopetalosa (6.2%) was observed during the dry season at sub-regional level (Table 4.3 and 4.4). Further, forbs such as; *Asaparagus flagellasis* and *Ocimum canum* experienced considerable decline in abundance during the dry season (Table 4.4). District wise, some of the browse plants such as: *Urena* spp, *Sida* spp, *Vernonia, Cadaba farinosa, Leonotis nepetifolia,* and *Festuca abyssinica* that were previously observed during the wet season could not be observed during the dry season in Kotido district. Variations were similarly observed in Moroto and Napak districts (Table 4.4).

Table 4. 4: Abundance of woody species in the grasslands during the dry season

Sub-regionally	%	Moroto	%	Napak	%	Kotido	%
Triumfetta anua	27	*Desmondium* spp.	23.5	*Triumfetta annua*	23.2	*Triumfetta anua*	36.3
Desmondium spp.	22.6	*Triumfetta anua*	16.2	*Indigofera spp.*	18.8	*Desmondium* spp.	22.6
Grewia holstii	7.7	*Grewia holstii*	15.4	*Desmondium spp.*	15.9	*Indigofera* spp.	11
Maerua pseudopetalosa	6.2	*Urena spp.*	8.1	*Cadaba farinose*	11.6	*Maerua pseudopetalosa*	10.3
Indigofera spp.	5.3	*Acacia oerfota*	6.6	*Maerua pseudopetalosa*	7.2	Others(n=8)	19.9
Others(n=22)	31.5	*Clotalaria* spp.	5.1	*Grewia holstii*	7.2		
		Others(n=16)	24.6	Others(n=7)	15.8		

In the woodlands, a total of twenty six (26) grass species were recorded during the wet season (Table 4.5). *Panicum maximum* (14.7%), *Cynodon dactylon* (14.7%), *Microloa hunthii* (9.2%), *Hyparrhenia rufa* (7.3%) and *Sporobolus pyrimidalis* (6.4%) had a high abundance at sub-regional level in the woodlands during the wet season (Table 4.5). At district level, *Panicum maximum* (18.5%), *Microcloa hunthii* (15.4%), *Hyparrhenia rufa* (12.3%) and *Sporobolus pyrimidalis* (10.8%) posted high abundance in Moroto district. On the other hand, *Cynodon dactylon* (27.3%), *Echincloa* spp (11.4%), *Panicum maximum* (9.1%) and *Chloris pychnothrix* (9.1%) recorded high abundance in the woodlands of Kotido district.

Table 4. 5: Abundance of grass species in the woodlands during the wet season

Sub-regional observation	%	Moroto	%	Kotido	%
Panicum maximum	14.7	*Panicum maximum*	18.5	*Cynodon dactylon*	27.3
Cynodon dactylon	14.7	*Microcloa hunthii*	15.4	*Echinocloa pyrimidalis*	11.4
Microcloa hunthii	9.2	*Hyparrhenia rufa*	12.3	*Panicum maximum*	9.1
Hyparrhenia rufa	7.3	*Sporobolus pyrimidalis*	10.8	*Chloris pychnothrix*	9.1
Sporobolus pyrimidalis	6.4	*Cynodon dactylon*	6.2	*Sporobolus stapfianus*	6.8
Others(n=21)	47.8	*Eragrostis racemosa*	6.2	*Eragrostis cillaris*	6.8
		Hyparrhenia newtonii	6.2	*Aristida adscensiones*	6.8
		Others(n=10)	24.4	Others(n=8)	22.8

Results from the dry season (Table 4.6) showed that eighteen (18) grass species were observed; this was 30.7% lower than those observed during the wet season. Further, results showed that *Hyparrhenia filipendula* (14.1%), *Setaria sp* (13.0%), *Cynodon dactylon* (13.0%), *Chloris pychnothrix* (13.0%) and *Hyparrhenia rufa* (9.8%) had high abundance in the woodlands at sub-regional level. Like the wet season; variation in abundance of grass species existed in the dry season; *Setaria sp* (22.6%), *Hyparrhenia rufa* (17%), *Hyparrhenia filipendula* (11.3%) and *Chloris pychnothrix* (9.4%) were the most abundant grasses in the woodlands during the dry season in Moroto district. On the other hand, *Cynodon dactylon* (27.3%), *Echnocloa* sp (20.5%), *Chloris pychnothrix* (15.9%), *Sporobolus stapfianus* (6.8%) and *Aristides sp* (6.8%) had high abundance in Kotido district woodlands (Table 4.6).

Table 4. 6: Abundance of grass species in the woodlands during the dry season

Sub-regional		Moroto		Kotido	
Hyparrhenia filipendula	14.1	*Setaria spp.*	22.6	*Cynodon dactylon*	27.3
Setaria spp.	13	*Hperrhania rufa*	17	*Echnocloa spp.*	20.5
Cynodon dactylon	13	*Hyparrhenia filipendula*	11.3	*Chloris pychnothrix*	15.9
Chloris pychnothrix	13	*Hyparrhenia filipendula*	11.3	*Sporobolus stapfianus*	6.8
Hperrhania rufa	9.8	*Chloris pychnothrix*	9.4	*Aristides spp.*	6.8
Eichnocloa spp.	9.8	*Eragrostis racemosa*	5.7	Others(n=8)	22.8
Others(n=12)	27.4	Others(n=8)	15.2		

Regarding woody species in the woodlands, a total of forty seven (47) species were observed during the wet season (Table 4.7). At sub-regional level; *Grewia holstii* (9%), *Acalypha bipartita* (6.7%), *Grewia vilosa* (6%) and *Fluegea virosa* (6%) had relative abundance in the woodlands during the wet season (Table 4.7). However, in Kotido district *Flueggea virosa* (10.4%), *Triumfetta anua* (7.5%), *Abutilon hirtum* (7.5%) and *Ocimum canum* (7.5%) were most abundant species. On the other hand, *Grewia holstii* (14.9%), *Acalypha bipartita* (9%), *Hibiscus tiliaceus* (9%) and *Grewia villosa* (7.5%) had a high abundance in the woodlands of Moroto district (Table 4.7). Additionally, woody tree species such as: *Lannea humilis* (28.7%), *Acacia campylacantha* (11.4%), *Gmelina arborea* (9.2%), *and Balanite aegptica* (9.2%) that provided browse were recorded in the woodlands. District wise, the abundance of these tree species deferred such that; *Acacia campylacantha* (18.5%), *Lannea humilis* (16.7%), *Balanite aegptica* (14.8%) and *Zizyphis abyssinica* (13.0%) were more abundant in Kotido district. On the other hand, *Lannea humilis* (51.6%), *Gmelina arborea* (25.5%) and *Acacia sieberiana* (12.9%) were more abundant in the Moroto woodlands.

Table 4. 7: Abundance of woody species in woodlands during the wet season

Sub-regional	**%**	**Moroto**	**%**	**Kotido**	**%**
Grweia holstii	9	*Grweia holstii*	14.9	*Fluegea virosa*	10.4
Acalypha bipartite	6.7	*Acalypha bipartita*	9	*Aloe rwenzorensis*	9
Grewia vilosa	6	*Hibiscus tiliaceus*	9	*Triumfetta anua*	7.5
Fluegea virosa	6	*Grewia vilosa*	7.5	*Ocimum canum*	7.5
Aloe rwenzorensis	5.2	*scilla edulis*	6	*Abutilon hirtum*	7.5
Abutilon hirtum	5.2	*Cadaba farinosa*	6	*Ricinus cumminis*	6
Others(n=42)	66	Others(n=48)	24	Others(n=23)	52.5

During the dry season, only thirty seven (37) woody forage plants were observed in the woodlands of the sub-region with *Grewia holstii* (8.1%), *Ocimum canum* (7.3%) and *Urena* spp (6.5%) showing a high abundance. At district level; *Ocimum canum* (7.9%), *Argeratum conyzoides* (7.9%) and *Dombeya rotundifolia* (6.7%) reflected a high abundance. The overall abundance of all species observed in the woodlands in the sub-region and respective districts during the dry season is summarised in Table 4.8.

Table 4. 8: Abundance of woody species in the woodlands during the dry season

Sub-regional	%	Kotido	%	Moroto	%
Grewia holstii	8.1	*Ocimum canum*	7.9	*Grewia holstii*	28.6
Ocimum canum	7.3	*Argeratum conyzoides*	7.9	*Urena spp.*	22.9
Urena spp.	6.5	*Dombeya rotundifolia*	6.7	*Asparagus flagellaris*	5.7
Aloe rwenzorensis	5.6	*Cassia obtusifolia*	6.7	*Euphorbia tiricalli*	5.7
Argeratum conyzoides	5.6	*Vernonia spp.*	5.6	*Acacia spp.*	5.7
Others(n=32)	66.4	Others(n=26)	64.7	Others(n=14)	31.5

Thickets and shrublands had twelve (12) grass species observed during the wet season in the thicket and shrublands at sub-regional level. *Chloris pychnothrix* (38.7%), *Aristida adescensiones* (24.4%), *Chloris virgata* (8.4%), *Eragrostis tenufolia* (6.7%) and *Hyparrhenia diplandra* (5.9%) were the most abundant grasses in this land cover unit (Table 4.9). District wise, *Chloris pychnothrix* (44.8%), *Chloris virgata* (14.9%) and *Eragrostis tenufolia* (11.9%) had a higher abundance. In Moroto district, *Aristida adescensiones* (55.8%), *Chloris pychnothrix* (30.8%) and *Hyparrhenia diplandra* (5.8%) reflected high abundance while in Kotido district *Bracharia platynota* and *Digitaria* spp grass species had a high relative abundance during the wet season (Table 4.9).

Table 4. 9: Abundance of grass species in the thickets and shrublands during the wet season

Sub-regional	%	Kotido	%	Moroto	%
Chloris pychnothrix	38.7	*Chloris pychnothrix*	44.8	*Aristida adescensiones*	55.8
Aristida adescensiones	24.4	*Chloris virgata*	14.9	*Chloris pychnothrix*	30.8
Chloris virgata	8.4	*Eragrostis tenuifolia*	11.9	*Hyparrhenia diplandra*	5.8
Eragrostis tenuifolia	6.7	*Pensisetum Polystachion*	7.5	Others (n=2)	7.6
Hyparrhenia diplandra	5.9	*Pennisetum unisetum*	6		
Others(n=7)	15.9	*Hyparrhenia diplandra*	6		
		Others(n=4)	9		

During the dry season, only nine (9) of the twelve grass species were observed at sub-regional level during the dry season in the thickets and shrublands. *Chloris pychnothrix* (33.1%), *Aristida adescensiones* (24.3%) maintained higher abundance however, there was increased abundance of *Sporobolus stapfianus* to 17.6% up from 2.5% level observed during the wet season. *Bracharia* *platynota* took a similar trend (Table 4.10). When these results were disaggregated at district level, results showed that; *Chloris pychnothrix* (45.5%) and *Aristida adscensiones* (13.6%) maintained a higher abundance in Kotido while *Arisitida adscensiones* (34.3%) and *Chloris pyschnothrix* (21.4%) maintained high abundance in Moroto district with an increased presence of *Sporobolus stapfianus* to 21.4% (Table 4.10).

Table 4. 10: Abundance of grass species in the thickets and shrublandsduring the dry season season

Sub-regional	%	Kotido	%	Moroto	%
Chloris pychnothrix	33.1	*Chloris pychnothrix*	45.5	*Aristida adscensiones*	34.3
Aristida adscensiones	24.3	*Aristida adscensiones*	13.6	*Sporobolus stapfianus*	21.4
Sporobolus stapfianus	17.6	*Sporobolus stapfianus*	13.6	*Chloris pychnothrix*	21.4
Bracharia platinota	9.6	*Cynodon dactylon*	10.6	*Bracharia platinota*	15.7
Cynodon dactylon	8.8	*Hyparrhenia rufa*	6.1	*Cynodon dactylon*	7.1
Others(n=4)	6.5	Others (n=10.5)	10.5		

Tables 4.11 and 4.12 present a summary of woody species abundance observed during the wet and dry seasons in the thickets and shrublands. During the wet season, a total of forty three (43) browse species were observed with *Maerua pseudopetalosa* (12.2%), *Triumfetta anua* (10.4%), *Cadaba farisnosa* (7.3%) and *Acacia drepanolobium* (6.9%) showing high abundance in the sub-region. The disaggregated results however showed that; *Triumfetta anua* (13.7%), *Acacia drepanalobium* (8.9%), *Maerua pseudopetalosa* (8.1%) had high abundance in Kotido district while *Maerua pseudopetalosa* (16.1%), *Cadaba farinosa* (12.9%), *Caparis tormetosa* (9%) and *Acacia kirkii* (9%) had higher abundance in Moroto district (Table 4.11). *Triumfetta annua* (14.3%), *Maerua pseudopetalosa* (11.8%), *Acacia drepanalobium* (9.3%), *Desmodium sp* and *Acacia kirkii* at 8% had high abundance during the dry season. Disaggregated results showed an increase of *Maerua pseudopetalosa* to 12.3% to become the most abundant herb in the thickets and shrublands of Moroto district (Table 6.12). Other browse forage plants with high abundance in Moroto district included; *Triumfetta anua* (11.8%), *Acacia kirkii* (11.2%), *Desmodium sp* (10.7) and *Cadaba farinosa* (8.6%). On the other hand, *Triumfetta anua* (14%), *Acacia drepanolobium* (12.1%), and *Maerua pseudopetalosa* (9.3%) maintained high abundance in the thickets and shrublands of Kotido district during the dry season (Table 6.12).

Table 4. 11: Abundance of woody species in thickets and shrublands in the wet season

Sub-regional	%	Kotido	%	Moroto	%
Maerua pseudopetalosa	12.2	*Triumfetta anua*	13.7	*Maerua pseudopetalosa*	16.1
Triumfetta anua	10.4	*Acacia drepanalobium*	8.9	*Cadaba farinosa*	12.9
Cadaba farinosa	7.3	*Maerua pseudopetalosa*	8.1	*Caparis tormentosa*	9
Acacia drepanalobium	6.9	*Abutilon hirtum*	6.5	*Acacia kirkii*	9
Caparis tormentosa	5.6	*Solanum incanum*	5.6	*Triumfetta anua*	8.4
Acacia kirkii	5.6	Others(n=28)	56.8	*Acacia oerefota*	5.6
Others(n=37)	52.2			*Acacia brevispica*	5.6
				Todalia asiatica	6.5
				Others (n=18)	26.3

Table 4. 12: Abundance of woody species in the thickets and shrublands in the dry season

Sub-regional	%	Moroto	%	Kotido	%
Triumfetta anua	14.3	*Maerua pseudopetalosa*	12.3	*Triumfetta anua*	14
Maerua pseudopetalosa	11.8	*Triumfetta anua*	11.8	*Acacia drepanolobium*	12.1
Acacia drepanolobium	9.3	*Acacia kirkii*	11.2	*Acacia drepanolobium*	12.1
Desmondium sp.	8	*Desmondium SP*	10.7	*Maerua pseudopetalosa*	9.3
Acacia kirkii	8	*Cadaba farinosa*	8.6	*Acacia oerfota*	9
Acacia oerfota	5.8	*Grewia holstii*	6.4	*Acacia kirkii*	6.7
Acacia mellifera	5.6	*Sida spp.*	5.9	*Acacia melifera*	6.5
Acacia oreberiana	5.5	*Caparis tormentosa*	4.3	Others (n=15)	30.3
Acacia mellifera	5.5	*Acacia drepanolobium*	4.3		
Others (n=27)	26.2	*Acacia oerfota*	3.2		
		Others(n=18)	21.3		

4.4.2 Abundance of grass and woody species as perceived by the community

A total of sixty five (65) grass species were documented by the community (herders, scouts and elders) as forages within the different grazing land covers in Karamoja (Table 4.13). This is slightly higher than the number (33 species) documented from the onsite monitoring plots. The perceived relative abundance of grasses ranged from 10% to 80% during both wet and dry seasons. Nyesiloit (*Setaria sphacealata*), Emaa (*Hyparrhenia newtonii*), Elet (*Bracharia brizantha*), "Nyepipa," "Ngiiru" (grass species whose botanical names have not yet been established) grasses were perceived to have a high relative abundance of up to 80% in the grazing land covers during the wet season. This was closely followed by “Ekosimatuk” and “Nyejaao” and “Lochen” (*Harpachne schimperi*) at 70% and 60% respectively (Table 4.13). On the other hand, “Nyekaletete”, Ekutukutachwe (*Bracharia decumbens*) were indicted as having a high relative abundance during the dry season of 80% and 70% respectively. This was followed by “Okwarath”; a mountain and highland grass species perceived to have a relative abundance of 60% in the grazing land covers during the dry season. Grass species that showed a high perceived relative abundance during both dry and wet seasons included: Ngiletio (*Eragrostis pilosa),* Erereng (*Hyparrhenia rufa*), and Ekode (*Chloris pychnothrix*) at 70-80% relative abundance range. This was followed by Lomedotin (*Setaria pumila*), Ngejenet (*Eragrostis ciliaris*), and Nyemuria/Emuria (*Cynodon dactylon*) all at 60% relative abundance during both dry and wet seasons (Table 4.13). Grasses with perceived low relative abundance (10%) included; Lojomio (*Dinebra retroflexa*), Ereirei (*Testrapogon villosus*), Ewor/Nyewuroth (*Aristida sp*), “Ekoriebu”, “Nyetuko”, “Nyemekui”, “Nyekou”, “Nyekuleu” and “Nyenyimanyim” .

In terms of woody species, a total of one hundred ten (110) plants were identified by community participants in the focus group discussions (Table 4.14). This was higher than fourty seven (47) that were documented in the monitoring sites. Eregai (*Acacia mellifera*- also invasive in nature), Eiring (*Cadaba farinosa*), Epeet (*Acacia oerfota*-also invasive in nature), Eyelel (*Acacia drepanolobium*), Erogorogoit (*Caparis tormentosa*), and Ekwanyaro (*Triumfetta anua*) were perceived to have a high relative abudance (80%) in the grazing land covers during both wet and dry seasons. During the dry season; Nyemuleria (*Leonotis nepetifolia*), Emotwai (*Grewia villosa*), Ngaturikeso (*Acalypha bipartite*), Edome (*Cordia sinesis*), Lomethegin/Lok (*Acathospermum hispidium*) and Etiatia (*Crotalaria ochroleuca*) had a high perceived relative abundance (>50%). On the other hand, Ekalitete (*Portulaca orereceae*), Emaret (*Vigna membrancea*), Aboinakinei (*Otiophora pauciflora*), Ekwanga (*Abutilon hirtum*), Lokiriketa (*Urena lobata*), Amana akuri-Asangsang (*Cyphostema serpens*) and Lowaturot (*Pentasia ouranogyne*) were perceived to have a higher relative abundance (>80%) during the wet season (Table 4.14). The abundance of other browse forage plants is also presented in Table 4.14 including location charateristics description.

Table 4. 13: Abundance of grass species in Karamoja sub-region as perceived by the community

Local name	Scientific name	Description of location characteristics	%Perceived abundance	Season
Abirir	*Eragrosti racemosa*	Open grasslands and some low lying areas with limited flooding occurrence	20	Wet
Ajanet (Ngajien)	*Sporobolus pyrimidalis*	Areas where grazing pressure has been high; may either be grassland, thicket and shrublands or woodlands where movement routes exist.	30	Both
Apanakwuachin	-	Occurs near homesteads and is a common delicacy for donkeys.	10	Wet
Ebirwae	*Sorghum arundainacium*	open grasslands and areas where former kraals (bomas) had been established		
Edodo*	-	Bushlands to woodlands and grasslands. These places are locally known as Atalewo and Ekuwath	30	Dry
Egwogwong	*Chloris virgata*	Lowland grasslands with easily flooding soils	30	Wet
Ekawuduwudu	*Microcloa kunthii*	Mainly in areas with black cotton soils in lowland grasslands	30	Both
Ekirao	*Loudetia simplex*	Associated with bushlands and woodland environments	20	Both
Ekodareng	*Cynodon SP*	Common around homesteads (manyattas) and former bomas	60	Both
Ekode	*Chloris pychnothrix*	Common on gentle slopes in thicket and shrublands to areas with stony soils (these locations were locally addressed as *Nyangromit*).	70	Both
Ekopir	-	Grasslands to shrublands (e.g. Borders with Turkana)	50	Both
Ekoriebu	-	Open grasslands with limited trampling.		
Ekosimatuk	-	Open low land grasslands (e.g. around Arecheke in Iriiri, Napak)	70	Wet
Ekutukutachwe	*Bracharia decumbens*	In grasslands and around manyattas (homesteads)	70	Dry
Elepane**	*Bracharia jubata*	Grasslands with black cotton soils	50	Both
Elet	*Bracharia brizantha*	Grasslands and lowlands (e.g. Iriiri)	80	Both
Emaa***	Hyparrhenia newtonii	Grasslands with sandy to black cotton soils in parts of Kacheri sub-county and Longor in Kotido district	80	Wet
Emogorat	-	Grasslands	40	Wet
Epetareng	*Dactyloctenium aegyptica*	Occur in areas with sandy soils and black cotton soils may include grasslands, thicket and shrublands and woodlands	40	Both
Epinyait/Etidot	*Loudetia kagerensis*	Grasslands with black cotton soils	50	Both
Ereirei	*Tetrapogon villosus*	Grasslands and thicket and shrublands with sandy soils	10	Wet
Erereng	*Hyeperrhania rufa*	Grasslands with black cotton and sandy soils	70	Both

Etanako	*Setaria verticilata*	May occur in thicket and shrublands and bushlands with sandy soils; areas locally called *Nyekuwath*.	30	Both
Ethali	*Cynodon nlemfuensis*	Wide spread in bushlands, grasslands and woodlands	40	Both
Ewat/Euwat*	*Oxytenanthera abyssinica*	Along river streams (e.g. Lomogol river near Nagololapolon in Kotido)	20	Both
Ewuroth/Eworoi	*Aristida sp*	Lowland grasslands with light cracky soils (generally black cotton soils)	10	Wet
Lochen	*Harpachne schimperi*	Grasslands. This grass species is locally known to have a bitter taste.	60	Wet
Lojokopolon	Hyparrhenia	Grasslands with sandy to black cotton soils in parts of Kacheri sub-county and Longor in Kotido district	80	Wet
Lojomio	*Dinebra retroflexa*	Associated with slaughter places such as shrines and other bushlands	10	Wet
Lokala	-	Open grasslands to thicket and shrublands in the eastern parts of Kotido towards the espcarpments with Turkana. This grass is believed to have been brought by the Turkana livestock.	29	Dry
Lomedotin	*Setaria pumila*	Woodlands and bushlands locally referred to as Ekitela and may also occur around manyattas (homesteads).	60	Both
Lomirio	*Pennisetum mezainum*	Grasslands (within the black soils-*Nyaro*)	40	Both
Lomukur	*Aristida adscensiones*	Lowland grasslands that tend to rapidly flood; areas in the *Nyaro* particularly sections locally called *Nyakao*.	30	Wet
Lomurio	*Cenchrus ciliarus*	Grasslands with black cotton soils	40	Both
Losaricoo	*Panicum maximum*	Areas with black cotton soils may either be woodlands and/or grasslands	70	Both
Neymuria/Emuria	*Cynodon dactylon*	Common around homesteads (manyattas) and former bomas	60	Both
Ngejenet	*Eragrostis ciliaris*	Areas with sandy and light soils may include thicket and shrublands on gentle slopes	60	Both
Ngeletio***	*Eragrostis pilosa*	Grasslands and lowlands	60	Both
Ngiiru	-	Grasslands and bushlands (e.g. Kopori and Nalos)	80	Wet
Nyakwuanga	-	Marshy Grasslands	30	Wet
Nyapuna/Apuna	*Bulbostylis pusilla*	Occurs in low land grasslands with black cotton soils that often tend to easily waterlog	40	Both
Nyejaao***	-	Hilly and valley areas	70	Wet
Nyekala	-	Shrublands and Grasslands (e.g. Kacheri-Longor)	20	Wet
Nyekaletete	-	Lowlands, hilly areas and old bomas	80	Dry

Nyekipiit**	-	Open valleys and low lands	20	Wet
Nyekoromuar	-	homesteads	30	Wet
Nyekou	*Hyparrhenia cymbaria*	Grasslands with black cotton soils. In particular parts of grasslands locally called Akao	30	Wet
Nyekou***	-	Marshy Grasslands	10	Wet
Nyekuleu	-	Homesteads and thicket and shrubland areas; these may have sandy soils and were locally referred as asinyonoit.	30	Wet
Nyelalojait/Elalajait	-	Grasslands (e.g. areas of Kapeta and Lolelya)	60	Wet
Nyemekui	-	Homesteads and shrublands	10	Wet
Nyemirierit	*Setaria sphacealata*	Open lowland grasslands (*Nyaro-Nyakao*) attributed to be common in the Apeitolim-Lopei-Toor apex.	50	Wet
Nyemomwa (sorghum straws)	*Sorghum bicolor*	Raised areas on grasslands, former thickets and shrublands converted to farmlands.	60	Wet
Nyenyimanyim	-	Broad valleys and hilly areas (e.g. Apeitolim, Lopei river areas)	10	Wet
Nyepipa	-	Around homesteads and old bomas inparticular in areas locally referred to as Asinyonoit (areas with sandy soils).	80	Wet
Nyerau*	-	Bushlands to woodlands and grasslands. These places are locally known as Atalewo and Ekuwath	20	Dry
Nyereirei/Ereiri ***	-	Grasslands	20	Wet
Nyesiloit**	*Setaria sphacealata*	Lowland grasslands with easily flooding soils	80	Wet
Nyetuko***	-	Grasslands and bushlands (e.g. Koteen grasslands)	10	Both
Nyetuko/Lolepan	*Echinocloa haplocada*	Lowland grasslands with black soils	40	Both
Nyewu	*Rottboeria cochinchinensis*	This is wild sorghum common in grasslands and thickets that have ever been cultivated and around homesteads and former bomas. Open grasslands with sandy and light soils with gentle slopes	10	Wet
Okwarath****	-	Mountains and hills of the Kaabong, Napak, Labwor and Moroto	60	Dry

These grasses are generally known as Asakatan; and are grasses that are said to bring disease to livestock. **These grasses were associated to induce cattle to provide high milk yields.*Grasses perceived as very good for livestock. ****These grasses that are generally found on mountains and hills. Several hills identified included: Kogwele, Kanamerinjor, Katipus, Morutit, Kapernakori in Kotido district; Koromwae, Napakgngaran, Turusuk, Nyanga, Theno, Arakas, Kolung, Nakithilet hills in Kotido-Kaabong.There were also grasses identified in Kotido FGD as bad grasses including: Nyabune, Nyemurecho, Nyakouma, Nymadong, and Nyethak. These grasses were identified to be in some parts of Nagirigiroi in Kotido district. The botanical names of these grasses still need to be identified.*

Table 4. 14: Abundance of browse forage species in Karamoja as perceived by the community

Local name	Species scientific name	Consumption	Description of location characteristics	Perceived abundance (%)	Season
Aboinakinei	*Otiophora pauciflora*	GS	Loam and sandy	60	Wet
Ajim/Edomeo	*Achyranthes aspera*	GSC	Loamy	60	Dry
Alolot	*Corchorus olitorius*	GSC	Loam soils	80	Wet
Alolot -Eligo	*Hisbiscus abyssinica*	GSC	Loamy	70	Both
Amanakuri-Asangsang	*Cyphostema serpens*	GS	Loam and sandy	60	Both
Athuran	*Paviona arabicum*	GSC	Sandy soils	50	Both
Athuran	*Sida cordifolia*	GSC	Loam and sandy	50	Both
Ecucuka	*Aloe rwenzorensis*	GSC	Loam and sandy	80	Wet
Edodo	*Crotalaria olitorius*	GSC	loams soils/river sides en sawmpy	60	Dry
Edodoi	*Kigelia africana*	GS	Loamy, along river banks with marhness	80	Both
Edome	*Cordia sinensis*	GSC	Loam and sandy	80	Both
Edondongmuroi	*Solanum anguivii*	G	Sandy soils	50	Wet
Edupamal	*Hisbiscus micrantha*	GSC	Loam and sandy	80	Both
Egigith	*Cissus quadrangularis*	GSC	Loam and sandy	40	Dry
Egirigiroi	*Acacia campylacantha*	GSC	Loam and sandy	60	Dry
Ejojor	*Balanite grabra*	GSC	Loam and sandy	80	Both
Ekaburu	*Maytenus heterophylla*	GSC	Sandy soils	60	Wet
Ekadele	*Commiphora africana*	GSC	Loam and sandy	40	Both
Ekaleruk	*Cucumis figarei*	GSC	Loam and sandy	40	Dry
Ekalitete	*Portulaca orereceae*	GSC	Sandy soils	60	Wet
Ekaliye	*Grewia mollis*	GSC	Sandy	70	Wet
Ekarei	*Ficus natalensis*	GSC	Loam and sandy	60	Both
Ekedeloi/Ekadoliae	*Caparis fascicularis*	GSC	Loam soils and and at times in low land areas	70	Both
Ekere	*Harrisonia abbisinica*	GSC	Loamy and along river banks	60	Wet
Ekisemejo	*Lanata trifolia*	GS	Loam and sandy	30	wet
Ekobeko	*Solanum taitense*	GSC	Loam and sandy	50	Wet

Ekodokodoi	*Acacia senegal*	GSC	Loam and sandy	80	Dry
Ekorete	*Balanite aegyptica*	GSC	Loam and sandy ls	80	Both
Ekoromwai-Lokwang/Ekapelimen	*Acacia nilotica*	GSC	Loamy	60	Both
Ekoromwai-Loreng	*Acacia xanthopholea*	GSC	Loam soils and along marshlands	60	Both
Ekotachwe/Abotachwe	*Commelina benghalensis*	GS	Loam and sandy	40	Wet
Ekuleo/Emini	*Cyathula orthancantha*	GSC	Loam and sandy	80	All
Ekurr	*Rhus kwanoensis*	GSC	Loam and sandy	60	Both
Ekurutapim	*Plectranthus longipes*	GS	Loam and sandy	80	Both
Ekutukutacwe/Ekalitet	*Cynotis arachnoidea*	GSC	Loam and sandy	60	Wet
Ekwanga	*Abutilon hirtum*	GSC	Loam soils	60	Both
Ekwangyaro	*Triumfetta annua*	G	Loam and sandy	80	Dry
Ekwanpen/Achepa	*Leucas martinicensis*	GSC	Loamy	80	Dry
Eliaro	*Ipomea kituiensis*	CS	Loamy	70	Wet
Eligoi	*Euphorbia tirucalli*	GS*Ca	Loam and sandy	80	Both
Emalakan	*Hisbiscus diversifolius*	GSC	Loams soils with marshy conditions	60	Wet
Emaler	*Vangueria apiculata*	GSC	Loam soils and valley soil river valleys	80	Both
Emaret	*Vigna membrancea*	GSC	Sandy soils	80	Both
Emejan	*Acanthospermum hispidium*	GSC	Loam and sandy	80	Wet
Emejan/Epopong	*Euphorbia candlebrum*	GS	Loam and sandy	60	Both
Emekwe	*Crossandra subacautis*	C	Sandy	70	Wet
Eminii	*Barleria submollis*	GSC	Sandy	40	Both
Emotwai	*Grewia villosa*	C	Loam and sandy	30	Both
Emuleria	*Leonotis nepetifolia*	GS	Loam and sandy	50	Wet
Enaminam	*Crabbea velutina*	GS	Loam and sandy	80	Wet
Enyuri	*Hisbiscus sp*	GSC	Loamy	80	Both
Epedur/Eperu	*Tamarindus indica*	GSC	Loam and sandy	80	Both
Epeet	*Acacia oerfota*	GS	All landscapes	80	Both
Epiee	*Gmelia arborea*	GSC	Loam and sandy	60	Both
Epuook	*Buddelia polystachya*	GSC	Loam and sandy	70	Dry

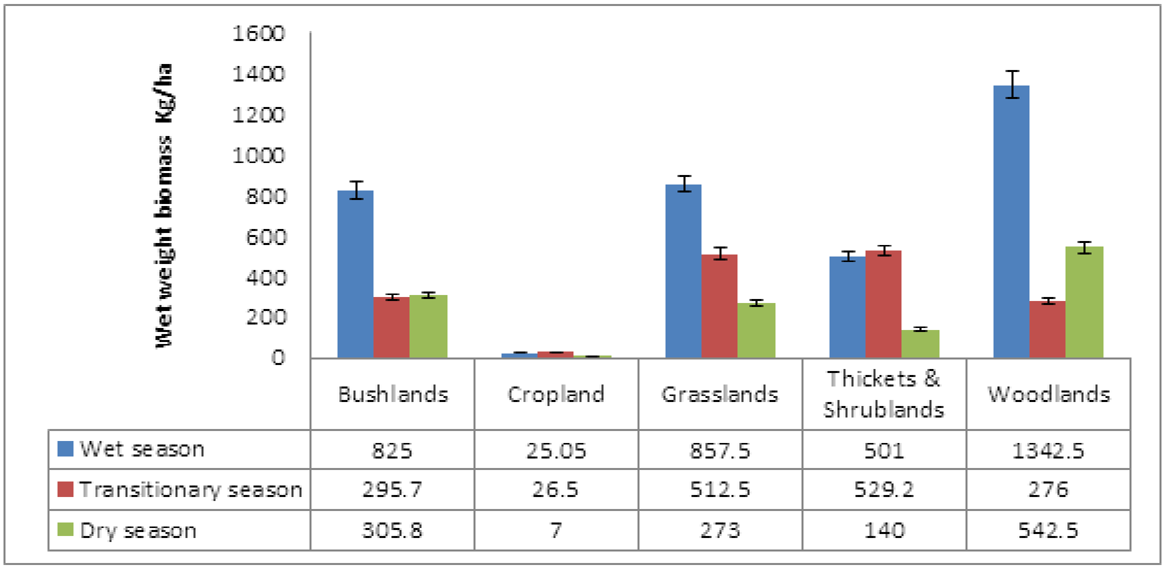
Erakanakui	*Codia quercifolia*	GSC	Sandy	60	Both
Eregai	*Acacia mellifera*	GS	All landscapes	90	Both
Eriring	*Cadaba farinosa*	GSC	All landscapes	90	Both
Erogorogoite	*Caparis tormentosa*	GSC	Along river banks	80	Both
Erugwa	*Grewia similis*	GSC	Loam and sandy	40	Wet
Erut	*Maerua edulis*	GSC	Loam and sandy	80	Wet
Eseperwai	*Ormocapum trichocarpum*	GSC	Loam and sandy	90	Both
Esikarakiru	*Asaparagus flagellaris*	GSC	Loam and sandy soils	50	Wet
Esilang	*Ziziphus abyssinicus*	GSC	Loam and sandy	80	Both
Ethithi	*Justicia flavus*	GSC	Loam and sandy and has its origins in Turkana	50	Both
Etiatia	*Crotalaria ochroleuca*	GSC	Loam and sandy	80	Wet
Etiatia/Ekayeriyeri	*Cassia obtusifolia/Senna obtusifolia*	GSC	Loam and sandy	60	Wet
Etir/Ewoi	*Acacia totilis*	GS	Loam and sandy	90	Both
Etirai/Nyetirai	*Dicrostachys cinerea*	GSC	Loam and sandy	50	Both
Etirir	*Acacia spirocarpa*	GSC	Loamy and marshy areas	40	Both
Etopojon	*Lannea humilis*	GSC	Loam and sandy	80	Both
Etulelo	*Solanum incanum*	GSC	Loam and sandy	80	Wet
Eurukanyim	*Maerua parviflora*	GSC	Loam soils with marshy conditions	60	Both
Eusugu	*Zanthoxylum calybeum*	GSC	Loam and sandy	80	Both
Ewoi	*Acacia tortilis*	GSC	Loam and sandy	60	Both
Ewologweth	*Heliotropium steudneri*	GSC	Loams soils with marshy conditions	60	Wet
Eyelel	*Acacia drepanolobium*	C	Dry and sandy areas	80	Both
Lak	*Alternanthera sessilis*	GSC	Loam soils and along marshlands	50	Both
Lochikutai	*Indigofera erecta*	GSC	loam water available	80	Wet
Lojokosimat	*Striga gesnerioides*	GSC	Loam and marshy soils	60	Both
Lokalabocho	*Marsdenia robicunda*	GSC	Loam and sandy	50	Wet
Lokeny	*Barleria acanthoides*	GSC	Loam and sandy	80	Both
Lokile	*Euphorbia prostrata*	GS	Loamy	80	Both
Lokiriketa	*Urena lobata*	GSC	Loam and sandy	90	Both

Lokwaturot	*Pentasia ouranogyne*	GSC	Loam and sandy	50	Both
Lomerekin	*Bidens pilosa*	GSC	swampy loam soil	60	Both
Lomethegin/Lok	*Acanthospermum hispidium*	GS	Loam and sandy	40	Wet
Losigiria	*Maerua sp*	GSC	Loam and sandy	80	Both
Lotere	*Ruellia patula*	GSC	Swampy and sandy loams	50	Both
Lotheru	*Ocimum canum*	GSC	Loam and sandy	60	Both
Lothiru	*Orthisiphon sp*	GSC	Loam and sandy	80	Both
Loururosi	*Tagetes minuta*	GSC	Sandy soils	40	Wet
Nakankwen/Epwatadele	*Gymnema sylivestre*	GSC	Loamy	80	Dry
Ngaturikeso	*Acalypha bipartita*	GSC	Loam and sandy	60	Both
Nyalakas	-	GSC	Loam and sandy	50	Both
Nyechogoromoit	-	GSC	Loam and sandy	80	Both
Nyedurokoit	*Acacia albida*	GSC	Loam and sandy	60	Both
Nyekadetewua	-	GSC	Loam and sandy	80	Both
Nyekapangiteng	*Albizia anthelmintica*	GS	Loam and sandy	80	Both
Nyekorith	-	GSC	Loam and sandy	40	Wet
Nyekuri	*Talinum caffrum*	GS	Loam soils that often are amrshy and flood	80	Both
Nyelel/Eyelel	*Acacia seyal*	GSC	Loam and sandy	60	Wet
Nyelel/Eyelel	*Acacia seyal*	GS	Loam and sandy	50	Wet
Nyesaguru	-	GSC	Loam and sandy	60	Dry
Nyesobosob	-	GSC	Loam and sandy	40	Wet
Nyetiaro	-	GSC	Loamy, along river banks and lowlands	60	Wet
Tataiikokol	*Pavetta gardenifolia*	GSC	Sandy soils	40	Wet

G=Goats, S=sheep, C=Cattle, Ca=camel, Both = wet and dry season.

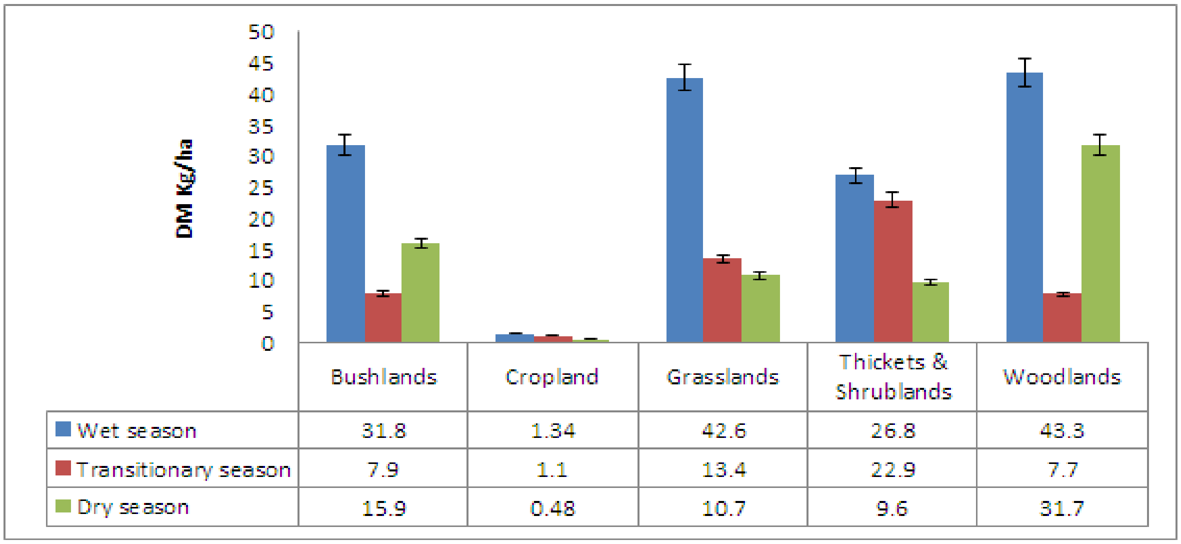
4.4.3 Quantity of forage in different land use/cover types

The results revealed that during the wet season woodlands had the highest herbaceous biomass quantity of 1342.5±104.5 kg/ha followed by grasslands with 857.5±29.4 kg/ha, bushlands 825±50.2 and thickets and shrublands at 501±43.9 kg/ha. Similarly, during the dry season 542.5±57.6 kg/ha was realized in the woodlands, 273±6.4 kg/ha, 305.8±24 kg/ha in the bushlands, 140±9.2 kg/ha in the grasslands and thickets and shrublands respectively (Figure 4.2). This represented a 59.6%, 62.9%, 68.2% and 72.1% decline in aboveground biomass in the woodlands, grasslands and thicket and shrublands respectively between the wet and dry seasons. On the other hand, results from the transitionary season assessment revealed that the thickets and shrublands had the highest wet weight biomass of 529.2 kg/ha which was slightly higher than that observed during the wet season (Figure 4.2). This could be attributed to the fact that thickets and shrublands are less grazed by cattle during dry season because much of the grazing in the thickets and shrublands is mainly undertaken by ruminants (sheep and goats). As such, grasses have the opportunity to flourish. Grasslands revealed a 512.5 kg/ha wet weight biomass in the transition season which was a decline from the wet season average of 857.5±29.4 kg/ha (Figure 4.2). The pattern was not any different in the woodlands with only 276 kg/ha of wet weight biomass realized. This was slightly lower than the dry season average of 542.5±57.6 kg/ha (Figure 4.2). This could be attributed to fire and croplands that affected some of the monitoring plots.



	Bushlands	Cropland	Grasslands	Thickets & Shrublands	Woodlands
🟦 Wet season	825	25.05	857.5	501	1342.5
🟥 Transitionary season	295.7	26.5	512.5	529.2	276
🟩 Dry season	305.8	7	273	140	542.5

Figure 4. 2: Wet weight biomass in different landuse/cover-biomes for all seasons



	Bushlands	Cropland	Grasslands	Thickets & Shrublands	Woodlands
🟦 Wet season	31.8	1.34	42.6	26.8	43.3
🟥 Transitionary season	7.9	1.1	13.4	22.9	7.7
🟩 Dry season	15.9	0.48	10.7	9.6	31.7

Figure 4. 3: Dry matter from different landuse/cover-biomes for all seasons

In terms of dry matter (Figure 4.3), woodlands had 42.3 kg/ha and 31.7 kg/ha during the wet and dry seasons respectively. This represented 3.2% and 5.8% of the standing crop available as dry matter in the woodlands. On the other hand, grasslands had 42.6 kg/ha and 10.7 kg/ha of dry matter during the wet and dry seasons accordingly, indicating that 4.9% and 3.9% of the wet weight biomass could be available as dry matter. In the thickets and shrublands, the situation was not any different with 26.8 kg/ha and 9.6 kg/ha obtained during the wet and dry seasons respectively which was equivalent to 5.3% and 6.9% of the wet weight biomass available as dry matter (Figure 4.3). In all seasons, thicket and shrubland vegetation had relatively lower quantities of dry matter. However, it had higher dry matter rates of recovery at 5.3% and 6.9% for wet and dry season respectively. The patterns in thickets and shrublands could be attributed to the fact that there is lower grass and herbaceous plant cover due to the predominance of thorny twigs and plants that provide browse. Secondly, grass and other herbaceous plants within the thickets and shrublands tended to be hardy compared to those occurring in the grasslands and woodlands. Results from the transitionary season revealed that thickets and shrublands had the highest dry matter of 22.9±9.6 kg/ha, followed by grasslands, bushlands and woodlands. Not surprising, croplands performed poorly in terms of dry matter just as they did in determinations of wet weight biomass (Figure 4.2; 4.3). The differences in the quantity of forage observed in Figure 4.2 and 4.3 are owed to the significant ($P \leq 0.05$) differences in land use/cover type as well as the differences in the location by district (which resprensents the different livelihood zones in the region). Furthermore, rainfall seasonaility significantly ($P \leq 0.05$) accounted for the observed forage dynamics. Further, results showed that there was a significant ($P \leq 0.05$) interaction between season and land cover types as well as between district and season.

4.4.4 Pattern of land use/cover change in Karamoja (1986-2013)

During the last twenty seven years, there have been significant changes in land use/cover of the grazing lands of Karamoja sub-region (Figures 4.4, 4.5 and 4.6). The trend patterns are presented in Table 4.15. Results show that in 1986 grasslands (75%) dominated the region followed by bushlands (12.8%), woodlands (6.6%) and thickets and shrublands (4.5%). Subsistence farmlands (indicated as croplands) only covered 0.3% of the land area (Table 4.15). By 2000, bushlands had increased by 2.2% to 15%. Similarly thickets and shrublands experienced a fivefold increased. On the other hand, grasslands experienced a decline by 1.6% to 74.2% of the land area. This pattern was also observed in the woodlands and subsistence farmlands. Woodlands coverage in 2000 decreased by 5.3% while croplands decreased by 0.24% of 1986 level.

The period between 2000 and 2013 also recorded continued increase in the cover of bushland vegetation to 25% which represents a 10% increase in cover between 1986 and 2013. Surprisingly, woodland land cover experienced a recovery to 2.7% indicating a 1.4% increase. A similar pattern was observed in subsistence farmlands which experienced a gain to 0.6% indicating a 0.54% increase in land area cultivated over the period of thirteen years. However, in terms of change, the period from 2000-2013 revealed a nearly tenfold increase in croplands. This could be attributed to increased advocacy and promotion for cropping by the Government of Uganda and Development partners through provision of seeds and tractors. On the other hand, grasslands continued to experience a decline, falling to 66.0% which represents an 8.2% decrease. Likewise, thickets and shrublands decreased to 5.8% representing a 0.9% decline (Table 4.15). When the confusion matrix was computed, it showed an overall land cover change classification accuracy of 82.6% (producer’s accuracy) and 75.3% user’s accuracy.

Table 4. 15: Land use/cover change in Karamoja sub-region

Land use/cover types	1986		2000		2013	
	Area (ha)	% area	Area (ha)	% area	Area (ha)	% area
Bushlands	352948.3	12.8	415175.9	15.0	689614.0	25.0
Cropland	7520.7	0.3	1695.5	0.06	15686.4	0.6
Grasslands	2093308.1	75.8	2047648	74.2	1820488.6	66.0
Thickets and Shrublands	123996.2	4.5	259863.8	9.4	159841.5	5.8
Woodlands	182576.8	6.6	35971.1	1.3	74730.8	2.7
Total	2760350.2	100		100		100

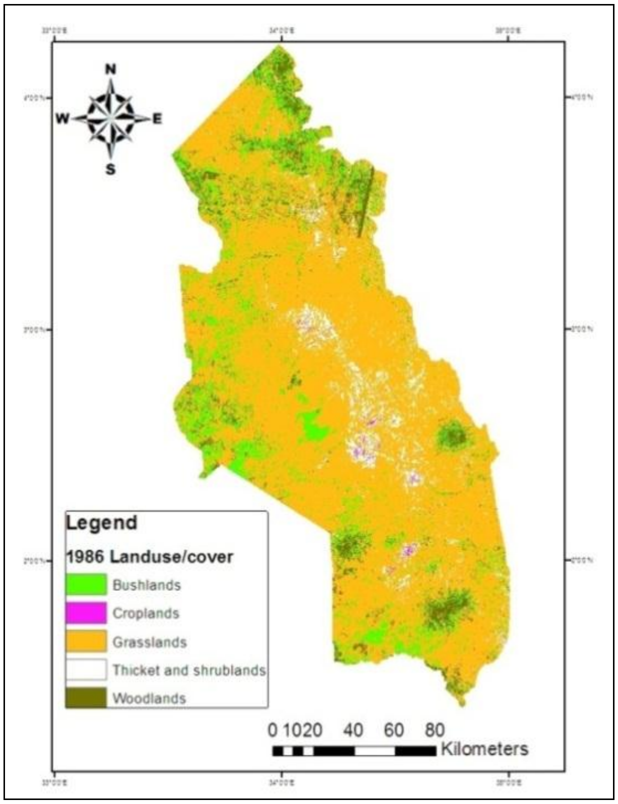


Figure 4. 4: Land use/land cover 1986

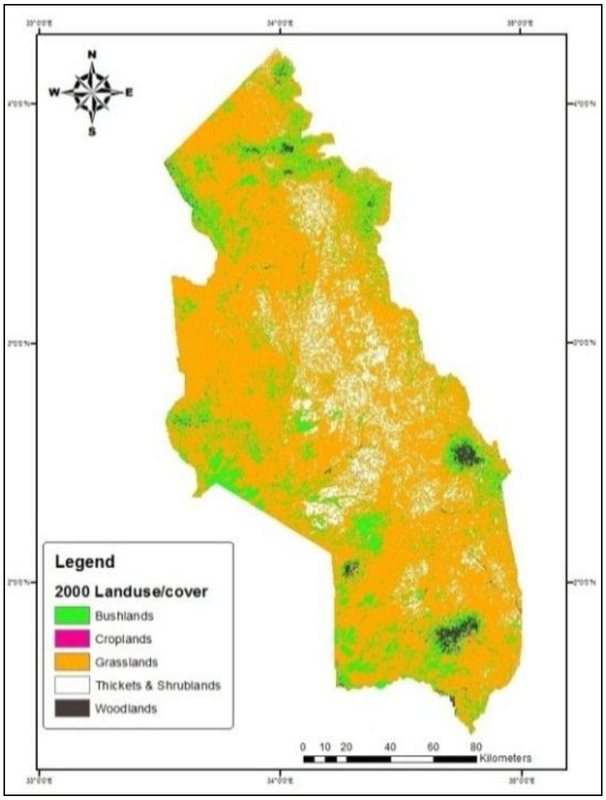


Figure 4. 5: Land use/land cover 2000

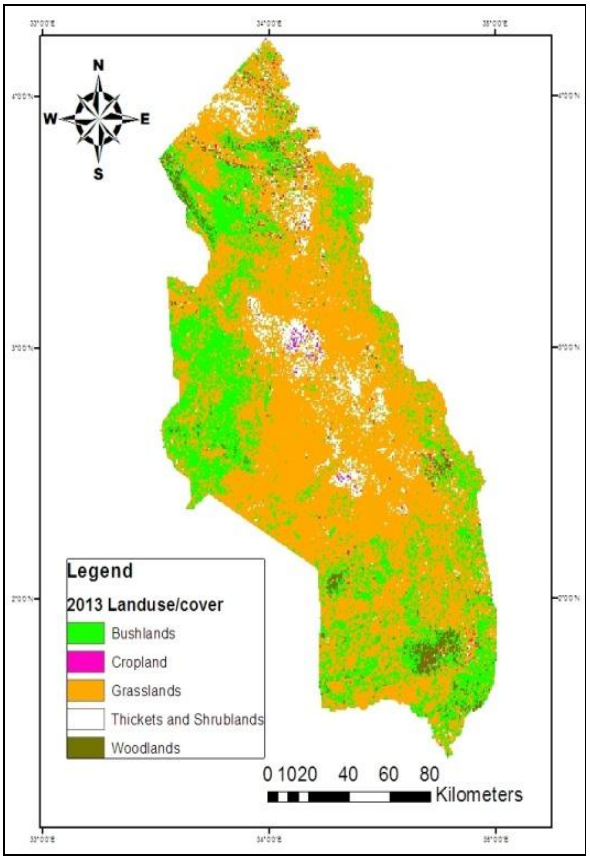


Figure 4. 6: Land use/land cover 2013

Plate 2: A heap of charcoal in Abim district and firewood (that measured over 5 feet high and 15 meters in length) at Lobel, Kotido district

4.4.5 Land use/cover change for rate 1986-2013

Tables 4.16, 4.17 and 4.18 present the process of land use/cover change within the land covers in Karamoja sub-region from 1986 to 2013. Three change phases are presented, the first from 1986-2000, the second from 2000-2013 and the third from1986-2013. Results in Table 4.16 (1986-2000) reveal that much of the woodlands (78.5%) changed to grasslands, 11.9% to bushlands and 9.4% changed to thickets and shrublands. Most of the bushlands (66.2%) changed to grasslands while 2.0% changed to woodlands. Bushland to croplands experienced a marginal change. It was also observed that 36% of the grasslands converted to bushlands 14% to woodlands and 0.4% to cropland during the same period. Meanwhile, 52.6% of the thickets and shrublands converted to grasslands, 3.4% to bushlands and 0.2% to croplands. About 52% of cropland converted to thicket and shrubland, 44% to grasslands and 1.7% to bushlands. There was no transformation of croplands to woodlands during this period.

Table 4. 16: Land use/cover change for 1986-2000

	Land use/cover types in 2000					
Land use/cover types in 1986	Woodlands	Bushlands	Grasslands	Thickets and shrublands	Croplands	Total
Woodlands	**0.2**	11.9	78.5	9.4	0.0	100
Bushlands	2.0	**30.2**	66.2	1.5	0.1	100
Grasslands	14.0	36.0	**48.1**	1.5	0.4	100
Thickets and Shrublands	0.1	3.4	52.6	**43.7**	0.2	100
Cropland	0.0	1.7	44.0	51.7	**2.5**	100

Note: The figures marked in bold indicate the unchanged percent area during the period.

Table 4.17 presents the land use/cover change patterns for 2000-2013. During this period, a considerable proportion of woodlands (46.6%) remained unchanged. This could be attributed to the fact that most of the woodlands that are now in existence occur in the highlands and are thus relatively inaccessible to the local community. However, most of the woodlands were converted to bushlands (39.5%). These are probably the woodlands in the low lying areas preferred for their perceived fertility and 'soil coolness' (as indicated by the local community during focus group discussions). A further 11.3% of the woodlands were converted to grasslands, 1.6% to thickets and shrublands and 1.1% to croplands. In the same period, 31.1% of the bushlands were converted to grasslands compared to 47.5% of the grasslands that converted to bushlands. It is also observable that 43.6% of the croplands reverted to bushlands, 15.9% to grasslands and 29.3% to thickets and shrublands. Only 9.9% of the croplands remained unchanged. This result has confirmed what was observed during the ground truthing exercise in which most of the former croplands were being colonized by bushes as well as the prevalence of thicket and shrubland vegetation on abandoned cropland sites.

Table 4. 17: Land use/cover change rate (2000-2013)

	Land use/cover types 2013					
Land use/cover types 2000	Woodlands	Bushlands	Grasslands	Thickets and shrublands	Croplands	Total
Woodlands	**46.6**	39.5	11.3	1.6	1.1	100
Bushlands	6.6	**60.1**	31.1	1.7	0.5	100
Grasslands	1.4	47.5	**45.9**	4.8	0.4	100
Thickets and Shrublands	0.5	9.6	66.7	**21.4**	1.8	100
Cropland	1.3	43.6	15.9	29.3	**9.9**	100

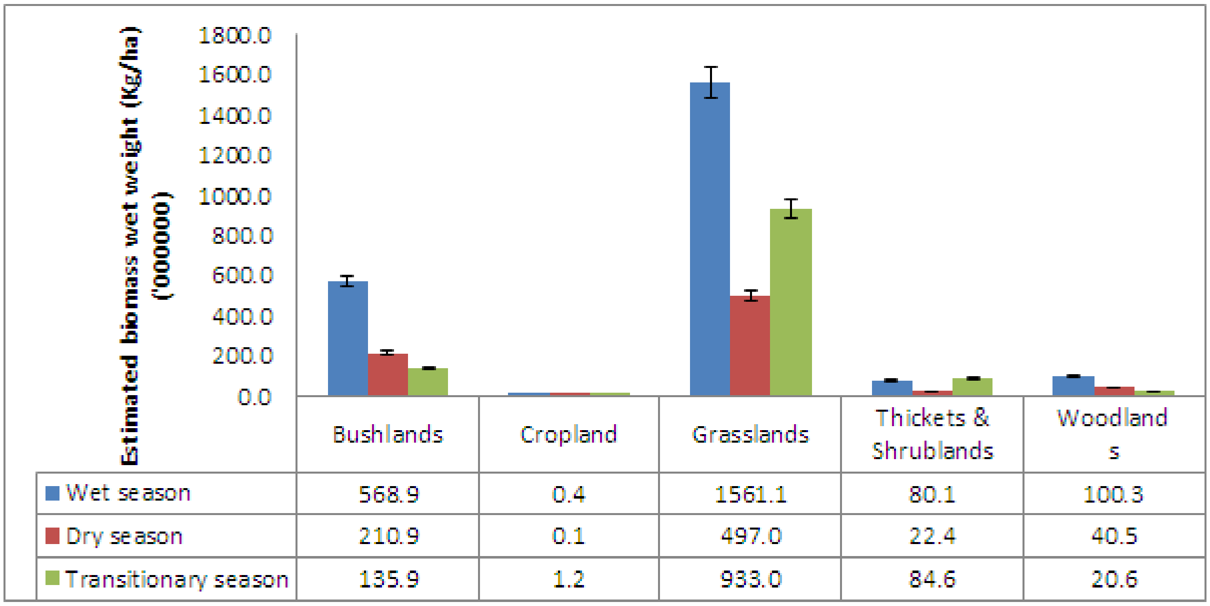
Table 4.18 portrays the change in land use/cover between land cover units from 1986-2013. With only 1.3% of the woodlands remaining unchanged the data show that over the last 27 years, 98.7% of the woodlands have undergone conversion to one or more land cover type. Thus, woodlands converted to bushlands, grasslands, thickets and shrublands and croplands respectively (Table 4.18). Vegetation clearance for charcoal (Plate 2) has rapidly grown in the recent past in Karamoja sub-region and the traditional demand for wood for constructing manyattas (homesteads) with defense walls could have contributed to the disappearance of woodlands in the region. This study also reveals that from 1986-2013 bushlands converted to woodlands, grasslands, thickets and shrublands and croplands at varying levels (Table 4.18). The grassland land cover experienced the greatest conversion to bushlands by almost six fold and woodlands by about two fold. It is also observable that some croplands reverted to grasslands (42.9%) and to thickets and shrublands (35.8%).

Table 4. 18: Land use/cover change for 1986-2013

	Land use/cover types 2013					
Land use/cover types 1986	Woodlands	Bushlands	Grasslands	Thickets and shrublands	Croplands	**Total**
Woodlands	**1.3**	44.1	49.1	5.3	0.3	100
Bushlands	5.3	**60.6**	31.4	2.1	0.6	100
Grasslands	16.1	59.3	**21.1**	2.4	1.0	100
Thickets and Shrublands	0.3	12.6	53.2	**30.3**	3.6	100
Cropland	0.1	7.2	42.9	35.8	**14.0**	100

4.4.6 Sub-regional quantity of forage during 2013

The extrapolated results of wet weight biomass show that the grasslands had the highest potential quantity of biomass in both wet and dry seasons estimated at 1561.1 and 210.9 million kilograms respectively. This is not surprising given that grasslands occupy the largest land area in the sub-region as indicated from the land use/cover results. This was followed by bushlands, woodlands, thickets and shrublands and cropland areas (Figure 4.7). The pattern of forage quantity revealed by this extrapolation is largely influenced by the extent of land area occupied by a particular land use/cover type. In this respect, grasslands are the most important grazing land covers particularly for cattle in the sub-region in both the wet and dry season. Thickets and shrublands revealed a relatively higher quantity of wet weight biomass; however, this land cover is mainly used for grazing sheep, goats and some calves.



	Bushlands	Cropland	Grasslands	Thickets & Shrublands	Woodlands
🟦 Wet season	568.9	0.4	1561.1	80.1	100.3
🟥 Dry season	210.9	0.1	497.0	22.4	40.5
🟩 Transitionary season	135.9	1.2	933.0	84.6	20.6

Figure 4. 7: Extrapolated estimates of wet weight forage biomass in 2013

4.4.7 Relationship between NDVI and herbaceous forage quantity

During the wet season, sub-regional average NDVI was 0.46±0.09. Land cover wise, woodlands revealed an average NDVI of 0.53±0.09, grasslands 0.49±0.07, thickets and shrublands 0.40±0.04, croplands/subsistence farmlands 0.30±0.00 and bushlands 0.52±0.08. On the other hand, the sub-regional average NDVI during the dry season was 0.41±0.11. There was however slight variation at land cover type level (Figure 4.8). For example, a slightly higher average

NDVI was observed in bushlands (0.51±0.05) during the dry season. This was followed by woodlands (0.49±0.08) and grasslands (0.45±0.09). Further, a 0.31±0.05 and 0.28±0.0 average NDVI was observed in the thickets and shrubland and croplands respectively during the dry season. A remarkably high average NDVI (0.50±0.11) was observed during the transitionary season (Figure 4.8). In this season, woodlands had an average NDVI of 0.65±0.07, grasslands 0.51±0.08, thickets and shrublands 0.43±0.07, bushlands 052±0.07 and croplands 0.38±0.07. Thus, all land cover types reflected a progressive improvement in vegetation greenness from 2012/2013 dry season to 2013/2014 transition season. This can be explained by the fact that during the monitoring period, rainfall withdrawal occurred around May before the June peak was reached. However, rainfall later resumed intermittently between August and October leading relatively high vegetation vigour observed until early November.

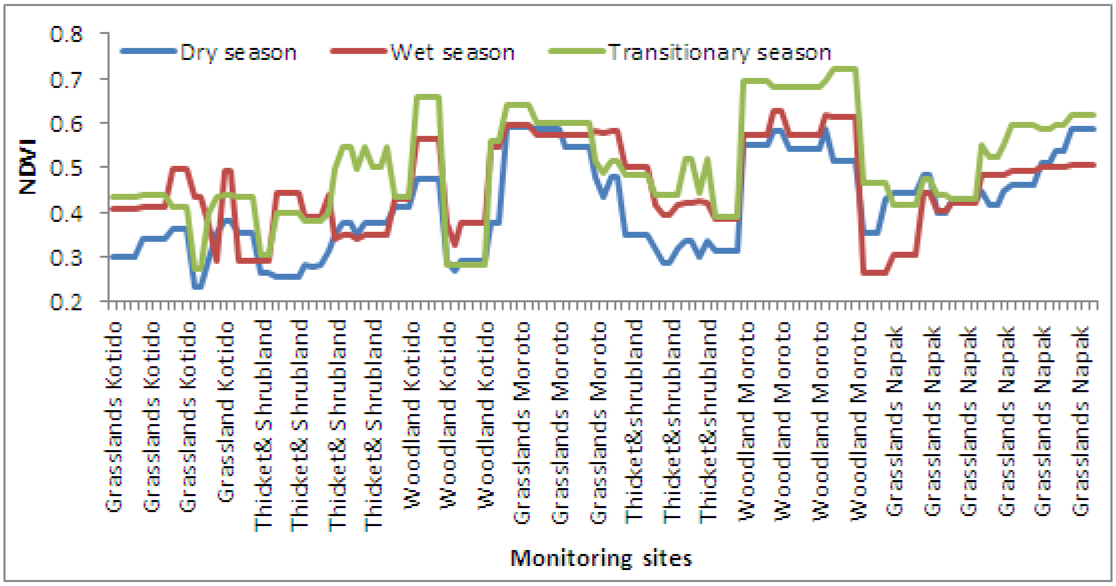


Figure 4. 8: Pattern of NDVI in the monitoring sites

Table 4.19 shows that there is generally a strong correlation between above ground wet weight biomass and NDVI, with R^2 varying between 0.62 and 0.98. The strength of the relationship varied from one location to another, with the season and land use/cover types. The strength of the relationship was highest for Moroto and the least at the sub-regional level. During the dry season, the grasslands, thickets and shrublands as well as the woodlands of Kotido showed a very strong relationship with NDVI. On the other hand, the few pockets of woodlands in the area generally provide a distinctive NDVI signature from the rest of the land cover types with a very high (R^2 = 0.98) biomass/NDVI relationship. Similarly, the grasslands of Napak also showed a very high biomass/NDVI relationship (R^2 = 0.878). During the wet season all land cover types (i.e. grasslands, woodlands and thickets and shrublands) showed a very high biomass/NDVI relationship. Grasslands and woodlands in Moroto had relatively low rates of change during the wet season. During the transitionary season, the strength of the relationship was relatively lower in Moroto and the sub-region compared to other locations. Differentiated positive gradient of change was observed for all sites and land cover types. They ranged from 0.0015 (wood land in Moroto) to 0.1422 (grassland at sub-regional level).

Table 4. 19: Relationship of NDVI and herbaceous forage quantity (g/m^2) in Karamoja

Land use/land cover type	Location	Model Equation	R^2
Dry season			
Grasslands	Sub-regional	y=0.1422x+0.2656	0.7485
	Moroto	y=0.0059x+0.4662	0.7353
	Kotido	y=0.0473x+0.2421	0.9259
	*Napak	y=0.1370x+0.2778	0.8783
Woodlands	Sub-regional	y=0.0210x+0.3662	0.7474
	Moroto	y=0.0108x+0.4630	0.8001
	Kotido	y=0.0054x+0.3714	0.9888
Shrublands	Sub-regional	y=0.0225x+0.2987	0.8517
	Moroto	y=0.0147x+0.3021	0.8596
	Kotido	y=0.0044x+0.3565	0.8182
Wet season			
Grasslands	Sub-regional	y=0.0211x+0.3396	0.7040
	Moroto	y=0.0029x+0.5485	0.9518
	Kotido	y=0.0345x+0.2546	0.9764
	Napak	y=0.0629x+0.0686	0.9472
Woodlands	Sub-regional	y=0.0214x+0.3324	0.9382
	Moroto	y=0.0095x+0.4824	0.8929
	Kotido	y=0.0209x+0.3271	0.9333
Thickets and Shrublands	Sub-regional	y=0.0105x+0.3311	0.7589
	Moroto	y=0.0124x+0.3034	0.9898
	Kotido	y=0.0321x+0.2561	0.9643
Transitionary season			
Grasslands	Sub-regional	y=0.0516x+0.3411	0.8409
	Moroto	y=0.0297x+0.4483	0.7615
	Kotido	y=0.0253x+0.3732	0.9438
	Napak	y=0.0590x+0.3120	0.8905
Woodlands	Sub-regional	y=0.0280x+0.4546	0.6810
	Moroto	y=0.0015x+0.6776	0.6208
	Kotido	y=0.0246x+0.4141	0.9992
Thickets and shrublands	Sub-regional	y=0.0225x+0.2911	0.6940
	Moroto	y=0.0287x+0.2358	0.7633
	Kotido	y=0.0500x+0.1525	0.8929

Note: *The Napak grasslands are reflective of the grasslands that stretch from Napak through most of the Bokora corridor down to Pian-upe and the southern rangeland (the NDVI within this corridor showed very high correlation). The Moroto woodlands were located between Moroto and Nakapiririt district thus represent woodlands in central and southern Karamoja. Owing to the fact that minimal clipping was conducted in the bushlands and croplands, it was not possible to conduct a relationship analysis due to data limitations*.

4.5 Discussion

4.5.1 Herbaceous and woody forage plant species in Karamoja

The Karamoja land cover types are dominated by annual grasses that provide a diversity of forage for livestock in the sub-region. The relatively large number of herbaceous and woody forage species observed in the sub-region can be explained by the transhumant livestock herding practiced by the Karamoja cluster (Karamojong, Uganda; Toposa, South Sudan; Turkana, Kenya and Nyangtom, Ethiopia). Some of the grasses (*Digitaria* spp and *Eragrostis* spp) that were observed in this study have previously been documented in neighbouring Turkana as preferred species (Lusigi et al., 1984). The presence of such species could perhaps explain the continued grazing by the Turkana in the Uganda territory besides their search for water during the dry season. Herbivore grazing in the rangeland ecosystems has been found to promote growth of grasses, dispersal and fecundity of seeds (Notenbaert et al., 2012); this appears to be the case in the current study area.

During the dry season, it was observable that perennial grasses such as *Hyparrhenia* spp, *Sporobolus* spp, *Aristida* spp, *Setaria* spp, and *Chloris* spp. were more abundant in the rangelands. This pattern is attributable to the tolerance abilities of these grasses to survive harsh conditions in the sub-region (Roschinsky, 2009). However, these species have also been documented to have low nutritive value because of their low protein content (Keba et al., 2013). This implies that during both seasons, livestock (in particular cattle) in the sub-region are subjected to poor forage diets. This exposure to poor forage diets has been observed to inadvently affect livestock production and performance in terms of milk yield, body condition and growth rates as well as reproduction (Kgosikoma et al., 2012). It is also important to note that while there was a relatively high prevalence of grass species in the sub-region, legumeneous plant species were relatively low to absent in most of the grazing land covers. This could be attributed to the frequency of disturbance associated with intense fires that ravage the region destroying seeds thereby limiting seed recruitment. However, leguminous plants have an important role of mediating livestock diet because of their high nutritive value (Abusuwar and Ahmed, 2010); their absence in the grazing land covers in the presence of grass species with low nutritive quality leads to poor livestock nutrition particularly during the dry seasons.

This study also revealed that the sub-region has a large number of woody plants that serve as browse for livestock. Browse has been noted to be dependable forage that is available over a longer growing season than grass. Its production may equal or exceed that of grass, and it may be the only forage available in heavily utilised areas (Illius et al., 2000) and during a drought period (Hungwe et al., 2013). Participants in the focus group discussions similarly reported the importance of browse forage species particularly during drought events. However, this relatively large presence of browse plants is not beneficial to cattle; the key livestock kept by the Karamojong in the sub-region. Cattle are essentially not suited to eating browse because they have an inflexible upper lip and use their tongues to grasp and pull forage into their mouths (Hamilton, 2003). It nonetheless offers a great opportunity for herding of goats, sheep and camels in the sub-region. It is also important to note that some of the woody browse species (e.g. *Acacia mellifera*) identified by the community as having high abundance have been associated with bush encroachment such as in the Kalahari (Thomas and Twyman, 2004). Bushland encroachment in the sub-region has similarly been confirmed by this study.

4.5.2 Quantity of forage under various land use/land cover types and at sub-regional level

The quantity of forage in the land covers of Karamoja documented in this study is generally within the range of those observed in other studies such as Angerer (2008) over East and the Horn of Africa, Ooro Olang (1984) in Turkana. However, this study’s results are considerably lower than those observed in managed grassland pastures such as in western Canada (Iwaasa et al., 2012). This study has also been able to document inherent variation in the quantity of forage that exists between different land covers, seasons and locations in Karamoja sub-region. The differences between wet and dry season forage quantity is attributable to variation in rainfall over the seasons. In semi-arid areas of Chad and Cameroon, Awa et al. (2002) noted that forage quantity is directly related to rainfall and gets poorer in areas with rainfall below 1000 mm. This appears to be a similar situation in the Karamoja rangelands. However, this pattern reveals the major reason for transhumant livestock grazing practices exercised in the region. In fact, the decline in wet weight forage quantity around the transitionary season (between August and November) provides a good indicator for pastoral mobility. Informal interviews with herders during the monitoring period revealed that these patterns in vegetation performance trigger scouting for grazing grounds and preparation for dry season movement. This study has also shown that grasslands have relatively lower yields compared to woodlands. However, because of their expansive nature in the region they form the major grazing grounds.

The variations in quantity of both wet weight and dry matter biomass documented in this study is diverse. As already noted, this pattern is linked to the type of land cover, location (district), seasonality, and the interaction between land cover and district, land cover and season and district and season. The seasonal variability of forage quantity has been documented elsewhere, for example in Cameroon and Chad (Awa et al., 2002); in the Sahelian flood plains (Scholte and Brouwer, 2008) and South Dafur state, Sudan (Abusuwar and Ahmed, 2010). Seasonality also influences forage quantity due to its control on moisture availability which in turn influences vegetation growth. Karamoja sub-region was therefore not an exception. The differences existing in quantity of forage from different land covers is in part a result of existing heterogeneity. Heterogeneity in semi-arid regions is associated with variability in rainfall patterns (Augustine, 2010). The rainfall patterns often coincide with the effects of seasonality which in turn has an effect on the productivity of grassland pastures (Ospina et al., 2012). This could explain the consistent negative slope in forage quantity from the wet season to the dry season observed in this study. However, because of the dynamic pattern of forage in the sub-region, multiple livestock species can be supported ranging from small stock (goats, sheep), medium (cattle) to large stock (camels).

4.5.3 Pattern of land use/ land cover change

Over the last 27 years, it is apparent that land use and land cover within the different land covers of Karamoja have been changing. The changes have been non-uniform in the three time steps (1986-2000; 2000-2013 and 1986-2013) observed in the sub-region. Notable in the process of change is the considerable disappearance of woodlands, the rapid rise in the croplands from 2000-2013 and the increase in woody vegetation associated with bushlands in the sub-region. Although the woodlands appear to be recovering in 2013, they are nonetheless lower than the 1986 period and perhaps even the earlier periods. Majaliwa et al. (2009) indicated that over the last 30 years deforestation has been rapid in the region.

Similarly, Kagan (2010) also noted the deforestation levels in the sub-region to be on the rise. The general trend in the loss of woodlands is attributable to three factors; the first of which is the increased cutting of hard wood trees for charcoal and firewood. During the field process, piles of charcoal and split firewood amounting to many tonnes could be observed along the roads and villages in mainly woodland areas of Abim, Napak (particularly Iriiri), Moruita in Amudat district and Tokora area and Namalu in Nakapiripirit district. This pattern is a result of the expansion of the charcoal belt to eastern and northern regions of Uganda as well as the increased demand in the urban areas surrounding the sub-region to the west. However to the Karamojong, this is the only means available to circumvent the impacts of poverty, hunger, and climatic variability. These practices have hitherto been identified as a host of mal-adaptation strategies employed in the sub-region following the loss of livestock (Levine, 2010).

The second reason for the loss of woodlands is a breakdown in traditional institutions in particular the control previously exerted by the elders over the youth in respect of natural resources management. This has left tree cutting to flourish unabated. Thirdly, expanding croplands is exerting pressure on woodland land cover. Locations where woodlands exist and are accessible to the communities are preferred for establishment of farmlands because they are believed to be fertile. During the interviews and focus group discussions, the soils in such areas were described as ‘cool’ thus good for sorghum and maize production.

Through the landuse/cover change matrix, this study has unearthed a rapid increase in the agriculturalisation of once pastoral Karamoja. The increase in crop cultivation in semi-arid and pastoral areas has been reported by studies elsewhere. For example, Ekaya (2005) reported a general increase of crop cultivation and sedentarisation over East Africa’s drylands. Meanwhile Zziwa et al. (2012) observed an increase in croplands in Nakasongola. Meanwhile, Sulieman and Ahmed (2013) further observed that in eastern Sudan state policies that favor crop farming over pastoralism were in part changing pastoral resources. As observed in this study, a tenfold increase in croplands with particular expansion in the grasslands means considerable lose of forage resoucres in the sub-region. Continued increase in croplands by encroaching on the grasslands (the key grazing land covers) will negatively impact on livestock production in the sub-region as constrained access to forage resources will be exacerbated, conflicts of grazing grounds and reduction in available pastures overtime.

In Karamoja, the increase in subsistence croplands can be explained by three factors. Firstly, the Government of Uganda has strengthened direct support for crop cultivation through provision of seeds and tractors. Tractors are provided to the communities to clear land for planting at no or a subsidized fee. This is viewed as a mechanism to stamp out persistent food insecurity in the region. Secondly, a similar effort is being exerted by development organizations both local and international through supporting agriculturalisation of the once pastoral society through provision of planting materials, gardens tools and seeds tied to 'food for work' systems.

Thirdly, the persistent livestock raids that existed in the region prior to the 2000-2007 peaceful and forceful disarmament led to a high number of pastoralist dropouts. This group of people has been quick to adopt crop cultivation to circumvent the deplorable livelihood situation. Having lost livestock to raids and incapable of performing herd reconstitution through normal pastoral channels and/or through subversive means (raids), the option provided by the government and other development partners has become handy in a situation of destitution. This crop-cultivation option has largely gained ground because it is championed by those with '*a chlorophyll syndrome*', that is those who believe in crops as precepts of food security.

As already pointed out in the results section, bushland encroachment is rapidly gaining hold and is threatening the existence of grasslands that once characterized the plains of Karamoja. The presence of some alien species such as *Prosopis spp* (not yet wide spread but pronounced in Amudat district and a few pockets in Moroto and Kotido districts) will further complicate bushland encourage in the sub-region a few years to come. *Prosopis spp* is already causing serious challenges in semi-arid areas of Kenya (Maundu et al., 2009). *Prosopis spp* was introduced into semi-arid Turkana and Baringo areas of Kenya as part of rangeland rehabilitation in the 1980s and 1990s; it is however expanding into Karamoja as a result of Turkana transhumant herders. The Karamojong attribute its spread to the presence of the Turkana and Pokot camels. Elsewhere in Uganda, bushland encroachment has been observed to be high in the semi-arid areas. For example it has been recorded in Nakasongola (Zziwa et al., 2012) and around Kagera basin of Uganda (Tolo et al. 2012). Similarly, bushland encroachment has been observed in semi-arid Afar region of Ethiopia (Tsegay et al., 2010) and Laikipia in Kenya (Causey and Lane, 2005). Bushland encroachment in semi-arid regions has generally been attributed to a reduction in the use of fire as the traditional management strategy (e.g. Gemedo et al., 2004) and the absence of grazing (Oba et al., 2000). Karamoja sub-region has not been an exception to these drivers except that fire use in Karamoja is still evident. In Karamoja, however, other reasons exist for the development and increasing dominance of bushland vegetation.

Firstly, parts of northwestern Karamoja (e.g. Lotukei, Morulem, Garegere, and parts of Alerek in Abim district, Karenga, Lodapal Kawanga, Lomaler in Kaabong district, Apalopama, Lobul, and Lomaria in Kotido district) were once affected by the Lord’s Resistance Army (LRA) rebels during the late 1990s to mid-2000s. This prohibited the normal grazing calendar of the pastoralists in these locations that are traditionally dry season grazing grounds. This allowed bush encroachment to occur in these locations due to the absence of grazing. However, the absence of grazing in these locations also created pressure in the central plains that became heavily grazed leading to the transformation of the vegetation into thicket and shrubland.

Secondly, the period from the mid-1980s to the mid-2000s was marked by ‘Karamoja at war with itself and without herself’. This was mainly a result of the increased proliferation of small arms in the area that increased livestock raids. It thus became highly risky to venture outside defensive positions with one’s animals because the risk of losing livestock to rustlers was high. During this time, normal grazing calendars became distorted and herders grazed livestock within the vicinity and peripheries where immediate reinforcements could be mobilized in the event of attack. At the same time, the neighbouring communities such as the Turkana that often relied on the dry season pastures in eastern parts of Karamoja could not access such grazing grounds as they were a sworn enemy (Quam, 1997). This allowed bushes to dominate in the once expansive eastern grasslands as a result of limited grazing.

Thirdly, out of the raids, came the military ‘restricted movement’ and ‘protected kraal’ system. In this system, the military regulated where and how far the herders could take the animals for grazing. This was partly because the herders relied on the military for security in defense of their livestock. Thus, the movements could barely exceed five kilometers from the manyattas (homesteads) and/or protected kraals since going beyond this distance increased the vulnerability of both the herders and the military to attack from raiders. This, therefore, left large parts of the region unutilized for grazing and the utilized areas were slowly encroached by the bushlands while the heavily grazed areas were transformed into thickets and shrublands.

Finally, areas that were croplands were rapidly encroached by bushlands because communities abandon such croplands once productivity declines. What is evident however is that bushland encroachment is affecting most of the dry season pastures in south eastern areas (e.g. parts of Karita, Lokales, Loporokocho, and around Morunyang in Amudat district), central to eastern areas (e.g. parts of Katekile, Lokwakipi, Lokisile, Mogos, Losagam, Kothoniok and Kobebe in Moroto district), in northeastern areas (e.g. Risai, Kamion, Oropoi, Kalapata, Pirre in Kaabong district), and in the parts of the southern rangelands in Nakapiripirit district among others.

4.5.4 Relationship between NDVI and herbaceous forage quantity

The significant relationship observed between NDVI and conventionally clipped above ground biomass is a good indication that remote sensing data can be applied in estimating forage quantity in the sub-region. The estimation equations obtained for both wet weight and dry matter biomass can thus be applied in a remote sensing environment. In a pilot study conducted in Kenya as part of a global assessment of land degradation and improvement, Bai and Dent (2006) also applied remote sensing successfully to quantify green biomass and net primary production. According to Bozkurt et al. (2011) remote sensing techniques provide greater flexibility and accuracy for grassland assessment and the integration performed in this study has provided evidence in this direction. Further, Dwyer (2011) conducted a spatial estimation of herbaceous biomass using remote sensing in Southern African savannas with great detail and success. Such assessments have been limited and/or virtually non-existent for Karamoja. This has been due to the lack of baseline information regarding forage quantity in different land covers. Also, for a considerable period of time (over 3 decades) the sub-region was plunged into civil strife orchestrated by the high proliferation of small arms. This made ground-based assessments involving forage clipping impossible in the sub-region. The situation has improved marginally although the Turkana and Pokot of Kenya still pose a security challenge because they are still armed and occasionally conduct armed livestock raids in the sub-region. Despite these challenges, this study has addressed the lack of ground based assessments of forage quantity in the sub-region.

4.6 Conclusions

This study was commissioned with the main objective of quantifying forage in the different grazing land use/cover types in Karamoja and to provide a long term portrait of how these grazing land use/cover types have changed. This study has successfully bridged the information gap on forage quantity at seasonal and regional level thus fulfilling one of the recommendations made in the 10th EU/KALIP project document seeking for a full forage assessment on seasonal and location basis in the sub-region. This study has not only provided a wet and dry season perspective, but have also provided a transitionary season view point which is critical in providing warning signals on the likely challenges that the pastoralists may face during the dry season. The study has also provided detailed pastoralists forage dynamics understanding by season in the sub-region. It is hoped that this information should be able to trigger early preparation and early response to the plight of pastoralists and agro-pastoralists.

This study has also highlighted the existence of spatial heterogeneity in different grazing land covers as well as districts in the region. Thus transhumance practices as exercised in the region are likely to continue and may offer the best option for coping and adapting to the variability in grazing resources as well as climate. Furthermore, this study has shown that the grasslands, which represent the most important grazing land cover in the sub-region, are under threat from bushland encroachment and in particular the proliferation of alien species such as *Prosopis spp* poses even a greater risk in a few years to come. This requires immediate management attention to reduce the apparent bushland invasion. Uniquely, this study has shown that while other grazing land covers decline in forage quantity, the thickets and shrublands have their peak production during the transitionary season.

The growth in cropping estates in the last thirteen years is unprecedented. It is therefore imperative that while supporting extensification and increase in crop cultivation, efforts are also geared towards integrated livestock-crop production systems in the sub-region. Therefore, the sustainability of livestock grazing in the sub-region will depend on the health of the grasslands for continued transhumant practices in order to ameliorate the low forage quantity per hectare. This study has also shown that it is possible to estimate above ground biomass using remote sensing technologies. The estimation equations developed in this study offer baseline information that could be utilised by decision makers to rapidly obtain forage information status. The varied response rates of land covers at different locations point to the existence of heterogeneity within the land covers and locations in the sub-region. It is recommended that long term monitoring studies be conducted in the sub-region within three main treatments: no grazing, controlled grazing and open-access grazing.

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CHAPTER FIVE

DETERMINANTS OF FORAGE DYNAMICS IN THE SEMI-ARID KARAMOJA SUB-REGION, UGANDA

ABSTRACT

Low input pastoral production systems provide up to 90 percent of livestock and livestock products consumed in Uganda. However, pastoral communities are increasingly faced with the challenge of meeting their livestock needs in terms of forage, a situation exacerbated by climatic variability. This study investigated the determinants of forage dynamics in Karamoja sub-region. Results showed that 75.3% of the respondent's perceived forage to be sufficiently available with differentiated dynamics in the livelihood zones and between livestock species (goats, sheep, cattle, donkeys and camels). Perceived determinants of forage dynamics include: length of residence by a livestock keeper, frequency of grazing, number of kraals, presence of governing rules, and presence of conflicts, knowledge of pasture locations, restricted movement and ease of access to grazing areas ($P \leq 0.05$). Results also showed that soil properties had varied influence on forage dynamics; in the grasslands, P positively ($P \leq 0.01$) influenced forage quantity while pH, K, Na, %sand, and %clay, N, and SOM had a negative influence on forage quantity ($P \leq 0.05$). Further, forage quantity in the thickets/shrublands was negatively influenced by P, Ca, and Mg and %clay but N and %silt were positive ($P \leq 0.05$). Only N and SOM were found to lead to higher forage quantity in the woodlands ($P \leq 0.05$). Further, the piospheres in the sub-region had both and negative effect on forage dynamics by influenceing species abundance and composition leading to identification of decreaser and increasr forage species in the sub-region. This study has shown that socio-ecological conditions operate jointly to influence forage dynamics in Karamoja.

Key words: *dynamics, livestock species, pastoral, semi-arid, Karamoja Uganda*

5.1 Introduction

Low input livestock production systems strongly depend on natural grazing pastures (Kerven and Behnke, 2011). In such systems, vegetation growth and management are of paramount importance because the dynamics of pasture and water are important in grazing and grazing management (Namgay et al., 2013). For example, the dynamics of pastures in space and time influences power relations, access rights, societal co-existence and the existence of either peace and/or conflict (Senay et al., 2013). In the event of shortage during the grazing calendar, livestock is negatively affected (Rahman, 2002). Thus, the presence and/or absence of a crisis in any given year are closely linked to water and pasture dynamics. The catastrophic emergency situations often observed in semi-arid areas of East Africa are attributable to negative deviations in the availability of water and pasture resources (Njiru, 2012).

Different perspectives have been fronted to explain the dynamics of pastures in pastoral systems with climate perhaps being the most documented component (Sulieman and Elagib, 2012). In the recent past, there has however been a push to understand the dynamics of forage resources in the rangeland ecosystems beyond the mere stochastic patterns induced by rainfall. As such, Xu et al. (2009) examined the influence of policies on pasture use and dynamics in China. They observed that changes in policies on pasture use in the Chinese Tibet led to increased fencing of pastures as well as a shift in rangeland management goals (Xu et al., 2009). Similarly, government interventions in the trans-Himalayan region of northern India to develop a market based economy led to higher preference for goats. This led to a shift in livestock herd composition with a relative increase in goats compared to traditionally herded sheep thereby offsetting the the traditional forage dynamics calendar (Singh et al., 2013).

In addition, prolonged livestock movement into grazing lands and watering around settled areas has been observed to negatively influence forage dynamics among the Baringo pastoralists of Kenya (Kaimba et al., 2011). This is owed to the fact that a gradient of activity often develops from such watering sources. It is this gradient of activity patterns that introduces the disturbance gradient called a piosphere. Accordingly, the activity patterns around the piosphere leads to distance dependent effects such as declines in perennial plant cover, variation in biomass defoliation and trampling, variation in forage species composition with increased presence of unpalatable perennial shrubs beyond the zone of extreme degradation and a decrease in the abundance of palatable native perennial grasses due to selective grazing (Brooks et al., 2006, Shahriary et al., 2012).

It is also generally accepted that soil and soil properties play a pivotal role in forage dynamics by influencing biomass growth and accumulation, species abundance and composition (Juice et al., 2006; Adjolohoun, 2008). Soil properties such as nitrogen (N), phosphorus (P), potassium (K) and soil pH have been identified as the four key soil components important in forage production (Mathison and Peterson, 2011). Considerably fewer studies have focused on understanding the influence such soil properties have on rangeland productivity. Studies that have attempted to examine rangeland productivity such as; Gemedo et al. (2006) and Mellado et al. (2012) have sought to provide rangeland productivity from a land degradation perspective. Thus, the understanding that soil characteristics contribute to the widely recoganised resilience and productivity of rangeland ecosystems has been missed (Doudill et al., 2003).

Further, it is evident that research into the dynamics of forage resources in the rangeland ecosystems has been an on-going activity but has been fragemented. Thus, there is barely any study that has attempted to provide an integrated understanding of forage dynamics determinants in the rangeland ecosystems. According to Kratli (2010) this lack of coordinated analysis of livestock resources and production regimes in pastoral areas has led to the development of prescriptive policies and '*system blind*' interventions in Karamoja sub-region. The setting of these abstract interventions with focus on 'technical' targets that have little connection to the pastoral production system and the societies of the producers led to the delivery of 'hardware' (borehole construction, pans and dams) solutions with limited attention given to 'software' (pastoral management arrangements). This in fact has overtime resulted into bigger problems in practice. For example, system-blind water development resulted in large-scale soil erosion and the dramatic disappearance of perennial grasses, as well as social unrest as the stocking rates supported by the expansion of accessible dry-season rangelands at the periphery of Karamoja became unsustainable for the (unexpanded) central belt during the wet season (Kratli, 2010).

A comprehensive understanding of the determinants of forage dynamics is an essential tool in guiding sustainable rangeland management by better guiding and understanding livestock distribution and redistribution (Ganskopp et al., 2007), probabilistic movements and utilisation of patchy resources (Matsumura et al., 2010), grazing decision management and pastoral mobility (Kavana et al., 2005), understanding competition and conflicts regimes in pastoral areas (Senay et al., 2013), understanding the underlying causes of feed deficits/surpluses (Angerer, 2008), and idenitification of environmentally sound and culturally acceptable natural resources management practices as well as strengthening traditional institutions (Angassa et al., 2012). It is against this background that this study set out to determine the drivers of forage dynamics in Karamoja sub-region. In order to achieve this objective, the study; identified perceived dynamics of forage resources, determined perceived factors influencing forage dynamics, analysed the influence soil properties and piospheres have on forage dynamics in Karamoja sub-region.

5.2 Materials and methods

For the description of study area, climate, vegetation, topopgraphy, soils and geology refer to Chaper 3 (3.1, 3.2. 3.3 and 3.4)

5.2.1 Perceived forage dynamics, quality and determinants

In order to identify perceived patterns of forage dynamics, quality and determinants; data was obtained using semi-structured questionnaires administered to 198 respondents in three of the seven districts of Karamoja sub-region. Districts were selected taking into consideration the livelihood zones in the sub-region with specific focus on pastoral and agro-pastoral zones as well as northern and southern Karamoja representation. Thus, Kotido district represented the agro-pastoral and northern Karamoja zone, Moroto district represented the pastoral zone (Rupa and Katikekile sub-counties) and Napak district represented agricultural and agro-pastoral of central to southern Karamoja (Lotome sub-county has close proximity to Lorengduat and Nabilatuk in southern Karamoja). Simple random sampling technique was utilised to select the respondents.

Questionnaires were proportionately allocated to the three districts thus; 75 households were interviewed in Napak district, 53 in Moroto district and 79 in Kotido district. Only 198 questionnaires were successfully filled of the 207 sample size reflecting a 94.3% success rate. Data was collected from two sub-counties and two parishes in each district. Thus, Lotome and Lokopo in Napak district, Rupa and Katikekile in Moroto district, and Nakapelimoru and Panyangara in Kotido district. Twelve parishes including: Moruongor, Akalale, Lorikitae, Namujit, Kalokengel, Lia, Mogoth, Watakau, Potoongor, Rikitae and Loposa were utilized in data collection. The survey team collected data from fifty three (53) villages in the sub-region.

Respondents assessed forage dynamics in terms of perceived availability across the grazing calendar from January to December based on their reflections of vegetation patterns in their grazing areas. Thus, dynamics and availability are interchangeably used in this chapter. Respondents were also asked to assess perceived quality of available forages using a likert scale (1= Excellent, 2 = very good, 3 = good, 4 = fair and 5 = poor). To make respondents arrive at a judgment of perceived forage quality, I jointly developed a list of indicators with the elders, youth and herders during the pre-test. These included: forage palatability, digestibility, animal health and size of faecal pats (dung deposits) deposited by animals when grazing. It is important to note that the use of rapid assessments, survey data and integration of traditional ecological knowledge in ecological assessment is not a new practice. Several studies have integrated traditional ecological knowledge and ecological methods in understanding how management practices affect indigenous vegetation as well as understanding the effect of grazing pressure on herbaceous cover (Angassa et al., 2012; Kgosikoma et al., 2012).

5.2.2 Forage biomass and soil sampling

In the same plots where herbaceous biomass was clipped as described in Chapter four (4.2.1), composite soil samples were taken at two depths 0-15 cm and 15-30 cm for determination of chemical properties (N, P, K, Mg, Na, Ca, and pH) and soil organic matter. Agronomic soil samples are often taken within this depth range which represents the large proportion of the active root zone (Vadas et al., 2006) and has previously been applied in the semi-arid and arid Mongolia (Cao et al., 2013).

5.2.3 Soil predictors

Soil physical properties including; soil structure, saturated hydraulic conductivity and soil organic matter (SOM) were analysed from the soil samples obtained. Soil structure was assessed using the dry sieving technique and the results expressed as Mean Weight Diameter (MWD) of the aggregates (Diaz-Zorita et al., 2002). Soil samples were passed through a 10 mm sieve (Kemper and Rosenau, 1986), thereafter passed through a nest of concentric rings of progressively declining sieve sizes; 6.36, 4.75, 2.36, 1.18, 0.425 and 0.212 mm. A vibratory sieve shaker-FRITSCH analysette 3E was set at amplitude 5 for 30 minutes during the processing of soil aggregates. Soil organic matter (SOM) was determined using the Walkley-Black method as described by Okalebo et al. (2002). Soil chemical properties were analysed using the procedures described by Okalebo et al. (2002) thus; available Phosphorus was determined using the Bray 1 method, Potassium-K determined using a flame photometer and nitrogen determined by digestion and titration.

5.2.4 Effect of piospheres on forage forage dynamics

In order to identify the influence piospheres have on forage dynamics, herbaceous forage species data was collected within and around the protected kraals and waterholes piospheres. A north-south-east-west transect approach was utilised for a distance of 100 m; each transect started 5 m away from the piosphere periphery. Herbaceous species were assessed after every 25 meters within 1 meter quadrat. Available species were identified, tufts counted and tallied. On the other hand, woody species were assessed on a 5 m quadrat; all species present were identified, counted and tallied. A total of eight (8) waterholes were assessed; four replicates in each district (Moroto and Kotido). The choice of waterholes for monitoring depended on accessibility and security status (briefing and clearance provided by the Uganda Peoples Defense Forces-UPDF stationed near all major livestock water sources). Owing to ephemeral nature of the streams in the sub-region, accessibility during the wet season was unpredictable. Thus, all waterholes considered for assessment were within 10-15 km foot walking distance from a motorable road (in at least the worst condition when the roads were cut-off). Four protected kraals including; two in Kotido district, one in Moroto district and Nakapiripirit district respectively were monitored. The protected kraals considered were those that had lasted at least two years in the same location. All species that could not readily be identified on-site were secured and transported to Makerere University for identification.

5.3 Data analysis

5.3.1 Perceived forage dynamics and quality patterns in Karamoja

Survey data was descriptively analysed. Responses from respondents were transformed into percentage values. Descriptive analysis was conducted at sub-regional level by livestock species, livelihood zones and at specific parameter of interest. Thereafter, plots were generated from Microsoft office Excel to provide a graphical summary of the results.

5.3.2 Perceived determinants of forage dynamics

Ordinary Least Squares (OLS) regression was used to identify the determinants of forage dynamics in the sub-region. An ordinary least-squares (OLS) regression is a generalized linear modeling technique that may be used to model a single response variable which has been recorded on an interval scale. The technique can be applied to a single and/or multiple explanatory variables and also categorical explanatory variables that have been appropriately coded (Hutcheson, 2011). Further, the usefulness of the technique can greatly be extended with the use of dummy variable coding to include grouped-categorical explanatory variables (Hutcheson and Moutinho, 2008). Owing to the fact that this study had both quantitative and dummy variables (Table 5.1), OLS was preferred. It was also selected because the dependent variable was drawn from a normally distributed population. In an OLS caution ought to be taken against multicolinearity thus a correlation analysis was conducted to test for multi-collinearity by identifying variables that are significantly correlated before the regression analysis was performed. The variables with higher t-values are preferable for use in the analysis process (Elhadi et al. 2012). The OLS utilised in this study took the following functional form:

$$DC = \beta_0 + \beta_1 NR + \beta_2 HS + \beta_3 LR + \beta_3 WC + \beta_4 AG + \beta_6 FG + \beta_7 ST + \beta_8 NK \\ + \beta_9 GR + \beta_{10} CF + \beta_{11} RM + \beta_{12} KP + \mu$$

Where:

DC: Distance covered in search of forage
AG: Ease of access to grazing site
CF: Presence of conflicts in grazing
FG: Frequency of grazing at a site
GR: Presence of rules governing grazing

HS: Herd size in TLUs

KP: Knowledge on pasture location

LR: Livestock rustling in TLUs

NK: Number of persons (kraals) grazing at a site

NR: Length of residence at a location

RM: Existence of restrictions in movement

ST: Perceived quality of soils in the area

WC: Perceived weather condition

β_0: Intercept

$\beta_{1...12}$: coefficients of determination

μ: Error term

Table 5. 1: Summary of perceived determinants used in the OLS regression analysis

Driver	Variable type	Expected effect
Herd size	Continuous	-
Distance covered in search of forage	Continuous	+
Livestock rustling	Continuous	-/+
Length of residence in a location	Continuous	-
Number of persons (kraals) grazing at a site	Continuous	-
Perceived rainfall condition	Dummy	+
Frequency of grazing at a site	Dummy	-
Perceived soil quality	Dummy	-/+
Existence of restrictions in movement	Dummy	-
Knowledge on pasture location	Dummy	+
Presence of conflicts in grazing lands	Dummy	-/+
Presence of rules governing grazing	Dummy	+
Ease of access to grazing sites	Dummy	-/+

5.3.3 Determining the influence of soil properties on forage dynamics

A Three stage analysis was used to identify the influence soil properties have on forage dynamics in Karamoja sub-region. Firstly, descriptive statistics were employed to understand the characteristics of soils in the woodlands, grasslands and thicket and shrublands. Secondly, correlations were thereafter conducted to test for the relationship between soil properties and forage quantity expressed in biomass kg/ha as well as the relationship between soil properties. Tjirdly, a multiple logistic regression analysis was then conducted to determine the extent to which soil properties influenced forage quantity in the land covers. In the analysis, only soil chemical and physical properties (N, P, K, Mg, Na, Ca, and pH; %SOM, %N, %sand, %silt, and %clay) obtained during the period of monitoring were considered. In order to normalize the distribution of soil properties a log transformation was applied. The analysis was performed in Gen-Stat 12th edition.

5.3.4 Determining the influence of piospheres on forage dynamics

In order to determine the influence of piospheres on forage dynamics, the factor under invstigation is essentially grazing intensity. Thus, inorder to determine the influence of grazing intensity on herbaceous and woody species dynamics a log-linear regression was applied. This is because both herbaceous and woody species data were count data and best analysed using a log-linear-poisson regression. This method can deal with several difficulties inherent in monitoring data such as missing values, over- and under-sampling of particular strata, serial correlation and deviations from the poisson distribution. Further, the method is capable of testing the effects of covariates on the changes so that the impact of activities on change can be investigated. The analysis was performed in Gen-Stat 12th edition.

5.4 Results

5.4.1 Perceived forage dynamics in Karamoja sub-region

Over a twelve month period, perceived average forage availability was deemed sufficient by 75.3% of the respondents. The availability assessment with respect to specific livestock species revealed that; 66.7%, 70.9%, 86.4%, 81.6%, and 70.6% believed that forage was sufficiently available for cattle, goats, donkey, camel and sheep respectively. The months of May to September were indicated as having better forage availability for cattle with 85% of the respondent's positive assessment (Figure 5.1). In Figure 5.1 (cattle) perceived forage availability decline begins around October, reaching a low in February. On average, 80% of the respondents observed that there was sufficient forage available for goats. This perceived availability was more pronounced during the months of April to September (Figure 5.2). The decline commenced from October but at a lesser rate than that of cattle. Perceived forage availability trend for Sheep took a similar trend to that of goats; ranging from April to September for the periods of high availability (Figure 5.3). The gap difference between perceived availability and unavailability was however minimal for sheep compared to goats. On the other hand, donkeys and camels were generally perceived to have high forage availability throughout the year (Figure 5.4 and Figure 5.4). Camels on the other hand experienced a contraction in perceived forage availability around August (Figure 5.5). These are the periods when vegetation in the region has reached maturity stage.

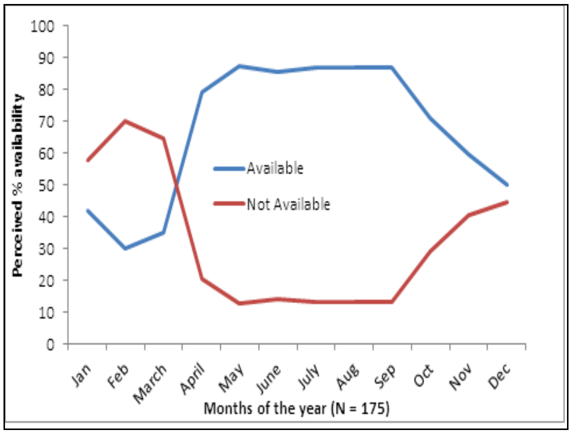


Figure 5. 1: Perceived forage dynamics for cattle

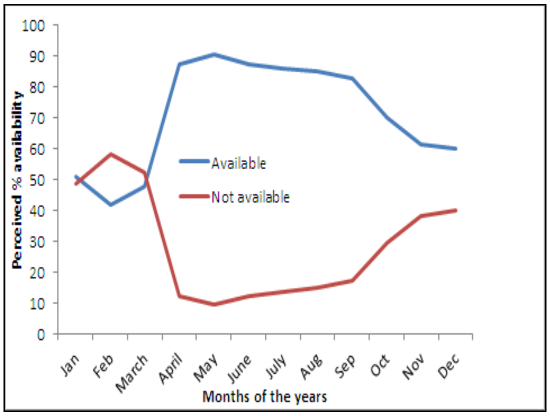


Figure 5. 2: Perceived forage dynamics for goats

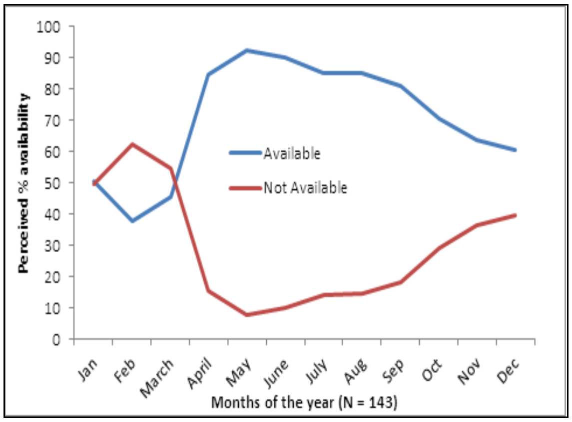


Figure 5. 3Perceived forage dynamics for sheep

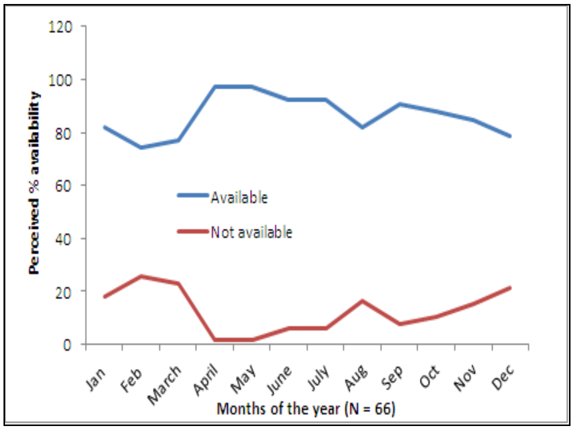


Figure 5. 4: Perceived forage dynamics for donkeys

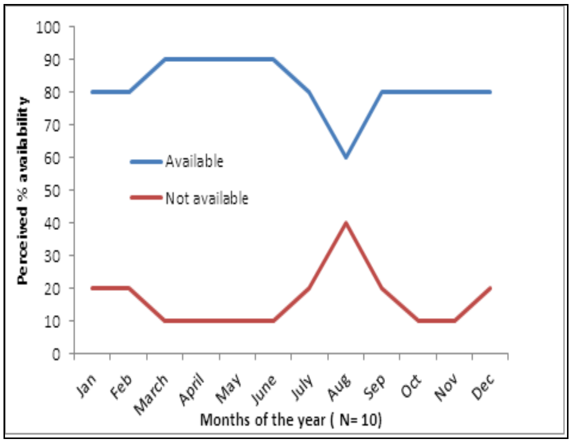


Figure 5. 5: Perceived forage dynamics for camels

Perceived forage dynamics from the different livelihood zones showed differences for cattle, goats; sheep and donkeys (see Figures 5.6a-5.6l). Patterns of camel forage dynamics remained unchanged because camels were only observed in the pastoral zone of Moroto district. Declines in perceived availability for cattle were observed to commence after the peak period in mid-September (agricultural zone) and in mid-August in the pastoral and agro-pastoral zones (Figures 5.6a-5.6c). However, in the pastoral zone, a rapid rise in limited forage availability for cattle is observed outstripping availability in October with an extreme low period in January. This leads to a 38.8% availability gap. On the other hand, the agro-pastoral and agricultural zones experience high availability gaps in February at 46.5% and 43.3% respectively (Figure 5.6a and 5.6c).

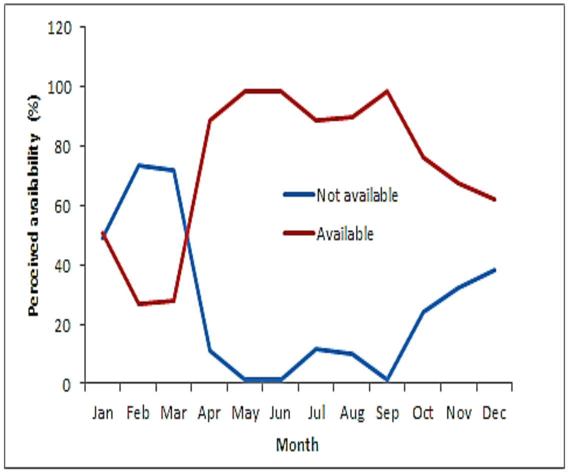
In the pastoral zone, perceived forage availability for goats was observed to rapidly reach a peak period in April before experiencing a fluctuating decline. This rise was however more rapid in agro-pastoral zone. Meanwhile, the agricultural zone was perceived to have a relatively prolonged period (April-September) of perceived forage availability for goats. Pastoral and agro-pastoral zones showed marked variability in forage availability for sheep with early perceived deficit occurring in the pastoral zone around November. The agricultural zone generally had five months of (April-August) of high sheep forage availability before a declining trend was observed around October. However, in the agro-pastoral, a prolonged period (April-September) of limited forage availability for donkeys was observed (Figure 5.6j). For donkeys, the months of low forage availability coincides with rainfall months in the sub-region. On the other hand, other livestock species' periods of limited forage availability coincides with low rainfall months in the sub-region.

Figure 5. 6: Perceived forage dynamics in different livelihood zones in Karamoja

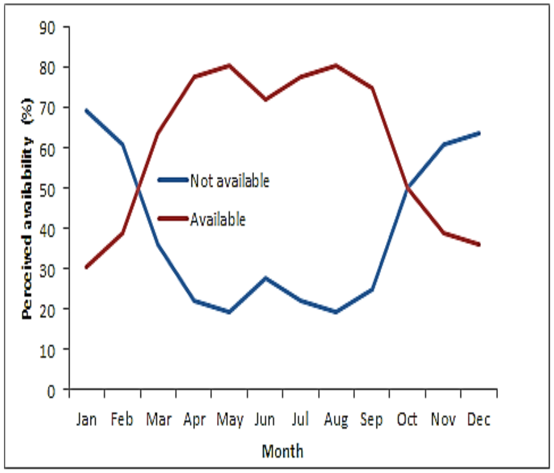
Perceived forage dynamics in Agro-pastoral livelihood zone by livestock species

Perceived forage dynamics in the Pastoral zone by livestock species

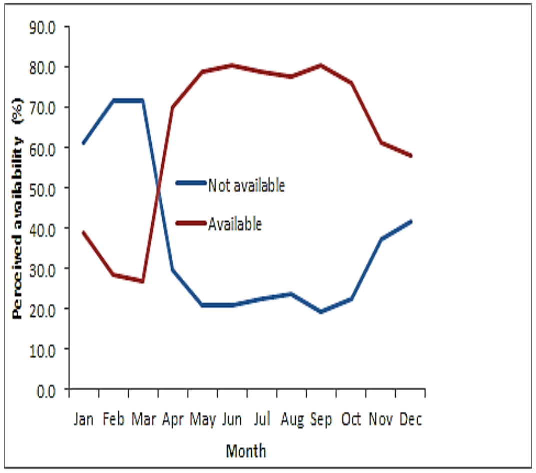
Perceived forage dynamics in the Agricultural zone by livestock species



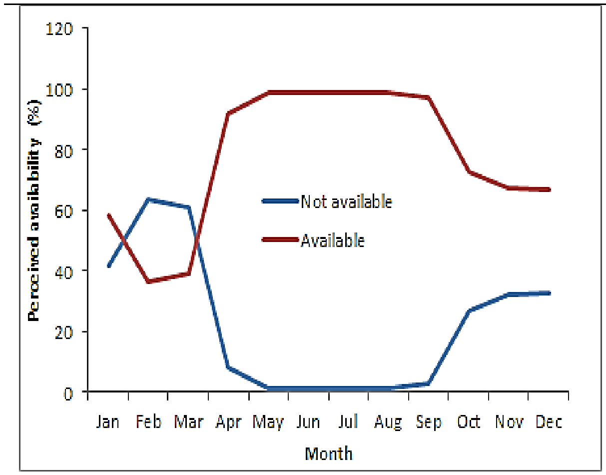
5.6a Cattle



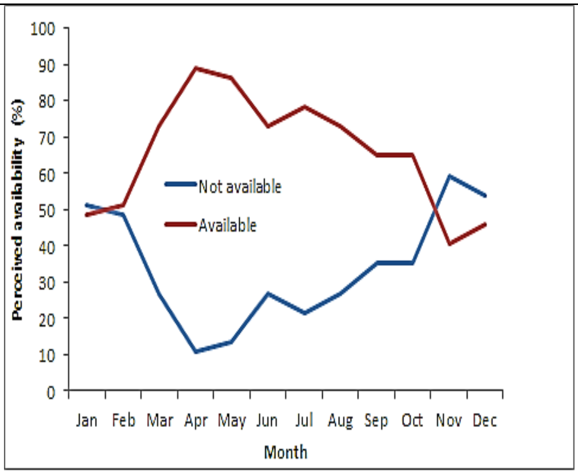
5.6b Cattle



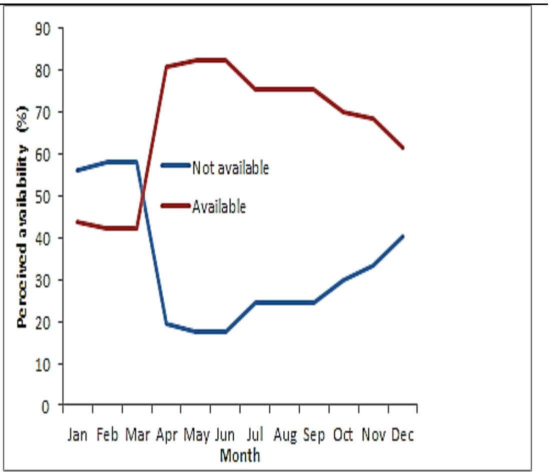
5.6c Cattle



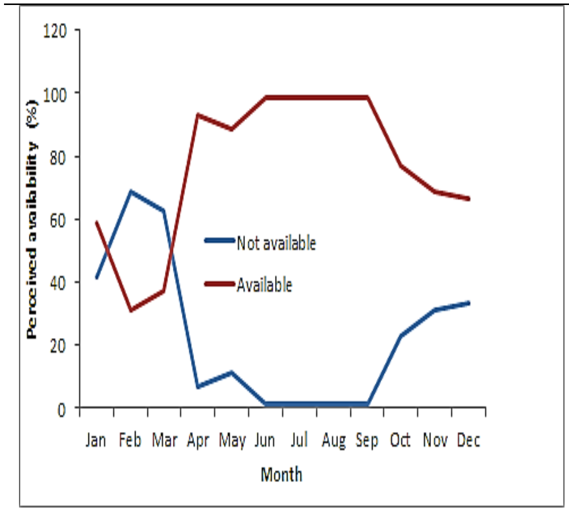
5.6d Goats



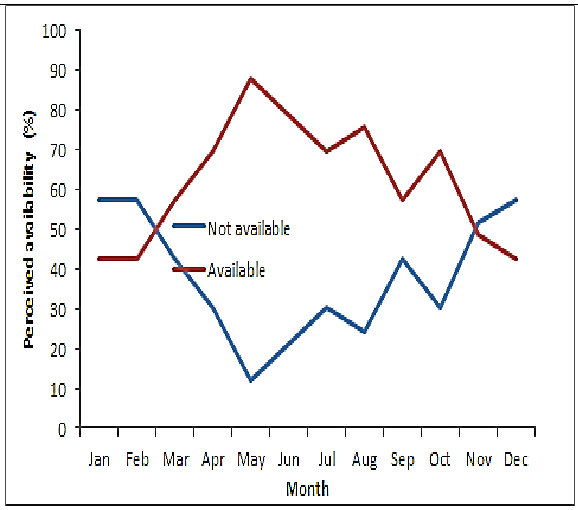
5.6e Goats



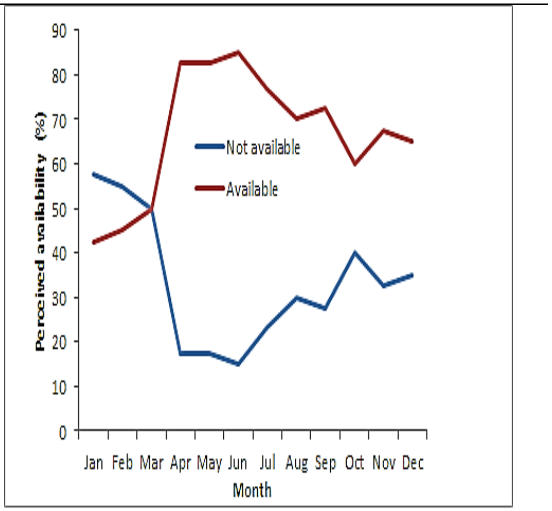
5.6f Goats



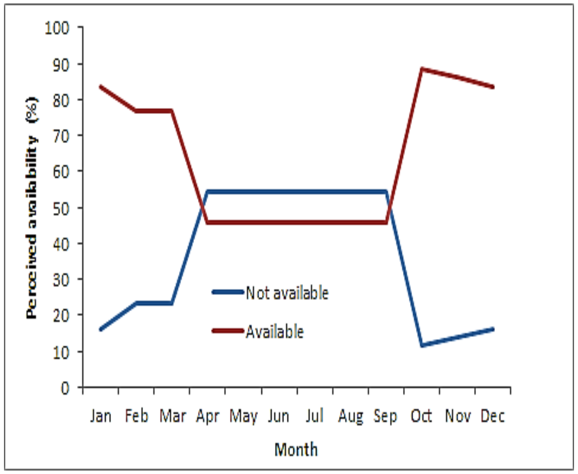
5.6g Sheep



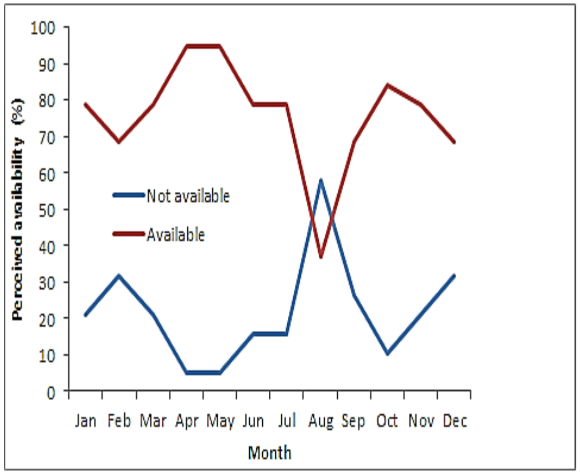
5.6h Sheep



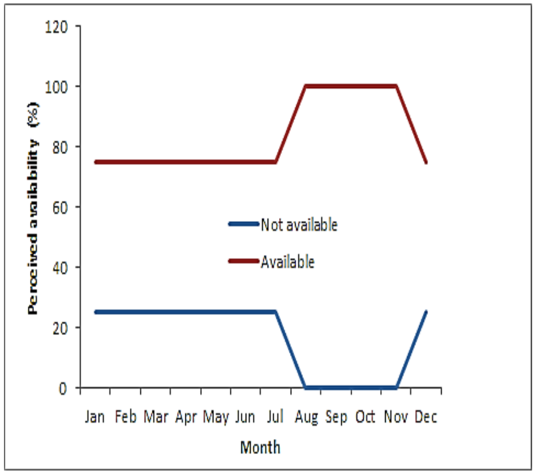
5.6i Sheep



5.6j Donkeys



5.6k Donkeys



5.6l Donkeys

5.4.2 Perceived quality of forage for different livestock species

For cattle, goats, sheep and donkeys; respondents observed that the available forages were generally very good (>35%). Only 8.3% of the respondents believed that the available forages were very good for camels. However, 67.6% observed that the forages were good for camels (Figure 5.7). Further, there was an observed rapid increase in the very good assessment of forage quality for cattle, goats and sheep from March reaching a peak between July and August. As perceived forage quality in the very good and good category begins to decline for cattle, sheep, goats and donkeys from around September, the fair to poor quality steadily increases in dominance (Figures 5.8, 5.9 and 5.10). The assessment also showed that donkeys generally maintained higher command of good to very good forage quality with less variability all year round. This was followed by camels whose good quality forage category dominated with a peak period occurring around August. However, a perceived decline in camel forage quality was observed to always occur between March and June for a period of four months.

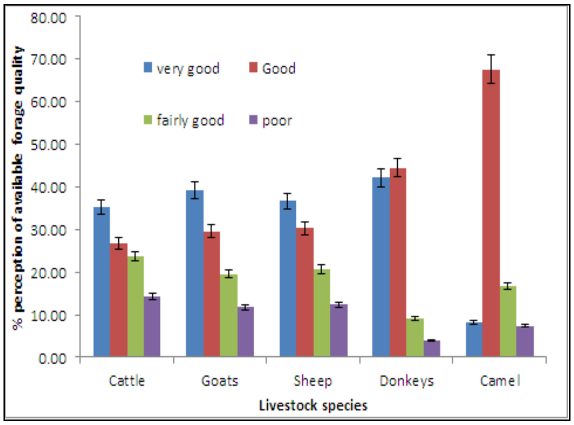


Figure 5. 7: Comparison of dynamics of perceived forage quality

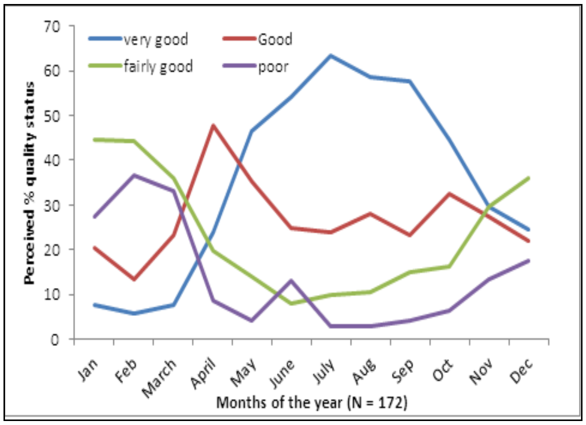


Figure 5. 8: Perceived dynamics of forage quality for cattle

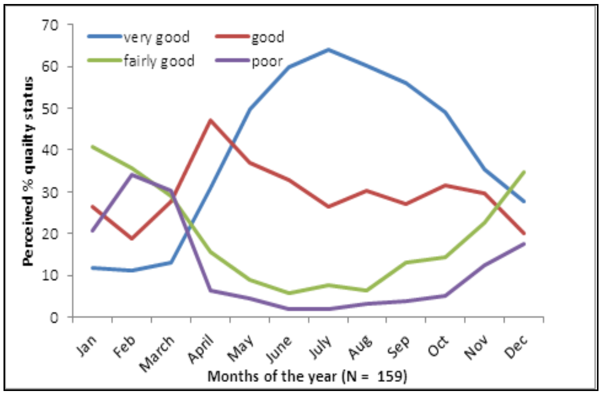


Figure 5. 9: Perceived dynamics of forage quality for goats

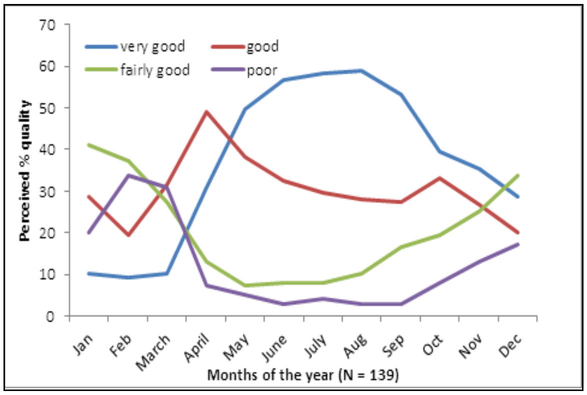


Figure 5. 10: Perceived dynamics of forage quality for sheep

5.4.3 Perceived determinants of forage dynamics

Table 5.2 presents a summary description of variables used to determine the factors perceived to influence forage dynamics in Karamoja sub-region. The results revealed that on average (daily) the respondents covered 14.8 km in search of forage when the wet and dry seasons distance is pooled together. However, when disaggregated the results showed 6.2 km and 23.5 km for wet and dry season respectively. The length of residence in a location reflected by the number of years a respondent had homestead in the area showed a mean of 37.5 years. On average the herd size was 7.9 in tropical livestock units (TLUs). On the other hand, the respondents reported that an average of 16.0 herd size was lost to cattle rustling in the last 10 years. On average, the distance covered to water sources was 13.5 km per day but when disagreggated between the wet and dry seasons, it was estimated at 5.5 km and 24.7 km respectively. About 53% of the respondents observed that temperatures were not good because they perceived them to be higher than in the past 10 years. The frequency of grazing in area was observed to be high by 52.5 percent of the respondents at the same time 64.6% of the respondents noted that burning of pastures was frequent. Sixty five percent (65.2%) of the respondents indicated that there was ease of access to grazing sites and 58.1% indicated that there were no conflicts in grazing and over grazing areas. Seventy percent (70.2%) had knowledge on location of pastures and 63.6% indicated that there were no rules governing grazing however, 76.8% indicted that restriction on movements exist.

The variables in Table 5.2 were subjected to a regression analysis to determine the extent of perceived influence on forage dynamics. The results of this process are presented in Table 5.3 Nine out of the twelve factors were significantly influencing forage dynamics at 5% while other two factors were significant at 10% as indicated by the corresponding t-value. The adjusted R^2 of 0.332 showed that about 33% of the variation in forage dynamics was explained by the explanatory variables. The F-statistic was significant at 5%; this indicated that explanatory variables jointly had a significant influence on forage dynamics. The results of this model indicated that forage dynamics was positively and significantly ($P \leq 0.05$) influenced by: length of residence by a livestock keeper, distance to water source, frequency of grazing, number of kraals, presence of governing rules, absence of conflicts and knowledge of pasture location. On the other hand, forage dynamics in terms of availability was negatively and significantly (P ≤

0.05) influenced by; restricted movement and ease of access to grazing areas. Herd size in TLUs and quality of soils was found to be positively and significantly ($P \leq 0.1$) influencing forage dynamics.

Table 5. 2: Description of variables used to model forage dynamics

Variable	Description
Distance covered in search of forage	14.8 km average distance per day
Length of residence at a location	37.5 average number of years resident in a location
Herd size in TLUs	7.9 average Tropical livestock unit
Livestock rustling in TLUs	16.0 average tropical livestock unit lost to rustling
Perceived rainfall condition	64.6% (good; code 1), 35.4% (not good; code 0)
Temperature	47% (good; code 1), 53.0% (not good; code 0)
Ease of access to grazing site	65.2% (easy; code 1), 34.8% (not easy; code 0)
Frequency of grazing at a site	52.5% (high; code 1) 47.5 (not high; code 0)
Frequency of burning the grasses	35.4% (not frequent; code 0), 64.6% (frequent; code 1)
Quality of soils in the area	26.8% (soils are poor; code 0), 73.2 (soils are good; code 1)
Number of persons (kraals) grazing at a site	39.1 average number of persons grazing at a location
Presence of rules governing grazing	63.6% (no rules; code 0), 36.4% (rules present; code 1)
Absence of conflicts in grazing	58.1% (no conflicts; code 0),41.9% (conflicts exist; code 1)
Existence of restrictions in movement	76.8% (restrictions exist; code 1), 23.2% (no restrictions; code 0)
Knowledge on pasture location	29.8 (no knowledge on pasture locations; code 0), 70.2% (knowledge on pasture locations; code1)

Table 5. 3: OLS estimates for the determinants of forage dynamics

Driver of forage availability	β	Std. Error	T	Sig.
Constant	-11.178	4.778	-2.339	0.02
Length of residence at a location	0.164	0.065	2.539	0.012*
Herd size in TLUs	0.158	0.085	1.849	0.066**
Livestock rustling in TLUs	-2.738	1.995	-1.372	0.172
Perceived rainfall condition	5.684	2.082	2.73	0.007*
Ease of access to grazing areas	-3.515	2.103	-1.671	0.097**
Frequency of grazing	7.564	1.947	3.886	0.00*
Quality of soils in the area	3.975	2.303	1.726	0.086**
Number of persons (kraals)	0.157	0.063	2.476	0.014*
Presence of rules governing grazing	6.669	2.109	3.163	0.002*
Absence of conflicts in grazing	5.889	2.308	2.551	0.012*
Existence of restrictions in movement	-11.64	2.519	-4.62	0.00*
Knowledge on pasture location	5.062	1.998	2.534	0.012*

*significant at 5%; **significant at 10%; $R^2 = 0.376$; Adj.$R^2 = 0.332$; F = 8.531; N = 198

The number of years a pastoralist stayed in an area positively influenced the distance to grazing areas and was therefore perceived to reduce forage availability. This indicates that the longer the residence period the longer the distance covered in search of forage, thus indicating less forage available in the grazing areas. Herd size was found to be negatively affecting forage availability. The larger the herd kept by a pastoralist the less the forage available in the area. On other hand, perceived rainfall conditions were found to positively influence forage availability as prior postulated that good rainfall conditions (e.g. improved quantity, delayed cessation and early onset) will facilitate growth and availability of forage in the grazing land areas.

Forage availability was found to be negatively driven by frequency of grazing indicating that the more frequent an area is grazed the less forage is available as indicated by the longer distance covered with such grazing patterns. Results also showed that the perceived quality of soils negatively influenced forage availability. The poorer soils, the longer distance that was covered by pastoralists in search of forage thus indicating poor forage dynamics. This pattern was similarly observed with the number of kraals present in the grazing areas. Regarding knowledge on pasture locations, a negative relationship was established. The more knowledge a pastoralist had on forage locations, the higher the likelihood of covering a larger distance thus exposure to more forage.

Presence of customary laws such as rules governing grazing were found to positively influence forage availability. These rules and regulations enhanced a circulating effect on grazing organisation that exposed pastoralists to forage differentially. The absence of such rules was observed to have created concentric circulation that reduced forage availability. The customary rules when applied enhanced dispersion allowing the herders to grazing differentially between the marshes and mountains in the dry season and lowlands in the wet season this exposed the pastoralists to more forage. On the other hand, the absence of conflicts revealed positive elasticity coefficient indicating that presence of a peaceful situation was perceived to lead better forage dynamics.

Ease of access to grazing areas within the region was negatively affecting forage availability indicating that the easier the access the more forage pastoralists were exposed to compared to when access is restricted. On the other hand, access to grazing outside the Karamoja sub-region was found to be a negative driver of forage availability as indicated by the restriction of movement imposed by the formal institutions.

5.4.3 Characteristics of soil properties and their influence on forage dynamics

Two soil textural characteristics were derived including sandy clay loam in the grasslands and thickets and shrublands and sandy loam in the woodlands. Table 5.4 presents a summary of soil characteristics of Karamoja sub-region. It shows that on average, soil pH was 7.7 in both 0-15 cm and 15-30 cm soil depth. Soil organic matter (SOM) averaged 1.4 and 1.2 at 0-15 cm and 15-30 cm respectively. On average, there were 2.7 ppm of available P; this varied with soil depth as a 47.0% overall decline was experienced at the subsoil (15-30 cm) depth. Grasslands had the highest decline in available P at the subsoil of 85.6 percent.

Table 5. 4: Summary of chemical and physical soil properties characteristics

Soil property	Soil sample depth sub-regional mean			Land cover type sub-regional mean (0-15 cm)			Land cover type sub-regional mean (15-30 cm)		
	0-15 cm	15-30 cm	% change	Grasslands	Thickets and shrublands	Woodlands	Grasslands	Thickets and shrublands	Woodlands
pH	7.7±0.8	7.7±0.92	0.6	7.9±0.5	8.1±0.6	6.9±0.8	8.1±0.6	8±0.9	7.1±0.8
N (%)	0.1±0.0	0.1±0.0	2.4	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0
SOM (%)	1.4±0.5	1.2±0.5	-11.7	1.7±0.5	1.2±0.4	1.3±0.5	1.4±0.5	1.1±0.3	1.3±0.5
P (ppm)	3.4±6.8	2.1±2.9	-47.0	5.7±12.9	0.4±0.3	4.6±4.0	0.8±0.7	1.5±2.0	3.3±3.5
K	0.7±0.2	0.6±0.2	-11.6	0.7±0.2	0.6±0.2	0.6±0.3	0.7±0.3	0.5±0.1	0.6±0.2
Ca	11.8±10.5	13.6±13.4	14.1	8.8±4.3	16.0±6.3	11.3±5.1	16.7±8.5	12.3±5.9	9.6±5.4
Mg	2.4±1.8	2.3±1.9	-6.9	2.0±1.4	3.1±1.5	1.9±2.1	2.8±2.1	2.3±1.6	1.4±1.7
Na	0.9±0.7	1.1±1.1	16.7	0.9±0.4	1.6±1.0	0.3±0.3	1.2±1.0	1.4±1.2	0.5±1.0
Sand (%)	56.3±11.9	58.8±10.9	4.3	53.7±10.8	52.2±5.6	63.4±15.1	57.5±7.6	55.3±8.1	66.7±14.2
Clay (%)	27.9±10.6	28.02±8.0	0.5	30.1±9.2	34.5±4.2	19.2±11.7	28.9±7.7	29.2±6.9	23.3±9.5
Silt (%)	17.0±6.8	16.8±6.1	-0.9	16.3±3.1	16.0±4.1	19.0±10.7	15.8±2.7	16.5±4.1	17.1±8.9

Woodlands did not experience a change however thickets and shrublands had an increase in available P (ppm) of 248.1% in the sub-soil. Decrease in Mg was also observed in general however variation existed between land covers because grasslands indicated a positive change (45.5%) while thickets and shrublands showed a 26.0% decrease in Mg in the subsoil. On the other hand, Ca had a 12.7 overall average with variations existing with change in soil depth resulting into a 14.1 % increase in Ca as depth changed from 0-15 cm to 15-30 cm. Grasslands indicated a positive change (89.5%) while thickets and shrublands showed a negative change (23.2%) in Ca as soil depth changed from 0-15 cm to 15-30 cm. On average, percent sand was 57.5% in all the areas sampled. However, when the two depths were compared it was observed that percent sand increased with increase in depth at a rate of 32.3 percent. Minimal increases of 2.2% were also observed in Na as soil depth increased. Percent Nitrogen had a 0.1 overall average with no changes experienced with change in soil depth. This variation in soil properties between depth and land cover units had impacts on forage dynamics by influencing the quantity of forage in different land covers in the sub-region.

Findings of the impact of soil properties on forage dynamics in the grasslands showed that soil pH, Potassium and Sodium, percent sand and percent clay were observed to be inversely significant ($P \leq 0.05$) 1.3%; 3.1%; 0.2% and 0.2% respectively. This means that a decline in these soil properties triggers an increase in forage biomass in the grasslands accordingly. This similar pattern was observed in SOM and Phosphorus at 10% significance level with the influence rates of 0.7% and 0.02% respectively (Table 5.5). On the other hand, Magnesium (Mg) had a positive significant influence on forage quantity at 0.5% rate indicating that a unit increase in Magnesium would lead to a 0.5% increase in biomass in the grasslands. Similarly, percent Nitrogen positively influenced forage-biomass quantity by 10.9 percent (Table 5.5). The N: P ratio (0.08) showed a high value compared to the Reified ratio (0.06). This indicates that Nitrogen is a limiting nutrient in the grasslands. However, this ratio is slightly within the Reified ratio margin.

Table 5. 5: Effect of soil properties on biomass in the grasslands

Soil property	Influence rate	Standard error	Wald Chi^2	Pr > Chi^2
Intercept	29.532	5.032	34.447	< 0.0001
pH	-1.261	0.206	37.415	< 0.0001
Nitrogen content (%)	10.915	3.907	7.804	0.005
SOM (%)	-0.724	0.333	4.718	0.030
Phosphorus (ppm)	-0.019	0.005	14.015	0.000
Potassium (Cmol/Kg)	-3.140	0.699	20.185	< 0.0001
Ca	-0.008	0.017	0.214	0.644
Mg	0.514	0.111	21.393	< 0.0001
Na	0.905	0.398	5.162	0.023
Sand (%)	-0.173	0.044	15.551	< 0.0001
Clay (%)	-0.225	0.050	20.152	< 0.0001
Silt (%)	0.000	0.043	0.000	0.991
N:P ratio	**0.08**			

$R^2 = 0.899$

In the thickets and shrublands (Table 5.6); Phosphorus, Calcium, Magnesium, and percent clay had an inverse significant influence on biomass by 3.8%; 0.2%; 1.4% and 0.2% respectively. This indicates that a decline in these soil properties would result to an increase in biomass quantity in the thickets and shrublands land cover type. This trend was also observed in pH and SOM that had a 0.6% and 0.8% negative influence rates on biomass quantity at 10% significance level respectively. Notably, Nitrogen was observed to have a relatively high positive significant ($P \leq 0.05$) influence on forage-biomass quantity at 42.9 percent. Indicating that a unit increase in Nitrogen in the thickets and shrublands would lead to a 42.9% increase in biomass quantity. A similar pattern was observed with respect to percent silt that positively influenced biomass quantity by 0.1 percent. A low N: P ratio (0.004) pertained in the thickets and shrublands. This was lower than the Reified ratio (0.06) indicating that Phosphorus was the limiting soil nutrient in the thickets and shrublands land covers.

Table 5. 6: Effect of soil properties on biomass in the thickets and shrublands

Soil property	Influence rate	Standard error	Wald Chi^2	Pr > Chi²
Intercept	13.836	2.808	24.282	< 0.0001
Soil pH	-0.618	0.169	13.345	0.000
Nitrogen content (%)	42.896	8.747	24.049	< 0.0001
SOM (%)	-0.806	0.249	10.482	0.001
P ppm	3.771	0.660	32.630	< 0.0001
Potassium (Cmol/Kg)	-10.460	1.553	45.341	< 0.0001
Ca	-0.160	0.029	30.417	< 0.0001
Mg	1.402	0.166	70.894	< 0.0001
Na	0.225	0.131	2.953	0.086
Sand (%)	-0.026	0.040	0.429	0.512
Clay (%)	-0.184	0.036	25.934	< 0.0001
Silt (%)	0.074	0.037	4.035	0.045
N:P ratio	**0.004**			

$R^2 = 0.848$

Two soil properties negatively influenced forage-biomass quantity in the woodlands ($P \leq 0.05$); these being Nitrogen and SOM at 15.3% and 0.9% influence rates respectively (Table 5.7). This essentially revealed that a reduction on Nitrogen and SOM would lead to an increase in forage-biomass quantity in the woodland grazing landscapes. On the other hand, Calcium, pH and percent sand showed a positive influence on biomass at 10% level. Apparently, woodlands had more soil properties that were non-significant at either 5% or 10% level; these included: Phosphorus, Potassium and Sodium and percent clay (Table 5.7). A lower N: P ratio (0.04) in the woodlands grazing was similarly found; this indicated a Phosphorus limitation.

Table 5. 7: Effect of soil nutrients on biomass in the woodlands

Variable	Influence rate	Standard error	Wald Chi^2	Pr > Chi^2
Intercept	-0.039	1.334	0.001	0.977
pH	0.254	0.102	6.149	0.013
Nitrogen content (%)	-15.313	2.386	41.192	< 0.0001
SOM (%)	0.926	0.166	31.234	< 0.0001
P ppm	-0.014	0.032	0.192	0.661
Potassium (Cmol/Kg)	1.146	1.181	0.941	0.332
Ca	0.048	0.014	11.322	0.001
Mg	0.000	0.000		
Na	-0.682	0.666	1.049	0.306
Sand (%)	0.031	0.011	7.503	0.006
Clay (%)	-0.016	0.019	0.685	0.408
Silt (%)	-0.036	0.016	5.470	0.019
N:P ratio	**0.04**			

$R^2 = 0.617$

5.4.4 Piospheric influence on forage dynamics

In both waterholes and protected kraals, grazing intensity had an effect on forage dynamics through its influence on species composition and abundance. The log-linear model results of the influence of waterhole piospheres on forage are contained in Tabe 5.8 and 5.9 below. The model results revealed that herbaceous species including: *Cynodon nemfuensis, Hyparrhenia rufa, Aristida adesciones, Oxytenanthera abyssinica, Hyparrhenia filipendula, Echinocloa haploclada, Chloris psychnothrix,* and *Chloris virgata* significantly increased with distance away from the waterhole piosphere (Table 5.8). This pattern revealed increasing distance dependence thus showing that these species have decreaser forage species characteristic; these species increase with a decrease in grazing pressure. On the other hand, *Cynodon dactylon, Hyparrhenia newtonii, Sporobolus pyrimidalis,* and *Sporobolus stafianus* significantly decreased with gradient distance; these consequently are indicative of increaser grass species. This indicated that as gradient distance increased, the abundance of these species consequently reduced; thus, they are persistent under high grazing pressure. Similarly, woody forage species depicted a positive and negative pattern with respect to waterhole piospheres influence on their abundance. *Acacia xanthopholea* steadily established itself as distance from the waterhole piosphere increased. On the other hand, species such as *Acacia senegal*, and *Cassia obtusifolia* decreased as distance increased away from the piospheres (Table 5.9).

Table 5. 8: Effect of waterhole piospheres on grass forage species

Herbaceous Species	Equation of the model	r	Chi pr
Hyparrhenia filipendula	$Ln(y) = 1.818+0.029*Distance$	0.983	0.001
Sporobolus pyrimidalis	$Ln(y) = 3.592-0.013*Distance$	0.905	0.001
Sporobolus stapfianus	$Ln(y) = 4.431-0.015*Distance$	0.878	0.001
Hyparrhenia rufa	$Ln(y) = 2.027+0.009*Distance$	0.911	0.044
Oxytenanthera abyssinica	$Ln(y) = 0.207+0.043*Distance$	0.980	0.001
Echinocloa haploclada	$Ln(y) = 2.855+0.018*Distance$	0.891	0.001
Chloris virgata	$L(y) = 2.551+0.032*Distance$	0.967	0.001
Cynodon dactylon	$Ln(y) = 6.021-0.026*Distance$	0.888	0.001
Chloris pychnothrix	$Ln(y) = 3.525+0.018*Distance$	0.948	0.001
Aristida adscensiones	$Ln(y) =2.962+0.008*Distance$	0.930	0.006
Cynodon nlemfuensis	$Ln(y) = 2.432+0.028*Distance$	0.963	0.001

*Significant at 5%; ** significant at 10%

Table 5. 9: Effect of waterhole piospheres on woody forage species

Browse species	**Equation of the model**	**r**	**Chi pr**
Triumfetta annua	$Ln(y) = 2.805+0.006*Distance$	0.927	0.05
Ocimum canum	$Ln(y) = 3.761-0.0228*Distance$	0.883	0.001
Acacia xanthopholea	$Ln(y)= 0.16+0.0131*Distance$	0.941	0.06*
Acacia Senegal	$Ln(y)= 2.018-0.019*Distance$	0.900	0.08*
Maerua pseudopetalosa	$Ln(y) = 0.187+0.026*Distance$	0.960	0.001

*Significant at 10%

In the protected kraals, the log-linear model results revealed that herbaceous grass species *Melinis repens* and *Panicum maximum* significantly increased with gradient distance ($P \leq 0.05$); this indicated that the abundance of these species increased away from the protected kraal; thus, these species increase as the grazing intensity reduces outward. On the other hand, *Cynodon dactylon, Bracharia jubata* and *Echinochloa haploclada* significantly decreased with distance away from the protected kraals ($P \leq 0.05$); indicating decreasing abundance as distance increased away from the protected kraal. Similarly, *Sporobolus stapfianus, Eragrostis superba, Digitaria velutina* and *Setaria* spp. were significant and negatively influenced by distance but *Pennisetum* *mezainum, Bracharia platynota, Melinis repens and Chloris pychnothrix* significantly ($P \leq 0.05$) increased away from the piosphere center (Table 5.10). Woody plant species in the protected kraal were generally non-significant with the exception of *Acacia drepanolobium* and *Solanum incanum* (Table 5.11).

Table 5. 10: Effect of Protected kraal piospheres on grass forage species

Herbaceous Species	Equation of the model	r	Chi pr
Panicum maximum	$Ln(y) = 3.972+0.006*Distance$	0.926	0.001
Sporobolus stapfianus	$Ln(y) = 1.778-0.012*Distance$	0.935	0.022
Cynodon dactylon	$Ln(y) = 5.115-0.003*Distance$	0.907	0.036
Bracharia jubata	$Ln(y) = 3.765-0.009*Distance$	0.896	0.009
Eragrostis superba	$Ln(y) = 6.699-0.0519*Distance$	0.900	0.001
Eragrostis ciliaris	$Ln(y) = 3.365-0.014*Distance$	0.890	0.006
Echinochloa haploclada	$Ln(y) = 5.764-0.042*Distance$	0.889	0.001
Digitaria vellutina	$Ln(y) = 4.045-0.033*Distance$	0.882	0.001
Pennisetum mezainum	$Ln(y) = 0.632+0.035*Distance$	0.971	0.001
Melinis repens	$Ln(y) = 1.339+0.023*Distance$	0.955	0.001
Chloris pychnothrix	$Ln(y) = 4.296+0.0063*Distance$	0.925	0.001
Hyperhannia newtonii	$Ln(y) = 3.612+0.013*Distance$	0.937	0.001
Hyperhannia filipendula	$Ln(y) =4.649-0.031*Distance$	0.838	0.001
Loudeta simplex	$Ln(y) =-2.461+0.093*Distance$	0.994	0.001
Bracharia Platynota	$Ln(y) =4.429+0.004*Distance$	0.921	0.011
Dactyloctenium aegyptica	$Ln(y) =2.964-0.032*Distance$	0.882	0.002

Table 5. 11: Effect of protected kraal piospheres on woody forage species

Herbaceous Species	Equation of the model	R^2	$p \leq 0.05$
Acacia drepanolobium	$Ln(y) = 0.460+0.028*Distance$	0.963	0.001
Solanum incanum	$Ln(y) = 2.573-0.013*Distance$	0.891	0.007

5.5 Discussion

5.5.1 Perceived forage dynamics and quality

Local people’s knowledge in assessing the status of vegetation is relevant in conducting integrated assessments (Angassa et al., 2012). This study has shown that pastoralists and agro-pastoralists have detailed traditional ecological knowledge of forage dynamics in Karamoja. Not only was it possible for the respondents to detail forage dynamics across the year based on long term to present time observations, they also possessed detailed understanding of forage dynamics with respect to particular livestock species. This depth of knowledge extended to perceived quality of the available forage. Such detailed understanding of vegetation dynamics is attributable to the community's detailed knowledge of ecosystem variability (Angassa et al., 2012). The unique differences that exist between livestock species with respect to forage availability dynamics and perceived quality were similarly revealed. In particular, on one hand; cattle, sheep and goats tended to have similar dynamics while camels and donkeys also showed a much closer pattern. The differences between species could probably be attributed to different livestock feeding behaviours. For example, the difference in perceived availability between goats, sheep and cattle could be attributed to the fact that goats and sheep are generalist feeders that have access to a wide variety of forages than cattle (Tabuti and Lye, 2009). This could also explain the differences in perceived availability during the months of October to March. In particular, it explains the smaller forage deficit gap that goats and sheep have during the months of January to March (often the long dry season) compared to the larger deficits for cattle during the same period. This could be attributed to the fact that goats and sheep have close feeding habits (browsing) following decline in forage resources during the dry season (Sano et al., 2007).

While goats and sheep were observed to have small forage availability deficits in the months of January and March compared to cattle, the deficit was slightly larger in sheep. This could perhaps be explained by grazing behaviours of respective livestock species. According to Rutagwenda et al. (1990) goats browse more than sheep, which in turn consume more browse forage than cattle; this exposes respective livestock species to differentiated forage availability dynamics. However, it is important to note that all livestock are generalist feeders but with expressed preferences when given a choice. Accordingly, predominant browsers will be inefficient grazers; predominant grazers will be particularly inefficient browsers (Schwartz, 2009). Therefore, the patterns reported by the respondents in this study reveal their in depth knowledge of vegetation dynamics and livestock feeding habits in Karamoja. According to Bolling and Schulte (1999) pastoral knowledge is built up around the interaction between herds and vegetation. Further, Oba and Kiatira (2006) have previously shown that the Masaai herders have detailed understanding of the grazing preferences of livestock species.

Differentiated forage availability across the three livelihood zones revealed the heterogeneity of Karamoja's rangelands. Particularly, the agricultural zone was observed with minimal forage variability for goats and sheep compared to the pastoral and agro-pastoral zones. Similarly, forage availability deficits (between October and March) were smaller in the agricultural zone compared to the agro-pastoral and pastoral zones. These differences can be explained by differences in total rainfall received in these zones and the predominance of vegetation types. Generally, the agricultural zone occurring in western Karamoja receives relatively higher total rainfall compared to the pastoral zone (eastern Karamoja) and agro-pastoral zone-running from north through central to southern Karamoja (Anderson and Robinson, 2009). Importantly, these patterns of forage dynamics in the region explain the existence of transhumant livestock grazing as practiced in the sub-region. Transhumant livestock herding is a key pastoralists coping and adaptation strategy for coping with resource uncertainty across space and time (Ickowicz et al., 2012). It allows pastoralists to opportunistically take advantage of patchy livestock resources as well as maintain multi-species herds (Mogamat, 2013) as well as continues strengthening the social networks (Bassett and Kone, 2006).

5.5.2 Perceived determinants of forage dynamics

This study established the significant effect of climate parameters-rainfall on perceived forage dynamics; this corroborates the observations made earlier by sevral other researchers (Oba, 2012; Sulieman and Elagib, 2012). In addition, the study identified that livestock related production factors such as herd size, number of kraals; environmental conditions such as soils and rainfall, institutional related conditions including rules and governance, restrictions on movement, conflicts in the grazing areas; and, socio-demographic factors such as length of residency at a location positively or negatively influenced forage dynamics. Herds and herd sizes have important controls they exert on vegetation dynamics; because livestock trampling tends to reduce plant cover, biomass, and, at its highest rates, vegetation regeneration (Mwendera et al., 1997). According to Mitra et al. (2013) herd density negatively affects forage regeneration thus leading to loss of pastures. In this study, livestock herd size has a negative influence on perceived forage availability dynamics. However, caution ought to be exercised that this result should be understood from a prospect of other results contained in this study such as existence of restrictions on movement and sedentarisation that constrain pastoral mobility.

In any case, the existence and application of such restrictions further exacerbates the challenge of forage availability in the region. Sendentarisation of pastoral communities for example has been found to initiate constraints and increase conflicts through changes in land use. These actions dictated by increased crop cultivation often restrict movement and force livestock herders into more marginal areas (Glover, 2005). Generally, a lengthy settlement is associated to trigger shortage of pasture (Dongmo et al., 2012). It is however important to note that in Karamoja, a distinction between the pastoral mobility and livestock herd mobility is clear. This is because the pastoral population is nearly sedentary but livestock herd mobility is exercised by a group of youthful herders. However, this mobility now occurs on limited land area as the Karamojong no longer access dry season grazing areas in the neighbouring Teso, Lango and Acholi sub-regions to the west and northwest respectively. Mobility of livestock herds without the entire household mobility has similarly been observed among the Fulani of Ferlo in the Sahelian Senegal (Adriansen, 2008).

Ease of access to grazing areas, knowledge of the location of pastures, and presence of rules governing grazing were hypothesized to have a positive influence on forage dynamics-availability in the area. Ease of access allows for mobility thus allows the herders to exploit pastures from different landscapes given the heterogeneity that often exists in rangelands (Lynn, 2010). Imposition of restrictions that restrict mobility and access to resources will create conditions that limit pasture availability (Lengoiboni et al., 2011). Pastoral rules and regulations are designed to allow for conservation, use and sustainability of available resources such as pastures and water source (Nelson, 2012). Therefore, rules and regulations that curtail the normal operations and affect the pastoral calendar create artificial junctures that constrain forage dynamics and will eventually affect its availability.

Additionally, knowledge of pasture locations was found to enhance forage availability. Pastoral knowledge controls management decisions; for example pastoralists often divide their grazing locations alongside wet versus dry season grazing areas; this therefore helps to manage grazing intensity in the sub-region. In northern Tanzania for example, a practice known as "*ngitili*" where forage locations are retained during rainy season and opened for grazing at peak dry seasons allows forage availability for pastoral and agro-pastoral communities (Selemani et al., 2012). Similarly, the Maasai have in-depth characterization of grazing landscapes that reveals vitality of herder knowledge in regulating grazing depending on the status of the landscape and available forage (Oba and Kaitira, 2006). On other hand, presence of conflicts initiates '*artificial forage shortage'* because it creates unnecessary restrictions on the mobility of herds and herders. Thus, as some areas become overly grazed during such times, other locations tend to have luxuriant forage. Pastoralists often move to areas where pasture is available and negotiate for use rights (Temesgen, 2010). In the presence of conflicts pastoralists become ineffective in making such movements as well as building and managing herding territories that play considerable influence in forage availability (Dongmo et al., 2012).

It was not unusual for the respondents to associate perceived existence of good soils with forage availability. This is because pastoralists contain robust knowledge of soils and soil quality; their soil classification is often based on the productivity of such soils on a given landscape. In a study conducted among the Maasai, Oba and Kaitira (2006) documented classification of degradation based on soils as one of the indicators. Their study revealed that there was a variation on forage availability and grazing patterns depending on soils in a given landscape. For example, landscapes categorized as *orpora* were dominated by annual grasses and usually grazed during the wet season while the *orkojita* landscapes were dominated by perennial grasses, more resilient and grazed during the dry season. Similarly, among the Orma, Afar and the Karamojong (Turkana and Karamojong of Uganda; forage availability and quality has been documented to be in consonant with the soils and soil moisture of a given landscape (Oba, 2012). The Orma pastoralists for example prefer soils of white-gray (*oomaar*) shade that are not only believed to provide adequate but also quality forage. On the other hand, the Orma observe that the black (*kooticha*) soils may have considerable forage however this could be of low quality (Oba, 2012). Like in an earlier study by Oba (2012) this study similarly through informal interviews and focus group discussions found associative existence of landscape grazing potentials to perceived soils productivity and forage availability patterns. For example, the sandy landscapes (*eketela*) were perceived to experience heavy grazing than the black soils (*arro*) landscapes. This is because the *arro* is grazed during the dry seasons thus associated with better forage availability compared to the *eketela*.

5.5.3 Influence of soil properties on forage dynamics in Karamoja sub-region

This study observed a positive relationship between nitrogen and the quantity of forage in thickets/shrublands and grasslands. This implies that an icrease in nitrogen within the soils of Karamoja leads to higher forage quantity. Song et al. (2012) also found a positive relationship between increased nitrogen and aboveground biomass. This also compares quite well with the findings of Augustine (2003) and Mbatha and Ward (2010) who previously showed that nitrogen had a significant influence on grass biomass in semi-arid savanna of Laikipia, Kenya and Northern Cape, South Africa respectively. Further, in the grasslands where N fertilization leads to increased net primary production (shoot biomass) and thicker stands; it demonstrates that N is the limiting factor in plant growth (Wang et al., 2012). On the other hand, nitrogen had an inverse effect on biomass in the woodlands this corroborates with the findings of Sankaran et al. (2008) who found a strong negative dependence of woody cover on soil nitrogen availability. Nitrogen often limits plant growth and productivity in grasslands, a fact that this study has underscored.

As has been noted, this study found phosphorus to be a limiting nutrient in the woodlands. This could be attributed to the relatively higher phosphorous content arising from frequent burning that the pastoralists use to facilitate forage regrowth and tick control. Riginos et al. (2009) previously established in the semi-arid Laikipia in Kenya that where trees exist; a negative effect prevails on grass and phosphorus. Meanwhile, Grunzweig and Korner (2003) noted that P limitation limits legume growth; this was evident in woodlands during the assessment period. What is however clear in this study is that differentiated nitrogen and phosphorus nutrient limitations as well as their margin of influence on forage-biomass availability are observable.

Potassium (K) is an indispensable macronutrient required for normal plant growt. In a deficient mode, potassium limits accumulation of crop/pasture biomass and leads to the stunting of crop/pasture as well as low yields (Lua-Kapu, 2012). In this study, potassium exhibited inverse relationship with forage-biomass quantity in all the landcovers. This contrasts with the findings Sawan et al. (2008) who have generally shown incremental effect of potassium on plant biomass accumulation. However, corroborates with the result observed in the woodland grazing landscape. The inverse relationship observed in this study is attributable to the fact that the average potassium levels (e.g. 0-15 cm (0.7±0.2 cmol/kg) and 15-30 cm (0.6±0.2 cmol/Kg) soil depth) were higher than the critical soil potassium (0.19 cmol/Kg) needed to achieve 90% maximum yield in crops such as sorghum and maize (Bell et al., 2008). This relatively high K concentrations observed in this study are attributable to continuous use of fire as a management tool to allow for vegetation re-growth as well as continuous grazing of livestock in the range. Biomass burning and continuous livestock grazing have previously been found to lead to relatively high potassium content concentrations in an experiement in savanna grassland in Kenya (Kioko et al., 2012).

An inverse significant impact of SOM was found on forage quantity in thicket and shrubland and grasslands while a positive significant effect was observed in the woodlands. This contrasts with the results of Bendfeldt (1999) who reported a non-significant influence of SOM on herbaceous biomass. Similarly, it contrasts with the findings of Powers et al. (2005) who reported total above ground biomass not to be affected by organic matter removal. The inverse relationship could perhaps explain why the herders from time to time set on fire in the range to allow for biomass regeneration.

5.5.4 Effect of piospheres on forage dynamics

Piosphere patterns are always detected in herbaceous species composition and species response to grazing is often varied (Wesuls et al., 2013). This study has shown differentiated species response to piospheric effect i.e. induced grazing intensity. For example, some herbaceous species such as: *Aristida adescensiones, Chloris pychnothrix, Chloris virgate, Cynodon nlemfuensis, Eichincloa haploclada* and *Hyparrhenia filipendula* increased away from the piosphere. This is indicative that these species are less tolerant to high grazing and trampling intensity and their potential to provide forage under high grazing pressure will be limited. This finding corroborates with the findings of Zemmrich et al. (2007) who established that as grazing pressure decreased, plant density per plot increased in western Mongolia. It further corroborates with the findings of Landsberg et al. (2002) who observed that watering points had a predominantly negative effect on species dynamics on a regional scale. Decreasing trends in species with increasing proximity to watering points have also been observed by several studies (Brooks et al., 2006). This study's results however contrast with the observation made in South Australia in which *Chloris* growth increased with grazing (Reseigh et al., 2008).

On the other hand, herbaceous species such as: *Sporobolus stapfianus, Sporobolus pyrimidalis,Cenchrus ciliaris, Bracharia jubaata, Dactyloctenium aegyptica, Eragrostis cilliaris, Digititaria vellutina* and *Cynodon dactylon* decreased with distance away from the piosphere; thus indicating species that are tolerant to high grazing and trampling intensity. This finding contrasts with the findings of Fusco et al. (1995) in which *Sporobolus spp*. was found to increase as distance from a watering point increased. Similarly, Thrash and Derry (1999) noted that *Cynodon dactylon* has been observed to increase away from the piosphere.

However, this study's results corroborate with earlier findings of Mansour et al. (2012) who observed that species such as *Eragrostis spp.* and *Sporobolus spp.* are often considered as increaser II species; these species increase in abundance when the rangeland is over utilised (Du Toit, 2009). Our findings corroborate with these earlier findings because herbaceous forage species *Eragrostis superba, Eragrostis ciliaris, Sporobolus stapfianus* and *Sporobolus pyrimidalis* were in close proximity to the piosphere. These species have previously been used as indicator species of rangeland degradation. For example, Mansour et al. (2012) discussed that rangeland condition can be classified using these increaser species thus; moderate condition can be identified using increaser I (e.g. *Hyparrhenia spp.);* poor-increaser II (e.g. *Eragrostis spp*. and *Hyparrhenia spp.);* and highly degraded-increaser III (e.g. *Aristida spp*.). This study has shown the existence of all these species in the piospheres of Karamoja indicating existence of multiple states at the piospheres. The existence of increaser I (increase in abundance with under-utilisation e.g. *Hyparrhenia filipendula, Hyparrhenia rufa*) and increaser III (increase in abundance in areas that are selectively grazed, e.g. *Aristida adsceniones*) species in the study area can be explained by the observed variation in piospheres status. It is important to note that increaser III species (e.g. *Aristida adecensiones*) were only observed around the waterhole piospheres; indicating higher degradation level of waterholes compared to protected kraals. This finding corroborates to an earlier finding of Mugerwa et al. (2014) that documented a similar experience in Karamoja sub-region.

In the Karamoja piospheres, differentiated dynamics of woody forage species pertains. Both increasing and decreasing patterns with proximity to and away from the piosphere were observed. *Acacia drepanalobium, Acacia xanthopholea, Maerua pseudopetalosa,* and *Aspilia mosambecensis* increased away from the piospheres. This reveals that these woody species have rapid regeneration ability after the establishment of the piosphere. However, they are also susceptible to decline in quantity as a result of increased grazing pressure because their mean presence declines with proximity to the piospheres. Thus, their ability to provide browse under high grazing pressure may be limited. Pastoralists in Amboseli Kenya, when building kraals (bomas) have been found to clear trees with 20 cm basal diameter and less within 150 m of the boma (Muchiru et al., 2008). Vegetation clearance at the protected kraal is not only mandatory for security reasons but also for the establishment of kraals because woody plants, particularly thorny acacia provide building materials. On the other hand, when establishing waterhole piospheres, woody plant clearance is not as wide spread as in protected kraals because clearance concentration is localized at the point where the waterhole is to be established (Egeru, per.obs). This study's results corroborate with those of Chamille-Jammes et al. (2009) who observed lower woody cover average at close proximity to the piosphere with an outward increase. Further, this study's results corroborate with the findings of Mphinyane (2001) who found that *Acacia gerrardii* density increased with distance away from the piosphere (cattle post). Similarly, this study established some woody species (e.g. *Acacia drepanalobium, Acacia xanthopholea, Maerua pseudopetalosa and Triumfetta anua*) whose density increased with distance away from the piospheres.

Acacia nilotica, Acacia senegal, Ocimum canum, Lannea humilis, Solanum incanum, and *Leucas martinicensis* decreased with increase in distance away from the piosphere. *Acacia nilotica* has been identified as type III increaser specie (Strohbach, 2000). In the Karamoja piospheres, these species that decreased away from the piosphere revealed a limited abundance in the rangeland. This corroborates with species-wise findings of Strohbach (2000) in northern Oshikoto region of Namibia and Muchiru et al (2008) in Amboseli, Kenya. Further, *Acacia nilotica* has been observed as a significant threat to native vegetation, as it leads to decline in cover and abundance of native species (Howes and McAlpine, 2008). In Karamoja, it was observed that *Acacia nilotica* had formed a bush; and a deficiency in herbaceous understory as well as other woody plants. A few tufts of both woody and herbaceous plants existed at the base of *Acacia nilotica* trees; these were not accessible to livestock for grazing. Consequently, livestock; mainly goats and sheep foraged on the outside branches up to the maximum stretch of their height; this constitutes a threat to the potential existence of both herbaceous and other woody forage species in the rangeland ecosystem of Karamoja.

However, where mature *Acacia nilotica* trees existed, goats and sheep foraged on their fallen pods. The negative slope observed with respect to *Acacia senegal* can be explained by traditional conservation practice and it’s lack-off in which it is preserved for its resin used locally (no large commercial use in Karamoja has been documented as in say Sudan e.g. Eisa et al., 2008). It also tends to form a bush around the piosphere that shields waterholes from strong winds and goats browsed on it. According to Eisa et al. (2008) *Acacia senegal* availability is affected by fires that kill off seedlings and damage trees; this could perhaps also explain its reduced presence away from the water sources that rarely get burned due to openness. Further, cutting off large branches (in this case for establishing kraals/bomas), defoliation by goats and camels, attack from fungi and termites can be probable explanations for the negative slope observed at the piospheres. These, need further study. *Solanum incanum* had a negative slope indicating a high mean density of plants in proximity to the piospheres. High abundance of *Solanum incanum* in disturbed patches has similarly been observed in Ithala game reserve, KwaZulu-Natal (Hebbelmann, 2013).

5.6 Conclusions

This study has shown that in semi-arid areas such as Karamoja, there is variability in the forage for different livestock species. The dynamics is differentiated across various locations (in Karamoja these are known as livelihood zones) with differentiated deficit gaps; leading to existence of heterogeneity, this supports the pastoral livestock herding practice. Owing to the detailed information on perceived forage dynamics and quality, the people of Karamoja have detailed traditional ecological knowledge of vegetation dynamics with regard to species types, growth forms, livestock species preferences, locations, and temporal patterns. This study has also shown that the respondents are not short of attribution; thus, the perceived determinants of forage dynamics in Karamoja relate to: livestock related production factors (herd size, number of kraals); environmental conditions (soils, rainfall), institutional related factors (rules and regulations, movement restrictions) and socio-demographic factors such as length of residence at a location exert influence on forage dynamics.

This study has also validated community perception on soil quality as a determinant of forage dynamics. Variation in soil nutrients was in influencing forage quantity in the woodlands, grasslands and thickets/shrublands. With the exception of potassium, most of the soil nutrients in the sub-region were generally low in the land covers. Nitrogen was observed as a limiting nutrient in the grasslands while phosphorus was the most limiting nutrient in the thicket and shrubland and woodlands. Thus, any improvement on pasture production as well as crop production (particularly sorghum that is commonly grown in the region) ought to address these nutrient limitations. In addition, this study has confirmed the influence of piospheres on forage dynamics through creating localized grazing pressure. This localized grazing pressure leads to differentiated presence of forage species i.e. both increaser and decreaser species. Thus, it is imperative that action is taken to minimize the potential surge of increaser forage species because these will negatively impact on forage dynamics and fore quality in the sub-region. Further, there is need for continuous monitoring of the identified determinants of forage dynamics because some of which have the capacity of creating '*artificial forage shortage'* situations.

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CHAPTER SIX

CLIMATE CHANGE INDUCED VARIABILITY IN FORAGE PRODUCTION IN A SEMI-ARID ECOSYSTEM IN NORTH EASTERN UGANDA

ABSTRACT

Climate change constitutes a major threat to semi-arid vegetation productivity. Few studies have simulated the effect of climate change on forage production in East Africa. This study determined the trend of climate variability and intensity, projected change in climate and determined potential forage production under different time slices and emission pathways (RCP 4.5 and RCP 8.5). The climate of the area is variable (coefficient of variation-CV > 35.0%) with spatio-temporal oddities in rainfall and temperature. Between 1979 and 2009; minimum, maximum and mean temperature increased by 1.6°C, 0.9°C, and 1.3°C respectively. There were more dry months (< 1.0 threshold) from 1979 to 1994 than between 1995 to 2009, with wetness intensity increasingly common after 2000. Rainfall is projected to increase in total amount under all time slices and emissions pathways but with prounouced inter and intra-variability. Minimum temperature will significantly increase during mid-century by 1.8°C (RCP 4.5) and 2.1°C (RCP 8.5) and by 2.2°C (RCP 4.5) and 4.0°C (RCP8.5) during end-century. Forage production under rain controlled conditions will progressively increase but with a non-significant trend under RCP 4.5 and RCP 8.5. Results also showed that temperature induced forage production under RCP 4.5 will moderately increase however continued increase in temperature to RCP 8.5 level will lead to a negative trend in forage production. Therefore, higher temperature will become a limiting factor to forage production in the sub-region in the future.

Keywords: *Climate variability, forage, variability index, Karamoja*

6.1 Introduction

During the last two decades, concern has been rife over the debilitating effects of climate variability, particularly in sub-Saharan Africa where production systems are heavily rain fed. Although current global efforts are more focused on climate change, climate variability remains a formidable challenge in semi-arid regions. At the same time, scientific research into climate variability and change has increased tremendously (Boisvenue and Running, 2006). Climate variability has had and will have wide ranging impacts on ecosystems, economies and societies' wellbeing. These impacts include: disease, food insecurity, a surge in displaced populations associated with extreme events such as floods and drought, insecurity; and natural resource conflicts (Slegers, 2008, Cutter et al., 2009; Ndaruzaniye et al.,2010). Developing countries whose resilience has already been eroded by entrenched poverty, degraded and/or threatened environments, and a host of other problems will be most affected (Mwiturubani and Ansie van Wyk, 2010).

The African climate system is characterised by variability and it is particularly potent in the drylands (Claessens et al., 2012). Over the years significant patterns in variability of rainfall and temperatures have been observed; for example, in the Sahel, where rainfall has declined by 20-40 percent while temperature has risen by 1.3°C since the 1960s (Dai et al., 2004; Claessens et al., 2012). A similar pattern in much of West Africa has been observed (Boko et al., 2007). In Eastern Sunda, a significant increase in rainfall variability and seasonality and intensification of aridity conditions during the start and end of the wet seasons has been reported (Sulieman and Elagib, 2012). These shifts have had wide ranging impacts including; decline in vegetation cover, changes in land use, and degradation of grazing areas (Sulieman and Elagib, 2012). Meanwhile, an intensifying dipole rainfall pattern on a decadal time-scale has been recorded in Eastern Africa (Boko et al., 2007). This pattern is attributed to a dipole influencing increased rainfall in the northern sector and declining amounts in the southern sector (Schreck and Semazzi, 2004).

Projections over East Africa are presented with mixed uncertainty regarding the scope, timing and magnitude of climate variability and change (Thornton et al., 2009). There is some agreement that there will be an increase in rainfall by as much as 10-20 percent (Collier et al., 2008). Similarly, a progression in temperature rise is anticipated with an increase in the margin of 0.7°C and 1.5°C in the short term (2020 to 2029) and between 1.5°C and 4.3°C by the 2080s. It is also anticipated that the severity and frequency of extreme events will change (USAID, 2013). Most of these projections are however made at continental and country level using the global climate models (GCMs) this has led to considerable gaps in information at seasonal time scales as well as at local level (Rabbinge, 2009). Yet, projections at regional and local scales are required for political negotiations, policy reforms, adaptation, and land management planning (van de Steeg et al., 2009). Regional climate models (RCMs) are now addressing the inadequacy of global climate models (GCMs) to provide climate information needed for assessing impacts of climate change and variability at local to regional level (Leung et al., 2003). A regional climate model (RCM) is a downscaling tool that adds fine scale (high resolution) information to the large-scale projections of a global general circulation model (van de Steeg et al., 2009). The ability of the RCM to provide local to regional scale details arises from its ability to resolve features down to 50 km or less. In so doing, the RCMs use GCMs to provide grid-scale averages of spatio-temporal hydro-climatic state variables, as well as soil hydrology and thermodynamics and some vegetation dynamic variables (UNFCCC, 2008).

Climate variability and change influences ecosystem functioning in dryland environments by influencing vegetation patterns and water patterns on both spatial and temporal scales (Borgogno et al., 2007; Kgosikoma et al., 2012). This in turn influences the forms and patterns of use adopted by the pastoral and agro-pastoral communities that inhabit these locations such as those that occur in Uganda. This has resulted in a complex production system – pastoralism, whose functioning relies on stochastic events (Birch and Grahn, 2007). The increased variability is, however, putting the sustainability of this production system under scrutiny in East Africa because unprecedented varation in climate has led to degradation of forage resources in recent times, leading to large scale losses of livestock reducing both marketing and management options (Kaitho et al., 2007). Tackling the challenges that climate variability poses on pastoral and agro-pastoral communities, therefore, requires a better understanding of the frequency and intensity of variation in climate and its impacts on forage dynamics in the present and the future; this will facilitate planned and strategic adaptation.

Forage production analysis has received limited attention in East Africa despite reported vulnerability and changes in climate as well as the importance of the livestock sector in the region. In a state of climate change, limited RCM studies have been undertaken in East Africa and those that have been conducted have focused on evaluating the performance of a single RCM in simulating mean climate (Endris et al., 2013). Further, the few applications of RCM output in agriculture have largely focused on the high value crops such as coffee (Jassogne et al., 2013), tea (Seitz and Nyangena, 2009) and food crops such as maize (Cairns et al., 2013).

Planned and strategic adaptation requires reliable and timely information however this information can not easily be obtained from field based forage production assessments this because such undertakings over wide areas is tedious, time consuming and costly. In addition, there is limited availability of field based forage assessment time series data that can be utilised for long term forage projections and evaluations (Monterroso Rivas et al., 2011). Consequently, net primary productivity (NPP); which is the amount of new plant growth which occurs within a given area over a specified time period (g m^{-2} y^{-1}) comes in handy because it can be estimated indirectly through ecosystem models (Squires et al., 2010). Net primary productivity is a key integrator of ecosystem function thus; it is the mechanistic basis of harvest yield (Global Terrestrial Observing System, 1997). In that case, changes in carbon cycling expressed in terms of net primary production (NPP) can be a key indicator of forage production (and dictates forage availability and animal production in rangelands (Nemani et al., 2007). It is thus imperative that site-specific evidence of climate variability and change and its influence on future dynamics of forage production are analysed to provide a basis for semi-arid resource use planning and management interventions that are responsive to the inherent variability in the sub-region

6.2 Materials and methods

For the description of study area, climate, vegetation, topopgraphy, soils and geology refer to Chaper 3 (3.1, 3.2. 3.3 and 3.4)

6.2.1 Determination of climate variability

Climate variability (C_v) was determined using the coefficient of variation (CV) computed as:

$$C_v = \left[\frac{Std_{ij}}{mean_{ij}}\right]*100 \qquad (1)$$

Where C_v represents the coefficient of variation; Std_{ij} is the standard deviation of a station for the period of analysis (1979-2009) and $mean_{ij}$ is the mean rainfall for period of analysis at a given station. A coefficient of variation is the ratio of the standard deviation to the mean of the rainfall at any given station. The coefficient of variation has previously been applied by Ellis and Swift (1988) in assessing rangeland dynamics. Since the coefficient of variation is inadequate for revealing the intensity of variation, there is a risk that a misleading agglomeration of landscapes may occur (Unal et al., 2003). Therefore, besides determining the CVs we have computed the intensity of variability.

6.2.2 Determination of climate variability intensity

Owing to the limitation of the coefficient of variation to disaggregate the intensity of variability; this study computed climate variability intensity for rainfall (rainfall variability index, RVI; equation 1) and temperature (temperature variability index, TVI; equation 2). This study adopted a computation protocol developed by Balint et al. (2011) with a slight modification. The computation protocol is represented by the following equations:

$$RVI_{i,m} = \frac{\frac{1}{IP}\sum_{j=0}^{IP-1} P^{*}{}_{i,(m-j)}}{\frac{1}{(n*IP)}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP-1} P^{*}{}_{(m-j),k}\right]} * \sqrt{\left[\frac{RL_{m,i}^{(P*)}}{\frac{1}{n}\sum_{k=1}^{n} RL_{m,k}^{(P*)})}\right]} \qquad (1)$$

$$TVI_{i,m} = \frac{\frac{1}{IP}\sum_{j=0}^{IP-1} T^{*}{}_{i,(m-j)}}{\frac{1}{(n*IP)}\sum_{k=1}^{n}\left[\sum_{j=0}^{IP-1} T^{*}{}_{(m-j),k}\right]} * \sqrt{\left[\frac{RL_{m,i}^{(\mathrm{T}*)}}{\frac{1}{n}\sum_{k=1}^{n} RL_{m,k}^{(\mathrm{T}*)})}\right]} \tag{2}$$

Where P*is the monthly precipitation; T* is the modified monthly temperature; IP is the interest period (months); RL (P) represents the run length (1979-2009); that is the maximum number of months below long term average rainfall in the interest period; RL (T) is the maximum number of months above the long term average temperature; n is the number of years with relevant data; j are the summation running parameter covering the IP, and k is the summation parameter covering the years where relevant data are available, in this case 1979 to 2009. In computing for RVI and TVI, the combined variability index (CVI) is simultaneously computed. The combined variability index (equation 3) is computed as the weighted average of rainfall and temperature variability indices. This was computed following the modified equation:

$$CVI_{i,m} = w_{RVI} * RVI_{i,m} + w_{TVI} * TVI_{i,m} \tag{3}$$

Where w is the weight of the individual variability index. Balint et al. (2011) recommended a weight of 50% for rainfall and 25% weight for both temperature and vegetation. Where either temperature or vegetation data are missing, the precipitation index is assigned a weight of 67 percent while the other is assigned 33%. This study subsequently implemented the latter specification in this study because vegetation data were not used as they did not serve the interest of this study. Climate variability intensity for Karamoja sub-region and respective stations was computed to discern underlying spatial oddities. The Balint et al. (2011) approach, as presented above, was initially developed for drought monitoring. Thus, it only considers the lower end point indices that show a graduating level of dryness in a location. Since Karamoja is known to experience two extreme events including, dryness and wetness, indices that take care of wetness margins (see Table 6.1 and Table 6.2) were included. The indices range from 0 to 1 for dryness margin and 1.01-2.6 (may exceed 2.6 depending on the extreme occurrence of the wet event) for the wetness margin intensity. In inferring the intensity levels, it was held that the smaller the index the more intense the dryness variability, thus indicating a potential drought in a location. On the other hand, the smaller the wetness index, the less intense the variability; indicating modest rains. As the index value increases, the variability intensity margin rises. These indices were used to disaggregate variability intensity margins for the Karamoja sub-region. The analysis was performed in the combined drought index calculator (CDI).

Table 6. 1: Climate variability intensity indices

Index	Description	
0-0.49	Extreme dryness	↑
0.5-0.69	Severe dryness	
0.7-0.89	Moderate dryness	
0.9-1.0	Mild dryness	Graduating level of intensity
1.01-1.59	Normal wetness	
1.6-2.09	Moderate wetness	
2.1-2.59	Severe wetness	
2.6+	Extreme wetness	↓

Table 6. 2: Climate variability intensity indices (with a color ramp)

Index	Description	
0-0.49	Extreme dry	↑
0.5-0.69	Severe dry	
0.7-0.89	Moderate dry	
0.9-1.0	Mild dry	Graduating level of intensity
1.01-1.59	Normal rains	
1.6-2.09	Moderate rains	
2.1-2.59	Severe rains	
2.6+	Extreme rains	↓

6.2.3 Future climate prediction

This study utilised the Agricultural Intercomparison and Improvement Project (AgMIP) delta method analysis protocol to project the future climate state in Karamoja (Rosenzweig et al., 2013). The delta method is a statistical downscaling procedure that is based on the sum of interpolated anomalies to high resolution monthly climate surfaces. The method produces a smoothed (interpolated) surface of changes in climates (deltas or anomalies) and then applies this interpolated surface to the baseline climate, taking into account the possible bias due to the difference in baselines (Ramirez-Villegas and Jarvis, 2010). This approach was applied to seven individual sites covering the seven districts (Abim, Kaabong, Kotido, Moroto, Napak, Nakapiripirit, and Amudat) in the sub-region.

Twenty models (ACCESS1-0, bcc-csm1-1, BNU-ESM, CanESM2, CCSM4, CESM1-BGC, CSIRO-Mk3-6-0, GFDL-ESM2G, GFDL-ESM2M, HadGEM2-CC, HadGEM2-ES, inmcm4, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC5, MIROC-ESM, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, and NorESM1-M) embedded in AgMIP protocol were utilised (Rosenzweig et al., 2013). Projection was conducted under two time slices; mid-century (2040-2069) and end-century (2070-2099) and two representative concentration pathways-RCP (RCP 4.5 and RCP 8.5). RCP 4.5 and RCP 8.5 are part of radiative forcing pathways that will have potential influence on the climate system in the 21st century (Van Vuuren et al., 2011; IPCC, 2013). RCP 4.5 describes the medium stabilization scenario without overshoot pathway (Wise et al., 2009; Van Vurren et al., 2011). On the other hand, RCP 8.5 describes rising radiative forcing pathway leading to very high emissions scenario (Riahi et al., 2007; Van Vuuren et al., 2011). In the analysis, both concentration pathways in all the two time-slices were applied and the analysis was performed in R software environment. Projection outputs were summarised into maximum, minimum and mean temperature. Annual average rainfall at regional and spatial location basis was similarly computed and rainfall distribution-surface maps were thereafter developed using the geostatistical deterministic method based on inverse distance weighting in ArcGIS 10.1 software. The analysis was performed in R statistical software.

6.2.4 Projected onset and cessation of rainfall

The onset and cessation of rainfall was determined by dividing the projected rainfall into five day annual total periods (pentads) such that 01-05 days in January were equated to pentad one. According to Mubiru et al. (2012) pentads are useful in studying onset and cessation of rainfall. This is because they are a useful unit in dealing with meteorological phenomena in the tropics, in particular if the data have to be relevant to applications in agriculture. In this study, a wet pentad was defined as that with 10 mm or more of rainfall with at least three rainy days to determine the start of the season. In order to identify onset dates, a line was drawn across the 73 pentads at 10 mm level (Mubiru et al., 2012).

6.2.5 Climate change induced forage production

This study utilisied the Miami model as indicated by Gommes (2014) Equation 1 to determine the future forage production in Karamoja sub-region. The Miami model was originally developed by Helmut Lieth (1972) as an empirical approach to link environmental factors to biological production potentials (Gommes, 2014). The Miami model has been utilised by Fronzek and Carter (2007). As proposed by Lieth, the following equations (1b-1d) portray the Miami model.

$$y = min \begin{Bmatrix} 3000/(1 + \exp(1.315 - 0.119.tmp)) \\ 3000.(1 - \exp(-0.000664.pre) \end{Bmatrix} \text{...Equation 1a}$$

Where y denotes net primary productivity (g DM m^{-2} yr^{-1}), tmp mean annual temperature (°C) and pre mean annual precipitation (mm); in this study taken inform of rainfall. Equation 1a above can be disaggregated into Equation 1b-1d.

$$NPP[Rain(y)] = 3000(1 - e^{-0.000664Rain(y)}) \text{..Equation 1b}$$

$$NPP[Temp(y)] = \frac{3000}{1+e^{1.315-0.119Temp(y)}} \text{..Equation 1c}$$

$$NPP\_1 = min\{NPP[Rain(y)], NPP[Temp(y)]\} \text{..Equation 1d}$$

In this case, NPP is based on annual climate variables for year *y*, *Rain(y)* and *Temp(y)*, the total annual rainfall (mm), the annual average temperature (˚C) and *NPP_1* expressed in grams of dry matter per square meter per year. The Miami model has been found to generate realistic NPP patterns (Dai and Fung 1993). Rainfall and temperature data are obtained from the projection analysis conducted for the sub-region. It is assumed in this study that soil and its management, government and other stakeholder interventions will not affect forage productivity.

6.3 Results

6.3.1 Trend of climate variability (1979-2009)

Results showed that there was a significant and progressive rise in temperature. At sub-regional level, long term minimum temperature rose by 0.9°C ($R^2 = 0.66$), mean temperature by 1.3°C (R^2 0.54) and maximum temperature by 1.6°C (R^2 0.35) (see Figures 6.1, 6.2, 6.3). This pattern was observed across all the sixteen stations that were analysed in the sub-region. A consistent rise in minimum temperatures across all stations in the sub-region was observed. The coefficients of determination for minimum temperature were observed to be above 50% in most locations in the sub-region. Areas of Dopeth and Matheniko had the highest significant and positive increase in minimum temperature at 71.3 percent. A phenomenal rise in temperatures was observed in 1998 that affected the entire sub-region (Figures 6.1, 6.2 and 6.3). We observed three phases of long term mean temperature rise in the sub-region. The first phase was indicated by a crest emerging from the 1970s and breaks about 1985 (first trough). This was followed by a gradual rise that peaks about 1991-1993 with a break point between 1996/1997 (second trough). The third and sharper rise of relatively higher temperature was observed from 1998 cresting about 2000-2002 followed by a break about 2007 (third trough). The 2007 break was not as pronounced as the previous variation in temperature but the temperature generally stayed high for the remainder to the study period (Figure 6.3).

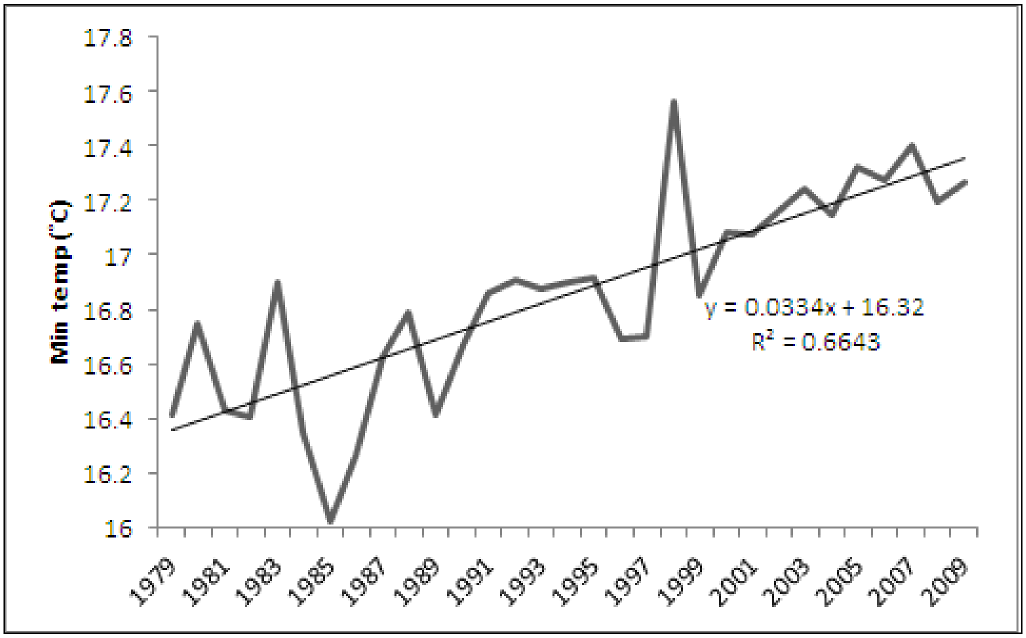

Figure 6. 1: Long term trend in minimum temperature

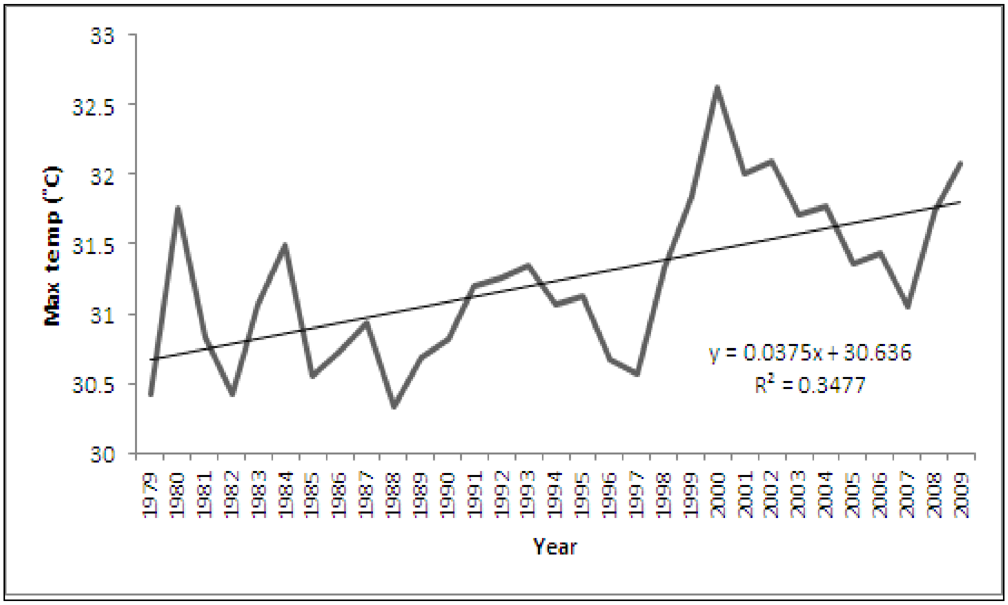

Figure 6. 2: Long term trend in maximum temperature

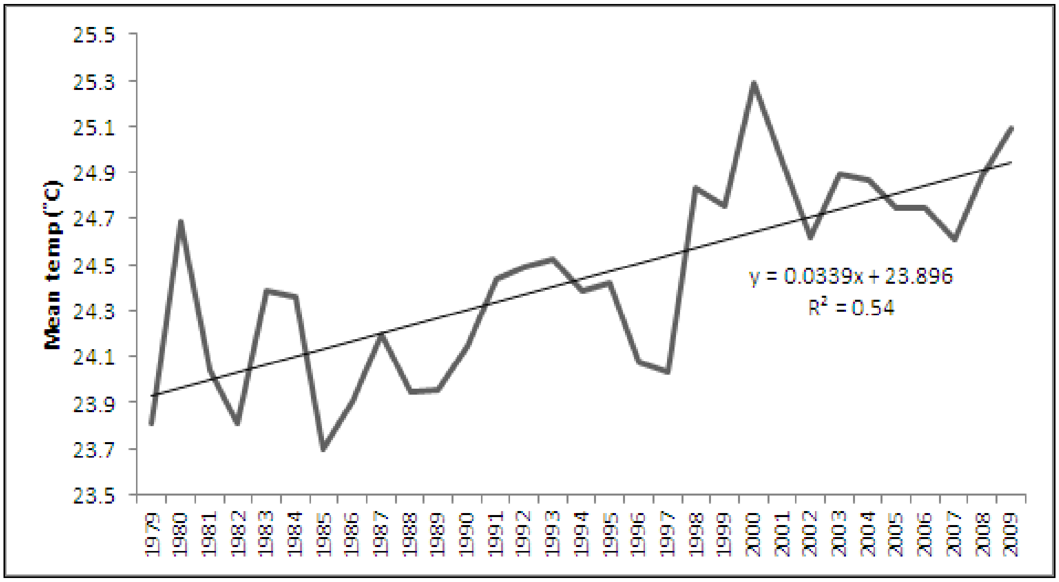

Figure 6. 3: Long term trend in mean temperature

Rainfall times series analysis (1979-2009) showed a positive but non-significant trend (R^2=17.1%; Figure 6.4) over the sub-region. The trend reflected a fluctuating pattern characterised by increases and decreases above and/or below the sub-regional average. The decreases reflected periods of significantly low rainfall totals with a return period of between 3-7 years. This corresponds with the La Niña events observed in Uganda at large. The first major and general decrease in rainfall totals during the period of analysis was observed in 1984 (Table 6.3). This was followed by a sporadic rise that peaked in 1988 (Figure 6.4). Thereafter, rainfall declined to nearly a uniform average total followed by another significant decrease which reached a low in 1993. This was, however, interrupted by an abrupt increase in 1994, and sudden decrease in 1995. During this period, nine out of the sixteen stations analysed (Matheniko, Namalu, Pian-Upe, Lolachat, Okere, Kokeris, Panayangara, Abim and Kidepo) received rainfall below 300 mm for the year.

However, this was followed by three years of progressively high rains with peak levels occurring between 1997 and 1998. Despite rainfall peaking for all stations then, there was marked variability. Stations of Namalu, Pian-Upe, Lolachat all occurring in southern Karamoja recorded lower total rainfall compared to areas of Dopeth, Komuria and Nga-Moru in northern Karamoja.

In 2009, the sub-region experienced a general decline in rainfall after six years of relatively stable total rainfall.

Results of variability analysis showed that the sub-region's rainfall was variable with observable deviations from the total annual rainfall long term-mean (Figure 6.5). This variation led to a pronounced coefficient of variation at 35.0 percent. The coefficients of variation showed spatial variation (Figure 6.6) such that areas such as Nga-Moru, Dopeth and Komuria posted relatively lower coefficients of variation of 30.68%; 30.2% and 25.8% respectively. On the other hand, Pian Upe 1 (60.5%); Pian Upe 2 (58.2%); Namalu (52.5%) and Lolachat (47.8%) areas recorded the highest coefficients of variation. Further, the areas of Kotido-Panyagara (40.2%); Kokeris (41.2%); Matheniko (42.2%); Okere river area (46.5%); Abim (42.5%); Kidepo (36.6%) and Nakiloro (37.5%) were observed with high coefficients of variation (Figure 6.2).

Table 6. 3: Highest and lowest rainfall received by station (1979-2009)

Station area	Lowest rain total annual received	year	Highest annual total rain received	year	Long term average (1979-2009)
Abim	141.1	1984	808.9	2007	373.8±158.9
Dopeth	271.8	1984	1002.8	1998	647.7±195.5
Kidepo	183.3	1984	783.6	2007	426.9±156.3
Kochokyo	149.2	1984	813.9	1988	468.7±157.6
Kokeris	109.1	1984	826.3	2007	399.0±164.3
Komuria	411.6	1984	1413.9	1988	922.7±238.4
Kotido-Panyangara	117.5	1984	687.7	2007	352.7±141.9
Lolachat	33.9	1984	449.8	2007	194.9±93.2
Matheniko	74.1	1984	572.5	1998	302.3±127.5
Moroto	130.8	1984	814.1	2007	507.2±170.4
Nakiloro	87.3	1984	697.5	1998	404.7±151.9
Namalu	39.4	1984	590.7	2007	212.6±111.7
Nga-Moru	239.1	1984	932.6	1988	568.0±174.3
Okere	116.3	1984	890.3	2007	391.3±181.8
Pian Upe 1	27.4	1984	624.9	2007	208.4±126.1
Pian Upe 2	33.9	1984	543.3	2007	187.6±109.1

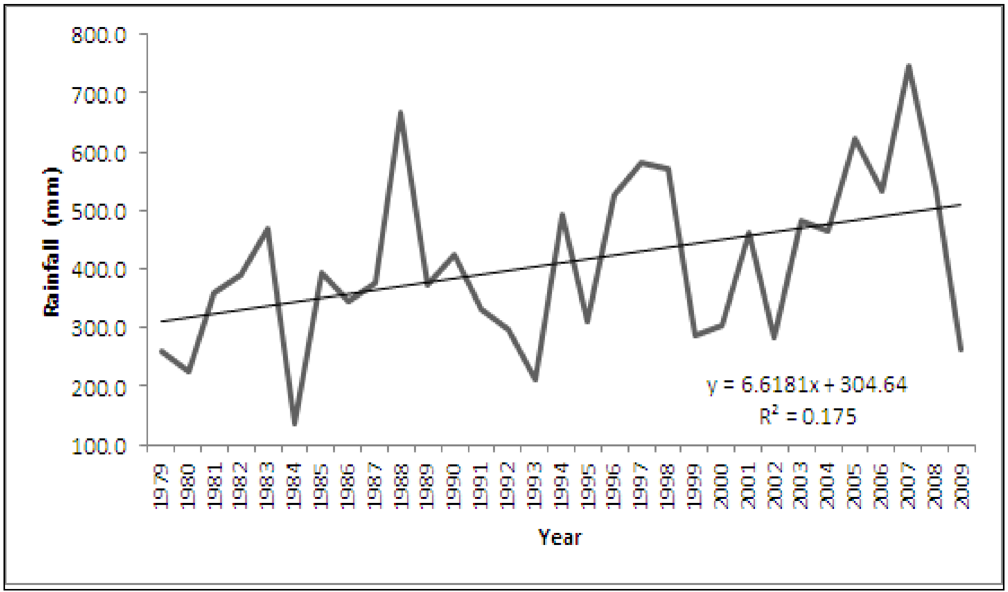

Figure 6. 4: Long term annual rainfall total for Karamoja

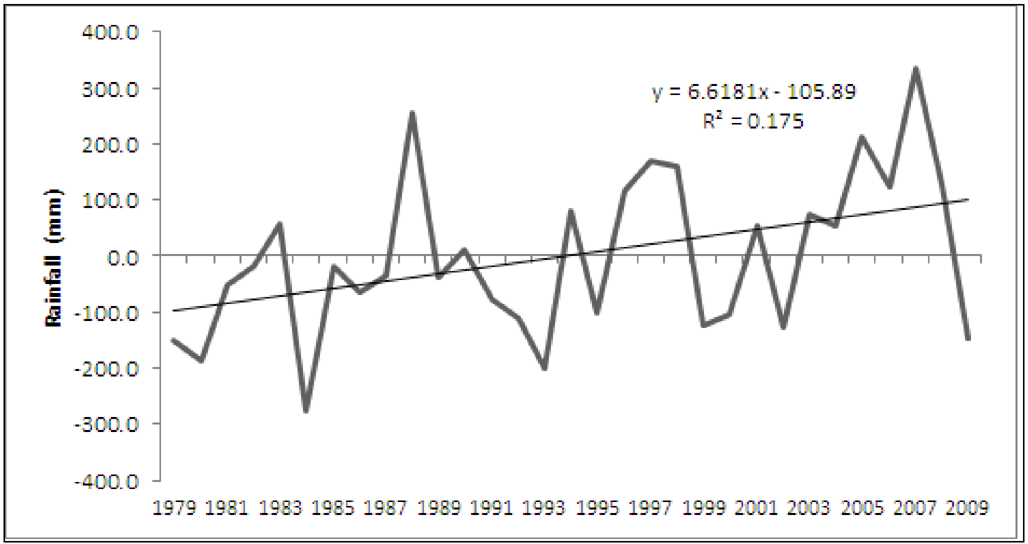

Figure 6. 5: Total annual rainfall deviation from the long term annual rainfall mean

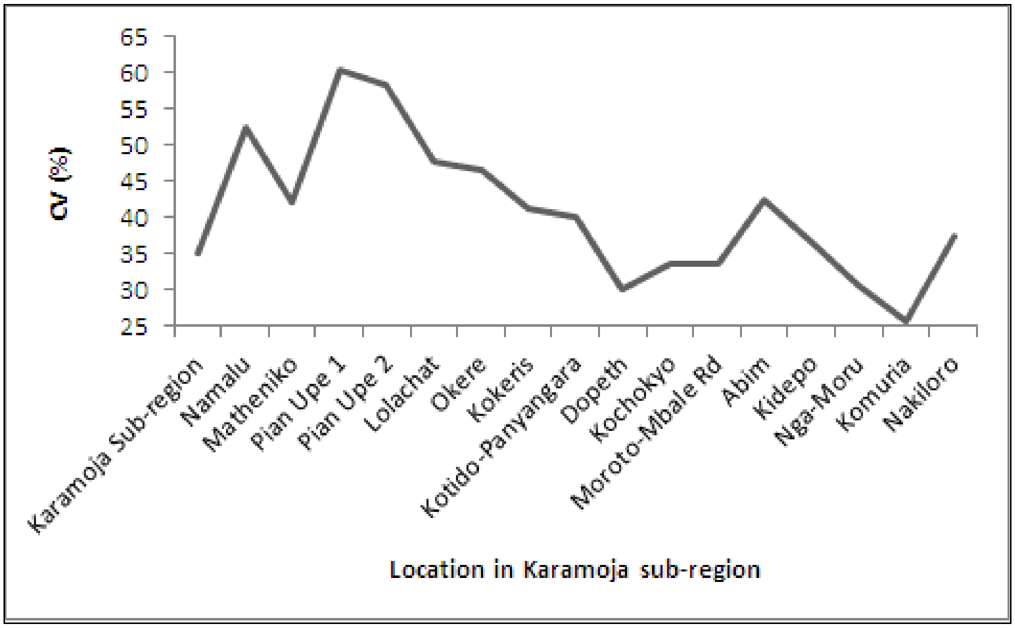

Figure 6. 6: Coefficients of variation at sub-regional and location level

6.3.2 Climate variability intensity in Karamoja (1979-2009)

Results of the analysis showed the existence of both extreme dryness and wetness intensity in the sub-region (Figure 6.7). The rainfall variability intensity results revealed that from 1979-1995 there was a predominance of extreme dryness intensity (Table 6.4). This indicated the occurrence of multi-year droughts with a lack of smooth transition between the extreme events. A transition to pronounced wetness intensity was observed to have started about March 1996 with extreme wetness intensity experienced in 1997 and on into 1998 (Table 6.4). It was also observed that from about 2000 there has been a break in the occurrence of multi-year extreme dryness intensity. This indicates a reduction in the recurrence of multi-year drought events. In terms of the temporal evolution of variability intensity, the results showed that severe to extreme rainfall variation intensity (RVI) was pronounced during early (January to April) and late (September to December) months of the year.

Variability indices (RVI = 0.04-0.43) showed that much of 1984 to early (March) 1985 had the most severe to extreme dryness intensity patterns. From December 1983 to March 1985, there were 16 months of severe to extreme dryness intensity. The frequency in severe to extreme dryness intensity continued for most of the 1980s to early 1990s. From 1995, dryness intensity started easing and by 1997, it switched from pronounced dryness to pronounced wetness intensity. During the 1997/1998 rains, the months of April (RVI = 3.4), November and December (RVI = 4); January and February (RVI = 4) of 1998 experienced extreme wetness intensity. A unique trend started about 2003 that reflected a general increase in the prevalence of wetness intensity with a conspicuous intensification of wetness from 2006 to 2008 (Table 6.4). Although most of 2009 was dry (0.1-0.97 index), rainfall intensity rose rapidly up to extreme levels in December (RVI = 3.12).

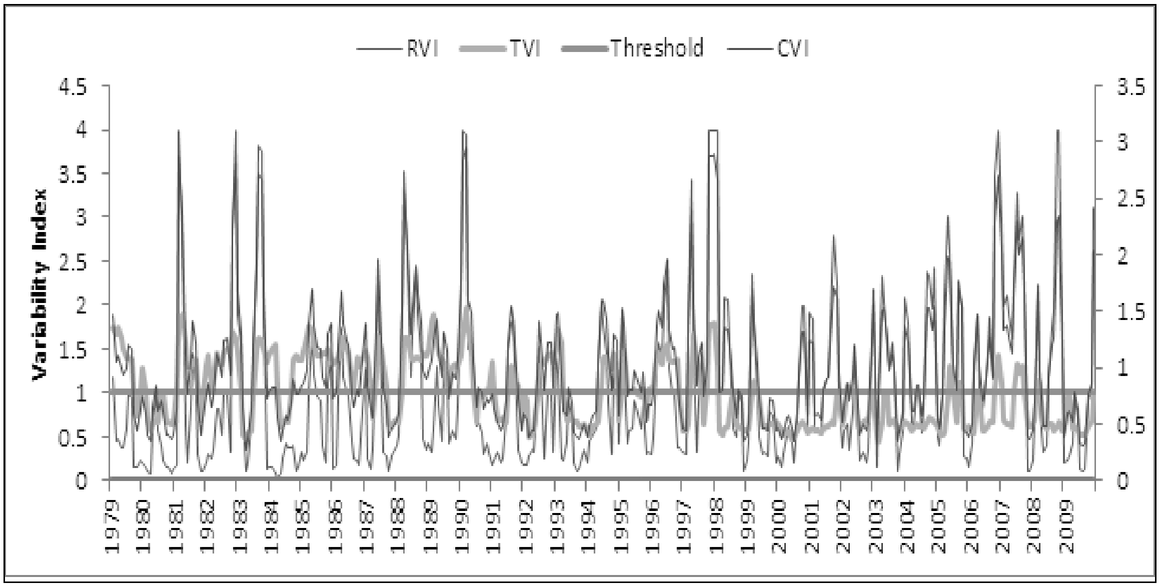

Figure 6. 7: Combined temperature and rainfall variability intensity index

Table 6. 4: Karamoja long term (1979-2009) rainfall variability intensity (RVI) indices

RVI	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Jan		0.21	0.13	0.2	1.9	0.15	0.32	0.12	1.29	0.39	0.42	2.14	0.17	0.17
Feb	1.18	0.16	0.19	0.3	1.55	0.16	0.24	0.18	0.26	0.53	0.32	4	0.24	0.17
Mar	0.45	0.11	4	0.26	0.73	0.09	0.32	0.96	0.14	2.02	0.6	3.95	0.32	0.27
Apr	0.46	0.09	2.81	0.36	0.1	0.04	0.99	1.73	0.37	3.53	1.31	1.49	0.2	0.36
May	0.37	0.67	0.63	0.82	0.2	0.08	1.68	1.18	1.51	2.5	0.86	1.54	0.26	0.33
Jun	0.37	0.99	0.21	0.81	0.7	0.25	1.21	1	2.27	1.17	0.44	1.08	0.74	0.89
Jul	0.59	0.56	0.83	0.52	1.39	0.43	0.95	0.95	0.98	1.66	1.27	0.62	1.48	1.51
Aug	1.02	0.4	1.46	1.02	2.43	0.38	0.91	0.45	0.33	2.4	1.22	0.66	1.79	0.77
Sep	0.93	0.23	1.06	1.02	3.81	0.37	0.39	0.26	0.27	1.91	0.43	0.55	1.84	0.25
Oct	0.15	0.15	0.29	0.32	3.75	0.4	0.2	0.23	0.11	1.4	0.58	0.3	0.87	1.03
Nov	0.16	0.16	0.1	2.79	1.84	0.1	1.11	0.17	0.28	0.48	0.47	0.43	0.34	0.98
Dec	0.22	0.08	0.11	4	0.12	0.16	1.4	0.78	0.32	0.35	0.87	0.33	0.2	0.32

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1.42	0.2	0.43	0.29	0.33	4	0.22	0.27	1.91	0.38	2.19	2.08	0.49	0.15	2.95	0.24	0.21
1.23	0.45	1.95	0.49	0.31	4	0.44	0.15	1.85	0.58	0.16	1.8	0.39	0.42	1.99	0.73	0.22
0.25	0.52	1.25	1.32	1.83	0.99	2.36	0.3	0.57	0.64	1.07	0.66	1.01	1.35	2.11	2.23	0.28
0.22	0.59	0.43	1.56	3.42	1.09	1.72	0.52	0.59	0.34	2.34	0.62	2.14	1.89	1.92	0.85	0.43
0.44	1.35	0.57	1.39	1.46	2.09	1	0.61	0.51	0.78	2.04	1.03	3.01	1.03	1.63	0.32	0.97
0.93	2.06	0.6	1.99	0.32	2.06	0.49	0.43	1.02	1.39	1.49	1.04	2.59	0.81	2.26	0.39	0.71
0.7	1.8	0.9	2.39	0.9	1.08	0.31	0.2	1.15	0.68	1.28	0.55	1.06	0.95	3.27	1.17	0.12
0.2	1.46	0.77	1.28	1.46	0.6	0.32	0.68	1.19	0.23	1.58	0.85	0.93	1.46	2.75	1.75	0.1
0.1	0.89	0.6	0.98	0.86	0.49	0.28	1.21	2.31	0.33	1.25	2.37	2.28	1.86	3.02	1.93	0.14
0.12	0.3	0.88	1	1.03	1	0.8	1.98	2.78	0.21	0.11	2.34	1.98	1.15	2.28	4	0.91
0.28	1.15	0.31	0.38	4	0.89	0.74	1.99	2.22	0.35	0.29	1.97	0.27	3.48	0.1	4	1.06
0.35	1.35	0.32	0.38	4	0.1	0.21	0.59	0.95	1.45	0.57	2.42	0.26	4	0.1	1.82	3.12

Results further showed variation in variability intensity within the sub-region. For example, in Abim, the years 1979 (RVI = 0.1-0.56), 1980 (RVI= 0.11-0.56), 1984 (RVI = 0.11-0.57), 1991 (RVI = 0.17-0.67), 1993 (RVI = 0.08-0.98) and 1995 (RVI = 0.18-0.92) all reflected severe to extreme dryness intensity. There were, however, some episodic wetness reflections in the 1980s observed in 1981 during the months of March (RVI = 4) and April (RVI = 3.9), and in 1983 during the months of September (RI = 3.31) and October (RVI = 3.9). All other months remained within the moderately dry and extremely dry segment. Between 2004 and 2008, the area experienced a rise in the number of severe to extreme wetness periods. Consequently, in total, 18 months could be classified in this category with nine out of the 18 occurring in 2007 alone.

At Dopeth, the period between December 1983 and April 1985 had 17 months (RVI = 0.03-0.6) in the severe to extreme dryness intensity category. Of the first 72 months (1979-1984), fifty four (54) months could be classified into severe to extremely dry (RVI = 0.07-0.65) months. In this station, 1983 and 1988 were the only years that could be classified as relatively good years with rainfall variability intensity being within the normal (RVI = 1.01-1.59) to moderate (RVI = 1.6-2.09) range. Like Abim, Dopeth had 18 months of extreme wetness intensity. However, when the analysis period from 1994-2009 was considered; Dopeth had 37 months in the severe to extreme wetness intensity category compared to Abim with 25 months. Meanwhile, in Lolachat, out of 168 months (1979-1992), there were 107 months in the severe to extreme dryness category (RVI = 0.04-0.6). In the same period, the area received sporadic intense rains; 18 months could be classified as severe to extreme wet months. There were only 33 months in the mild range (RVI = 0.9-1.0) category. This shows that this area experienced multiple drought years between 1979-1992 periods. When the remaining 17 years (204 months) are considered (1993-2009), 119 months experienced (RVI = 0.06-0.69) severe to extreme dryness conditions. In the same period, 37 months with severe to extreme wetness (RVI = 2.01-4) conditions were found. Only 26 months could be observed within the mild (RVI = 1.01-1.59) intensity category. This indicates scarcity in good months/years despite indications of relative increase in rainfall total.

The Kokeris area was one with a high number of months that received severe to extreme dry conditions between 1979 and 1992. Out of 168 months, there were 109 months that experienced severe to extreme dryness intensity conditions. In the same period, 13 months experienced severe to extreme wet conditions. From 1993-2009, 96 months could be classified into severe to extreme dry intensity while 39 months fell into the severe to extreme wet intensity category. Four stations in southern (Lolachat), central (Kokeris) and northern (Abim and Dopeth) areas of the region demonstrate the spatial variability intensity across the region. The remaining twelve stations oscillate within these ranges. There was one exception, Pian-Upe. This site had increased wetness intensity extremes in 1983, 2006 and 2007.

Table 6. 5: Karamoja long term (1979-2009) temperature variability intensity indices

TVI	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Jan		1.29	0.68	1.32	1.46	1.43	1.37	1.33	1.48	0.68	1.48	1.42	1.34	1.01
Feb	1.73	1.04	1.09	1.43	1.02	1.5	1.48	1.37	1.41	0.66	1.81	1.66	1.04	0.9
Mar	1.67	0.69	1.74	1.06	0.53	1.54	1.64	1.41	1.11	1.02	1.89	1.95	0.7	0.49
April	1.75	0.58	1.9	1.12	0.46	1.05	1.77	1.63	0.72	1.61	1.54	1.72	0.7	0.52
May	1.62	0.64	1.57	1.44	0.54	0.61	1.72	1.62	1.2	1.62	1.44	1.44	0.71	0.56
Jun	1.49	0.69	1.31	1.32	0.57	0.64	1.52	1.5	1.65	1.43	1.37	1.03	0.67	0.94
Jul	1.41	0.67	1.31	1.32	0.95	0.7	1.43	1.45	1.48	1.37	1.36	0.67	0.98	1.31
Aug	1.39	0.99	1.35	1.45	1.48	0.67	1.43	1.07	1.32	1.41	1.06	1	1.3	1.33
Sep	1.38	1.01	1.38	1.49	1.62	1	1.45	1.06	1.05	1.39	1.02	1	1.05	1.35
Oct	1.04	0.66	1.09	1.53	1.59	1.38	1.46	1.39	0.64	1.38	1.31	0.97	1.09	1.43
Nov	0.73	0.66	0.7	1.69	1.5	1.42	1.49	1.31	0.63	1.46	1.32	1.03	1.09	1.45
Dec	1.03	0.65	0.98	1.62	1.34	1.37	1.38	1.4	0.66	1.43	1.31	1.04	0.7	1.34

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1.5	0.58	0.7	1.06	0.58	1.79	0.58	0.65	0.56	0.65	0.95	0.67	0.62	0.61	1.1	0.65	0.57
1.72	0.52	1.06	1.06	0.58	1.31	0.6	0.56	0.59	0.71	0.49	0.65	0.54	0.57	0.69	0.69	0.97
1.56	0.62	1.48	1.44	0.64	0.56	1.02	0.53	0.56	1.09	0.45	0.56	0.52	0.55	0.64	1.12	0.96
0.99	0.65	1.05	1.45	1.36	0.51	1.12	0.58	0.58	1.06	0.66	0.59	0.55	1.02	0.64	1.11	0.59
0.69	0.67	1.02	1.33	1.68	0.6	1.04	0.54	0.54	1.03	1.02	0.64	0.97	0.98	0.61	0.65	0.61
0.71	1.07	1.02	1.49	1.35	0.62	0.94	0.48	0.59	1.01	0.98	0.63	1.31	0.58	1	0.59	0.57
0.68	1.41	1.03	1.55	1.28	0.94	0.62	0.5	0.62	0.61	0.65	0.61	0.99	0.57	1.33	0.64	0.52
0.66	1.39	0.99	1.37	1	0.95	0.62	0.56	0.62	0.59	0.66	0.6	0.66	0.63	1.24	0.64	0.51
0.67	1.31	0.95	1.35	0.64	0.63	0.62	0.61	0.67	0.67	0.68	0.67	1.1	0.67	1.3	0.58	0.51
0.62	1.29	1.03	1.36	1.05	0.62	0.65	0.66	0.65	0.69	0.58	0.71	1.11	0.66	1.02	0.62	0.61
0.63	1.44	0.71	1.37	1.76	0.6	0.65	0.65	1.01	0.7	0.58	0.7	0.6	1.07	0.65	0.67	0.66
0.65	1.12	1.03	0.98	1.76	0.57	0.66	0.54	0.95	1.01	0.65	0.66	0.59	1.42	0.63	0.56	0.95

Results of temperature variability intensity (TVI) analysis showed two phases of temperature variability intensity pattern in the region. The first phase (1979-1996) was generally characterised by TVI in the normal intensity range (Table 10.5). The second phase (1997-2009) was marked by a shift in temperature variability intensity to moderate and severe intensity category (Table 6.4). Temperature variability intensity (TVI) findings also showed that there was a synchronicity between temperature and rainfall in the sub-region. When TVI intensity decreases, RVI follows suit. Thus, depression points in temperature are analogous to depression points in rainfall. The combined variability index takes a similar trend. These patterns have been observed in all other individual stations where similar analysis was performed.

It was also observable that when temperatures rose above the threshold, the rainfall index also increased. Four years (1983, 1992, 2000 and 2003) recorded months with extreme temperature intensity during April 1983 (TVI = 0.46); March 1992 (TVI = 0.49); June 2000 (TVI = 0.48); February 2003 (TVI = 0.49) and March (TVI = 0.45) (Table 6.5). Further, it was evident that between 1979 and 1992, there was a dominance of mild TVI (104 months) with severe intensity observed in 24 months, and moderate intensity in 22 months. But, between 1993 and 2009 TVI shifted to severe intensity with 116 months most pronounced (Table 6.5). As with RVI, spatial oddities in TVI in the sub-region were observed.

6.3.3 Projected rainfall in mid-century and end century

The mean ensemble of all 20 models showed a similar pattern of rainfall in all time slices (mid-century 2040-2069 and end-century 2070-2099). The long term (2040-2099) means of annual rainfall will be 1084.7±137.4 mm and 1205.5±164.9 mm under RCP 4.5 and RCP 8.5 respectively. Although RCP 8.5 projected slightly higher rainfall total; both RCP 4.5 and RCP 8.5 projected a similar trend in total rainfall (Figure 6.8). Marked inter-annual variability in mid-century (2040-2069) and end century (2070-2099) will be expected (Figure 6.9).

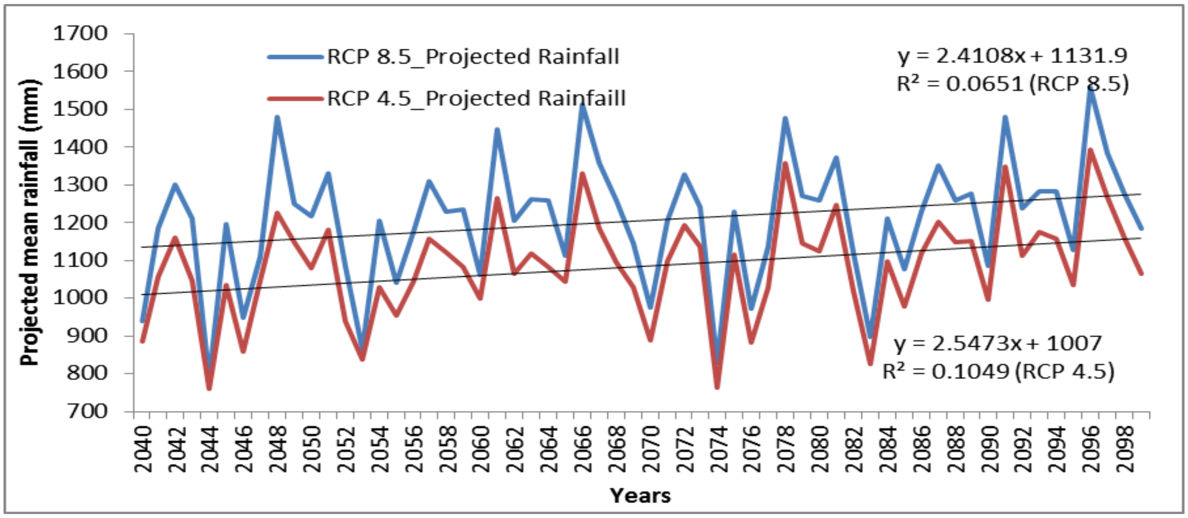

Figure 6. 8: Projected total rainfall (2040-2099)

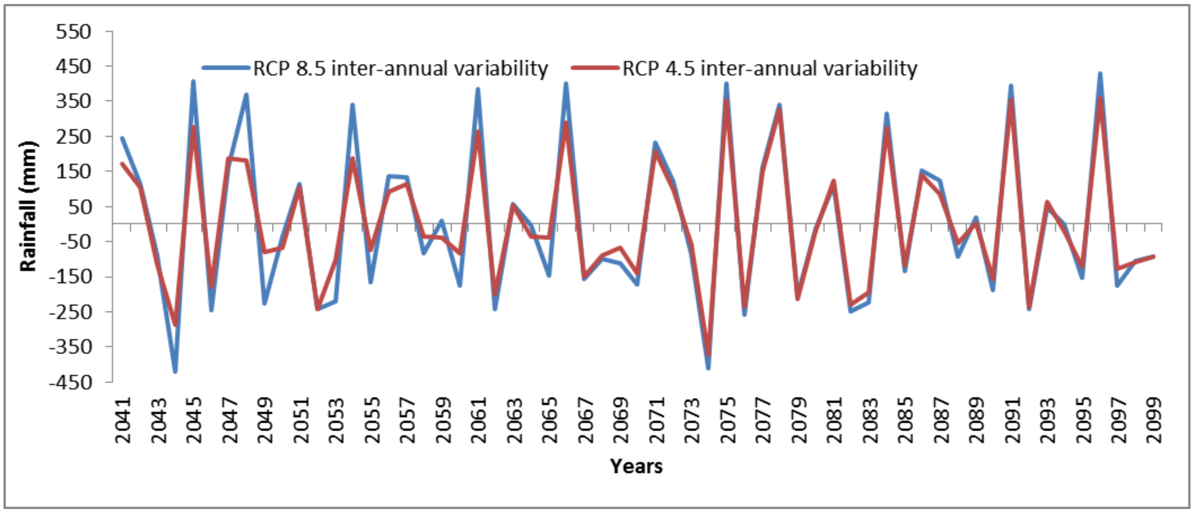

Figure 6. 9: Inter-annual variability in projected rainfall (2040-2099)

Disaggregated results showed that mean annual rainfall between time slices (mid-century 2040-2069 and end-century (2070-2099) will continue to rise. Despite the existence of a positive trend in total rainfall in all time-slices, the trend will be non-significant. Further, variability within and between time-slices as well as in different scenarios will generally remain high (Table 6.6). Spatially, projected total annual rainfall will generally be above 700 mm mark under both RCP 4.5 and RCP 8.5 scenarios in all locations. However, spatial and temporal variability within and between locations in all scenarios (Table 6.6; note the high standard deviations) will be expected (see Figures 10-13). In mid-century, Abim, Amudat, Nakapiripirit and Napak districts will be the only areas with a more pronounced presence of above 1000 mm rainfall total under all scenarios (Figure 10, 11). Abim is the only area that will experience an overall rainfall decline under RCP 4.5 in mid-century (Table 6.6) but return to a positive average during end-century (2070-2099). Notably, under all-time slices, projected total rainfall will be higher under RCP 8.5 scenario (Table 6.6).

Table 6. 6: Projected rainfall in Karamoja sub-region

Analysis time slice	Projected mean annual rainfall (mm)		Change in rainfall (mm)	
Sub-regional level	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Mid-century (2040-2069)	1084.7±137.4	1190.6±166.3	180.8±180.5	206.6±229.7
End-century (2070-2099)	1107.5±147.3	1220.3±165.1	177.3±203.7	210.0±228.0
Century period (2040-2099)	1084.7±137.4	1205.5±164.9	180.8±180.5	244.9±226.1
Station area level				
Mid-century (2040-2069)				
Abim	1401.9±139.9	1407.4±143.2	-99.4±223.2	33.6±226.3
Amudat	1024.5±149.3	1046.6±154.2	212.5±200.8	236.1±206.2
Kaabong	829.6±172.0	1686.4±350.2	197.9±235.5	428.3±478.2
Kotido	799.1±123.2	800.9±124.9	113.1±153.6	123.1±156.6
Moroto	999.9±141.8	998.5±143.9	188.3±184.9	202.3±187.2
Nakapiripirit	1024.5±149.3	1046.6±154.2	212.5±200.8	236.1±206.2
Napak	1354.1±196.9	1348.0±197.9	174.5±281.8	186.9±282.5
End-century (2070-2099)				
Abim	1463.4±151.3	1610.8±163.7	25.4±238.2	39.6±258.8
Amudat	1079.0±158.2	1248.9±185.1	236.3±210.3	293.1±247.0
Kaabong	856.8±177.6	949.3±201.4	217.9±242.4	261.3±274.4
Kotido	827.7±127.3	924.9±146.9	126.9±158.9	157.7±185.2
Moroto	1037.5±147.6	1165.8±170.0	207.0±191.7	251.7±221.5
Nakapiripirit	1079.0±158.2	1248.6±185.1	236.3±210.3	293.1±247.0
Napak	1408.8±206.2	1563.6±231.4	192.1±293.8	230.4±328.0

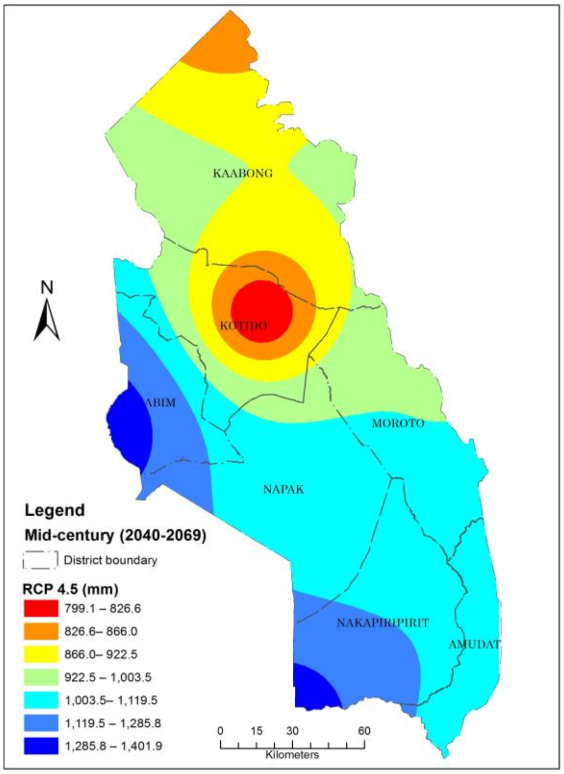

Figure 6. 10: Rainfall distribution under RCP 4.5 mid-century

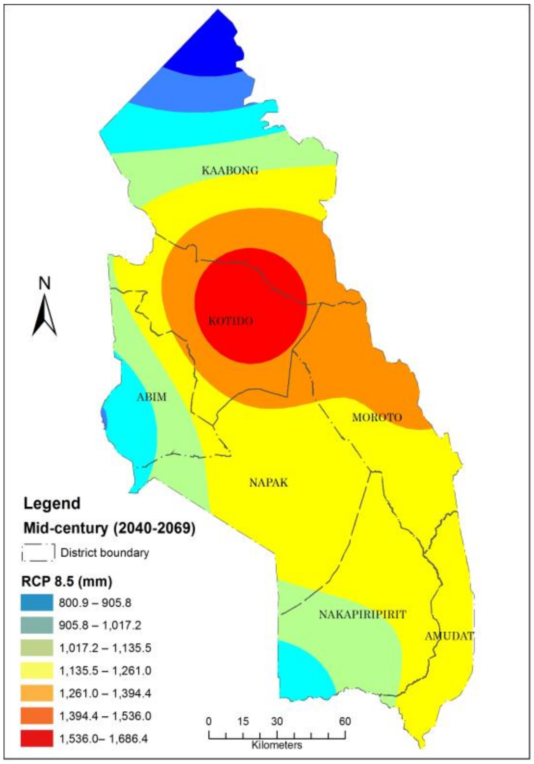

Figure 6. 11: Rainfall distribution under RCP 8.5 mid-century

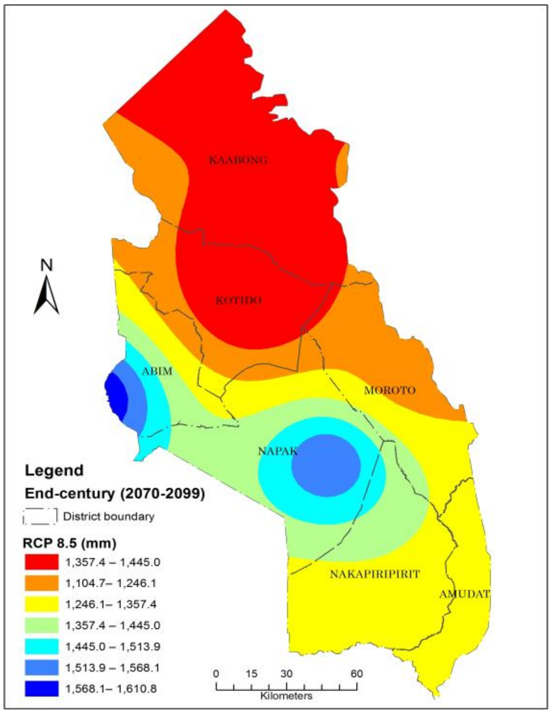

Figure 6. 12: Rainfall distribution under RCP 4.5 End-century

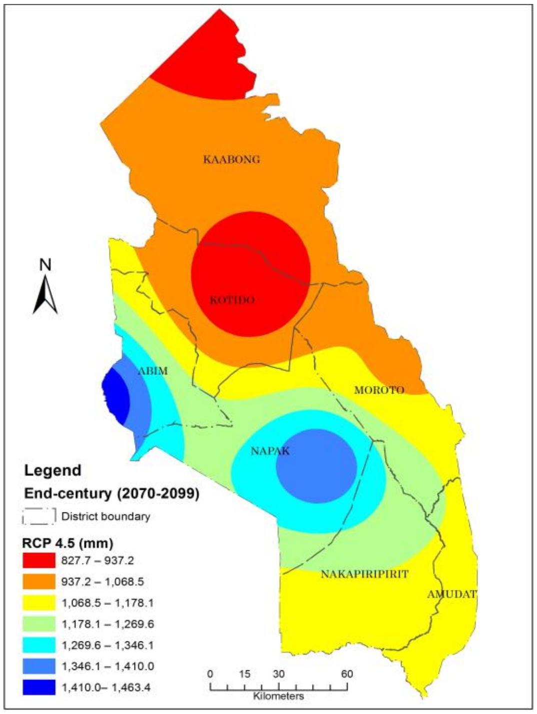

Figure 6. 13: Rainfall distribution under RCP 8.5 End-century

6.3.4 Projected rainfall onset and cessation in Karamoja

The onset, cessation and peak rainfall pentads summary are presented in Table 6.7. At sub-regional level and under all emission scenarios (RCP 4.5 and RCP 8.5) and time slices (2040-2069, and 2040-2099), average onset and cessation pentads will change to 16th and 63rd pentad respectively. Spatial variation in onset and cessation will be expected in the different locations in the sub-region. Under all projection scenarios and time slices, onset and cessation in Napak and Abim areas will be expected to shift to the left and right leading to an expansion of growing season. The districts of Kotido and Kaabong will be expected to experience an early cessation during the end century as opposed to the mid-century under RCP 4.5 (Table 6.7). The sub-region will generally maintain a unimodal rainfall pattern with observable peak pentads (Figure 6.14) around the 21st and 28th pentads (mid-April to mid-May) and about the 40th and 49th (mid-July to early-September).

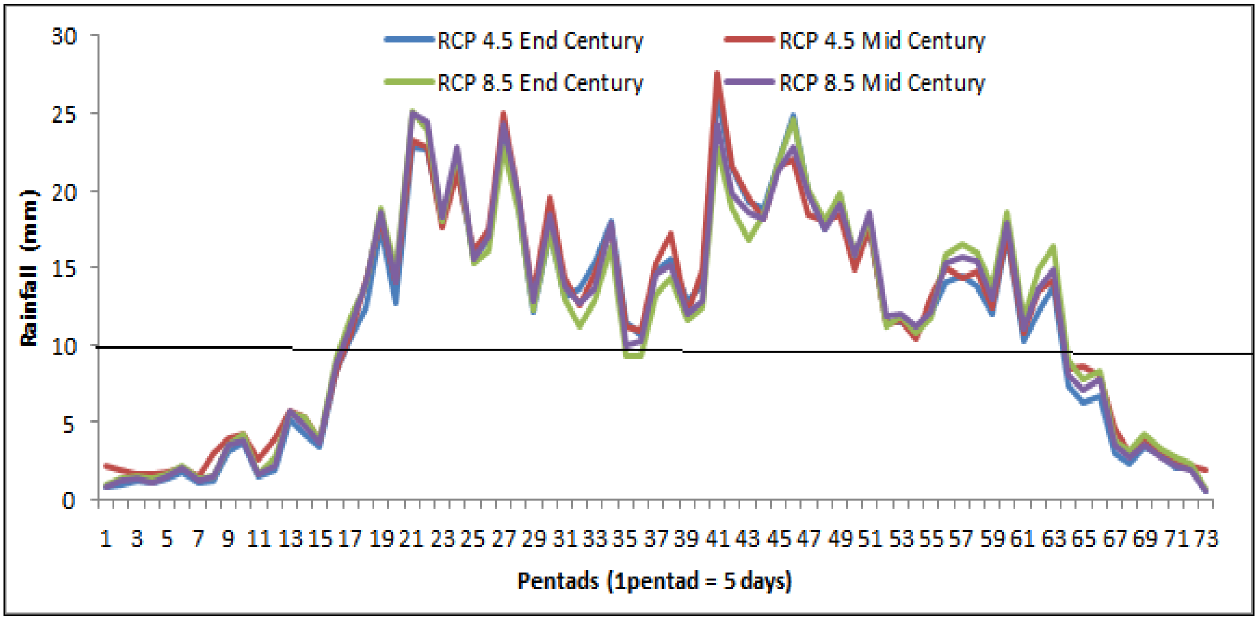

Figure 6. 14: Projected rainfall pentads for Karamoja

Table 6. 7: Projected onset, cessation and peak rainfall pentads in Karamoja

	Onset	Cessation	Peak rainfall pentads	Onset	Cessation	Peak rainfall pentads
	RCP 4.5			RCP 8.5		
Mid-century (2040-2069) Median				**Median**		
Sub-regional	17	63	21-28	17	63	20-23, 41-46
Abim	16	66	21-28, 44-51	17	66	21-22, 41-51
Amudat	17	63	21-27	17	63	21-24
Kaabong	18	67	40-43	18	50	41-43
Kotido	18	52	41-42	18	51	41-42
Moroto	17	63	21-24	17	63	21-23
Nakapiripirit	17	63	21-27	17	63	21-24
Napak	16	66	21-27, 41-51	17	63	21-26, 44-51
End-century (2070-2099)						
Sub-regional	17	63	21-24, 41-45	17	63	19-27, 41-45
Abim	16	66	21-28, 41-51	16	66	19-28, 41-51
Amudat	17	63	21-24, 41-46	17	63	21-24
Kaabong	22	49	23-24	21	49	21-24
Kotido	18	49	41-42	17	63	25-28, 40-43
Moroto	17	63	21-28	16	63	19-28
Nakapiripirit	17	63	21-24, 41-42	16	63	19-22, 44-49
Napak	16	64	21-24, 41-53	17	63	19-22, 40-43

6.3.5 Projected temperature in mid-century and end-century

All the 20 models showed a similar trend in projected maximum, minimum and mean temperature in respective time slices and emission scenarios. Under RCP 4.5, maximum temperature will rise slightly in mid-century and rapidly during end-century. On the other hand, maximum (Figure 6.15) and minimum (Figure 6.16) temperature under RCP 8.5 scenario will continuously rise throughout the 21st century. Similarly, mean temperature will experience a progressive rise throughout the 21st century (Figure 6.17) under both RCP 4.5 and RCP 8.5. Only mean temperature will be significant under RCP 4.5 over the 21st century (long term trend). On the other hand, maximum, minimum and mean temperature will all be statistically significant under high emissions pathways-RCP 8.5 (Table 6.8).

Table 6. 8: Projected temperatures in Karamoja sub-region

Analysis time slice	Projected temperature (°C)				Change in temperature (°C)	
	RCP 4.5	R^2	RCP 8.5	R^2	RCP 4.5	RCP 8.5
Mid-century (2040-2069)						
Tmax	31.9±0.3	0.3206	32.3±0.4	0.2597	0.8±0.3	1.1±0.4
Tmin	18.5±0.5	0.5455	18.9±0.5	0.5044	1.2±0.3	1.3±0.4
Tmean	25.2±0.4	0.5414	25.6±0.4	0.4813	0.9±0.3	1.2±0.3
End-century (2070-2099)						
Tmax	32.3±0.4	0.0151	33.6±0.5	0.0151	1.1±0.4	1.3±0.4
Tmin	18.9±0.5	0.4515	20.8±0.5	0.4521	1.2±0.4	0.2±0.4
Tmean	25.6±0.4	0.2199	27.2±0.4	0.22	1.2±0.3	0.7±0.3
Long term period (2040-2099)						
Tmax	32.1±0.4	0.4519	33.2±0.7	0.7774	1.4±0.4	1.4±0.4
Tmin	18.7±0.5	0.4326	20.1±1.0	0.8585	1.7±0.3	3.0±0.4
Tmean	25.4±0.4	0.5372	26.7±0.9	0.8640	1.6±0.3	2.2±0.3

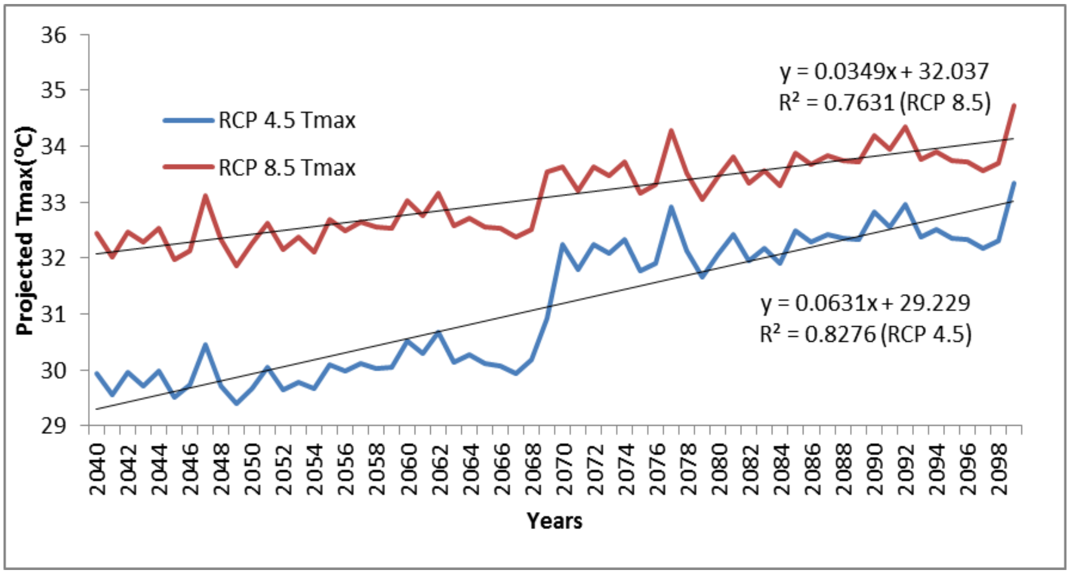

Figure 6. 15: Long term trends in projected maximum temperatures (2040-2099)

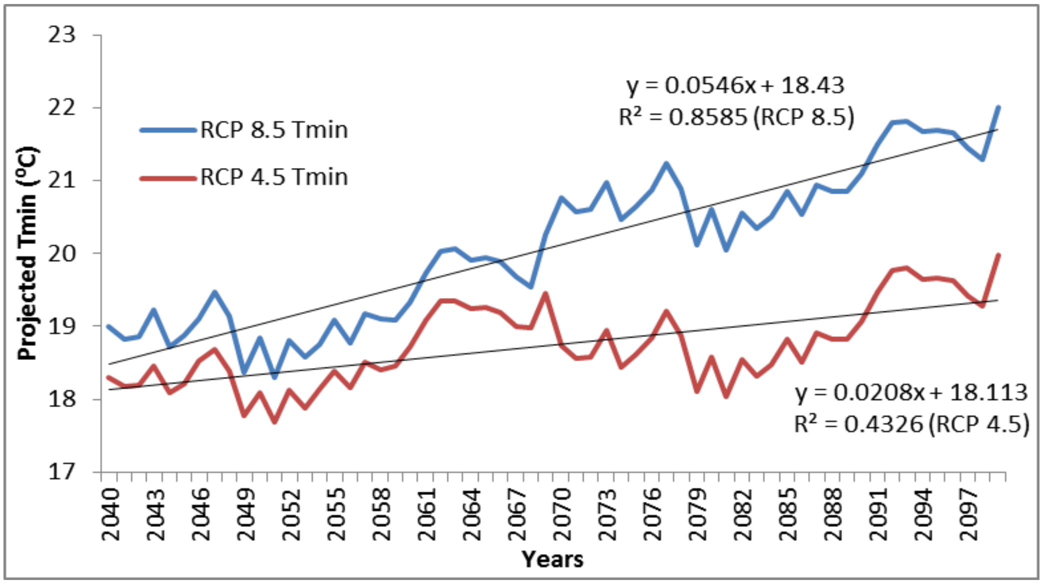

Figure 6. 16: Long term trends in projected minimum temperature (2040-2099)

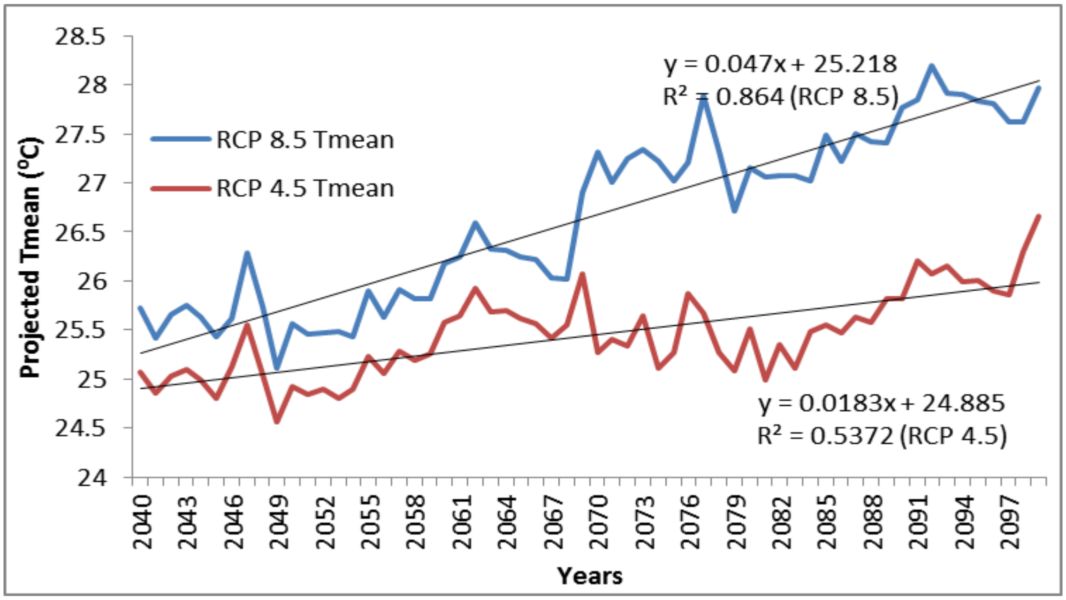

Figure 6. 17: Long term trends in projected mean temperature (2040-2099)

Disaggregated results based on the specific time slices (mid-century 2040-2069 and end-century 2070-2100) showed a positive trend for maximum, minimum and mean temperature under both RCP 4.5 and RCP 8.5 scenarios. The strength of rise in temperature however varied within and between time slices. Only RCP 8.5 simulated above 1.1˚C increase in maximum, minimum and mean-temperature during mid-century. At location level, Napak and Abim districts will generally have higher maximum, minimum and mean temperatures compared to Nakapiripirit, Kotido, Kaabong, Amudat and Moroto districts under all time scales and emissions scenarios (Figure 6.18 and 6.19).

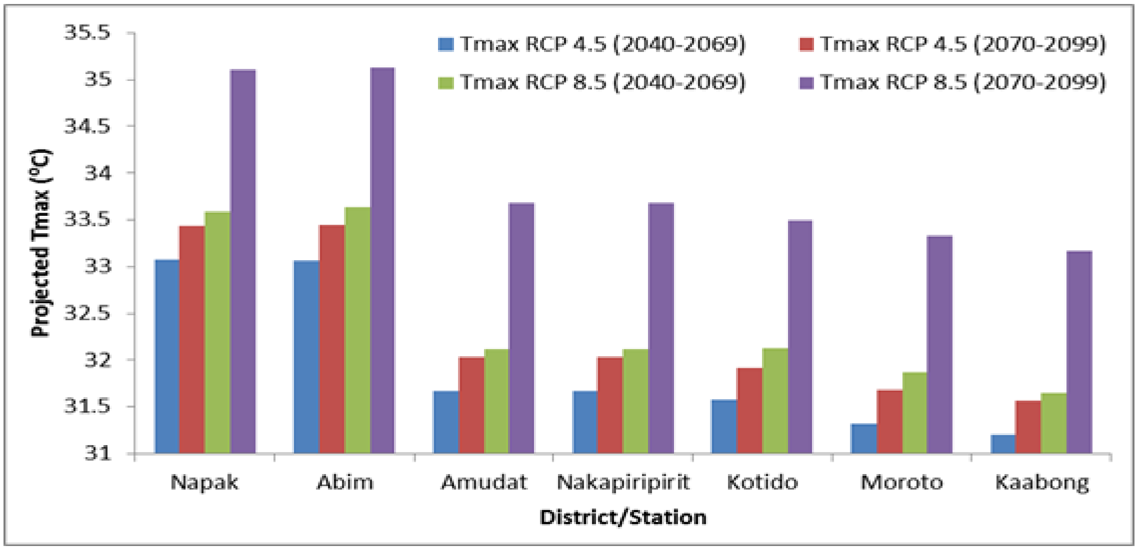

Figure 6. 18: Projected maximum temperatures at district level in Karamoja

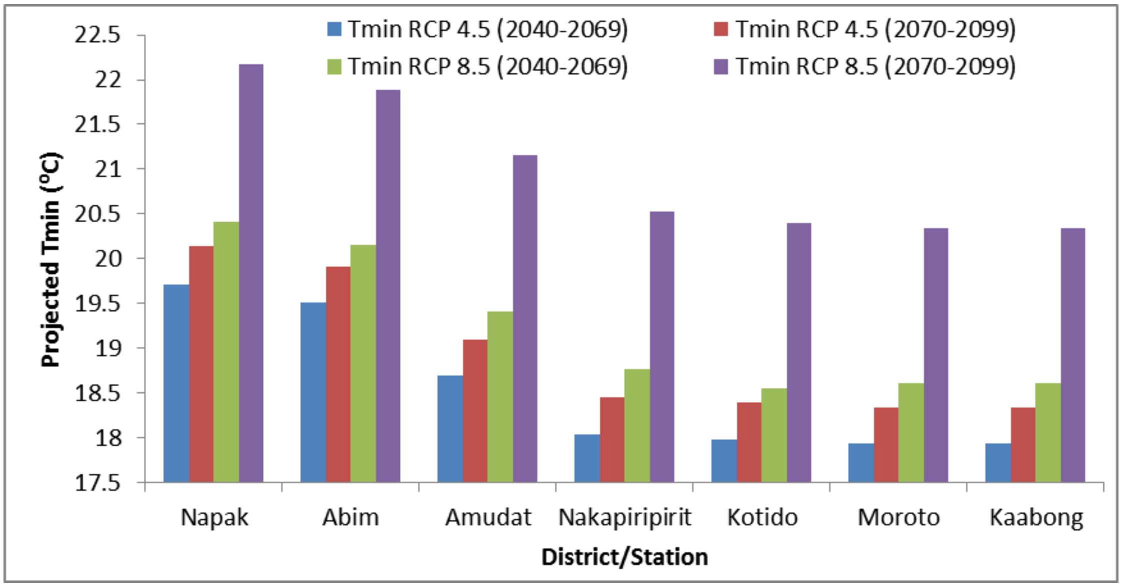

Figure 6. 19: Projected minimum temperatures at district level in Karamoja

When the baseline climate was compared to the projected climate states; results showed that there will be an increase in both maximum and minimum temperatures. At sub-regional level, minimum temperature in the mid-century (2040-2069) will be expected to have increased by

1.8°C and 2.1°C from the 1980-2009 baseline period under RCP 4.5 and RCP 8.5 respectively. The increase in minimum temperature from the baseline period is expected to continue with the end century expected to be much warmer than the mid-century and the baseline period. During the end century, minimum temperature is expected to have increased by upto 4.0°C under RCP 8.5 scenario. Similarly, maximum temperature will increase but the increase will be lower than that expected under minimum temperature (Table 6.9).

Table 6. 9: Comparison of change in temperature from the baseline (1980-2009) period

Projected change in Minimum temperature (°C) from baseline (1980-2009) period				
	RCP 4.5 Mid	**RCP 8.5 Mid**	**RCP 4.5 End**	**RCP8.5 End**
Napak	0.6	1.0	1.0	2.9
Abim	0.8	1.2	1.2	3.1
Kotido	1.6	2.0	2.0	3.9
Moroto	2.3	2.7	2.7	4.6
Kaabong	2.3	2.7	2.7	4.6
Amudat	2.4	2.8	2.8	4.7
Nakapiripirit	2.4	2.8	2.8	4.7
Sub-regional	1.8	2.1	2.2	4.0
Projected change in maximum temperature (°C) from baseline (1980-2009) period				
	RCP 4.5 Mid	**RCP 8.5 Mid**	**RCP 4.5 End**	**RCP 8.5 End**
Napak	0.2	0.6	0.6	1.9
Abim	0.2	0.6	0.6	1.9
Amudat	1.6	2.0	2.0	3.3
Nakapiripirit	1.6	2.0	2.0	3.3
Kotido	1.7	2.1	2.1	3.4
Moroto	2.0	2.4	2.4	3.7
Kaabong	2.1	2.5	2.5	3.8
Sub-regional	0.3	1.7	1.7	3.0

6.3.6 Climate change induced forage production

Climate induced variability in forage production was explored by determining the potential contribution of rainfall and temperature on net primary production (NPP) as a proxy for forage production. Simulated rain derived net primary production (NPP) showed that there will be a progressive rise in NPP (2040-2099) in the region under all emissions scenarios (Table 6.10).

Both RCP 4.5 and RCP 8.5 will have a similar NPP pattern. Results also showed that rain derived NPP will generally be high under RCP 8.5 during mid-century and end-century (Figure 6.20).

Under the temperature domain, potential NPP presented two different responses. RCP 4.5 projected a positive and significant trend in potential NPP during the century (Figure 6.21). On the other hand, a negative and significant trend in potential NPP was projected for 21st century under RCP 8.5 (Figure 6.22). Despite showing, a potential negative trend in NPP, the simulated quantity of NPP under RCP 8.5 remains considerably high closer to that expected under RCP 4.5 scenario.

The disaggregated results showed that potential mean rain derived NPP will be higher in Abim district and lowest in Kotido district under both RCP 4.5 and RCP 8.5 scenarios. However, under temperature derived NPP, the variation in NPP between locations is minimal under all time slices and emissions scenarios (Table 6.10).

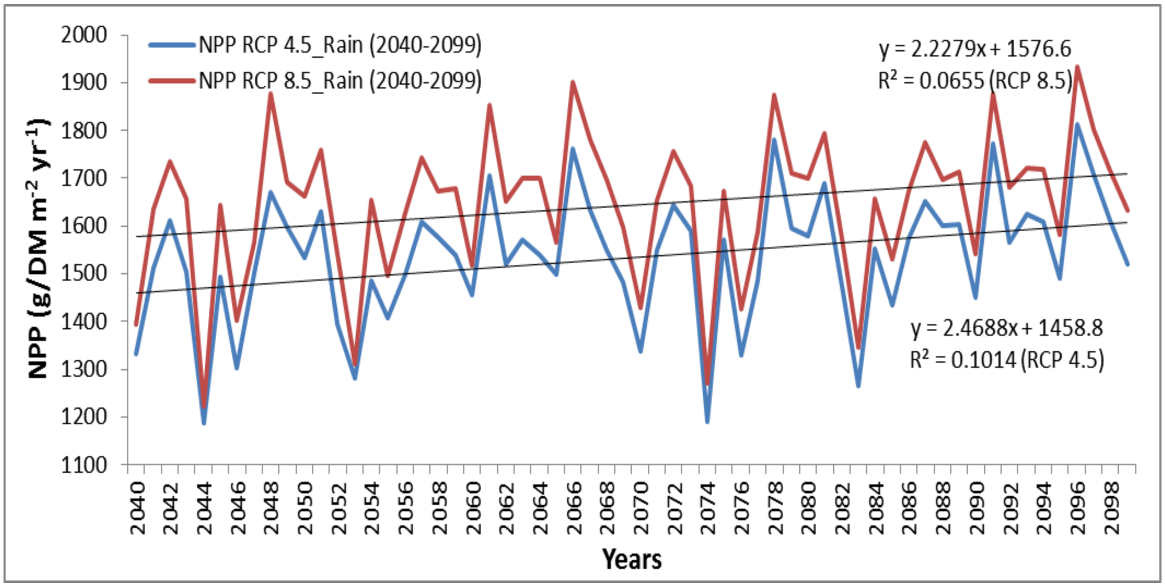

Figure 6. 20: Long term trends in rain derived potential NPP (2040-2099)

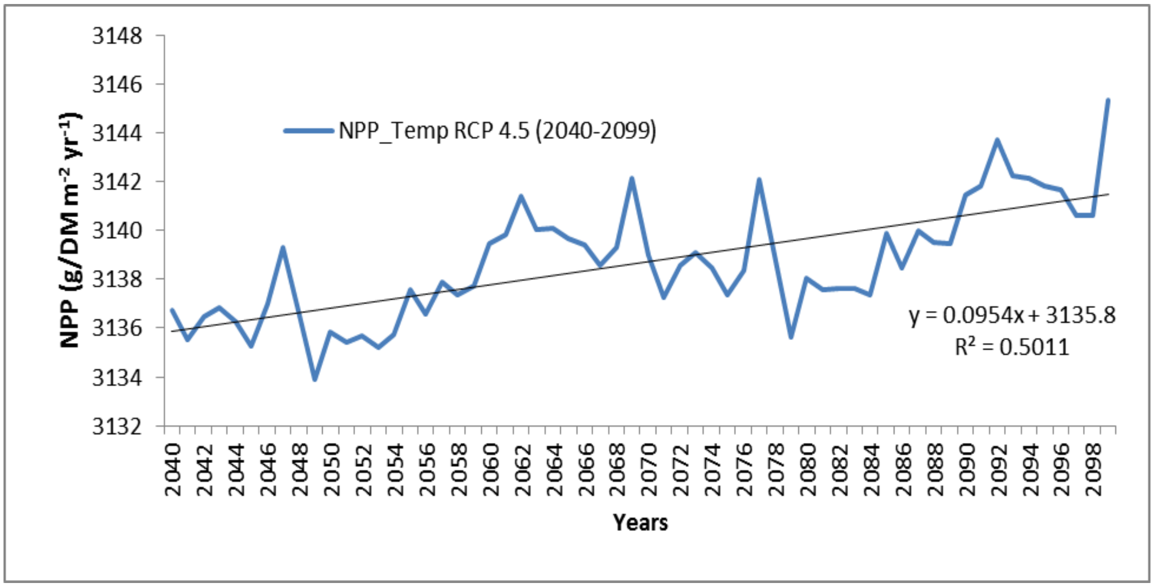

Figure 6. 21: Long term trend in temperature derived NPP under RCP 4.5 (2040-2099)

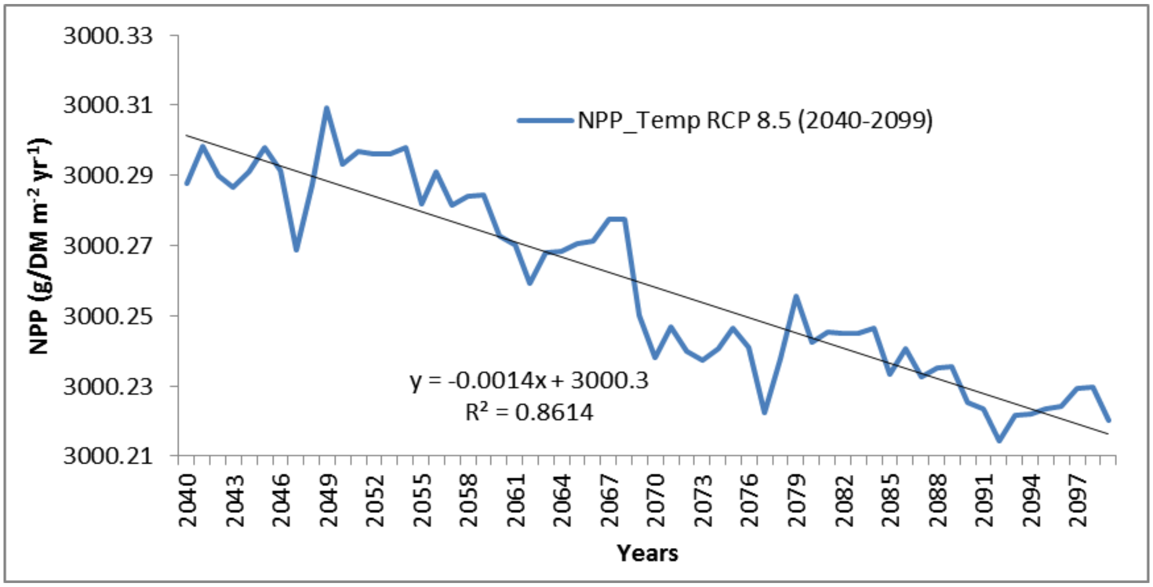

Figure 6. 22: Long term trend in temperature derived NPP under RCP 8.5 (2040-2099)

Table 6. 10: Projected Net primary production in Karamoja sub-region

Analysis time slice	Projected NPP_rain (g/DM m^{-2} yr^{-1})		Projected NPP_temp (g/DM m^{-2} yr^{-1})	
Sub-regionally	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
Mid-century (2040-2069)	1512.9±125.2	1631.1±154.9	3137.6±2.0	3000.3±0.01
End-century (2070-2099)	1555.3±143.8	1657.9±150.5	3139.7±2.2	3000.2±0.01
Century period (2040-2099)	1534.1±135.4	1644.5±152.0	3138.7±2.4	3000.3±0.02
Station area level				
Mid-century (2040-2069)				
Abim	1818.1±0.000	1816.5±111.9	3143.3±2.2	3000.3±0.01
Napak	1768.9±164.6	1763.9±166.4	3143.8±2.6	3000.2±0.01
Amudat	1473.3±153.6	1494.9±156.5	3135.3±2.3	3000.3±0.01
Nakapiripirit	1473.3±153.6	1494.9±156.5	3135.3±2.2	3000.3±0.01
Moroto	1448.9±148.3	1447.2±150.7	3134.6±2.2	3000.3±0.01
Kaabong	1259.5±204.0	1259.4±205.6	3134.1±2.2	3000.3±0.01
Kotido	1229.5±145.2	1231.5±147.1	3137.1±2.1	3000.3±0.01
End-century (2070-2099)				
Abim	1859.1±113.8	1964.6±111.9	3145.5±2.1	3000.2±0.00
Napak	1811.9±166.4	1925.4±170.3	3146.0±2.6	3000.2±0.01
Amudat	1526.7±156.9	1925.4±170.3	3137.3±2.3	3000.2±0.01
Nakapiripirit	1526.7±156.9	1680.9±165.2	3137.3±2.3	3000.2±0.01
Moroto	1486.5±150.7	1607.9±160.2	3136.7±2.2	3000.2±0.01
Kaabong	1289.9±207.7	1388.6±223.3	3136.2±2.2	3000.2±0.01
Kotido	1262.4±147.4	1369.3±159.4	3139.1±2.1	3000.2±0.01

6.4 Discussion

6.4.1 Climate variability trend in Karamoja sub-region (1979-2009)

In Karamoja, between 1979 and 2009, the first major decline in rainfall occurred between 1983 and 1984 and it affected the entire sub-region. Several other researchers have identified this period in East Africa and in Uganda (Ogwang et al., 2012) as the period of the early 1980s great drought. Rainfall totals display episodic variability which has been identified as an inherent characteristic of dryland environments (Abdi et al., 2013). Episodic variability as well as a shift in rainfall patterns has been observed in the semi-arid Tigray region of Northern Ethiopia over a similar period (1980-2009) of analysis and in most of semi-arid Ethiopia (Urgessa, 2013). In the Tigray region, a non-significant declining trend in total annual rainfall was observed, contrary to the non-significant increase observed in this study. However, some stations in Tigray experienced an increasing trend in total annual rainfall similar to that observed in this study.

Further, in the Sahel (Dai et al., 2004), most of West Africa (Boko et al., 2007) and in Eastern Sudan (Sulieman and Elagib, 2012) significant patterns of variability occurred with a decline in annual rainfall. This was contrary to the relative, although non-significant, increase in total annual rainfall observed in this study. In spite of the decline in rainfall for Sahel, an increase in rainfall has also been observed within the Sahel in recent decades. This increase is said to have helped abate the drought which afflicted the region from the 1960s to the 1980s (Hermann et al., 2005). Further, the increase observed in the Sahel, emerges slightly after the 1980s (Funk et al., 2012) and shows a recovery from the drought years that prevailed in the Sahel as well as in East Africa (Dai et al., 2004). These patterns are consistent with the findings of this study. The pattern reported in this study could be attributed to the intensifying dipole rainfall pattern over Eastern Africa that has been held to be the cause of increased rainfall over the region (Schreck and Semazzi, 2004). These data support the climate projections for East Africa that show that the area will have an increase in rainfall (Collier et al., 2008). This increase will be non-uniform as some areas will be experiencing a downward trend while others will have an upward trend (Funk et al., 2012). The Karamoja sub-region appears to fall in the latter category.

The inherent climatic variability in semi-arid regions makes them non-equilibrium ecosystems (Ellis and Galvin, 1994). This study observed relatively high coefficients of variation characteristic of semi-arid regions. Overall, the sub-regional coefficient of variation (CV = 35.01%) is above the 33% threshold margin identified by Ellis and Swift (1988) and Ellis and Galvin (1994) as the lower limit above which a location is described as a non-equilibrium ecosystem. But, there is spatial variation between locations in the sub-region. In the areas of Nga-Moru, Dopeth, and Komuria, coefficients of variation were below the 33% threshold. In line with the classification of equilibrium and non-equilibrium ecosystems of Ellis and Swift (1988) and Ellis and Galvin (1994), these areas would be considered equilibrium ecosystems. There are reservations in accepting this suggestion since the location’s rains varied greatly during the period of analysis (1979-2009). Firstly, Komuria’s annual total rainfall ranged from 411.16 mm to 1800.8 mm with an annual average of 950.2 mm; Dopeth 271.8 mm to 1363.5 mm (670.1 mm) and Nga-Moru 239.1 mm to 1190 mm (568 mm). Secondly, relatively stable rainfall only occurs after rainfall increases but it does not eliminate the intra-annual and inter-annual variability.

Thirdly, there is not a uniform agreement on the standard cut-off point to be used as a decision rule to declare locations as either equilibrium and/or non-equilibrium ecosystems. Ellis and Galvin (1994) used a 33% CV threshold and Shepherd and Caughley (1987) used a 30% CV cut-off. Conversely, Briske et al. (2003) used < 300 mm while Coppock (1993) indicated < 400 mm as a threshold indicative of non-equilibrium systems. Treating Nga-Moru, Dopeth, and Komuria as equilibrium ecosystems based on a single parameter would, therefore, not suffice and the 33% threshold cut-off level was arguably a rule of thumb. An investigation of a range of other ecosystem parameters such as ecohydrological feedbacks will be necessary for proper classification of the Karamoja ecosystem and other semi-arid areas in general. In the meantime, this study suggests that a dynamic state description for the Karamoja ecosystem is preferable.

With regard to the trend in temperature, three issues emerge; first, temperatures are rising; second, the rise displays a spatial and temporal character and third, all the long term temperature changes are above 0.5 degrees Celsius. Earlier studies of 1950-2008 temperatures had also indicated that temperatures in Africa are warmer than they were 100 years ago. The warming over the 20th century has been at a rate of 0.5˚C (Hulme et al., 2001). In Uganda, temperatures have also been generally rising by as much as 1.5°C in most areas (Mubiru et al., 2012; Funk et al., 2012). The results of this study are within comparable margins of between 1.2°C and 1.4°C for mean; 0.5°C and 1.1°C for minimum and 1.4°C to 2.2°C for maximum temperature. A shift to warmer climate has the potential of amplifying the effect of periodic droughts with a further likelihood of reducing crop harvests and pasture availability (Funk et al., 2012).

Earlier, it was stated that rainfall in the region has shown a positive but non-significant trend. Given the observed positive trend in temperatures, this could imply that the rainfall patterns may not be able to offset the potential impacts of progressively rising temperatures. However, Neely et al. (2009) have observed that temperature increases of up to 3.0-3.5° C could increase the productivity of crops, fodders and pastures. In south eastern Australia (Barraba and Mutdapilly areas), Cullen et al. (2009) have shown that given minimal change in annual rainfall, a temperature increase of up to 4.4˚C will lead to increased pasture production. As shown in the results, the sub-region experienced slight, but consistent rise in total annual rainfall from about 2000 to 2008. This may have resulted in an improvement in forage availability. The growth could be sufficiently rapid that some of the grazing landscapes could be converted into bushland. Secondly, the slight progressive improvement in rainfall after 2000 could have altered pasture patterns as well as grazing regimes. This may be due to the influence of increasing biomass growth that, in turn, influences available fuel load. Thirdly, the likelihood of attracting many pastoral people (in particular those that have lost their livestock through livestock raids) to transition into cultivated agriculture thereby increasing cultivable land becomes higher. This pattern has been observed in this in chapter 4 in which croplands increased by tenfold over the last decade (2000-2013) alone.

6.4.2 Climate variability intensity in Karamoja sub-region

The evolution as well as the spatial dimension of extreme climatic events, such as a drought, is important if superficially drawn conclusions are to be avoided (Balint et al., 2011). Rainfall variability intensity and temperature variability intensity results were able to identify spatio-temporal variability characteristics of rainfall and temperature. The variability indices in particular, rainfall variability, showed the spatio-temporal evolution of extreme events including drought and potential flood events in the sub-region. Intensity of extreme climatic events has hitherto been observed in Southern Africa with the occurrence of droughts and devastating floods (Mason et al., 1999). However, the coefficients of variation in semi-arid locations can only reveal the existence of variability without revealing the distinctive spatio-temporal pattern of such variability. In their work, Balint et al. (2011) showed that combined drought indices were relevant in monitoring the evolution of drought and spatial distribution of such droughts in the affected areas. The results of this study underline this. The pattern of variability in the sub-region suggests a lack of smooth transition between events and this has also been observed in semi-arid areas of Ethiopia (Urgessa, 2013).

Additionally the results of this study have shown a reduction of multiyear droughts in the recent past (from about 1997 to 2008) compared to the period between 1979 and 1996. This corresponds to the La Niña events that have been observed in semi-arid areas of Uganda and Uganda in general (Barasa et al., 2013). These patterns hold implications for pastoralists and their livestock; by influencing forage (Niamir-Fuller and Turner, 1999), water (as has been observed in the Transjordon plateau) (Hill, 2010), and disease patterns (as has been observed among East African pastoralists when there are disease epidemics and livestock starvation associated with recurrent drought events) (Quaas and Baumgartner, 2011). Further, these patterns could lead to the existence of multiple states. In particular, the spatial oddities allow for reinforcements and sustenance of livestock from other locations through opportunistic management. Opportunistic livestock management has been noted as a key management and coping strategy used in semi-arid regions (Quaas and Baumgartner, 2011; Weber and Horst, 2011). This is because plant-cover in arid and semi-arid environments shifts across dynamic thresholds between different ecological states in response to disturbance such as grazing, drought and fire (Heshmati and Squires, 2010). In the event of floods, the presence of good pastures for several months has been observed (Tschakert et al., 2009). Nevertheless, flood events tend to affect poorer herders, and those with small herds much more than those with more resources (Ngugi and Conant, 2008).

6.4.3 Projected rainfall in Karamoja sub-region

This study has shown a uniform agreement in the twenty models projecting a similar trend in rainfall over the region. The total annual rainfall for the sub-region will progressively increase within and between time-slices (2040-2069 and 2070-2099). This corroborates with the earlier findings of Shongwe et al. (2011) and the observed trend attributable to the thermodynamic effects and changes in the structure of the Eastern Hemisphere Walker circulation over the East African region (Shongwe et al. 2011). The non-significant trend in rainfall expected during both mid-century and end century observed in this study has been observed in Uganda (Caffrey et al. 2013). This pattern could be a result of high inter-annual and spatial variability in rainfall observed in Karamoja. Despite the lack of a significant trend within time-slices, the simulated mean rainfall between time slices was significantly differently. This corroborates the findings of Shongwe et al. (2011) that point to a wetter climate despite uncertainty in the rate of change.

Both singular and multi-year negative deviations in annual rainfall were observed indicating that there will be extreme climate events in the coming future. This corroborates earlier findings of Caffrey et al. (2013) that show that Uganda will experience an increase in the frequency of extreme events including heavy rainstorms, and floods among others. This similar pattern has been observed for the Sahel region in mid to late century under RCP 8.5 scenario (Vizy et al. 2013). This study also observed a unique occurrence in which one of the locations in the region (Abim district) would experience a decrease in rainfall in the mid-century under RCP 4.5. This corroborates with earlier findings of Sarr (2012) that have shown divergent future rainfall patterns in the Sahel.

6.4.4 Projected onset and cessation of rainfall in Karamoja sub-region

This study has shown that there will be adjustment in onset and cessation compared to the historical period (1980-2009). This adjustment from 20th-62nd to the 17th -63rd is an improvement when compared to other areas in Uganda with a unimodal rainfall regime (Mubiru et al. 2012). This provides a rather peculiar opportunity of hope of an expanded growing season length. This is because the timing of rainfall onset and cessation are important indicators of growing season length and climate change (Linderholm et al. 2008). This apparent expanded growing season length could perhaps explain the relatively high projected net primary production (NPP) in the sub-region. However, this contrasts with the findings of (Mbuvuma 2013) who reported a contraction in growing season days in Zimbabwe. Given the projected expansion in growing season length and projected increase in total rainfall; an escalation of bushland encroachment in the sub-region will potentially be exacerbated; because vegetation in semi-arid areas is sensitive to changes in precipitation (Funk and Brown, 2006) and seasonality (Zhang et al. 2005). These changes will potentially alter the dynamics of herbaceous forage species essential for grazers such as cattle but the green-up may support the availability of browse in the sub-region.

6.4.5 Projected temperature in Karamoja sub-region

Projected warming arising from increase in minimum, maximum and mean temperature over Karamoja sub-region corroborates with the findings that have shown that there will be a warming over East Africa (Waithaka et al. 2013). This projected warming will be a direct effect of continued increase in carbon dioxide emissions during the 21st century. The projected warming in minimum temperature is for example within comparable margins to the global mean average (1.1°C-2.6°C) projected by the IPCC. Further, this study's results also compare quite well with the findings of Shongwe et al. (2011) and Sarr (2012) that have shown a potential increase in temperature during the 21st century.

Three scenarios will be expected with regard to temperature in Karamoja sub-region. Firstly, a unique uniformity in the rising trend of minimum temperature under both RCP 4.5 and RCP 8.5 but with a sharper rise under RCP 8.5 leading to an increasing gap between the two emissions pathways. This is attributable to continued rise emissions concentrations that the fifth assessment report (AR5) has shown will continue rising (RCP 4.5 near-term 423 ppm, mid-century 499 ppm and end-century 532 ppm) (Stocker et al. 2013). Already, the carbon dioxide concentrations in the atmosphere have reached 400 ppm as of May, 2014 (WMO 2014); thus providing evidence for the progressive rise in temperatures over the sub-region.

Secondly, a sluggish rise in maximum temperature under RCP 4.5 during the mid-century but a sudden and a progressive rise in the end century will be experienced. Further, compared to the growing gap expected in minimum temperature, maximum temperatures reveal a closing gap pattern. This finding is indicative of a declining effect of rising carbon dioxide emissions on temperature. Thus, revealing that any additional increases in carbon dioxide emissions in the end-century will lead to marginal increases in maximum temperatures over the sub-region.

Thirdly, there will be an increasing gap after 2070 between mean temperature under RCP 4.5 and RCP 8.5 emissions scenario. Despite this gap, all concentration pathways will lead to higher mean temperatures. This is in agreement with the findings of Stocker et al. (2013) who show that temperatures will continue to rise during much of the 21st century and that mean temperature will generally be higher under higher emissions pathways. This is attributable to the differences in warming potentials exhibited by different RCPs (Reisinger et al. 2011).

6.4.6 Climate change induced forage production in Karamoja sub-region

Different carbon dioxide emission concentrations will have differentiated influence on net primary production in semi-arid Karamoja. Despite attaining the conventional value of 3000 gDM/(m^2.day); a value that expresses the maximum production that can be achieved as a function of temperature (basically a proxy for solar energy) and water availability (Gommes 2014), increase in temperature will lead to a negative trend in forage production in the sub-region. Under RCP 8.5 a negative relationship between vegetation and greenhouse gas emissions concentration exists with subsequent decline in pasture availability (van Vuuren et al. 2011). Elevated temperatures affect plant phenology, reduce stomatal conductance and subsequently, reduce photosynthesis and growth of many plant species leading to reduction in net primary production (Notenbaert et al. 2007). The decrease in NPP associated with increased temperature under RCP 8.5 could also be a result of water stress arising from increased evapotranspiration (Zhao et al. 2013). The projected increase in temperature under RCP 8.5 may further worsen the already evapotranspiration in the sub-region thus constraining plant growth. In addition, at present, the sub-region is dominated by C4 grasses that are already efficient carbon dioxide users; further increases in carbon dioxide in the atmosphere will have negibile beneficial effect on their productive potential.

In contrast to the findings of Chang et al. (2013) a strong relationship between projected rainfall and NPP was observed with a twofold rise in NPP under the highest emission scenario (RCP 8.5). These positive changes in NPP result from synergistic effects of carbon dioxide concentration, climate changes, and vegetation changes (Alo et al. 2008). Climate change has considerable influence on vegetation productivity but indicated that the range of effect depends strongly on the climate scenario used and the persistence of carbon dioxide effects (Reyer et al. 2014). In addition, the positive response of vegetation productivity under changing climate can only be realised if water and nutrient supplies are not limited. This is because nutrient deficiencies limit photosynthetic responses to elevated carbon dioxide (Boisvenue and Running 2006).

Spatial differences in forage production will continue to exist in the sub-region. Moroto (NPP_rain 1336 g/DM m^{-2} yr^{-1}, NPP_temperature 2377 g/DM $m^{-2}yr^{-1}$) and Kotido (NPP_rain1066 (g/DM m^{-2} yr^{-1}), NPP_temperature 2424 (g/DM m^{-2} yr^{-1}) districts will experience an increase in NPP under all-time slices and emissions scenarios. However, Kaabong district's NPP performancewill be lower than (NPP_rain 1710 g/DM m^{-2} yr^{-1}, NPP_temperature 2349 g/DM m^{-2} yr^{-1}) the present estimates (Grieser et al. 2006). Indicating that projected improvement in rainfall total and a slight expansion in growing season window will have minimal impact in NPP production in this location. This variation is a direct result of differences in projected rainfall in the various locations. The total annual precipitation of a location influences its NPP (Epstein et al. 2006).

6.5 Conclusions

This study has been able to show that Karamoja's climate is typified by climatic variability with episodic occurrence of high wetness intensity and drought events. This study has revealed that these patterns of variability occur on a spatio-temporal scale with a lack of a smooth transition and evolution of the extreme events. The return period of the extreme events in this study region has been shown to be variable. For example, in the recent past (1997-2008) multi-year drought recurrence has generally reduced yet at the same time there has been an increased occurrence of extreme wet events in the same period compared to the period between 1979 to1996. This study has also shown that projected rainfall will progressively increase in total under the two projection scenarios (RCP 4.5 and RCP 8.5) but the increase will be non-significant within the time slices and across the 21st century. Projections also revealed that spatio-temporal rainfall variability will continue in the sub-region with total rainfall remaining higher in western Karamoja compared to eastern Karamoja. An early onset and late cessation in rainfall will be expected in the sub-region. However, all temperature regimes under both RCP 4.5 and RCP 8.5 will be expected to increase during the course of the 21st century. These patterns in temperature and rainfall will be expected to induce variable production in forage in the sub-region. Notably, increase in temperature under RCP 8.5 will lead to a negative trend in forage production.

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CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7. 1 Spatio-temporal dynamics of forage in Karamoja sub-region

It was found that forage dynamics vary significantly in space and time. This spatial and temporal variation in forage quantity is a strong indicator of heterogeneity in the sub-region; a key attribute that supports transhumant livestock production as exercised in Karamoja sub-region.

The sub-region has a high diversity of grass forage species but their abundance is dominated by fewer species that vary by location and season. The key forage species included perennial grasses such as *Hyparrhenia rufa, Sporobolus stafianus, Sporobolus sphacealata, Chloris pychnothrix, Pennisetum unisetum, Setaria sphacealata, Hyparrhenia diplandra* and *Panicum maximum* and a few annuals such as *Aristida adscensiones.*

The pastoralists and agro-pastoralists in the sub-region have a complex-diverse local ecological knowledge of forage species interms of; their habitat characteristics, growth forms, and growth periods, preferences by livestock species and perceived dynamics by season. This knowledge is both individual and collective based on the pastoralists'day-to-day interaction with their environments and lived experiences that are passed from one generation to the other over the years. It is therefore imperative that this type of knowledge is integrated with the more tehnical knowledge and procedures so as to better understand forage dynamics in the sub-region.

The geospatial analysis shows significant land use and land cover changes in the last three decades (1986-2013) with accelerated increase in croplands and bushlands over the last decade (2000-2013) alone. These heightened increase in croplands and bushlands constitute a major threat to the positive dynamics of forage resources in the sub-region because they mainly affect the grasslands, the key grazing land covers in the sub-region. The rapid increase in croplands also point to a shift in livelihood options in the sub-region with an increased adoption of crop farming.

It was also found herbaceous and woody forage strongly correlated with NDVI in the different land cover units. This pattern was also variable a cross space and time. Different regression equations existed for different vegetation types (woodlands, grasslands and thickets/hrublands). This shows that a combination of rapid field assessments and moderate satellite imagery such as MODIS NDVI offer a sound option for monitoring forage resources at local to regional scale level.

7.2 Determinants of forage dynamics in the study area

Besides rainfall-seasonality, livestock related production factors (herd size, number of kraals); environmental conditions (soils), institutional related factors (rules and regulations, movement restrictions) and socio-demographic factors such as length of residence at a location were identified to influence forage dynamics in the sub-region. This demonstrates the community's ability to observe and monitor their environment and forage resources dynamics in particular. A number of the factors identified, influence forage dynamics by determining access to forage resources rather than the forage quantity at a given location in time. This further reveals that the community recognises the fact that even in the event of actual availability, various factors may either create 'artificial forage scarcity' and/or enhance its availability by increasing access to forage resources in the rangelands.

The study also recoganises the significant effect soil nutrients such as N, P, K, Mg and Ca have on forage dynamics by influencing the quantity of forage obtained from different land cover types (woodlands, grasslands, and thickets/shrublands. This confirms the fundamental role soil nutrients play in plant growth and biomass accumulation. The results also showed that the sub-region generally has low availability of soil nutrients thus revealing the assymmetrical distribution of soil nutrients that leads to spatial and temporal heterogeneity that typifies semi-arid rangeland ecosystems.

Development interventions such as indiscriminate development of watersources and protected kraals significantly influence forage dynamics by influencing forage species composition and abundance along the grazing gradient. This is because piospheres are characterized by localized grazing pressure within a location and their effects and zones of maximum impact gradually expand outward over a period of time. The results showed emergence of increaser species such as *Eragrostis superba, Eragrostis ciliaris, Sporobolus stapfianus* and *Sporobolus pyrimidalis* at the expense of decreaser species that are desirable forage species. These patterns were particularly high around the waterholes than in the protected kraals. This variation could be attributed to the convergence effect of livestock from different kraals at waterholes leading to higher grazing and trampling intensity at the waterholes than at the protected kraals.

7.3 Climate change induced forage production

Historical climate trends (1979-2009) revealed that climate variability is an inherent characteristic of Karamoja sub-region. The area has been experiencing pronounced inter and intra-annual variability particularly in rainfall occurring in both space and time at differentiated intensities. Further, the sub-region is vulnerable to extreme events (droughts and floods) with a lack of a smooth transition between the two events.

The climate of Karamoja is projected to change with minimum and maximum temperatures expected to increase during the 21st century against the baseline period (1980-2010). Minimum temperature will be expected to increase by 1.8^{0}C and 2.1^{0}C under RCP 4.5 and RCP 8.5 during mid-century (2040-2069) and by 2.1^{0}C and 4.0^{0}C under RCP 4.5 and RCP 8.5 respectively in the end-century (2070-2099). Strong inter-annual and intra-annual rainfall variability accompanied with early onset and late cessation will be expected in the future.

The observed changes in rainfall and temperature in the region will be expected to induce variable forage production. Continued increase in temperature to RCP 8.5 level for example will be expected to induce negative forage production trend in Karamoja sub-region, indicating that higher temperatures will become a limiting factor in forage production in the sub-region in future.

7.4 Recommendations

There is need to undertake community based land use planning so as to better guide the development of crop farming whilst preserving key grazing areas as well as providing for smooth access to the grazing lands. Further, there is need to continue monitoring the current trends of land use and land cover change because the drive to increase land area under croplands to address food insecurity is still on-going, the rate of bushland encroachment is increasing, land use and cover change influences livestock resources dynamics, and may further influence socio-political perturbations in the sub-region.

Undertake participatory management of rangelands in the sub-region by tapping into the traditional ecological knowledge of the community. This is because this study has shown that this knowledge is reliable, can be measured and can add value to the scientific body of knowledge thus can be rallied upon in participatory rangeland planning and management. In doing this, the development of environmentally and culturally acceptable management actions and the strengthening community institutions will be enhanced.

Decision makers should use location specific and sub-regional level climate information in developing adaptation measures and provision of early warning information to the communities and other actors within and outside the sub-region. This will facilitate their ability to pro-actively plan and respond to potential micro-shocks, meso-shocks and macro-shocks of climate variability and change in the sub-region.

A nutritional quality assessment of key forages (grass and browse) in the sub-region needs to be undertaken. This is because information on nutritional quality of forage is important in sustaining growth and improving livestock production. In addition, forage nutiritional information is vital for attaining proper stage utilisation, and envisaging nutrient deficiencies, as well as in proposing relevant supplemental requirements for the livestock. In doing this, attention should be paid to the grasses identified by the communities as either good or bad forages.

There is need for a comprehensive sub-regional soil mapping and nutrient assessment as well as institute a long term monitoring of soil properties and biomass dynamics under different grazing land covers in the Karamoja sub-region. This is important in guiding land use planning, and management of soils for long term productivity, sustainability and health.

Investigate nutrient distribution along the piosphere gradient for an extended distance to determine whether there is continued plant species variation with soil nutrients and landscape. In addition, there is need to compare herbaceous and woody forage species abundance in former protected kraals and abandoned kraals to analyse plant recolonization in the piosphere zones, as well as model out piosphere dynamics and structuring of herbaceous and woody plant composition and abundance in the sub-region. This will provide information relevant for rangeland rehabilitation and restoration.

In light of the projected climate change in the sub-region, there is need to undertake vulnerability assessment and mapping as well as model potential livestock herd dynamics. In addition, it will be imperative to understand how the social and cultural conditions affect adaptation at present and in the future. This is particularly important as climate change impact studies and projections such as this current study require additional information on vulnerability pathways, behavioural and societal aspects and local level systems functioning for proper utilisation.

APPENDIX A: HOUSEHOLD SURVEY QUESTIONNAIRE

ASSESSMENT OF FORAGE DYNAMICS AND ITS DETERMINANTS UNDER VARIABLE CLIMATE IN KARAMOJA SUB-REGION OF UGANDA

Location Details

This section **MUST** be filled before the interview.

Name of Interviewer
Date of Interview

Time of interview (start)	Time of interview (End)	Number of minutes taken
Household identification code	Sub-county	
District	Parish	
County	Village	

Section 1: Household characteristics

Name of household head	Type of marital union
Sex of household head (1) Male (0) Female	Education level of household head
Age of household head	Number of years completed in school
Marital status of household head	Number years resident in the current location
Number of wives married	Number of household members
	Primary Activity of household head (list all possible combinations)

Key:

1.**Marital status:** 1= married, 2= divorced, 3= widow, 4= widower, 5= single (for members of above 15 years).6= not applicable (for children of 15 years and below). 2. **Education level:** 1=Never attended formal education, 2=Primary, 3= secondary (O level), 4= secondary (A'level), 5=Tertiary education, 6=adult education, 7= others, specify 3. **Type of marital union**: 1=

monogamous, 2= polygamous, 3= wife inherited 4. **Primary activity of household members:** 1= livestock grazing, 2 = milking cattle, 3 = crop production, 4= informal trade, 5= formal employment, 6 = domestic household chores, 7= craft, 8= security provision, 9 = mining/quarrying, 10 = others specify

2. Household basic assets

Type of asset	**Availability (1 = Yes, 0= no)**	**Number available**	**Ownership of the asset**
Mud and wattle			
house			
Pit latrine			
Solar panel			
Bicycle			
Car			
Radio			
Cell phone			
Television			
Security equipment			
Cattle			
Goats			
Sheep			
Camels			
Donkeys			

3. Livestock Production

3.1 Do you own livestock? 1 = yes, 0 = no. If yes, why do you keep livestock?

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……………………………………………………………………………………………………….

3.2 If no, why don’t own livestock?

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3.3. Livestock asset holding

Livestock type	**Does your H/H own any of the mentioned livestock type**	**Total no.**	**born**		**Number that have died**		**Sold**	**Number received**	**Number given away**	**No. stolen**	**No. purchased**
			Wet	**Dry**	**Wet**	**Dry**					
Cattle											
Goats											
Sheep											
Camels											
Donkeys											

3.4 What is the state of the livestock herd?

Livestock type	**Livestock number**	**What is the sex distribution**		**How many are**		
		Male	Female	Juveniles	Sub-adults	Adults
Cattle						
Goats						
Sheep						
Camels						
Donkeys						

3.5 Livestock management

Do you have access to the following livestock services	Livestock type							
Livestock service	Cattle	goats	sheep	donkeys	camel		How much do you spend on each category of service	
Feed supplements								
Medicines								
Vaccines								
Water								

4. Forage resources dynamics

4.1.1 Describe the status of forage resources across the year (For month state whether the forage is 1= available; 0 = not available

Livestock type	Months of the year											
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Cattle												
Goats												
Sheep												
Donkeys												
Camels												

4.1.2 How severe or good is the status of forage resources in the months mentioned above

Livestock type	Months of the year											
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Cattle												
Goats												
Sheep												
Donkeys												
Camels												

1 = very good; 2 = moderately good; 3 = very severe,, 4 = moderately severe

4.1.3 What are the currently dominant forage species in the grazing areas?

Forage species (local name)	Dominance (1 = very dominant, 2 = moderately dominant, 3 = not dominant)	Location (1 = hill slopes, 2= lowlands, 3 = wetlands, 4 = woodlands, 5 = open lands)	Intensity of grazing (1 = very intense, 2 = moderately intense, 3 = not intense)

4.1.4 What forage resources are present today but were not available 30 years ago?

Forage resource (local name)	Reason for current presence and source of origin if any known

4.1.5 What are the most preferred forage resources by livestock types?

Most preferred forage resource	Livestock type				
	Cattle	Goats	Sheep	Camels	Donkeys

5. What is the status of the following conditions in your area?

Condition	Description	Selected option
Rainfall	1 = good, 0 = not good	
Temperature	1 = good, 0 = not good	
Gentle slopes	1= good, 0 = not good	
Flat lands	1 = good, 0 = not good	
Low lands/wet lands	1 = good 0 = not good	
Livestock numbers	1 = high 0 = not high	
What use the land is under	1 = many uses 0 = one use cattle grazing	
Frequency of burning grass	1 = very common, 0 = not common	
Ease of access to grazing site	1= very easy, 0 = not easy	
Frequency of grazing at the site	1 = very often, 0 = often	
Dependence livestock	1 = very high, 0 = not high	
Type of soils	1 = good, 0 = poor	

Additional information	
How many people graze in the grazing grounds you use?	
How far are the grazing grounds during the wet season?	
How far are the grazing grounds during the dry season?	
Are there any grazing rules governing grazing in your area? (1= yes, 0 = no)	
Do you experience conflicts over grazing areas?	
When are the conflicts more intense (1 = wet season, 0= dry season, 2 = same throughout)	

6. What problems are you facing in livestock production?

Problem	Severity (1 = very severe, 2 = moderately severe, 3 = not severe)	Problem	Severity (1 = very severe, 2 = moderately severe, 3 = not
Diseases		Drought	
Low yields		Insecurity	
Water shortage		Feed shortage,	
Poor market access		Poor veterinary services,	
Low market prices		Land shortage,	
Poor breeds		Grazing lands conflict	
Floods		Cattle rustling	
Human-wildlife conflicts		Restricted movement	
Others specify			

7. **What actions have you taken to cope with the mention problems?**

Problem	Actions taken	
	Wet season	Dry season
Diseases		
Low yields		
Water shortage		
Poor market access		
Low market		
prices		
Poor breeds		
Floods		
Drought		
Insecurity		
Feed shortage,		
Poor veterinary services,		
Land shortage,		
Grazing lands conflict		
Cattle rustling		
Human-wildlife conflicts		
Others, specify?		

1. **Climate variability trends and perceptions**

8.1 Have you experienced variability in climate in your area? 1= Yes 0= No.

8.2 What indicators are there to show that there is climate variability occurring in this area?

Too much rainfall	Late rainfall onset
Little rainfall	Early rainfall cessation
Drought	Late rainfall cessation
Floods	New diseases (example??)
Early rainfall onset	New pests (example???)
Hailstorms	Others specify

8.3 What do you think is the cause of climate change?

……………………………………………...

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8.4 How has climate variability affected your livestock and what measures you have undertaken to overcome it?

	Effect	Tick	Coping/adaptive measures
1	Pastures are not enough (no longer available)		
2	Livestock growth rate has changed		
3	Pasture types in the area have changed (specify)		
4	New diseases have emerged (specify)		
5	Disease incidences are high		
6	Yields (milk and meat) have changed (Specify)		
7	Animal health is poor		
8	Breeds have changed		
9	Water is not available		
10	Accessibility to markets has been affected (specify)		

Thank you for your cooperation

APPENDIX B: CHECKLIST FOCUS GROUP DISCUSSIONS (FGD) AND KEY INFORMANT INTERVIEWS

Note: Provide purpose of the FGD, introduce the team and ensure to create ambient conditions

A. Checklist for FGD.

1. How are the animals doing?
2. What grasses and browse (explain the browse) are in the grazing lands? (generate list of both)
3. In which season are the above named grasses and browse plants present? (draw columns on flip chart-specify against each)
4. How abundant is each of the named grasses and browse in the grazing areas? (provide each participant with 10 stones each for proportional pilling)
5. In which areas are these grasses and browse plants found? (continue filling the table)
6. Which grasses and browse species are preferred by which animals?
7. Why are these grasses or browse preferred by the livestock ?(What are the good forages; and what are the indicators of good forages)
8. Which grasses and browse plants are now here which were not there 30 years ago? (use this question among the elders)
9. What changes are occurring in the grazing areas? (allow general discussions)
10. Which grasses have disappeared and/or reduced in abundance in the grazing areas in the last 30 years?
11. What problems do you face in search of grasses and browse for your animals?

B. Check list for Key informant interviews

1. What is the status of livestock production in the Karamoja sub-region?
2. Describe the state of climate in the sub-region? How has it affected livestock?
3. Describe the status of forage resources in the District and the sub-region?
4. What challenges have you seen the pastoralists/herders facing with regard to livestock rangeland resources?
5. What efforts are being undertaken to improve livestock production in the district/sub-region
6. What environmental changes have you observed in the district/sub-region?. What are the causes of these changes?
7. What is the status of security in the region; and how does this relate to livestock resources (water and forage)?
8. How may forage resources management be improved in sub-region?