

**CLIMATE VARIABILITY EXTREMES, PASTORALISTS ADAPTATION
STRATEGIES AND FUTURE LIVESTOCK PRODUCTIVITY IN THE RANGELANDS
OF UGANDA**

BY

**OWOYESIGIRE BRIAN BRITEX
M.Sc. ANIMAL SCIENCE (MAK),
2011/HD02/18331U**

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DECLARATION

I Owoyesigire Brian Britex, hereby declare that this thesis is my work and has not been submitted for a degree award in any University. All reference materials contained herein have been duly acknowledged.

Signed: Owoyesigire Brian

Date: 11-01-2023

OWOYESIGIRE BRIAN BRITEX

This thesis has been submitted with our approval as University Supervisors

Signed: Denis Mpairwe

Date: 11/01/2023

ASSOCIATE PROFESSOR DENIS MPAIRWE,
Department of Agricultural Production,
School of Agricultural Sciences, CAES,
Makerere University.

Signed: Polly Erickson

Date: 11/1/2023

DR. POLLY ERICKSEN,
Senior Scientist/ Program Leader,
Sustainable Livestock Systems,
International Livestock Research Institute (ILRI).

DEDICATION

This thesis is dedicated to my dear parents, the family of Mr. and Mrs. Kamukugize Steven, my dear wife Mrs. Loyce Mpairwe Owoyesigire and children (Esther, Timothy, Philip and Ethan).

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ABSTRACT

A study was conducted to determine trends of variability and extremes of rainfall and temperature; pastoralists' perceptions to the changes in rainfall and temperature extremes and predict future livestock productivity in the pastoral rangelands under changing climatic conditions. Data on daily rainfall, maximum and minimum temperatures from 1960 - 2013 were obtained from the National Meteorological Authority (NMA). Daily rainfall and temperature data were subjected to trend analysis using non-parametric Mann-Kendall tests. Rainfall and temperature extremes were analysed using RClimdex. Data to establish farmer's perceptions to trends in climate extremes were collected from 240 respondents through household interviews using a pre-tested questionnaire. Data was analysed by descriptive statistics and multinomial logistic regression models using SPSS software. To predict future livestock productivity heat stress was determined and used to derive its implication on future milk production. Temperature –relative humidity index (THI) was used as an indicator of heat stress. ARIMA models in SPSS Expert modeller were used to predict futuristic trends of heat stress. Annual rainfall received showed non-significant increasing trends. Annual total wet days were increasing but not significant ($p > 0.05$). Consecutive wet days (CWD) were increasing while consecutive dry days, CDDs revealed increasing trends ($p < 0.05$). Trends in annual temperature indices revealed significant increases in hot days (TX90p) and warm nights, TN90p ($p < 0.05$). The number of warmest nights (TNx) and hottest days (TXx) was significantly increasing ($p < 0.05$). Mean diurnal temperature range, DTR showed significant decreasing trends ($p < 0.05$). Severe droughts and floods, changes in day hot temperatures and warm nights, shift in start and cessation of rains, were the most perceived climate extremes. Key adaptation strategies pastoralists used included; fencing off grazing land, integration of crop into livestock production systems, diversification of livestock species kept, control of stocking rates and changing grazing time. Age of the household head, marital status of household head,

household size, cattle herd size per household and land acreage available per household significantly ($p < 0.05$) influenced pastoralists adaptation strategies. ARIMA (1, 1, 0) (0, 0, 0)¹² was found the best fit model as it could perfectly produce an excellent match with THI values. Predicted THI values revealed increasing trends of heat stress at a rate of 0.032 per year. By 2040 the predicted THI will be 80 far higher than 72 maximum threshold beyond which Friesian lactating cows begin to suffer heat stress. Consequently, livestock will suffer increased heat stress which is likely to negatively impact on milk production since the current livestock production system is predominantly grassland based with open grazing as the major feed source. Therefore the current drive of pastoralists improving to high grade animals (pure Friesian) is likely not to be sustainable unless appropriate interventions are adopted. Therefore, it's recommended that pastoralists in the rangelands of Uganda should keep livestock genotypes that will tolerate the increasing heat stress specifically indigenous genotypes or their F1 crosses. In addition pastoralists should adopt strategies that minimize heat stress like planting of trees (Silvo-pastoralism) to provide shade in open grazing lands and construction of shades.

CHAPTER ONE

GENERAL INTRODUCTION

1 Background

Globally, rangeland ecosystems cover about 40% of land area occupied by more than 38% of the total global population (ICPALD, 2020) supporting approximately 2 billion people worldwide (Hutchinson *et al.* 2011). In Africa, approximately 43% of land surface is classified as rangelands, more than half of the 70% of the terrestrial surface that is categorized as drylands (Galvin *et al.*, 2008; Reid *et al.*, 2014). With approximately 40% of the continent's land dedicated to pastoralism, it is the main source of livelihoods for the rural population in the vast rangelands of Africa (FAO, 2018). Rangelands are primarily arid and semi-arid lands frequently located in disadvantaged regions, with major constraints on human occupation that include; poor climate (wide variations and extremes of temperature and aridity), soils unsuitable for agriculture, absence of water and difficult to access.

Rangelands are mainly inhabited by pastoralists who are native communities and whose main livelihood activity is extensive livestock production, which relies mainly on natural vegetation. About 69% of the rangelands in developing countries are used for livestock production and contributes 10% of global meat production (Rodriguez, 2008). In Africa, rangelands inhabit 268 to 325 million pastoralists and agro-pastoralists (UNCCD, 2009). In the IGAD (Intergovernmental Authority for Development) region, rangelands comprise about 60 –70% of the total land area and are home to pastoralist and agro-pastoralist communities whose livelihoods mainly depend on extensive livestock production and rain-fed agriculture. With over 60% of livestock population found in the rangelands, livestock sector contributes 10% – 50% of the region's individual countries' agricultural GDP (UNCCD, 2009). Livestock production in rangelands accounts for between 50% and 80% of agricultural gross domestic

product (GDP) in developing countries (Neely *et al.*, 2009). In the Horn of Africa, livestock sector contributes 10% – 50% of the individual countries' agricultural GDP (Behnke *et al.*, 2011).

Rangelands are a vital arid to semi-arid but fragile eco-zones endowed with grazing pastures, wetlands, forests, arable land, and water bodies that support numerous pastoral and agro-pastoral livelihoods and other users who exploit the region's wildlife, woodlands, medicinal plants, minerals, scenic landscapes, water shades, and oil. The rangeland areas of East Africa constitute a basic resource, the use and orderly development of which demands an understanding of the nature and role of each of the components of the ecosystem. Although most of these areas fall in the semi-arid to arid lands they contribute significantly to the national economies, supporting large proportions of human, livestock and wild life populations, and considerable amounts of biodiversity. In Uganda, rangelands are predominantly inhabited by pastoralists and they are the backbone of livestock industry that provides various economic and livelihood opportunities along the value chain. Livestock production contributes 19% Agricultural GDP and 8% to the National GDP of Uganda (UBOS, 2019). Cattle are the most important and are mainly concentrated in an area commonly known as the cattle corridor, which occupies about 51% of the total land area (LDP, 2002) and constitutes the main rangelands of the country. It runs in a swath from the southwest to the north east and cuts across many of the districts, production systems and agro-ecological zones, occupying the lands considered more marginal for crop production. In Uganda, rangeland resources support the majority of livestock and wildlife species and a large human population dominated by pastoralists who hold 80% of the national livestock herd, 90% of the cattle and are the source of 85% of the milk and 95% of meat consumed.

Pastoral production is found at all scales of operations, with most being small herds, providing meat, milk, blood, hides and skins, as well as transport, storage of wealth, means of social security and obligations, security against disasters, obtaining goods and services through barter and generation of cash through local trade or export markets (ICPALD, 2020). Pastoral production is an extensive livestock production, characterized by seasonal herd mobility to track pasture and water over expansive rangelands. In Uganda, pastoralism is the dominant land use in the rangelands employing up to 90% of pastoralist populations. The livestock population stands at about 14.2 million cattle, 16 million goats, 4.5 million sheep, 47.6 million poultry and 4.1 million pigs (UBOS, 2019). About 90% of the country's cattle population are found in the rangelands. Besides livestock production, rangelands are habitats for a diversity of flora and fauna of both socio-cultural, environmental and economic significance (Kideghesho, *et al.*, 2013). They are a source of various goods such as timber and non-timber products such as fibre, gum and resins, honey, medicinal and food plants, minerals, oil, gas, among others. In addition, the rangeland ecosystems provide various services that include water catchment (Flintan, 2014) scenic beauty, as well as habitat for wildlife that form the basis of ecotourism (Moskwa, 2010) in respective countries. Rangelands also host sacred sites that are valued for spiritual and religious purposes (Sala, *et al.*, 2017). These sites often conserve islands of indigenous biophysical resources, including important biodiversity, as well as being linked to the cultural identity of certain ethnic groups (UNCCD, 2009). Rangelands therefore have high cultural diversity closely linked to the ecosystem diversity.

Despite their social and economic importance, rangelands in Uganda are facing a number of challenges. These include declining range condition and productivity due to degradation and land fragmentation; frequent droughts and climate change (Mussa, *et al.*, 2016; Sayre, 2017). The drought and erratic flood episodes normally result in depletion of water and pasture

resources, often leading to conflict over the scarce resources (Garg and Singh, 2013) as well as livestock losses. Other challenges are insecure land rights and tenure; restricted cross-border and inter-community herd movement; inadequate research, extension and human resource capacity to support implementation of rangeland management programmes; poor knowledge management system; low investment in sustainable rangeland management skills; poor regulation of access to rangeland resources due to weak governance institutions, and inadequate policies: legal, institutional and organizational frameworks.

Climate change manifests itself as rapid changes in climate in the short term (a couple of years) or more subtle changes over decades. Rainfall and temperature characteristics are continually changing due to climate change and frequency of extreme events such as drought and floods are posed to increase (Ayanlade *et al.*, 2018) which will significantly impact negatively on livestock production. Worse still, in pastoral rangelands where communities are transitioning into agro-pastoral systems by integrating crop production, severe droughts reduce soil moisture levels and quite often there is total crop failure (Belay *et al.*, 2005; Ayanlade *et al.*, 2018; Bosekeng *et al.*, 2020), causing serious household food insecurity.

Due to global climate extremes and increased climate variability, rainfall patterns have become more erratic and severe drought periods have become common and daily environmental temperatures are steadily increasing (Akwango *et al.*, 2017). The difficulty facing livestock is weather extremes including intense heat waves, floods and droughts. Livestock are adversely affected by the detrimental effects of extreme weather. Climate change effects in the rangelands have been mainly due to increased temperatures as evidenced by raising hot days and warm nights. In severe drought periods lack of pastures and water resources culminate into death of the livestock (Silvestri *et al.*, 2012). Climatic extremes and seasonal fluctuations in herbage

quantity and quality affects the well-being of livestock which lead to declines in production and reproduction efficiency (Sejian, 2013). Soro et al (2016) reported decreasing trends in consecutive wet days at 47% while the number of heavy precipitation days showed a significant negative trend in Côte d'Ivoire. Consequently, adaptation to, and mitigation of the detrimental effects of extreme climates play a major role in combating the climatic impact on livestock (Sejian *et al.*, 2016).

Understanding of climatic trends and variability of rainfall and temperature extremes is very critical in managing water and pasture resources which are often limiting livestock productivity in the rangelands of Uganda. However, there is no information on climate extremes and trends of rainfall variability and temperature that is available for the pastoral communities in the fragile rangeland ecosystems of Uganda. The only work that has been undertaken specifically for the pastoral rangelands is on change of seasons (Nimusiima *et al.*, 2013); seasonal rainfall variability (Kansiime *et al.*, 2013; Nanfuka *et al.*, 2020) and coping mechanisms to effects of climate change by Nalwanga et al., (2020). There is need to determine trends of climate extremes and variability so as to inform pastoralists other stakeholders in developing appropriate adaptation measures for enhanced resilience to climate extremes.

Studies conducted in rangelands on pastoralists perceptions of trends in precipitation and temperature variability (Alexander, *et al.*, 2006) and climate extremes (New *et al.*, 2006; Anguilar *et al.*, 2009; Leweri *et al.*, 2020) provided information such as the frequency of drought periods, percentage hot days, very heavy precipitation days, consecutive dry and wet days which are critical for planning appropriate adaptation strategies to climate change. In Uganda, studies undertaken (Okonya, *et al.*, 2013; Tiyo *et al.*, 2015; Ajak *et al.*, 2018) documented farmers perceptions to climate change. Atube et al (2022) documented farmer's

perceptions on trends of seasonal rainfall and cropping seasons for Apac district and concluded were highly variable. However, no work has been conducted to establish pastoralists' perceptions to climate extremes in the pastoral rangelands of Uganda. Therefore, there is need to establish pastoralists' perceptions of climate extremes in order to inform the process of developing appropriate adaptation strategies.

Climate change is a major threat to the sustainability of livestock systems globally. Generally climate change is associated with increasing global temperatures. Various climate model projections suggest that by the year 2100, mean global temperature may be 1.1–6.4 °C warmer than in 2010 (IPCC, 2018). There is little doubt that climate change will have an impact on livestock performance in many regions and as per most predictive models the impact will be detrimental. Studies for predictions have revealed what the future will be with certainty. Suresh *et al.* (2012) made a forecast of livestock feeds by 2030 in India. Kumar *et al.*, (2014) derived predictions for malaria in India. Although climate extremes are changing and consequently heat stress is increasing, future predictions of heat stress in the pastoral rangelands are not yet documented. It's therefore necessary to predict the future of heat stress and its implications on milk production in the pastoral rangelands of Uganda.

1.2 Statement of the problem

Uganda is divided into ten (10) agro-ecological zones (Appendix 1), based on various factors including edaphic and climatic conditions among others (MAAIF, 2010, 2018). These agro-ecological zones include; North eastern dry lands, north eastern savannah grasslands, para savannahs, Kioga plains, lake Victoria crescent, western savannah grasslands, pastoral rangelands, south western farm lands and highland ranges. Pastoral production is the main livestock production system in the pastoral rangelands agro ecological zone of Uganda and the

people that dwell in this ecosystem environment are referred to as pastoralists. Livestock production remains the main agricultural activity that sustains peoples' livelihoods in the rangelands (Egeru *et al.*, 2014; Muricho *et al.*, 2019; Godde *et al.*, 2020). In the pastoral rangelands of Uganda, livestock production largely depends on grazing natural pastures (Mpaiwe *et al.*, 2011). However, availability of pastures and water resources for both livestock and domestic purposes directly depend on rainfall (Nimusiima *et al.*, 2013; Zziwa, *et al.*, 2015). These changes in rainfall variability coupled with unprecedented increase in temperatures reduces pasture availability and promotes growth of invasive pasture weeds in the rangelands (Egeru *et al.*, 2016; Forest *et al.*, 2017; Sloat *et al.*, 2018).

The impacts of climate change on pastoral communities which thrive on grazing systems is manifested by reduction in pasture growth and biomass (Polley *et al.*, 2017; Sloat *et al.*, 2018), altering species composition, reduced water resources, and disease outbreaks among others (Murray *et al.*, 2011; IPCC, 2018). Hanson *et al.*, (1993) reported that sustained increase in mean temperatures result in significant changes in rangeland species, distribution, composition, patterns and biome distribution. Campbell *et al.*, (2000) reported that species composition in rangelands and some managed grasslands is an important determinant of livestock productivity. Consequently sourcing good quality pastures for grazing livestock in the rangelands becomes very challenging for pastoralists. In Uganda's pastoral rangelands, frequency of drought periods have increased coupled with reduction in availability of quality pastures and surface water sources (Nimusiima *et al.*, 2013). Shortage of pastures and lack of water resources for grazing livestock results into animals of very poor body condition scores and in lactating cattle milk production usually falls to very minimal levels (Gaughan *et al.*, 2015; Boone *et al.*, 2017; Sheikh *et al.*, 2017). In severe droughts livestock deaths especially of cattle have been reported (Gaughan and Cawsell-Smith, 2015; Egeru *et al.*, 2016).

Loss of livestock plunges households down the vulnerability path since livestock is the main source of food and income in pastoral communities that dwell in the rangelands. Increased livestock mortality and poor conditioned livestock coupled with crop failure extremely threatens survival of household livelihoods. Consequently, the pastoralists in the rangelands of Uganda face severe food shortage and reduced household incomes due to climate change. Reducing vulnerability to climate change and climatic extremes can be achieved through reducing exposure to hazardous conditions and/or through enhancing adaptive capacity to better deal with or manage hazardous conditions (IPCC, 2001; Smit, 2004). Availability of pastures and water resources in the rangelands always follow a rainfall gradient (Tegegn *et al.*, 2011; Muricho *et al.*, 2019).

Understanding trends of climate extremes alone is not adequate for pastoralists in designing and making appropriate strategic interventions to address impacts of climate change. Although climate extremes are changing, this does not mean that pastoralists perceive these changes in climatic conditions in the same perspective. Moreover, De Matos Carlos *et al.*, (2020) for example reported that the perceptions farmers have about climate change does not only inform their planting decisions but usually influence the adaptation measures used. Perceptions are influenced and shaped by the individuals' characteristics, their experience, the information they receive, and the cultural and geographic context in which they live (Whitmarsh and Capstick, 2018). Understanding climate change perceptions is a complex processes which encompasses a range of psychological constructs like knowledge, beliefs, attitudes and concerns if and how the climate is changing. Therefore perceiving that the climate is changing is seen as a precondition for the adoption of agricultural adaptation measures (Makuvaro *et al.*, 2018). Studies conducted elsewhere on the farmer's perceptions to climate variability have revealed vital information for adaptation to climate change (Gandure *et al.*, 2012; Eshetu *et al.*, 2016;

Asrat *et al.*, 2017). However, pastoralists' perceptions to climate extremes in the pastoral rangelands of Uganda remain not yet conducted. There is therefore need to know how pastoralists' perceive climate extremes and variability and the strategies they are adapting to enhance their resilience to impacts of climate extremes and increased variability in the pastoral rangelands of Uganda.

Climate extremes affect livestock production in various ways which include; change in reproductive efficiency, reduced growth rates and increasing heat stress among others. Heat stress is considered among the key impacts of climate change on livestock productivity (Kadzere *et al.*, 2013; Lallo *et al.*, 2018). Changes in climate extremes results in unprecedented increase in environmental temperatures and relative humidity which ultimately lead to increase in heat stress. Todorović *et al.*, 2011 observed that heat stress begins to occur in dairy cattle when temperature-humidity index, $THI > 72$. Animals can adapt to hot climates, however the response mechanisms that are helpful for survival may be detrimental to performance. Liu, *et al.*, (2019) documented that heat stress results in a significant financial burden to livestock producers through decrease in milk component and milk production, meat production, reproductive efficiency and animal health. Therefore determining future heat stress conditions in pastoral production systems will contribute to a comprehensive understanding of the livestock productivity dynamics that are critical for decision making in developing appropriate adaptation strategies for future changing climatic conditions in the pastoral rangelands of Uganda

1.3 Justification of the study

In Uganda, the pastoral production system is undergoing transition into an agro-pastoral system. This transition is attributed to a number of factors such as reduced pasture availability, a reduction in milk production, slow growth rates and weight gains and erratic rainfall patterns.

The impacts arising from climate variability and extremes have further increased the frequency of drought periods and floods thus compromising the survival of pastoral livelihoods. Climate extremes like prolonged drought periods, result into adverse effects such as reduced grazeable pastures and biomass yields (Godde *et al.*, 2020) and severe shortage of water (Kimaro *et al.*, 2018) which ultimately reduce livestock productivity.

Changes in the pastoral production systems has led to agro pastoral production which has led to challenges of reduced milk production which need to be addressed in the face of climate change extremes. Adaptation strategies employed by pastoralists to address impacts of climate extremes include; herd diversification, increase mobility, purchasing fodder, reducing livestock, part-time grazing and renting pasture among others (Mayanja *et al.*, 2020; Kemal *et al.*, 2022). In order to adapt to impacts of climate extremes, pastoralists need to perceive that climate extremes are changing and thereafter be able to take appropriate action. Asrat and Simane (2018) for example reported that farmers' perceptions of climate change influenced adaptation strategies in the Dabus watershed, North-West Ethiopia. Moreover, Makuvaro *et al.*, (2018) reported that perceiving the climate is changing is an important precondition for the adoption of agricultural adaptation measures. Therefore understanding pastoralist's perceptions provides better insights and information relevant for addressing challenges of sustainable agricultural development. It is therefore necessary to understand pastoralists' perceptions to climate variability and extremes so as to inform the process of developing appropriate adaptation strategies in the pastoral rangelands of Uganda.

Low livestock productivity has led to pastoralists to change their breeds by crossbreeding local breeds with high yielding exotic breeds to the extent that most of the pastoral rangelands are almost dominated by high grade (>62.5%) crossbreeds especially the Friesian genetics. The

local breeds have existed in these rangelands and adapted to the hot environments. However, it is not known how these breeds will respond to climate change extremes in terms of productivity. In addition the high grade exotic breeds which are replacing the local breeds, have not been studied how they will be affected by the climate change extreme environment. These breeding initiatives come with more challenges as they are always not informed of the future climate conditions. Effective planning must be guided by accurate and reliable information of what the future will most likely be in order to design appropriate and suitable interventions to ensure sustainable livelihoods. It is therefore important to predict future livestock productivity in the face of increasing temperatures and heat stress in order to inform pastoralists and policy of the appropriate interventions. This study was therefore necessary to predict future heat stress and further derive its implications on milk production in the pastoral rangelands of Uganda. It's anticipated the results will inform pastoralists and policy in making appropriate decisions aimed at ensuring a profitable sustainable dairy enterprise under changing climatic conditions.

1.4 Objectives of the study

The main objective of the study was to establish the pastoralists' adaptation strategies to climate extremes and variability and predict future livestock productivity in terms of milk production for the pastoral rangelands of Uganda.

Specific objectives of the study were to:

1. Establish the trends in variability of rainfall and temperature extremes on livestock productivity in the pastoral rangelands
2. Establish pastoralists' perceptions of climate extremes and strategies developed for adapting to the climate changes and extremes.
3. Predict the future heat stress conditions and their impact on livestock productivity in the pastoral rangelands.

1.5 Research questions

- a. What is the pattern of trend in rainfall and temperatures extremes in the pastoral rangelands of Uganda?
- b. Can pastoralists accurately perceive climate extremes and variability?
- c. What adaptation strategies have pastoralists developed to increase livestock productivity?
- d. What factors influence pastoralists' choice of such adaptation strategies?
- e. Which barriers constrain pastoralists' adaptation strategies to climate extremes and variability?
- f. How will rainfall, temperature and heat stress in the pastoral rangelands influence milk production in future?

1.6 The Conceptual Model

This study followed the conceptual model that links climate extremes and variability, pastoralists' perceptions and adaptation strategies. The model examines the linkage between climate extremes and variability to climate change which manifests as severe drought, floods, hot days and warm nights. These extremes have negative impacts to pastoralists' wellbeing as they could result in reduction of pasture availability, change in herd productivity, reduced forage intake, increased heat stress and a decrease in milk production among others. Pastoralists perceived changes including irregular rainfall patterns, change in start and end of rains and increasing temperatures among others as a result of increased climate variability. Pastoralists perceive these changes and develop strategies to adapt and enhance their resilience. Successful adaptation strategies will increase pasture availability, improve herd productivity, increase forage intake and increase in milk production and ultimately this will result into pastoralists' increase in wellbeing. However there are a number of factors which influence pastoralists' choice of adaptation strategies which should be established.

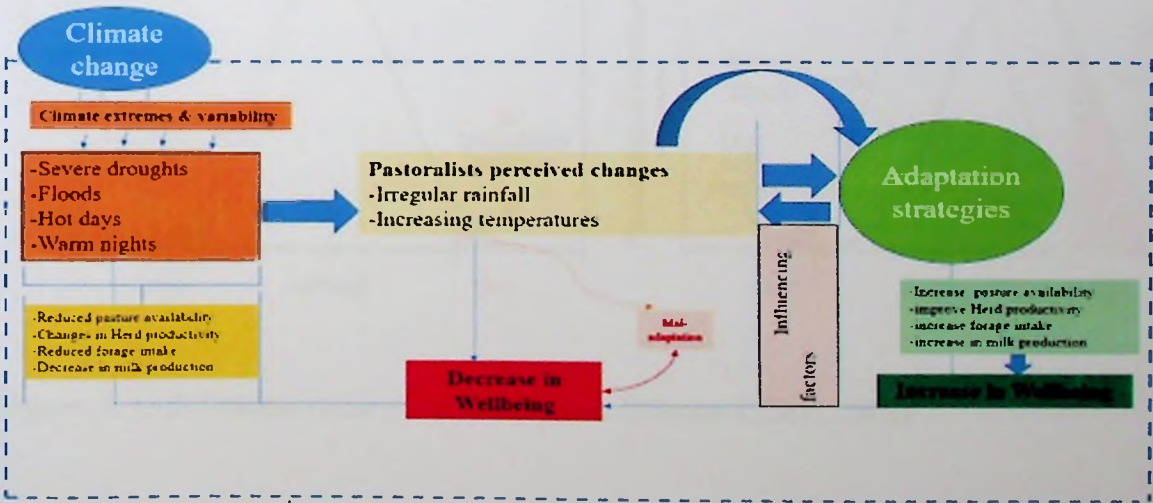


Figure 1. 1: A conceptual model linking climate extremes, pastoralists' perceptions and adaptation strategies

CHAPTER TWO

LITERATURE REVIEW

Climate extremes and variability

2.1 Global overview of weather, climate extremes and variability

Climate variability refers to shorter-term fluctuations around the average without causing the long-term average to change (IPCC, 2015). Climate and weather extremes refer to events that are unusual in their occurrence which may either lie in the upper or lower tenth percentile of the distribution (Figure 2.1). IPCC (2007) defined “an extreme weather event” as an event that is rare at a particular place and time of year. IPCC 2007 further defined “rare” as at least less common than the lowest or highest 10% of occurrences. When a pattern of extreme weather persists for some time, such as a season it’s classified as an extreme climate event (CCSP, 2008).

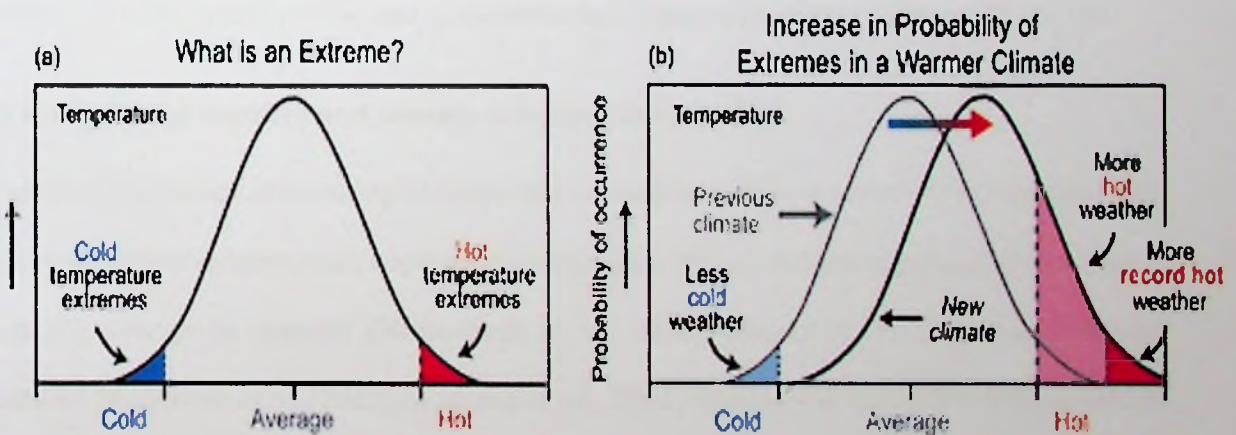


Figure 2. 1: Schematic occurrence of extremes (Source: CCSP, 2008)

Climate extremes include droughts, hurricanes, tornadoes, floods, storms and heat waves among others (IPCC, 2007). Extremes are a natural part of climate system that can cause serious property damage, injury, loss of life, and threaten the existence of some species.

However in some systems, extremes could be essential in for example keeping insect pests under control. The exact threshold for what is classified as an extreme varies from one analysis to another. Parmesan and Martens (2008) reported that extreme events drive changes in natural and human systems much more than average climate. Climate change is not only going to change long means but most likely to change the frequency of extremes as well. For example, extreme precipitation episodes (heavy downpours) have become more frequent and more intense in recent decades than at any other time in the historical record, and account for a larger percentage of total precipitation. The observed changes in temperature extremes are consistent with the observed warming of the climate (Alexander *et al.*, 2006) there has been an increase in the number of hot extremes, particularly very warm nights, and a reduction in the number of cold extremes, such as very cold nights, and a widespread reduction in the number of frost days in mid-latitude regions. Trenberth *et al.* (2007), highlights that ENSO is the leading mode of variability in the tropical pacific and it therefore has impacts on climate around the globe.

2.1.2 Overview of weather and climate extremes in Uganda

In Uganda information concerning weather and climate extremes is not yet documented. Most of the studies have documented; coping mechanisms to effects of climate change (Nalwanga *et al.*, 2022), change in seasons (Nimusiima *et al.*, 2013; Nkuba *et al.*, 2019) and rainfall variability (Kansiime *et al.*, 2013; Mugume *et al.*, 2016; Nanfuka *et al.*, 2020) among others. However, farmers perceive and understand climate extremes depending on the impacts and strength of weather phenomena like catastrophic floods, prolonged severe dry season, and hot winds among others. For example catastrophic floods that took place in Soroti and Katakwi are key examples of extreme events. Landslides have always been common and are reported in vulnerable high terrain areas like Mt. Elgon region. Studies conducted by DDMU (2012) observed that between 2010 and 2013, damages and losses in the agriculture sector caused by the 2010-2011 rainfall deficits were estimated at US\$ 907 million which included crop

production losses, reduced milk products, loss of livestock animal/deaths and higher production costs. FAO (2016) analysed projections of rainfall and temperature events using RCP 4.5 and RCP 8.5 models for various agro-ecological zones in Uganda. In the central area-agro-ecological zone VIII, rainfall and temperatures are projected to increase to 1260.8 mm and 27.0°C respectively by 2070. The likelihood of extreme events is most probable in Uganda for example FAO (2016) reported that in Nakasongola, a significant high risk of increases in extreme temperatures is most likely. FAO (2016) further reports that average rainfall and temperatures in central Uganda are predicted to decrease by -98.3 mm / -85.5 mm and increase of +1.8°C / +3.1°C respectively by 2080s. The percentage of rain days receiving less rain is expected to increase, while days with larger amounts of rain might decrease in future. The percentage of cooler days is expected to decrease significantly, while the temperature range might shift towards days with higher temperatures.

1.3 Climate change and the drought phenomenon

Increased frequency and duration of drought is among the most perceived impacts of climate change and increased climate variability. Drought is defined in different ways from region to another. NDMC (2006) defines drought as a protracted period of deficient precipitation resulting in extensive damage of crops, resulting in loss of yield. Drought can also be defined as a condition of low rainfall over prolonged periods and denotes extreme scarcity of water resources. There are three types of drought namely; meteorological, hydrological and agricultural. Meteorological drought is defined on the basis of the degree of dryness (in comparison to some “normal” or average amount) and the duration of the dry period. Hydrological droughts are usually associated with the effects of precipitation shortfalls on surface or subsurface water supply. Agricultural drought relates meteorological or hydrological drought to agricultural impacts like reduced ground water levels, precipitation shortages,

differences between actual and potential evapo-transpiration. Agricultural droughts affect available soil moisture and consequently limit crop production.

Droughts are characterized by intensity, duration and spatial coverage. Numerous indices have been developed to measure drought intensity such as Yield Moisture Index (Mishra and Singh, 2010; Sun *et al.*, 2017); standard precipitation Index (McKee *et al.* 1995) and Palmer drought severity index (Yu *et al.*, 2019) which uses crop Moisture Index (CMI). Although drought periods will affect and threaten key human livelihood sectors, agricultural based activities will always be the first to be affected by drought because of their dependence on soil moisture. Much of the east African rainfall is influenced by "El Niño/La Niña", and "Southern Oscillation" interactions which are collectively referred to as ENSO events (Nicholson, 1996). ENSO events have a strong influence on the inter-tropical convergence zone (ITCZ), regional monsoon wind circulation, and patterns of rainfall anomalies over many parts of the sub region. The impacts of ENSO events vary significantly from season to season and location to location. For example, El Niño episodes are often associated with above normal rainfall conditions over the equatorial parts of eastern Africa during October to December and below-normal rainfall over much of the Horn of Africa during the June to September rainfall season. On the contrary, La Niña events often give rise to below-normal rains over much of the Greater Horn of Africa during October to December and March to May and above-normal rainfall during the June to September rainfall season. However, seasons are changing due to climate change and the frequency of droughts is increasing.

Gomes and Petrassi (1996) reported that the worst drought occurred in 1910, which affected both the East and West African regions. Based on persistence characteristics, trends, and pseudo cycles, analysis of rainfall data from 1960 to 1993 classified the sub-Saharan Africa into eight groups (Gomes and Petrassi, 1996). They included; Group 1: Sahel and Sudan (Burkina Faso, Cape Verde, Chad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger, Senegal

and Sudan). The worst drought years were 1983, 1984, 1972, 1973 and 1977. Group 2: Southern-central Africa and Madagascar: (Madagascar, Malawi, Mozambique, Namibia, Zambia and Zimbabwe). The worst drought period was in 1991-1992. Group 3: Central Gulf of Guinea countries and Tanzania: Benin, Côte d'Ivoire, Ghana, Tanzania, and Togo. Severe drought periods occurred in 1977 and 1992. Countries in this region experiences bimodal rains. Group 4: East and West Gulf of Guinea: this was the wettest of all the groups. It included countries like Cameroon, Central African Republic, Equatorial Guinea, Gabon, Guinea, Liberia, Nigeria, Sierra Leone. Group 5: Southern Africa: involved countries like Botswana, Lesotho, South Africa, and Swaziland. This group has a relatively low rainfall index and the dry years were experienced in 1973, 1982, 1983, and 1992. Group 6: Horn of Africa and Kenya; group 7 which was the Central-west Africa region had a smooth rainfall pattern from 1964 to 1984. Group 8 included the great lakes region which involved countries like Burundi, Rwanda, and Uganda revealed a rainfall cycle of 7 years.

2.2 Pastoralism and pastoral production systems

MAAIF (2010) classified Uganda into 10 broad and distinct agro-ecological zones including the pastoral rangelands. The pastoral production system is characterized by the movement of both people and livestock in search for fresh greener pastures and water. Capital investment especially in terms of infrastructure development such as roads, schools and hospitals is still poor and at very minimal levels. Pastoralism can either be transhumance where there is seasonal movement of people and livestock herd or sedentary where mobility is high and there is no definitive permanent homes involved. Sere and Steinfeld, (1995) observed that pastoralism as a livelihood option has overtime developed very resilient grazing systems which manage and maintain relatively high human populations on rangelands of low and highly variable productivity. Pastoralists keep a diversity of livestock species such as cattle, sheep,

goats, mainly of indigenous genotypes which are mainly selected for adaptation to the harsh environment. The economic importance of pastoral systems vary widely for instance in Burkina Faso, 70% of the cattle population are herded by the transhumant Fulani (African Union, 2010) and contribute 85% and 75% of milk and beef production. In Niger, 81 % of livestock production comes from pastoral/agropastoral systems (Behnke, 2010). In Chad, pastoral livestock make up 80% of ruminants, 40% of agricultural production, 18% of GDP, and 30% of exports (Behnke, 2010). In Sudan, estimates indicate 90% of the national herd in pastoral systems (Behnke and Osman, 2011). In Tanzania, pastoral/agropastoral systems represent 94% of the livestock and supply 70% of the 1.38 billion liters of milk consumed in the country (African Union, 2010). In Kenya, 14.1 million animals, worth US\$860 million, are kept in pastoral production systems (Catley and Aklilu (2012).

In Uganda, pastoralists and agro pastoralists manage about 44% of the country's cattle, 34% of the goats, 60% of the sheep, 92% of the donkeys, and 98% of the camels. MacGregor and Hesse (2013) estimates that pastoralists contribute 19% of the country's agricultural GDP, make up 90% of the country's livestock owners, keep 95% of the indigenous cattle, and produce 85% of the milk. Muhereza, (2003) reports that the pastoral districts of Kotido, Sembabule, and Nakasongola derive 60%, 65% and 50% of the revenues respectively from livestock related activities, although what they invest into the sector is minimal. Key products from pastoralism and agro-pastoralism include milk, beef, chevron, mutton, camel meat, honey and beeswax, and donkey skins and meat. However, the pastoral production system is undergoing transition into agro-pastoral system by integrating crop production. Crops like maize, beans, sorghum, millet and bananas are increasingly becoming important although due to impacts of climate variability and extremes there is always total crop failure. It's therefore necessary that trends

of climate variability and extremes are thoroughly understood so as to enhance the resilience of the pastoralists for improved livelihoods.

2.3 Silvopastoralism as alternative livestock systems for resilience to climate change

Rigueiro-Rodríguez *et al.* (2011) defined silvopastoralism as an agroforestry system of livestock production where trees and shrubs, which provide diverse ecosystem services to humans are kept on pasturelands. Silvopastoralism is considered among the pastoral production alternatives in mitigation of greenhouse gases and enhancing adaptation to climate change (Blench, 2011) since it involves integration of trees, forage and livestock grazing in a mutually beneficial way. Silvopastoralism contributes to climate change mitigation and adaptation in a number of ways (i) foliage production from trees and shrubs is less affected by varying rainfall and temperature (Papanastasis *et al.* 2008); (ii) woody fodder species in a silvopastoral system increase the fertility of grazing lands by providing suitable conditions for grasses and improving micro-sites for grass growth and (iii) livestock productivity is higher under a silvopastoral system compared to traditional pasture based systems, since fodder trees are of higher quality than many of the herbaceous grasses. Blench (2011) noted that carbon sequestration is the most important environmental benefit of silvo-pastoralism, which utilizes the principle of managed grazing. A study conducted by Gallo (2005) reported that trees either planted or naturally occurring on pasture lands, backyards are used as a sole source of forage for livestock, while at the same time providing other multipurpose ecosystems services and benefits. In Africa, most silvopastoral systems involve extensive open grazing by free roaming animals under scattered natural stands of trees and shrubs (Nair, *et al.*, 2012). In smallholder farming systems, Kiptot and Franzel (2012) reported that the most intensive silvopastoral systems are the stall feeding of animals by fodder from trees grown elsewhere, which is becoming a very common practice.

2.4 Impact of climate change on pastoral livelihoods

Extreme climatic events such as floods and prolonged droughts which are as a result of climate change pose serious implications to survival of pastoral livelihoods. Although most of the impacts of climate extremes and variability will be negative, Thornton et al (2006) noted that not all changes in climate patterns and extremes will result into negative impacts. For example in Ethiopian highlands and in parts of southern Africa like in Mozambique, agriculture and the growing seasons may lengthen under climate change, due to a combination of increased temperature and rainfall changes. The impacts of climate extremes are not evenly distributed – the people who will be exposed to the worst of the impacts are the ones least able to cope with the associated risks (Smit *et al.*, 2001). Climate extremes manifests through increased frequency of extreme weather events like droughts and floods. These negatively affect agricultural production through increased crop failures and reduced livestock production. FAO (2015) reported that in Uganda failure to combat climate change and related impacts will cost Uganda's agriculture US \$ 293-513 million and US \$ 1,401- 2458 million by 2025 and 2050 respectively. IPCC (1996) reported four most likely potential impacts of climate change for livestock related systems as: (i) changes in availability of feed grain; (ii) changes in animal health growth and reproduction; (iii) changes on pasture and forage crops; and (iv) changes in distribution of disease and parasites.

Climate change will further impact on livestock production through changes in; rangeland vegetation structure, in forage quality and quantity, length of growing season and water quality and quantity among others. Ecological impacts like alteration in carbon storage capacity of the rangelands, alterations in greenhouse gas emissions and disturbances in the ecosystem functions. In Uganda, the impacts of climate change and variability are seriously disturbing for example DNN (2007) reported very serious prolonged drought spells were experienced in 1991-2000 and consequently agricultural production fell very drastically to minimal levels.

However, in events of increased rainfall intensities, floods are most rampant and they increase the incidence of water borne diseases such as malaria, bilhazia, cholera, dysentery as they provide a good environment for the proliferation of diseases causing germs and vectors. In addition, climate change and increased climatic variability will heighten tensions over the use of shared water bodies and also increase the likelihood of violent conflict over water resources.

Disputes/conflicts at community levels as a result of diminishing water sources and pastures are common among pastoral communities particularly the Karamojong and Pokot of North-eastern Uganda and Northern Kenya. Encroachment on Queen Elizabeth National Park by the Bansonbola resulting into increased conflicts among the Balaalo (pastoralists) and Banyoro in Buliisa. Furthermore, the melting of ice caps on the Rwenzori Mountains which has increased the erosive power of river Semuliki is as a result of climate change. This erosive power and the associated siltation downstream, compounded by intensive cultivation along the river course has caused the Semuliki to disproportionately erode the Ugandan side and literally blocking its original course. Consequently, river Semuliki has shifted one kilometre into Uganda initiating an on-going dispute on the actual boarder between the Democratic Republic of Congo and Uganda (NAPA, 2007).

Rötter and Van deGeijn (1999) suggested that any shifts in climatic conditions could affect animal agriculture in four primary ways: (i) feed grain production, availability, and price; (ii) pasture and forage crop production and quality; (iii) animal health, growth, and reproduction; and (iv) disease and pest distribution. Elsewhere, studies (Thornton *et al.*, 2014; CSIRO and BoM 2007) have documented and projected the impacts of climate variables on livestock production, however a huge gap of information exists concerning how climate extreme will impact livestock production in the pastoral rangelands of Uganda. There is a need therefore for greater understanding of trends of climate extremes and variability and how will they impact future livestock productivity in the pastoral rangelands of Uganda.

2.5 Pastoralists perceptions to climate variability and extremes

Studies conducted on the farmers perceptions to climate change and variability have revealed mixed reactions (Guoyong *et al.*, 2015; Eshetu *et al.*, 2016; Asrat *et al.*, 2017). For example Maddison (2006) conducted a study in eleven Africa countries and concluded that a significant number of farmers believed that temperatures have increased and that precipitation has declined. However, results from a study Gbetibouo (2009) revealed that farmers who had access to extension services were most likely to perceive changes in the climate because extension services provide information about climate and weather in South Africa. In Ghana, farmers' perceptions to changes in temperature and rainfall revealed mixed results of either decreasing or increasing temperatures and on the contrary there were some farmers who could not perceive any changes (Asante *et al.*, 2012).

In Senegal, Mertz *et al* (2009) reported that farmers were aware of climate variability which had manifested as high levels of rainfall and strong winds. In South Africa, Gandure *et al* (2012) investigated farmers perceptions to climate change impacts and results indicated that farmers perceived increase in temperature, and had observed that summer temperatures were warmer, while winter temperatures were colder. In Zambia, Nyanga *et al* (2011) reported that most farmers perceived no change in the duration of the hot season but reduction in the rainy season duration. However, farmers observed that there were increasing incidences of cold days or cold spells during hot and rainy season while the rainy season had shortened. In Kenya Laikipia district, Ogalleh *et al* (2012) reported farmers' local perceptions to climate change which included; decreasing rainfalls, increasing temperatures, increasing frosts and increasing hunger. Results further showed a trend towards severe droughts in the last four decades, which was in agreement with farmers' perceptions.

Smallholders use a combination of coping and adaptation strategies to respond to variability, including, among others, diversification of crop varieties, migration and sale of livestock.

Significant relationships existed between drought perceptions and some adaptations options such as migration and sale of livestock. However, a study conducted by Slegers (2008) investigated farmers' perceptions and different ways of forecasting rainfall were used by farmers in central semi-arid Tanzania. Results confirmed the use of indicators and signs like baobab tree when predicting rainfall however, not all the time such signs could be trusted. The study further revealed that some farmers could use predictors like the size of the star, the direction of the winds and cloud watching among others.

Farmers recognized differences in drought vulnerability between soil types, location and state of land, land management practices and farmer types (Slegers, 2008). Gedefaw et al (2018) confirmed that level of education, experiences on farming activities, extension services and availability of resources affect the smallholder farmers' perception on climate change.

2.6 Climate change adaptation and mitigation

2.6.1 Concept of adaptation to climate change

IPCC (2001) defined adaptation as an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploit beneficial opportunities. Other authors define adaptation as decision-making processes and actions that enhance adaptive capacity (Smit and Wandel 2006; Füssel, 2010). Ericksen et al., (2011) defined adaptation to climate change as the adjustment of a system to moderate the impacts of climate change, to take advantages of new opportunities or to cope with the consequences. However, UNDP's Adaptation Policy Framework (2005) defined adaptation as a process by which individuals, communities and countries seek to moderate and cope with the consequences of climate change, including variability.

Adaptation to climate change and variability can be pursued at four levels which can be considered as components of an adaptation strategy: improving Baseline resilience, adaptation

to climate hazards, policy and institutional mainstreaming and residue risk of climate change (Troni *et al.*, 2018). For example adaptation to climate change hazards requires system changes to prepare for climate change, which necessitates investments in human, social, physical, natural and financial assets, enabling capabilities and adaptive capacities. Adaptation is mainly about managing uncertainty, for which adaptive capacity development is critical. However, IPCC (2001) observed that adaptive capacity of any system is determined by an array of factors which are neither independent nor mutually exclusive. Factors identified included: economic development, education, technology, knowledge, infrastructure, institutions, equity and social capital as generic determinants of adaptive capacity (Kruse *et al.*, 2013). Furthermore, Smit and Wandel, (2006) reported that some determinants of adaptive capacity are also scale-specific and at the local level the capacity to undertake adaptation is influenced by factors like managerial ability; access to financial, technological and information resources; infrastructure; the institutional environment within which adaptations take place; political influence and kinship networks. However, most studies conducted in Africa, have revealed key livelihood adaptation practices to include; diversification of livelihood activities, institutional architecture, adjustments in farming operations, income generation projects and selling of labour and the move towards off or non-farm livelihood incomes (Osman-Elasha *et al.*, 2006). However, in the rangelands of Uganda such adaptation studies have not been conducted to inform the processes of designing appropriate adaptation strategies to ensure sustainable livelihoods.

2.6.2 Pastoralists adaptation strategies to climate variability and extremes

Key impacts of increased climate variability and extremes in the pastoral rangelands is unprecedented high temperatures and erratic rainfall patterns that result into severe drought periods and scarcity of pastures. Consequently, livestock herders find it very challenging to dwell in such conditions and must therefore develop adaptation strategies in order for

themselves and their herds to survive. Marais, (2011) reported that pastoralist people in Africa hold much of the knowledge on how to adapt, such as where to find water during droughts. Marais (2011) further documented that pastoralists have learnt to cope with droughts through a number of practices such as rotational use of pasturelands, division of livestock, raising different types of livestock which have different grazing habits and traditional knowledge of rainfall and seasonal changes among others. In northern Tibetan Plateau of China, Wang et al. (2014), observed that local herders developed various adaptation strategies, such as planting forage grass, buying fodder from the market, renting pastures, joining formal or informal cooperatives, and diversifying their livelihoods. In western Arunachal Pradesh of India, Maiti et al. (2014) reported that Brokpa pastoralists have developed different types of adaptation mechanisms for example: (i) migration to higher altitudes (ii) proliferation of yak-cattle hybridization (iii) change in timing of migration and (iv) herd diversification among others.

Tahmasebi (2012) found that Shahsevan pastoralists of Iran adjust their herd size or grazing period to the variation of rangeland vegetation based on prevailing and rapidly changing climate conditions. Hurst et al. (2012) reported that the Boran pastoralists change livestock husbandry practices during the droughts by: (1) maintaining herd mobility; (2) leave certain traditional communal grazing areas not utilized for a season to provide extra nourishment for weak and lactating animals in times of scarcity; (3) isolating the sick animals from healthy animals to prevent the spread of disease and (4) using local inherited knowledge to treat animal diseases and injuries. In Zimbabwe and Zambia, Nhemachena and Hassan (2007) reported various farm level adaptation strategies which included: crop diversification, changing planting dates, increased use of irrigation and soil and water conservation measures among others.

In Uganda, pastoralists in Karamoja region have developed physical adaptations measures like drought tolerant livestock breeds, agro-forestry, sustainable land management practices and

use of indigenous knowledge among others (Mubiru, 2010; Egeru *et al.*, 2014). Although numerous studies (Fosu-Mensah *et al.*, 2012; Ogalleh *et al.*, 2012; Zhang, 2019) have revealed a number of adaptation measures developed by pastoralists elsewhere, the exact adaptation strategies pastoralists have developed towards increased climate extremes and increased variability and the factors that influence such adaptation strategies in the pastoral rangelands of Uganda remain not yet documented. This study was therefore conducted to address the existing knowledge gap of pastoralists' adaptation strategies to climate variability and extremes in the pastoral rangelands of Uganda. The study in addition established pastoralists' perceptions to climate variability and factors that influence pastoralist's choice of such adaptation strategies.

2.6.3 Mitigation of greenhouse gases (GHGs) in agricultural based systems

Mitigation in climate change science refers to a reduction in greenhouse gases emissions and enhancement of carbon sinks (IPCC, 2007). A study conducted by Stern (2006) reported production of greenhouse gas (GHGs) emissions (mostly carbon dioxide) from human activities including agricultural production, industrialization, burning of fuels and deforestation among others as the major causes of climate change. The GHGs gases react and deplete the thin layer (Ozone) which protects the earth from direct heat from the sun. When this layer is depleted, sun rays hit directly on the earth resulting in temperature raises which influence climate on the earth and these changes manifest as global warming, prolonged droughts, and unreliable rainfall. Figure 3 shows contribution of various anthropogenic activities to greenhouse emissions.

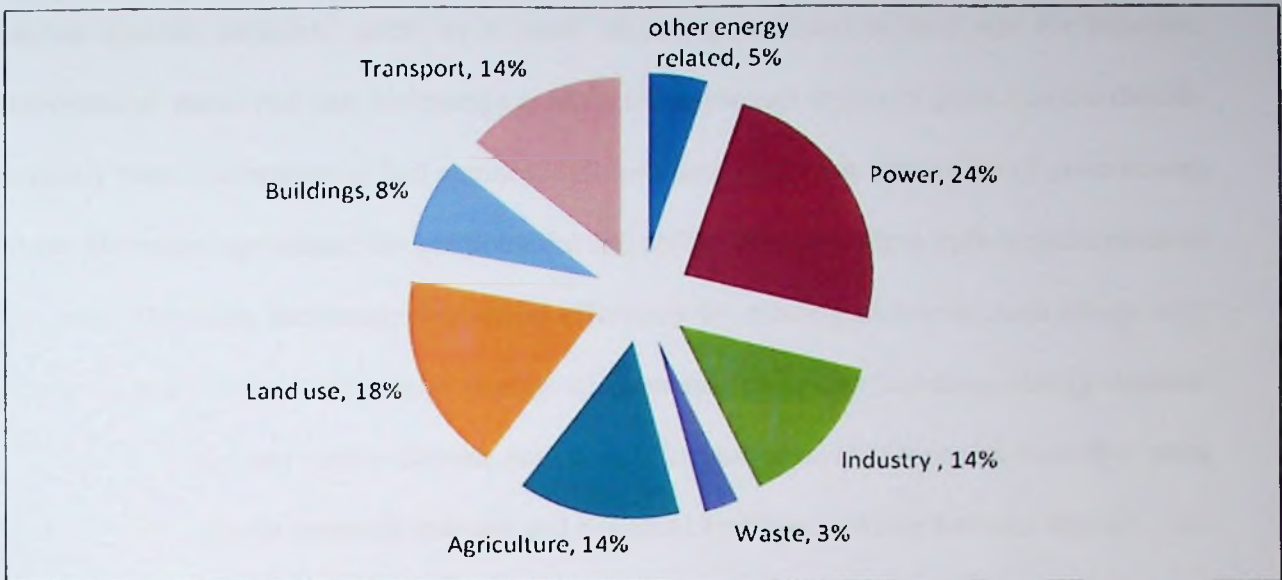


Figure 2. 2: Greenhouse gas emissions from various anthropogenic activities (Stern, 2006)

The greenhouse effect is attributed to the absorption of solar infrared (IR) radiation by gases and the earth’s surfaces, which, as a result, are heated and then re-emit IR radiation at low frequency with a high absorptive power. The gases involved are referred to as Greenhouse gases (GHGs). Key greenhouse gases include: methane, carbon dioxide, nitrous oxide and chlorofluorocarbons. The atmospheric concentrations of greenhouse gases and their rate of change are shown in Table 2.1.

Table 2. 1: The tropospheric concentrations, residence times and atmospheric trend of various greenhouse gases

	CO ₂	CH ₄	CFC-11 ¹	CFC-12 ²	N ₂ O
Atmospheric concentration	ppmv	ppmv	pptv	pptv	ppbv
Pre-Industrial	280	0.8	0	0	288
Present (1990)	355	1.72	280	484	310
Current rate of change (% per year)	0.5	0.9	4	4	0.25
Relative radioactive effectiveness					
Per molecule	1	21	12400	15800	206
Per unit mass	1	58	3970	5750	206

ppmv = parts per million volume; pptv = parts per trillion volume;
ppbv = parts per billion volume.

Source: IPCC, 1992.

Carbon dioxide emissions come as a result of changes related to land use for example, deforestation, diesel fuel use, and energy used for irrigation and drying of grain. Carbon dioxide is mainly from combustion of fuel engines, deforestation, irrigation and drying of grain among others. However, agriculture has got potential and ability to store carbon both in plant material and soils. Therefore increasing cultivation efficiency by moving to low-or zero tillage crop management practices, using more energy-efficient machinery, or reducing energy demand will reduce these direct carbon dioxide emissions. Nitrous oxide (N_2O) comes from two main sources which include livestock manure and chemical fertilizers. When bacteria interact with ammonia, N_2O is released. This means that for farmers to reduce N_2O emissions, they must decrease either direct emissions of N_2O or the amount of ammonia produced during normal agricultural processes. In dairy production systems large amounts of ammonia are produced when urea and livestock manure break down in water or slurry. Higher emissions also come from field operations, with the applications of nitrogen fertilizer and related cropping practices. Therefore appropriate fertilizer application rates can lead to reductions in nitrous oxide emissions.

2.6.4 Accounting for greenhouse gas emissions from agricultural related activities

Land use actions contribute 17 percent of the emissions, mainly from deforestation, and agriculture is responsible for 14 % (Duxbury, 1993). Glantz et al (2009) highlights that the emissions caused by agriculture can be reduced by more efficiently managing the carbon and nitrogen flows through changes in management practices. For example methane (CH_4) emissions can be reduced from livestock by increasing the feed use efficiency or from crop production by adopting practices that enhances Nitrogen use efficiency by crops decreasing the emission of nitrous oxide. Similarly, IPCC (2007) reported that key mitigation strategies could include: (i) reduction (at the source) of the use of fossil fuels (clean coal technology, renewable energies); capture of methane from landfills and rice paddies and (iii) creation of sinks for

storing carbon through processes like carbon sequestration which involves reducing tropical deforestation and increasing tree planting. The forest biophysical mitigation potential was estimated to be 5380 Mt CO₂e/yr on average up until 2050 (IPCC, 2001) and agriculture provides a technical mitigation potential of 5,500 to 6,000Mt CO₂e/yr by 2030 (IPCC, 2007). Blanco et al. (2014) estimates that between 1970 and 2010, greenhouse gases emissions from anthropogenic activities have increased from 27 ± 3.2 to 49 ± 4.5 Gt CO₂e / yr. The same authors also reported that greenhouse emissions grew on average by 1Gt CO₂e (2.2 %) per year between 2000 and 2010, compared to 0.4Gt CO₂e (1.3 %) per year between 1970 and 2000. These figures were the highest ever recorded in human history.

Carbon dioxide (CO₂) emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010, with similar percentage contribution for the period 2000–2010 (IPCC, 1992). Fossil fuel-related CO₂ emissions for energy purposes increased consistently over the last 40 years reaching 32 ± 2.7 Gt CO₂ / yr, or 69% of global greenhouse gases emissions in 2010. They grew further by about 3 % between 2010 and 2011 and by about 1 – 2 % between 2011 and 2012. Agriculture, deforestation, and other land use changes have been the second-largest contributors whose emissions, including other GHGs, have reached 12Gt CO₂e / yr (low confidence), 24 % of global GHG emissions in 2010 (Stern, 2006). Since 1970, CO₂ emissions increased by about 90 %, and methane (CH₄) and nitrous oxide (N₂O) increased by about 47 and 43 % respectively. Fluorinated gases (F-gases) emitted in industrial processes continue to represent less than 2 % of anthropogenic GHG emissions. In 2010, greenhouse gases emissions were estimated at 16 % which is an equivalent of 7.8 ± 1.6 Gt CO₂e / yr came from methane (CH₄), 6.2% (3.1 ± 1.9 Gt CO₂e / yr) from nitrous oxide (N₂O), and 2.0 % (1.0 ± 0.2 Gt CO₂e / yr) from fluorinated gases and the highest proportion 76% (38 ± 3.8 Gt CO₂eq / yr) were from carbon dioxide.

Studies have further shown that there is a temporal increase of atmospheric methane during the period 1980–1990 of about 18 ppbv (parts per billion per volume) per year (Rodhe, 1990). The rising concentration of methane is correlated with increasing populations and currently about 70% of methane production arises from anthropogenic sources and the remainder from natural sources (Duxbury and Mosier, 1993). Agriculture contributes about 21–25, 60 and 65–80% of the total anthropogenic emissions of carbon dioxide CO₂, methane CH₄ and Nitrous oxide N₂O respectively (Watson *et al* 1992). However, Steele *et al* (1992) reported that the current rate of increase in atmospheric methane concentration has subsequently slowed to about 10 ppbv per year. Methane is 25% more destructive to ozone layer as compared to carbon dioxide ((IPCC, 2001). A study conducted by Moss *et al* (2000) reported that about 70% of agricultural methane emissions comes from enteric fermentation while 25 and 5% come from the decomposition of manure, and rice cultivation respectively. Enteric fermentation is a natural process that occurs in the digestive systems of ruminant animals such as cattle, sheep, and goats. In the rangelands of Uganda, Kiggundu *et al* (2019) reported that the grazing cattle farming system (CFS) accounted for 88.5% of the total GHG emission.

2.6.5 Impact of livestock production on greenhouse gas emissions

The FAO's Livestock's Long Shadow estimates that livestock activities contribute an estimated 18 % to total anthropogenic greenhouse gas emissions from the five major sectors for greenhouse gas reporting which include: energy, industry, waste, land use, land use change and forestry (Steinfeld, 2006). It's further estimated that livestock account for 9%, 30-40%, 65 and 64% of global anthropogenic carbon dioxide, methane, nitrous oxide and ammonia emissions respectively (FAO, 2016). Animals release carbon dioxide during respiration and methane from ruminants during the process of enteric fermentation while nitrous oxide and ammonia from manure. However, carbon dioxide released during respiration can be accounted for in the normal plant photosynthetic processes and as such is not always considered in GHG emissions

under the Kyoto protocol. Indeed, since part of the carbon consumed is stored in the live tissue of the living animal, a growing global herd could even be considered a carbon sink. Methane is mostly contributed by enteric fermentation which takes place in ruminants during the process of anaerobic fermentation in the rumen under the influence of micro-organisms. However, FAO's Livestock Long Shadow has received a number of criticisms that livestock's contribution to GHGs has been over estimated (Glatzle, 2014). Besides livestock, rice production has also been highlighted to be a strong emitter of methane. This is due to anaerobic decomposition of plant wastes that remain after harvest in cultivation of wet rice. Goodland (2013) suggests that replacing livestock products with better alternatives would be the best strategy for reversing climate change, reducing GHG emissions and their atmospheric concentrations. The same author affirms that a 25% reduction in livestock products worldwide could translate into a 12.5% reduction in global anthropogenic GHG emissions. However, interventions that trap methane and utilize it as a source of energy on farm for example biogas are increasingly becoming useful on meeting on-farm energy needs and reduce electricity costs/demands.

2.7 Impact of climate extremes and variability on livestock productivity

2.7.1 Impacts of climate variability and extremes on growth and reproductive performance

Climate variability and extremes are certainly leading to increased hot environments and erratic rainfall patterns in the world. Hot environment impairs livestock production in terms of growth, meat and milk yield and quality, egg yield, weight, and quality) and reproductive performance, metabolic and health status, and immune response (Nardone, *et al.*, 2010). Raising temperatures directly affect the grazing capabilities of animals as a result of heat stress. Heat stress negatively affects the reproductive performance of animals (Ravagnolo *et al.*, 2000;

Amundson, *et al.*, 2006). The high rise in temperature and high intensity of radiant heat will directly affect reproductive rhythm via hypothalamic-hypophyseal-ovarian axis. Heat stress compromises oocyte growth in cows by altering progesterone, the secretion of luteinizing hormone (LH) and follicle stimulating hormone (FSH) and dynamics during the oestrus cycle. Khodaei-Motlagh *et al* (2011) reported that high environmental temperature reduces the duration and intensity of estrus, increases incidence of anestrus and silent heat in farm animals.

Furthermore, Wolfenson *et al* (2000) confirmed exposure to heat stress affects early organogenesis and can also lead to various teratological defects in female animals while in bulls' semen concentration, number of spermatozoa and motile cells per ejaculate of bulls are lower in summer than in winter and spring. The temperature of the testis is 2-6°C lower than core body temperature. This 2- 6°C lower temperature of the testis is important for the production fertile spermatozoa. If the testicular temperature is increased it may result to thermal stress that directly affects seminal and biochemical parameters leading to infertility problems in bulls (Cardozo, *et al.*, 2006). Increased climate variability greatly influences the behavior of animals due to neuroendocrine response to environmental variables that directly affect production and health status of animals. Berman (2005) observed that environmental temperatures above 35°C are enough to activate the stress response mechanisms in lactating dairy cows.

2.7.2 Impact of heat stress on performance of dairy cows

Studies conducted by Wheelock, *et al* (2010) confirmed that in response to heat stress dairy cows reduce feed intake leading to negative energy balance responsible for the drop in milk production. For example 50% drop in milk production in dairy animals could be due to reduced feed intake and rest due to metabolic adaptations to heat stress as heat stress response markedly

changes post absorptive nutrient metabolism (Baumgard and Rhoads, 2013). Heat stress is caused by a combination of prevailing ambient temperatures, relative humidity, solar radiation, air movement and precipitation. However, most studies on heat stress in livestock focus on the two main environmental stressors which include temperature and relative humidity (RH). This is because data on the amount of thermal radiation (sunlight) received by the animal, wind speed and rainfall are not available. All animals have thermal comfort zones to which they must power life processes for their survival (Figure 2.3).

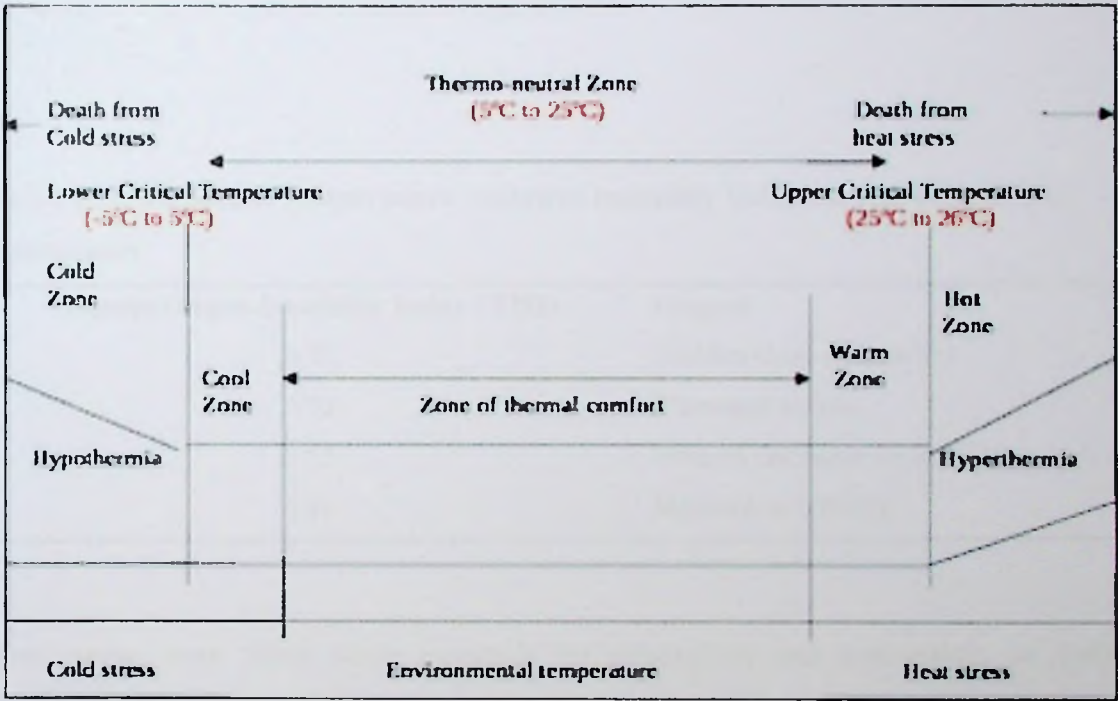


Figure 2. 3: Thermal comfort zone of lactating dairy cows (Gantner *et al.*, 2011)

West (2003) reported that the relative daily cows' production is constant when temperatures are low and medium, while after passing a threshold, starts to decrease. The rate of decline increases with rising temperatures. This means that exposing dairy cattle to high ambient temperatures (T_a), high relative humidity (RH) and solar radiation for extended periods decrease the ability of the lactating dairy cow to dissipate heat. The raising global temperatures

are therefore most likely to result into reduced milk production. Relative humidity (RH) is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature. RH majorly depends on the available moisture and prevailing ambient temperatures. The use of a temperature-humidity index (THI) is among the key measures of the combined effect of temperature and humidity (Gantner *et al.*, 2011; Kadzere, *et al.*, 2013). A mean daily THI value of 72 is considered to be the critical point at which milk yield is reduced (Atrian *et al.*, 2012; Niyonzima *et al.*, 2022). Table 2.2 shows the temperature-humidity index values and their impact on ruminant reproduction

Table 2. 2: Impact of temperature –relative humidity index on reproduction of Ruminants

Temperature-humidity index (THI)	Impact
>73	Sudden drop in fertility
>72	Thermal stress
>55	Start of decrease in fertility
≤41	Maximum fertility

Heat losses from cows occur primarily by conduction and convection, as well as by evaporation. As the temperature rises, it becomes increasingly difficult for a cow to dissipate heat. Rising relative humidity also affects a cow’s ability to lose heat via evaporation (Ravagnolo *et al.*, 2000; Kadzere *et al.*, 2013). Since heat loss depends both on temperature and relative humidity, a temperature-humidity index (THI) has been developed to indicate the amount of heat stress a cow is subject to. Although there is some variations in the range of THI values, it’s generally accepted that cows at THI < 72 experience little heat stress, 72 to 79 mild heat stress, 80 to 89 medium heat stress and above 90 severe heat stress (Todorović *et al.*, 2011)

Farooq et al (2010) reported that milk production notwithstanding environmental temperatures is influenced by various hormones like oxytocin and prolactin among others which are heavily involved in control of milk letdown. Heat stress can create a total imbalance in the endocrine system of cattle. Heat stress can cause changes in hormone profiles like prolactin, thyroid hormones, glucocorticoid, growth hormone, adrenocorticotrophic hormone (ACTH), oxytocin, estrogen and progesterone. Prolactin is an essential hormone for lactogenesis and mammogenesis in cattle (Tucker, 2000). Any change in prolactin concentration during dry period can have negative impact in subsequent lactation (Tao and Dahl, 2013). Changes in the prolactin secretion during heat stress were correlated with body temperature changes with increased rectal temperature reducing the prolactin concentration (Alamer, 2011).

CHAPTER THREE

TRENDS IN VARIABILITY OF RAINFALL AND TEMPERATURE EXTREMES AND THEIR EFFECTS ON LIVESTOCK PRODUCTIVITY

ABSTRACT

Daily rainfall and temperature data sets from 1960 to 2013 were used to determine trends of variability and extremes in rainfall and temperature in order to inform stakeholder's decisions in planning for appropriate adaptation strategies to climate change. Data were subjected to trend analysis using non-parametric Mann-Kendall tests while rainfall and temperature extremes were derived using RClimdex software. Coefficient of variation (CV) in annual rainfall was 25.3, 12.9 and 16.3% for Mbarara, Masindi and Soroti respectively. Mean daily maximum temperatures were 26.7, 29.6 and 30.8°C for Mbarara, Masindi and Soroti respectively. Annual total wet days were increasing but not significant ($p>0.05$). Consecutive wet days (CWD) were increasing only in Mbarara while consecutive dry days, CDDs revealed weak declining trends in Mbarara and stronger significant increasing trends in Soroti ($p<0.05$). The number of hot days (TX90p) and warm nights (TN90p) was significantly increasing ($p<0.05$) in Mbarara and Masindi. The number of warmest nights (TNx) and hottest days (TXx) was also significantly increasing ($p<0.05$). Mean diurnal temperature range, DTR showed significant decreasing trends in Mbarara and Masindi ($p<0.05$) while in Soroti it was significantly increasing. The observed increasing temperatures, coupled with declining CWDs and increasing CDDs with unstable rainfall patterns will negatively impact on livestock productivity in the pastoral rangelands.

Key words: *Trends, wet days, hot days, climate extremes and Uganda*

3.1 Introduction

Climate variability and changes in extreme weather events have significant impacts to societies and pose the most serious challenges to development (CCSP, 2008). Toreti and Desiato (2008), observed that climate change is characterized by variations in climatic variables in mean and extreme values. Moberg and Jones (2005) established that extreme climatic events, such as heat waves, floods and droughts, can have strong impact on society and ecosystems and are thus important to study. In Uganda, the pastoralists in rangelands must get concerned of climate extremes since it's considered among the most fragile regions to climate change (NEMA, 2001). Livestock which majorly depend on grazing of natural pastures are the main contributors to survival of livelihoods. Most common livestock species kept include cattle, goats, and sheep. Availability of natural pastures for grazing in the pastoral rangelands of Uganda is directly influenced by the amount of rainfall recieved and the prevailing ambient temperatures (MLWE, 2003). However, changes in rainfall extremes like concecutive dry days and very heavy precipitation days manifest as increased droughts and floods. These changes in rainfall extremes consquently result into depressed livestock productivity in the region through reduced grazing land, disease outbreaks and failure of some pasture species to survive among others.

Reducing vulnerability to increased rainfall variability and extremes can be achieved through reducing exposure to hazardous conditions and/or through enhancing adaptive capacity to better deal with or manage hazardous conditions (IPCC, 2001). However, increasing livestock productivity can be achieved through appropriate adaptation measures to climate extremes in the pastoral rangelands of Uganda. However, a clear understanding of trends and changes of extremes of rainfall and temperature is a prerequisite while planning for effective adaptation measures. Studies at a broad scale have attempted to characterise East African rainfall variability and have reported an increase in total amount of annual rainfall (Thornton *et al.*,

2009) Nicholson (1996), highlights the complexity of the equatorial Eastern Africa rainfall which is mostly regionally controlled, implying that generalities basing on global climatic patterns can not be relied upon. Therefore attention should always be paid to investigate trends of rainfall and temperature characteristics at very fine local scales to inform the process of adaptation to climate change. In this study trends in variability and extremes of rainfall and temperature in the pastoral rangelands of Uganda were determined in order to generate information necessary for developing appropriate adaptation strategies to climate extremes.

Studies have consistently shown that the prevailing climate changes pose a serious threat in improving agricultural productivity to achieve food security (Herrero *et al.*, 2006). Climate change has both direct and indirect impacts on livestock production including low milk yields, reduced off take rates, changes in availability of pastures, fodder, water and increased severity of diseases (FAO, 2015). NEMA (2001), reported that the pastoral rangelands are among the most fragile and vulnerable region to climate change because of its semi-arid conditions and increased burning of wood biomass for chacoal burning. Livestock production is the main agricultural activity and entirely depends on grazing natural pastures in the rangelands. Most common livestock species kept include cattle, goats, and sheep. Devereux and Edward (2004) observes that the poor countries and regions will be more vulnerable to adverse effects of climate change because of their low adaptive capacity. Reducing vulnerability to climate change can be achieved through reducing exposure to hazardous conditions and/or through enhancing adaptive capacity to better deal with or manage hazardous conditions (IPCC, 2001). Therefore understanding changes in climate variability and climate extremes is very critical in planning for better adaptation to climate change.

Hanson et al (1993) observed that an increase in mean temperatures usually result into changes in rangeland species distribution, composition, patterns and biomass distribution. However, little attention has been paid to investigate extreme temperature events and thier characteristics

at very fine local scales (Manton *et al.*, 2000). Moreover, Thornton *et al* (2009), notes that the impacts of increased frequencies of extreme heat stress on existing livestock breeds are not known. Klein Tank *et al.* (2009) observes that large uncertainties and gaps in our knowledge of climate change and extremes remain. Beniston *et al* (2007) further notes that changes in climate extremes are highly uncertain. This study therefore sought to establish trends in variability of rainfall and temperature and effects on vegetation/pasture biomass in the pastoral rangelands of Uganda in order to inform the processs of developing appropriate adapation strategies to climate extremes.

3.2 Materials and Methods

To determine trends in variability of rainfall and temperature extremes and their effects on livestock productivity required data on rainfall, temperature and vegetation cover of the pastoral rangelands for a period of 50 years.

3.2.1 Data collection

3.2.1.1 Rainfall and temperature

Daily rainfall and temperature data sets from 1963 to 2013 were used. Data from 11 stations including; Mbarara, Ruherengeri, Lyantonde, Kiruhura, Sembabule, Luwero, Kakooge, Nakasongola, Masindi, Soroti and Kotido were obtained from Uganda National Meteorological Authority (UNMA) in Kampala. After analysing the data from all the stations, most stations except Mbarara, Masindi and Soroti did not have complete data sets for evaluating the rainfall, temperature and milk production trends over the fifty years study period. Therefore only data sets from Mbarara, Masindi and Soroti were used to represent the entire pastoral rangelands studied. The locations of weather stations used in the study are shown in table 3.1.

Table 3. 1: Location of weather recording stations

Station	Latitude	Longitude	Altitude (a. s. l)
Mbarara	-0.51 °S	30.6 °E	4600ft
Soroti	1.70 °N	33.6 °E	3684ft
Masindi	1.68 °N	31.7 °E	3781ft

3.2.1.2 Assessment of vegetation biomass and land cover changes

In order to assess above ground vegetation biomass and land cover changes, satellite images were used. Landsat satellite images were obtained from the global land cover facility website (<ftp:glcf.umd.edu/glcf/Landsat/WRS2>). Landsat satellite images of 1986, 2000 and 2015 were acquired freely and downloaded from the website. The paths and rows for the scenes covering the study area were 172 _059, 172 _060 and 172_060 respectively. Several factors were considered in selecting the Landsat images for the study which included; the time of the year the images were taken, the degree of cloud cover, and the availability of Landsat images for the intended year and as well as quality of the images acquired. NDVI was used as proxy of the above ground net primary vegetative biomass production, using Landsat 7 images. Millington et al (1994) reported that NDVI data can be utilized as indicators of possible vegetation stress and particularly due to water shortage. For purposes of processing NDVI values images from the 3 & 4 bands were downloaded from the global land cover facility website.

3.2.2 Data analysis

3.2.2.1 Analysis of rainfall variability

Meteorological data was subjected to quality control measures to ensure homogeneity and identify outliers. Quality control procedures further identified outliers in daily maximum and minimum temperature values. The outliers were daily values outside the normal range values. Currently, this region is defined as n times standard deviation (std) of the value for the day,

that is, $(\text{mean} - n \times \text{std}, \text{mean} + n \times \text{std})$, where *std* for the day and *n* is an input from the user (Zhang and Yang, 2004). Initially, data from 11 meteorological stations were available however, after quality control tests only stations with less than 10% of missing data for a period of at least 50 years were considered. Consequently data from only 3 locations were used since the study areas fall in Mbarara, Masindi and Soroti climatological zones (Basalirwa, *et al.*, 2014). Rainfall variability was determined using standard variability index (SVI) procedures. In case of rainfall, SVI was computed as standardized precipitation departure from the long term mean as specified in Guntu and Agarwal (2020). The index helps to separate the time series into different climatic regimes (Oguntunde, *et al.*, 2011). Rainfall variability index (δ) was then calculated as:

$$\delta_i = (P_i - \mu) / \sigma$$

Where δ_i is rainfall variability index for year *i*, P_i is the annual rainfall for year *i*, μ and σ are the mean annual rainfall and standard deviation for the period 1963-2013. Mean values and coefficient of variation (CV) were also obtained to identify intra-station variability.

3.2.2.2 Analysis of trends in rainfall and temperature

Trends in rainfall and temperature were determined using the Mann-Kendall monotonic trend test and the Sen's slope estimator for the period 1963-2013 (Kendall, 1962). Presence of monotonic trends was determined using non-parametric Mann-Kendall test in XLSTAT. Mann- Kendall test statistics were preferred because of their insensitivity to outliers which is common in climatological data (Lazante, 1996). The products of the test are the statistics *S* and *Z*. For a given time series $X_1, X_2, X_3 \dots X_n$, given level of significance α , the null hypothesis of no presence of trend in the time series is rejected if $Z > Z_{\alpha/2}$ (Ahmad *et al.*, 2015). The null hypothesis H_0 is not rejected when $Z_{\alpha/2}$ at α level of significance ($P < 0.05$). If *S* is positive, then the trend is increasing and if *S* is negative then the trend is decreasing. Significance of

trends was determined at 95% confidence interval. The Mann-Kendall test statistic S is specified in the model (Kendall, 1962):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i)$$

Where n is the length of the time series $x_1, \dots, x_n$ and $\text{sgn}(\cdot)$ is a sign function, x_j and x_i are values in the years j and k respectively and $\text{Sgn}(x_j - x_i)$ is the sign function defined as:

$$\text{sgn}(y) = \begin{cases} 1 & \text{if } (y > 0) \\ 0 & \text{if } (y = 0) \\ -1 & \text{if } (y < 0) \end{cases}$$

3.2.2.3 Analysis of rainfall and temperature extreme indices

To determine extreme indices, daily rainfall and temperature data were subjected to RClimdex software for analysis following procedures as in Zhang and Feng (2004). Data was first checked to ensure no outliers and tested for homogeneity using “RHtestV3” software (Wang and Feng, 2009). RClimdex produces 29 annual time series indices as recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI). However, in this study only five precipitation and six temperature indices were selected as they were more relevant to prevailing climatic conditions of the pastoral rangelands. Table 3.2 showed the various indices that were selected and their definitions.

Table 3. 2: Definitions of rainfall indices used in the study

Indices	Indicator name	Indicator definitions	Units
PRCTOT	Annual total precipitation	Annual total precipitation from days $\geq 1\text{mm}$	Mm
R95PTOT	Very wet days	Annual total precipitation when RR> 95 percentile	Days
R10mm	Number of heavy precipitation days	Annual count of days when precipitation $\geq 10\text{mm}$	Days
CWD	Maximum length of wet spell	Maximum number of days when precipitation $\geq 1\text{mm}$	Days
CDD	Length of dry spell	Maximum number of consecutive days when precipitation < 1mm	Days
TXx	Hottest day	Monthly maximum value of daily max temperature	$^{\circ}\text{C}$
TNx	Warmest night	Monthly maximum value of daily min temperature	$^{\circ}\text{C}$
TN90p	Warm nights	Percentage of time when daily min temperature > 90th percentile	%
TX90p	Hot days	Percentage of time when daily max temperature > 90th percentile	%
DTR	Diurnal Temperature Range	Monthly mean difference between daily max and min temperature	Days
WSDI	Warm spell duration index	Annual count of days with atleast 6 consecutive days when Tx > 90 th percentile	Days

3.2.2.4 Analysis of vegetation biomass and land cover changes

Vegetation and land cover changes were determined by processing NDVI from Landsat satellite imagery. Processing Landsat images for extraction of NDVI was done using GIS tools in ARCGIS 9.3 (ESRI, 2014). The unprocessed image bands obtained from the Landsat satellites were imported and combined to form a single multispectral image by using the composite band tool in ArcGIS. The study area districts were clipped out from the composite image and used to classify land use/covers and derived NDVI values. The NDVI was calculated from atmospherically corrected reflectance from the visible red (RED) and near infrared (NIR) channels using the following formula:

$$\text{NDVI} = \frac{(\text{NIR}-\text{RED})}{(\text{NIR}+\text{RED})}$$

3.3 Results

3.3.1 Trends in annual rainfall

Annual mean rainfall received in Nakasongola district and adjacent pastoral communities was highest (Table 3.3). In Mbarara south west of the pastoral rangelands experienced the most unstable rainfall pattern with a coefficient of variation (CV) of 25% while the least variation was observed in Masindi. Sen's slope estimator revealed non-significant increasing trends in rainfall received for Mbarara and Soroti station while in Masindi the rainfall trend was decreasing (Table 3.3).

Table 3. 3: Annual rainfall characteristics for Mbarara, Masindi and Soroti

Location	N	Mean annual rainfall (mm)	CV (%)	Sen's slope estimator
Mbarara	51	1010 ± 256.1	25.3	5.278
Masindi	48	1359 ± 175.9	12.9	-0.336
Soroti	53	1402 ± 228.3	16.3	0.370

3.3.2 Rainfall variability

3.3.2.1 Annual rainfall variability

Figure 3.1, 3.2 and 3.3 revealed that the amount of rainfall received in Mbarara, Masindi and Soroti varied considerably. Mbarara experienced 7 wet years from 2007-2013 (Figure3.1). Figure 3.2 revealed that 1993 and 1998 Masindi station and the areas surrounding received the least amount of rainfall while 1972 recorded the highest amount of rainfall over the long-time mean. The driest year for Mbarara was experienced in 2012 (Figure 3.1). The driest years in Masindi were 1983, 1985 and 1998. From 1965-1968 and 1973- 1976 Masindi experienced 4

successive dry years while five successive dry years were experienced in 1982-1986 and 2001-2005. From 1961 until 2013 Soroti experienced 20 wet years and 32 dry years. From 1992-2000 Soroti experienced 8 dry years (Figure 3.3).



Figure 3. 1: Annual rainfall variability for Mbarara station

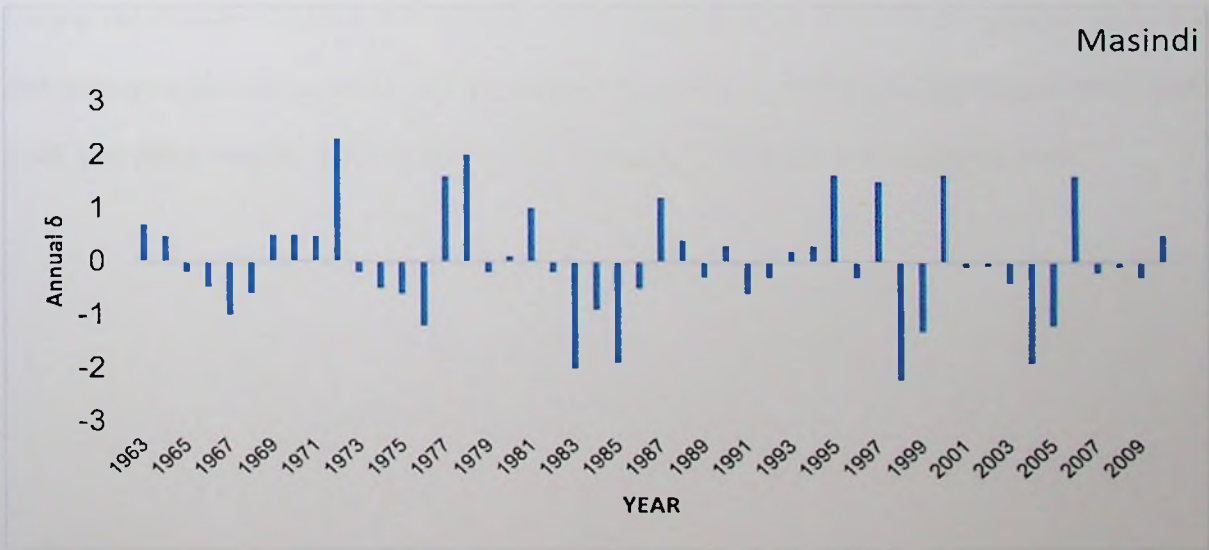


Figure 3. 2: Annual rainfall variability for Masindi station

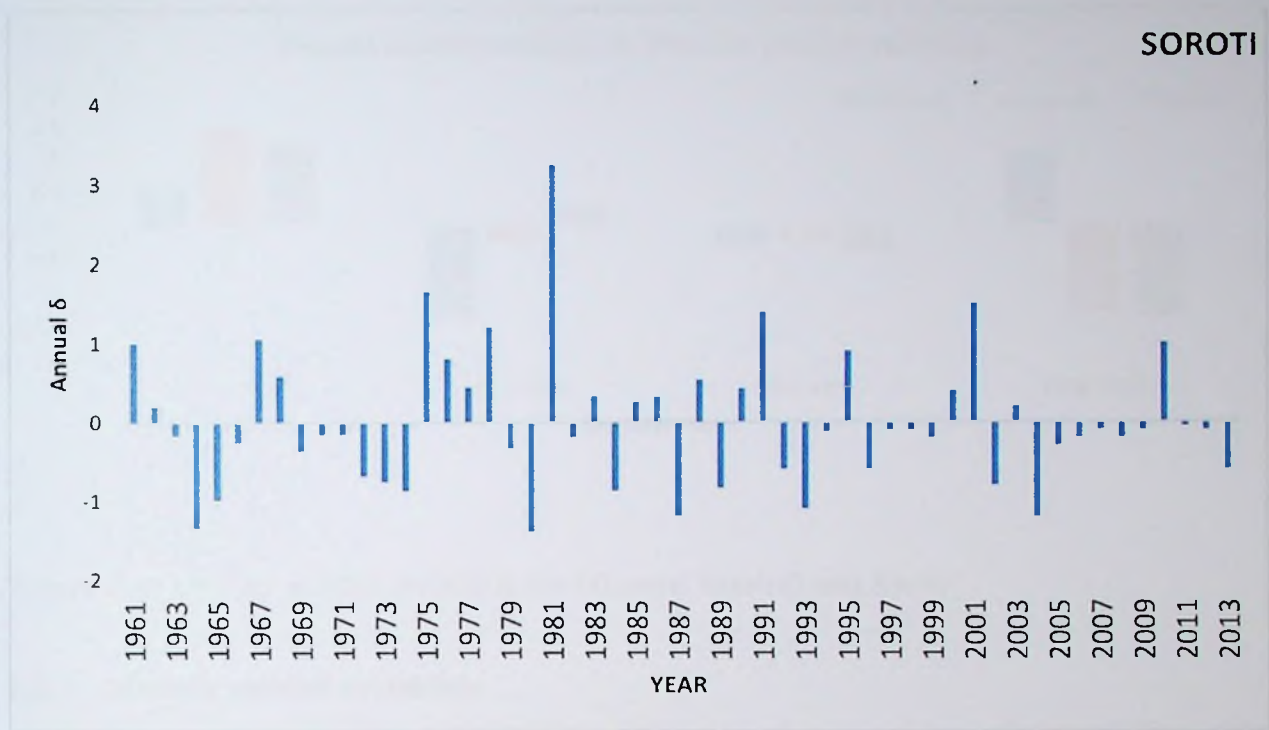


Figure 3. 3: Annual rainfall variability for Soroti station

3.3.2.2 Decadal rainfall variability

In Mbarara the wettest decade was experienced in 1970s while the driest decade was 1980s (Figure 3.4). The driest decade for Masindi and Soroti recording stations was in 2000-2009. During the decade of 1990s, decadal deviation was below “normal” in all stations indicating that the region experienced slightly dry conditions. Decadal deviations for Mbarara from 2000-2009 was above normal and higher than any other decade since 1970s (Figure 3.4).

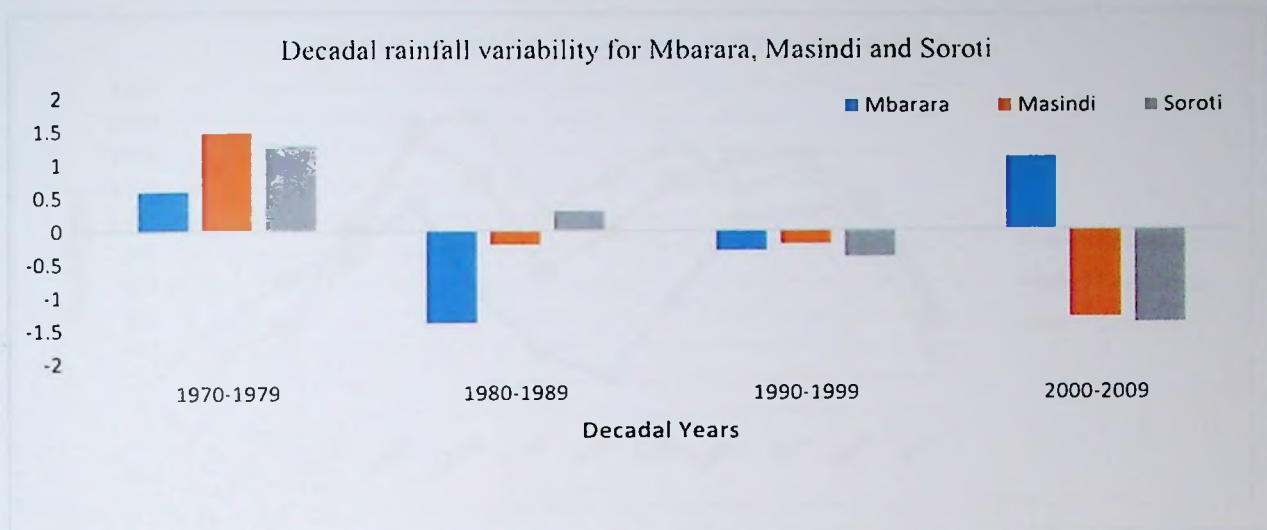


Figure 3. 4: Decadal rainfall variability for Mbarara, Masindi and Soroti

3.3.3 Monthly rainfall variability

Monthly rainfall in Masindi followed a perfect bi-modal rainfall pattern with maximum peaks in April and October throughout the 48 year period. However, the bi-modal rainfall pattern was slightly changing and three maximum rainfall peaks emerged in the southwest of the pastoral rangelands and in the central districts of the pastoral rangelands for February – April (FMA) and August- November were the wettest months while June- July remained the driest months in all stations (Figure 3.5).

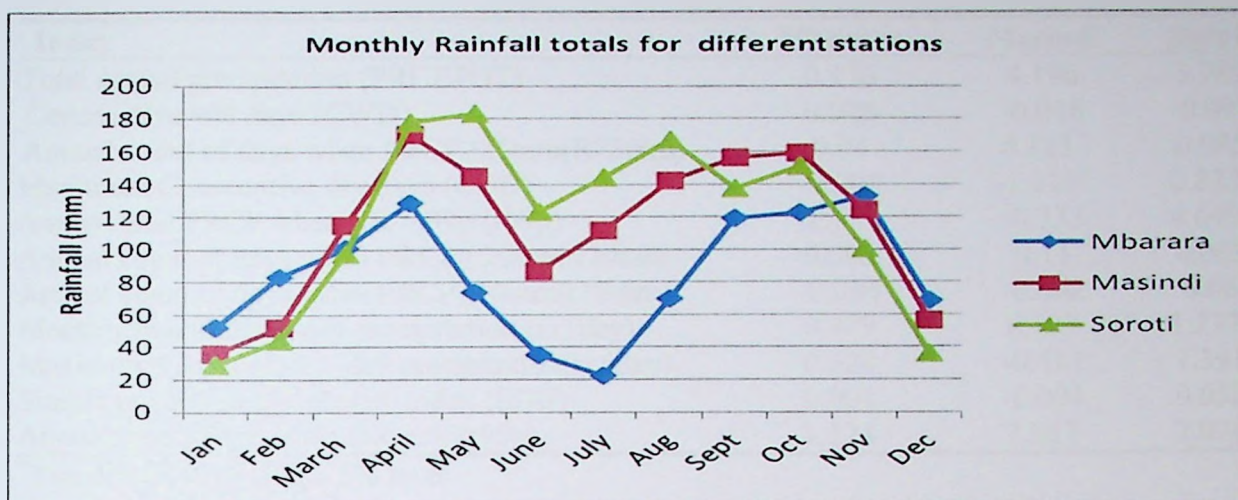


Figure 3. 5: Monthly rainfall received in Mbarara, Masindi and Soroti

3.3.4 Trends in precipitation extremes

The results of precipitation indices are shown in Table 3.4. Total annual precipitation (PRCPTOT) showed weak non-significant increasing trends in all stations. Heavy precipitation days ($R \geq 10\text{mm}$) revealed weak declining trend ($p > 0.05$) in Mbarara and Masindi. However, in Soroti heavy precipitation days were increasing. Heavy precipitation days were most frequent in 1978, 1981 and 2001 for Mbarara, Soroti and Masindi respectively. Consecutive wet days (CWD) showed a non-significant increasing trend only in Mbarara while in Masindi and Soroti CWD were declining (Table 3.4). Consecutive dry days (CDD) which measures for extremely dry days when precipitation is less than 1mm, showed weak decreasing trends in Mbarara while in Masindi the frequency of CDD showed significant decreasing trends ($p < 0.05$). In Soroti the frequency of CWD were reducing at a rate (0.091) higher than in Masindi (0.016). Frequency of CDD in Soroti showed strong significant increasing trends ($p > 0.05$).

Table 3. 4: Extreme precipitation indices for Mbarara, Masindi and Soroti

Index	Mbarara	Masindi	Soroti
Total annual precipitation (PRCPTOT)	0.176	4.196	3.789
Consecutive wet days (CWD)	0.026	-0.016	-0.091
Annual count of days when $PRCP \geq 25\text{mm}$ (R25mm)	0.04	0.123*	0.085
Maximum Consecutive dry days (CDD)	-0.005	-1.119*	0.822*
Annual total PRCP when $RR > 99p$ (r99p)	2.57*	-0.333	4.649*
Annual count of days when $PRCP \geq 20\text{mm}$ (r20mm)	0.005	0.11	0.069
Annual count of days when $PRCP \geq 10\text{mm}$ (r10mm)	-0.084	-0.062	0.06
Monthly maximum 1-day precipitation (rx1 day)	0.479	0.127	1.277*
Maximum consecutive 5-day precipitation (rx5day)	0.528	-0.417	1.391
Simple precipitation intensity index (SDII)	0.004	-0.004	0.052
Annual total PRCP when $RR > 95p$ (r95p)	1.124	2.987	2.074

*Trend significant at the 5% level

Table 3.4 further showed that annual total PRCP days when $RR > 99p$ was significantly increasing ($P > 0.05$) in Mbarara and Soroti areas and decreasing Masindi. The number of days when $PRCP \geq 10\text{mm}$ (r10mm) were significantly reducing in Mbarara south west of the pastoral rangelands and positively increasing in north eastern districts of Nakasongola. Results further indicated that monthly maximum consecutive 5-day precipitation was increasing only in Mbarara and Soroti. Simple precipitation intensity (SDII) index revealed positive increasing trends in Mbarara and Soroti.

3.3.5 Total annual precipitation (PRCPTOT) index

Total annual precipitation index showed increasing trends ($p > 0.05$) in all stations. The amount of rainfall received for annually for Mbarara fluctuated highly (Figure 3.6). The highest amount of rainfall for Mbarara station which is situated in the south west was recorded in 2000 at about 1353mm while the lowest was recorded in 1985 at 718.5 mm. Masindi registered the highest annual rainfall totals in 1988 of about 1075mm while the lowest values were recorded in 1984 of about 474.3 mm of rainfall (Figure 3.7)

Total Annual precipitation for Mbarara

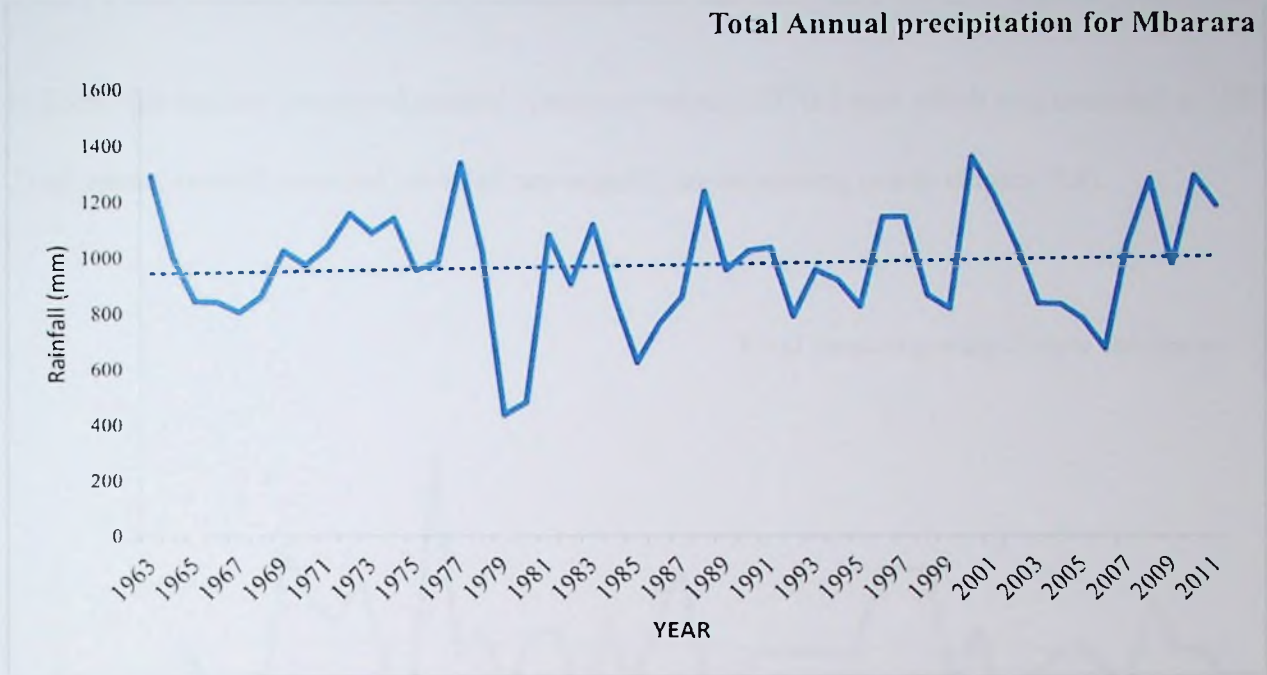


Figure 3. 6 : Total annual precipitation for Mbarara station

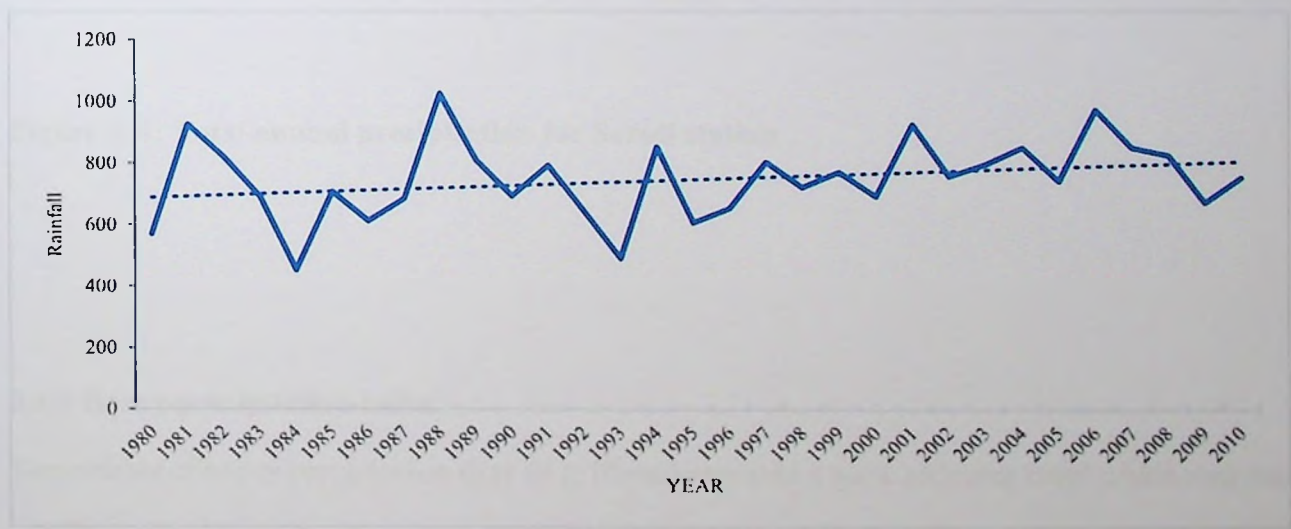


Figure 3.7: Total annual precipitation for Masindi

In Soroti the highest amount of rainfall ever received was 2270.5 mm which was recorded in 1981.

Total annual rainfall received revealed non-significant increasing trends (Figure 3.8).

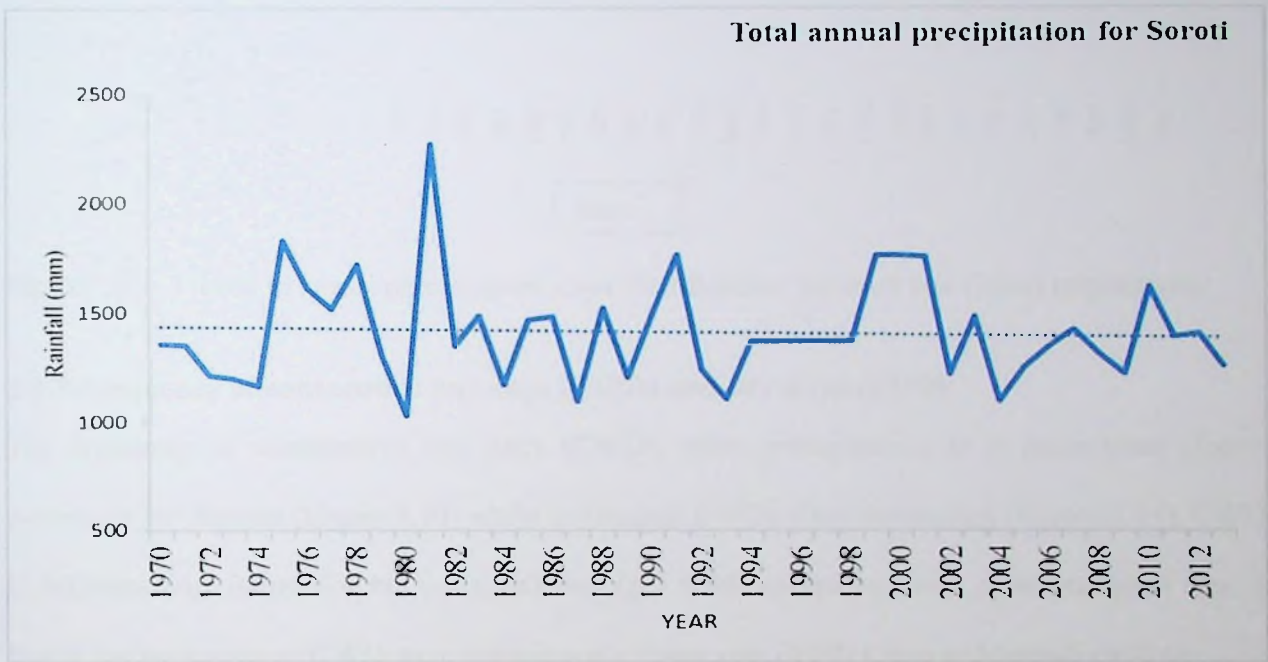


Figure 3. 8: Total annual precipitation for Soroti station

3.3.6 Heavy precipitation index

The number of heavy precipitation days ($R \geq 10\text{mm}$) revealed a weak reducing trend which was not significant ($p > 0.05$) in all stations (Figure 3.9). Heavy precipitation days were most frequent in 1978 and 1981 and 2001 for Mbarara and Soroti respectively. In Masindi, heavy precipitation days were experienced in 1981 and 2001 (Figure 3.9).

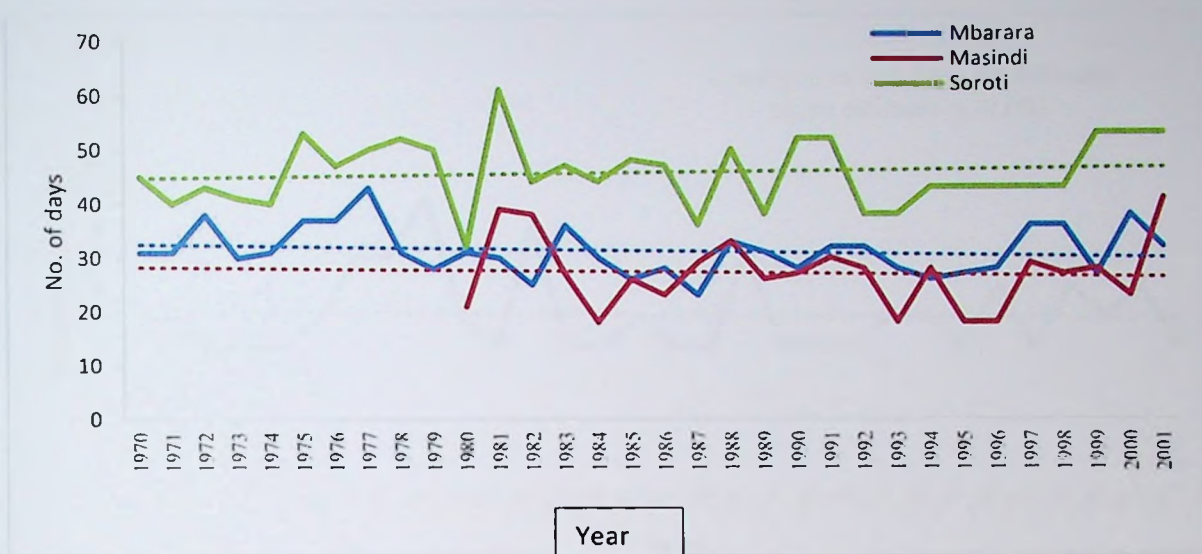


Figure 3. 9: Trends in heavy precipitation days for Mbarara, Masindi and Soroti respectively

3.3.7 Frequency of consecutive wet days (CWD) and dry days (CDD)

The frequency of consecutive wet days (CWD), when precipitation is $\geq 1\text{mm}$ were slightly increasing in Mbarara (Figure 3.10) while in Masindi CWDs were decreasing (Figure 3.11). CWDs in Mbarara were increasing but not significant ($p > 0.05$) except in Soroti meteorological area. In Soroti the frequency of CWD were reducing at a faster rate (0.091) than in Masindi (0.016).

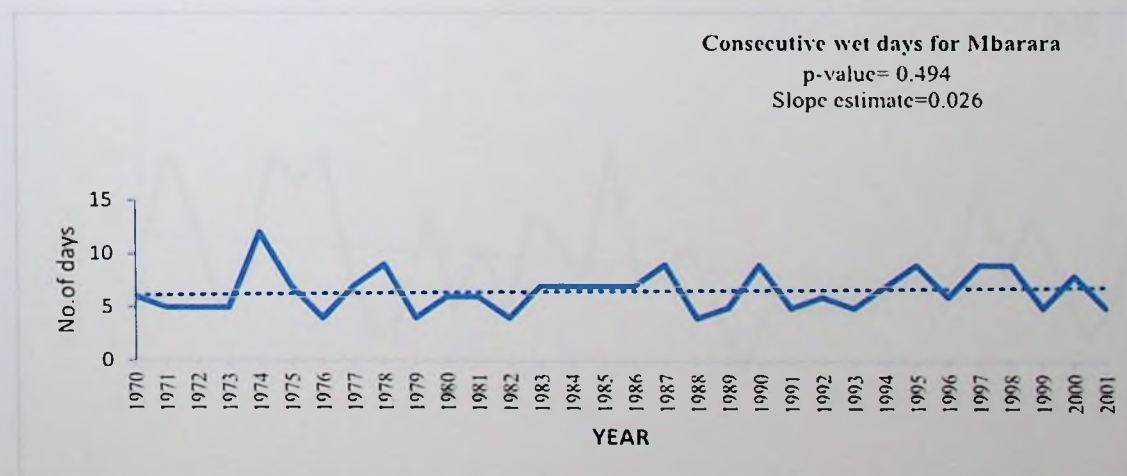


Figure 3. 10: Consecutive wet days for Mbarara

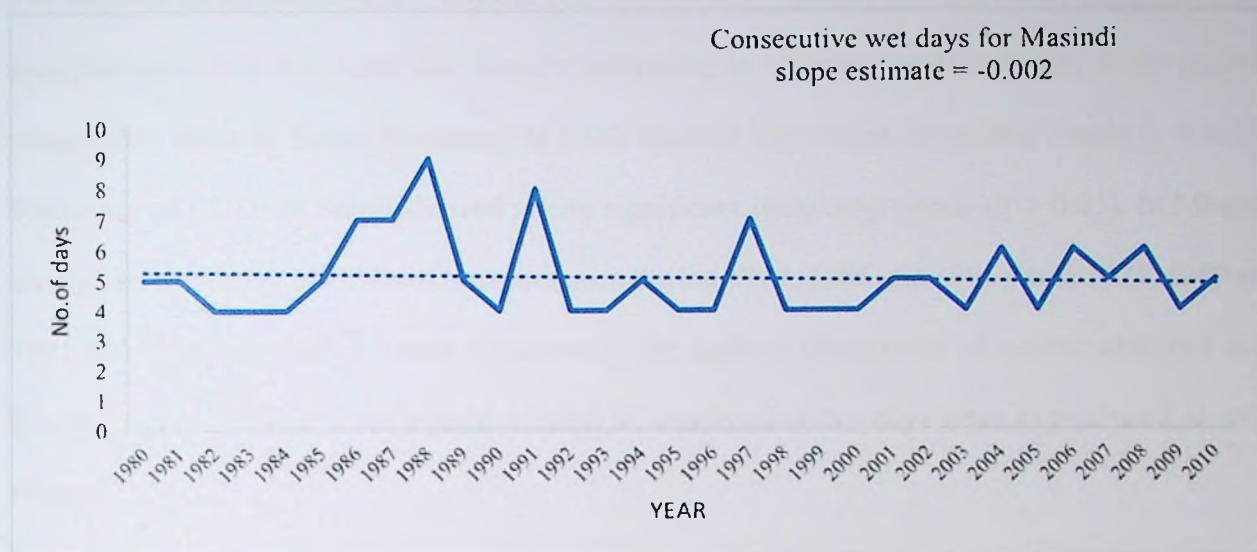


Figure 3.11: Consecutive wet days for Masindi

Figure 3.12 further revealed that areas that lie within in the soroti climatological area, experienced the most CWDs in 1972, 1977 and 1988. Results also showed a decreasing trend in number of CWDs.



Figure 3. 12: Number of consecutive wet days for Soroti

The number of consecutive dry days (CDD) which is a measure for extremely dry days when precipitation is less than 1mm was slightly decreasing in Mbarara- southwest part of the pastoral rangelands while in Soroti frequency of CDD showed significant increasing trends ($p < 0.05$). Frequency of CDDs in Soroti showed strong significant increasing trends ($P > 0.05$). In Mbarara the highest frequency of CDDs was experienced during 1984, 1986 and 1991 while 1971, 1989 and 1991 were the years when Soroti experienced the highest frequencies of consecutive dry days (Figure 3.15). In Masindi the highest number of consecutive dry days were experienced in 1993 (Figure 3.14).

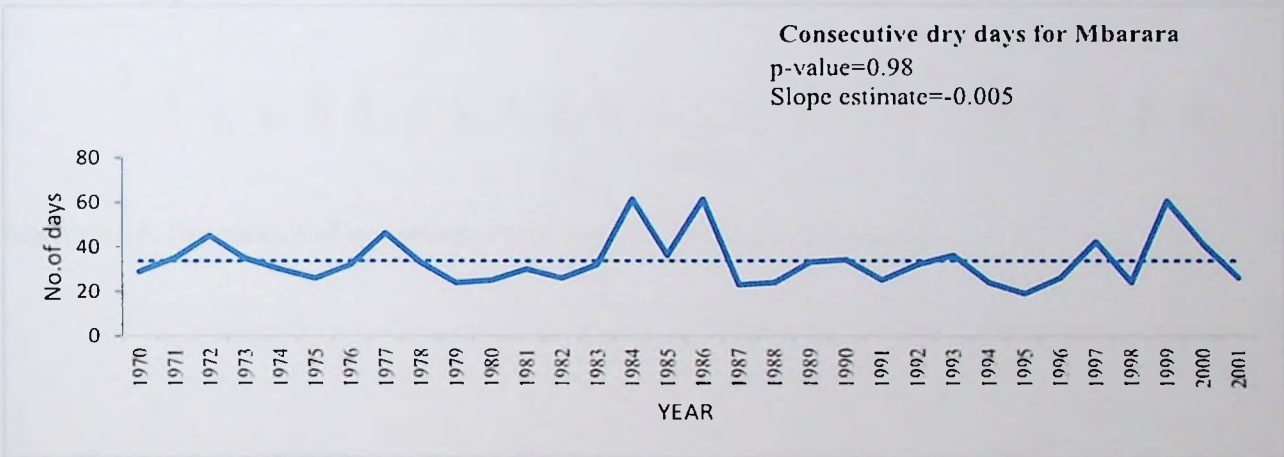


Figure 3. 13: Consecutive dry days for Mbarara

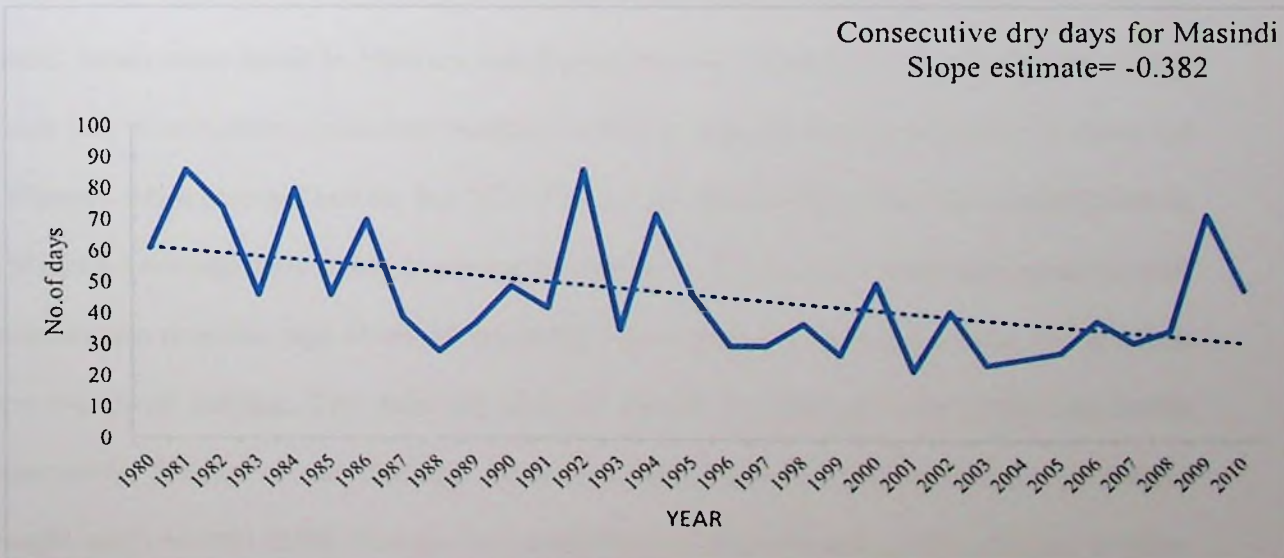


Figure 3.14: Consecutive dry days for Masindi

Consecutive dry days revealed a positive increasing trend (Figure 3.15) for areas in Soroti climatological zone. The highest CDDs were experienced in 1971, 1989 and 1992 while the lowest were in and 1980 and 1991.

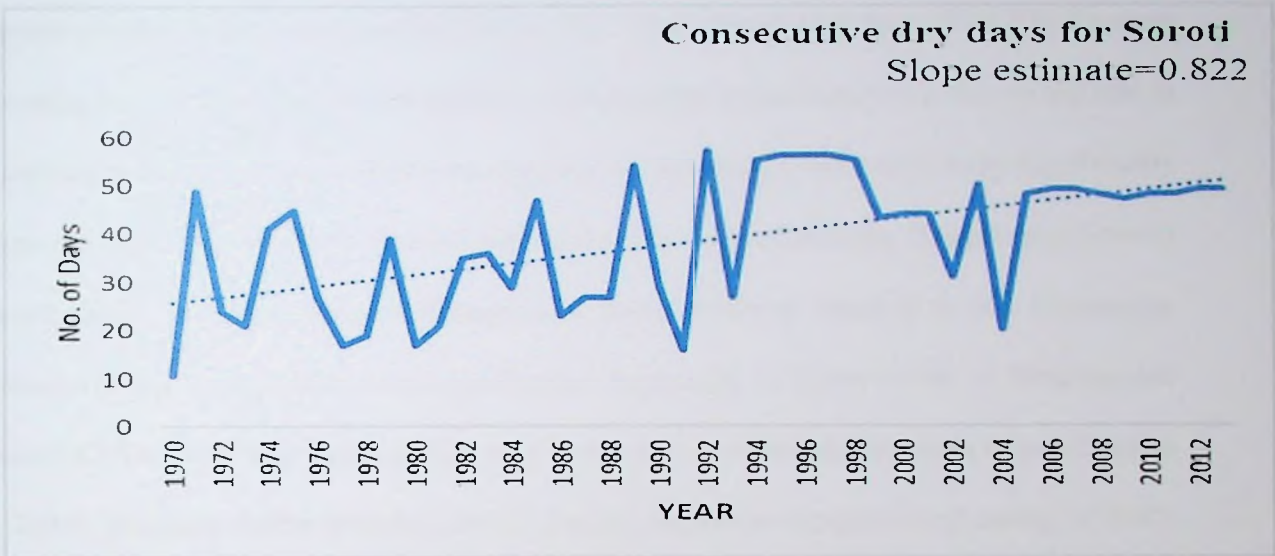


Figure 3.15. Frequency of consecutive dry days for Mbarara and Soroti

3.4 Discussion

The amount of rainfall received per year varied considerably in all stations. Positive increasing rainfall trends were found in Mbarara and Soroti while in Masindi the trend was decreasing (Table 3.3). The highest coefficient variation (25%) in annual rainfall received was observed in Mbarara while Masindi had the least CV (Table 3.3). This indicates that the rainfall patterns in Masindi were relatively stable compared to Mbarara and Soroti. Decadal and annual rainfall deviation also revealed high levels of variability. Most decades were dry except 1970s which were wet in all stations. The most dry and wet decade for Mbarara was 1980s and 2000s respectively. Similar to our findings, Nimusiima *et al* (2013) reported serious prolonged drought spells in 1991-2000. Perhaps this variability can be attributed to the influence of inter-

tropical convergence zone, the Zaire air boundary and El Niño – Southern Oscillation (ENSO) with tele-connections to Pacific and surface sea temperatures (Nicholson, 1996).

Extreme rainfall indices revealed mixed results. Total annual wet days (PRCPTOT) were increasing but not significant in all stations. Heavy precipitation days were also on the rise in all stations but not significant. However, consecutive wet days, CWDs were only significantly increasing in Mbarara while in Masindi and Soroti they were decreasing. Simple precipitation intensity index was increasing in Mbarara and Soroti while in Masindi it was decreasing. Consecutive dry days, CDDs were significantly increasing in Soroti while in Mbarara and Masindi CDDs were decreasing. CDDs are a measure for extremely dry days (Klein Tank *et al.*, 2009). The study further revealed that severe dry periods were experienced during 1979/80, 1983, 1989, and 1998 in most areas of pastoral rangelands (Figure 3.13). A study by Stampone *et al.* (2011), revealed similar findings that there has been an increase in the occurrence of droughts of which 1991-2000 decade recorded the highest frequency of droughts.

Results from this study are also consistent with those earlier reported by Makuma-massa *et al.* (2010) that the cattle corridor experienced severe droughts of 1980 to 1983, 1990 to 1992 and 1996 to 2000. The same authors further reported that there were outbreaks of FMD and contagious Bovine during those severe drought periods. Mduma *et al.* (1999) observes that vegetation and rainfall are positively correlated. This implies that increased frequency of CDD reduces availability of grazeable pastures which results into a decline in milk production levels, reduced weight gains and in extreme cases death of livestock. The decreasing number of wet days coupled with significant increases in CDDs indicates that Soroti in the North east of the pastoral rangelands is getting drier while the southwest in Mbarara it's slightly getting wetter.

Frequency of heavy precipitation days (R10mm) was declining in Mbarara though in Soroti it was increasing. Total annual precipitation index (PRCPTOT) showed slightly increasing non-significant trends ($p > 0.05$) in Mbarara. In Soroti, PRCPTOT index revealed a non-significant decreasing trend ($p < 0.05$) indicating that the amount of rainfall received in Soroti was gradually declining. Similarly, most pastoralists in Mbarara, Kiruhura and Luwero districts acknowledged increasing rainfall patterns (Figure 3.4), though the timing and start of the rains were slightly changing. These changes in rainfall extremes directly affect availability of pastures and surface water sources for watering livestock and domestic purposes. Vegetation vigour and survival of pasture species in the cattle corridor grazeable rangelands depends entirely on availability of soil moisture from rainfall. Moreover Ospina et al. (2012) noted that rainfall patterns often coincide with the effects of seasonality which in turn have an effect on the productivity of grassland pastures.

3.5.1 Trends in maximum and minimum temperatures

Maximum and minimum temperatures continue to rise in all stations (Table 3.5). Mbarara and Soroti experienced increasing significant trends ($p < 0.05$) in maximum temperatures while in Masindi the trend was increasing but not significant ($p > 0.05$). Table 3.5 showed that minimum temperatures were also significantly increasing in Mbarara ($p < 0.01$) and Masindi ($p < 0.05$) while in Soroti there was an increasing trend in minimum temperatures but not significant ($p > 0.05$).

Table 3. 5: Trends in maximum and minimum temperatures

Location	Maximum temperature		Minimum temperature	
	Mean	Sen's slope estimator	Mean	Sen's slope estimator
Mbarara	26.7 ± 0.48	0.023*	14.5 ± 0.92	0.051***
Masindi	29.6 ± 1.16	0.061	17.0 ± 0.68	0.023*
Soroti	30.8 ± 0.99	0.034*	18.1 ± 0.34	0.008

*Trend significant at $\alpha=0.05$ ***Trend significant at $\alpha=0.01$

Temperature extremes

The frequency of hottest days (TXx) in Soroti was significantly increasing while the number of warmest days (TXn) was slightly reducing. In Mbarara and Soroti, the number of warmest nights were significantly increasing ($p < 0.05$) indicating that minimum temperatures recorded at night since 1960 were rising (Table 3.6). Mbarara and Soroti experienced significant increases in hot days while for Soroti where the trend was increasing but not significant ($p < 0.05$). Frequencies of warm nights were also increasing except in Soroti where there was a decline in the frequency of warm nights. Daily maximum temperatures, Tx were increasing faster than daily maximum temperatures at all stations. The lowest rate of temperature increase in warm nights was observed at Soroti climatological area while Masindi experienced the highest increase rate of about 0.9°C per year. Percentage hot days were increasing at a rate of 0.42, 0.49, 0.46°C per year in Mbarara, Masindi and Soroti respectively. DTR showed significant decreasing trends in Mbarara and Masindi ($p < 0.05$). However, in Soroti the trend was significantly increasing ($p < 0.05$).

Table 3. 6: Extreme temperature indices for Mbarara, Masindi and Soroti

Index	Mbarara	Masindi	Soroti
Percentage Hot days (TX90p)	0.418*	0.49*	0.463
Percentage Warm nights (TN90p)	0.684*	0.954*	-0.172
Hottest days (TXx)	0.032	0.091	0.054*
Warmest nights (TNx)	0.108*	0.057	-0.023
Diurnal temperature range (DTR)	-0.065*	-0.047	0.055*
Warm spell duration Index (WSDI)	0.114	0.276*	0.235

* Trend significant at the 5% level

3.5.3 Percentage of extreme hot days (TX90p)

Percentage of hot days which is a measure of days/time when daily maximum temperatures, $T_x > 90^{th}$ percentile were significantly increasing in Masindi ($p < 0.05$) and in Mbarara and Soroti the trend was also increasing but not significant ($p > 0.05$). Most hot days were experienced in 1993, 2009 and 1992 for Mbarara, Masindi and Soroti respectively (Figure 3.16).

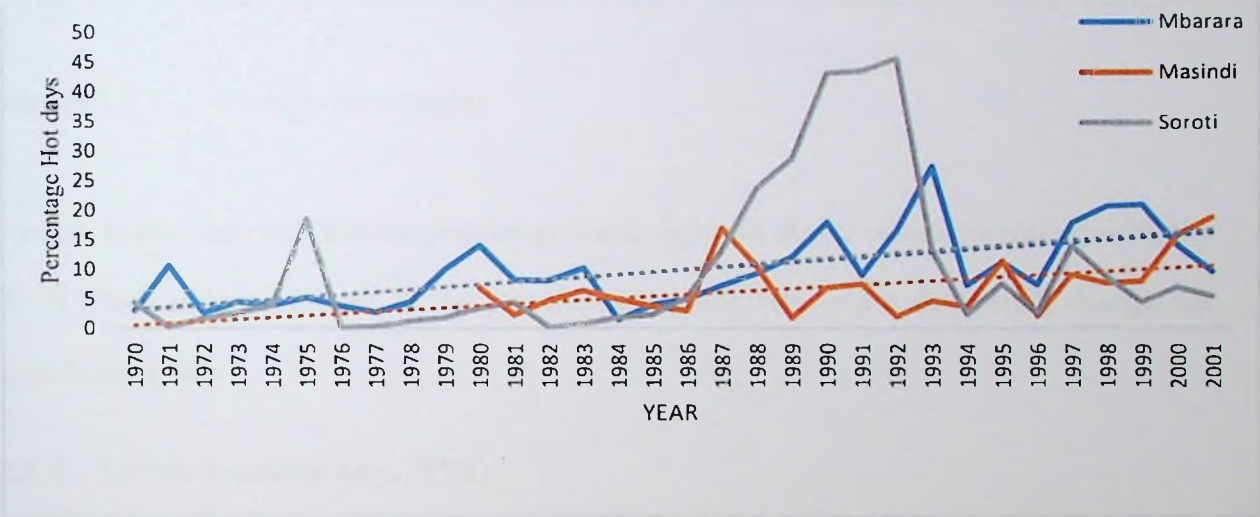


Figure 3.16: Percentage hot days

The number of hot days were increasing at a rate of 0.42, 0.49 and 0.46°C per year for Mbarara, Masindi and Soroti respectively. The current decade since 2000 has recorded the highest number of hot days in all stations.

3.5.4 Percentage warm nights (TN90p)

Figure 3.17 showed that percentage warm nights (TN90p) were significantly increasing in Mbarara and Masindi ($p > 0.05$). In Mbarara more frequent warm nights were experienced in 1989 while in Masindi more warm nights were experienced in 2002.



Figure 3. 17: Percentage warm nights

Results further indicated that the percentage warm nights in Soroti climatological area (Figure 3.17) which is in north east of the pastoral rangelands followed a decreasing though not significant trends.

3.5.5 Trends in hottest days (TXx)

Figure 3.18 shows trends in frequency of hottest days. Frequency of hottest days showed non-significant increasing trends in Mbarara and Masindi. However, in Soroti the trend of hottest days were significantly increasing ($p < 0.05$). The highest temperatures were experienced in 1991, 2005 and 1992 for Mbarara, Masindi, and Soroti respectively. In Soroti, frequency of hottest days rose sharply from the late 1970's. In all stations there was a general increase in the daily maximum recorded temperatures indicating rising temperatures since 1970. Daily maximum temperatures were increasing at a rate of 0.09, 0.54 and 0.03°C per annum in Masindi, Soroti and Mbarara respectively.

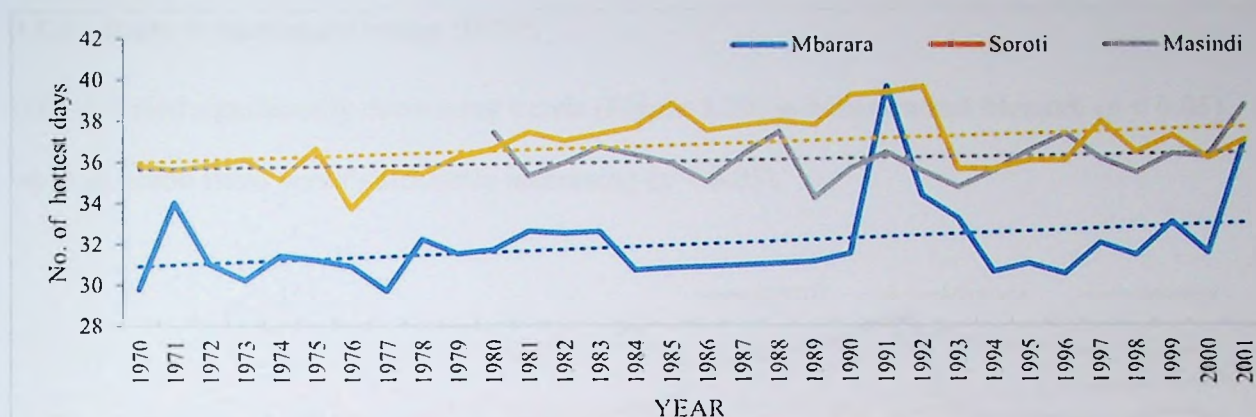


Figure 3. 18: Trends of hottest days

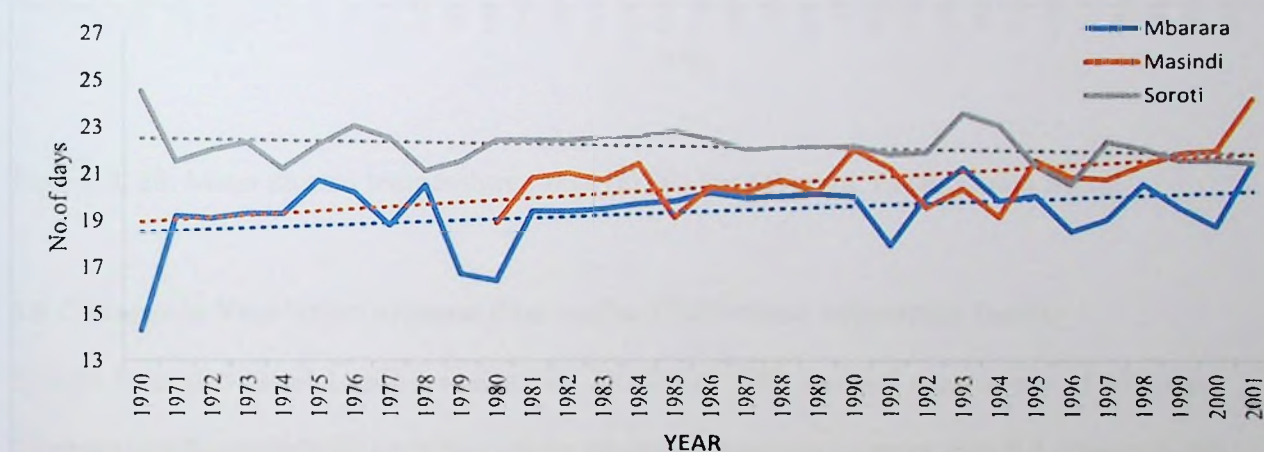


Figure 3. 19: Frequency of warmest days for Mbarara, Masindi and Soroti

Frequency of warmest nights, TNx were significantly increasing in Mbarara and Masindi however in Soroti TNx showed a non-significant decreasing trend (Figure 3.19). Most warm nights were experienced in 2000, 2001 and 1993 for Mbarara, Masindi and Soroti respectively. Although Mbarara recorded the lowest minimum temperatures (cold nights), it had the highest rate of increase ($0.68^{\circ}\text{C}/\text{year}$) in monthly maximum temperature values recorded at night. Soroti experienced the lowest rate of increase in warmest nights of about $0.43^{\circ}\text{C}/\text{year}$.

3.5.6 Daily temperature range (DTR)

DTR revealed significantly decreasing trends (Figure 3.20) in Mbarara and Masindi ($p < 0.05$) while in Soroti trend was significantly increasing ($p < 0.05$).

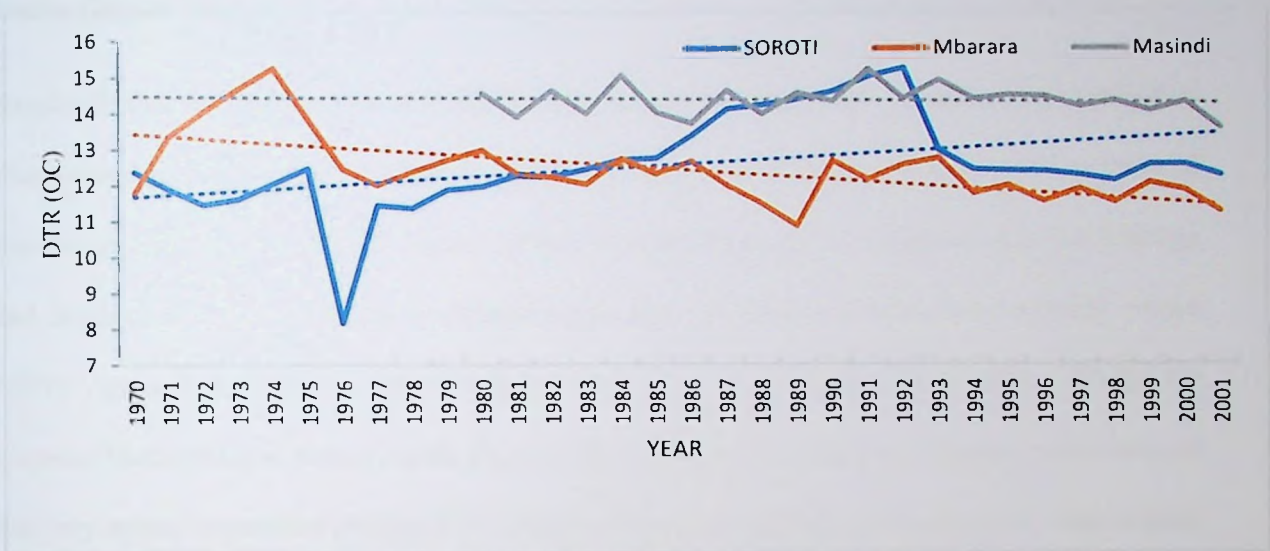


Figure 3. 20. Mean diurnal temperature range (DTR) for Mbarara, Masindi and Soroti

3.6 Changes in Vegetation biomass (Normalised Difference vegetation Index)

Results from processed Landsat images for NDVI in 1986 showed most areas of Mbarara, Kiruhura and Sembabule districts had a high vegetative biomass of more than 0.4 (Figure 3.20) indicating that shrubs, woodlots and woodland forests were abundant. These values are consistent with Flynn (2006) who reported that high NDVI values are highly associated with high vegetative biomass. NDVI results in 2000 indicated that most areas in Mbarara, Kiruhura and Sembabule district had less NDVI values as compared to 1986 confirming that most shrubs and forest woodlots were encroached and claimed. In 2015 NDVI values for Kiruhura, Mbarara and Sembabule districts revealed mixed results. For example the entire southern areas of Kiruhura district had very low NDVI values while the northern areas were dominated by bushes and short grasslands (Figure 3.20). NDVI values for most areas in Mbarara district were of short grasslands and bushes while Sembabule district had less vegetative biomass. However,

in contrast NDVI results for the districts of Luwero, Nakaseke and Nakasongola revealed the northern parts of the district's had low NDVI values < 0.3 and as such were dominated by bare /very sparse vegetation while the southern parts were dominated by shrubs and woodland forests (Figure 3.20).

Results further revealed by the year 2000 most of the greening (high vegetation biomass) had disappeared in the districts of Luwero, Nakaseke and Nakasongola. All the northern parts of the district had very low NDVI values of less than 0.15 except the southern areas in Kakoge and Butuntumura sub counties in Nakasongola and Nakaseke districts respectively where NDVI values were slightly higher ranging from 0.3 - 0.4 (Figure 3.21). NDVI results for Luwero, Nakaseke and Nakasongola showed that most of the district areas were either bare or had very sparse vegetation (Figure 3.19) except in the central parts of the districts where closed grasslands and bushes were observed. The proportion of land under dense vegetation like forest woodlands have highly been reduced as compared to NDVI values of 1986.

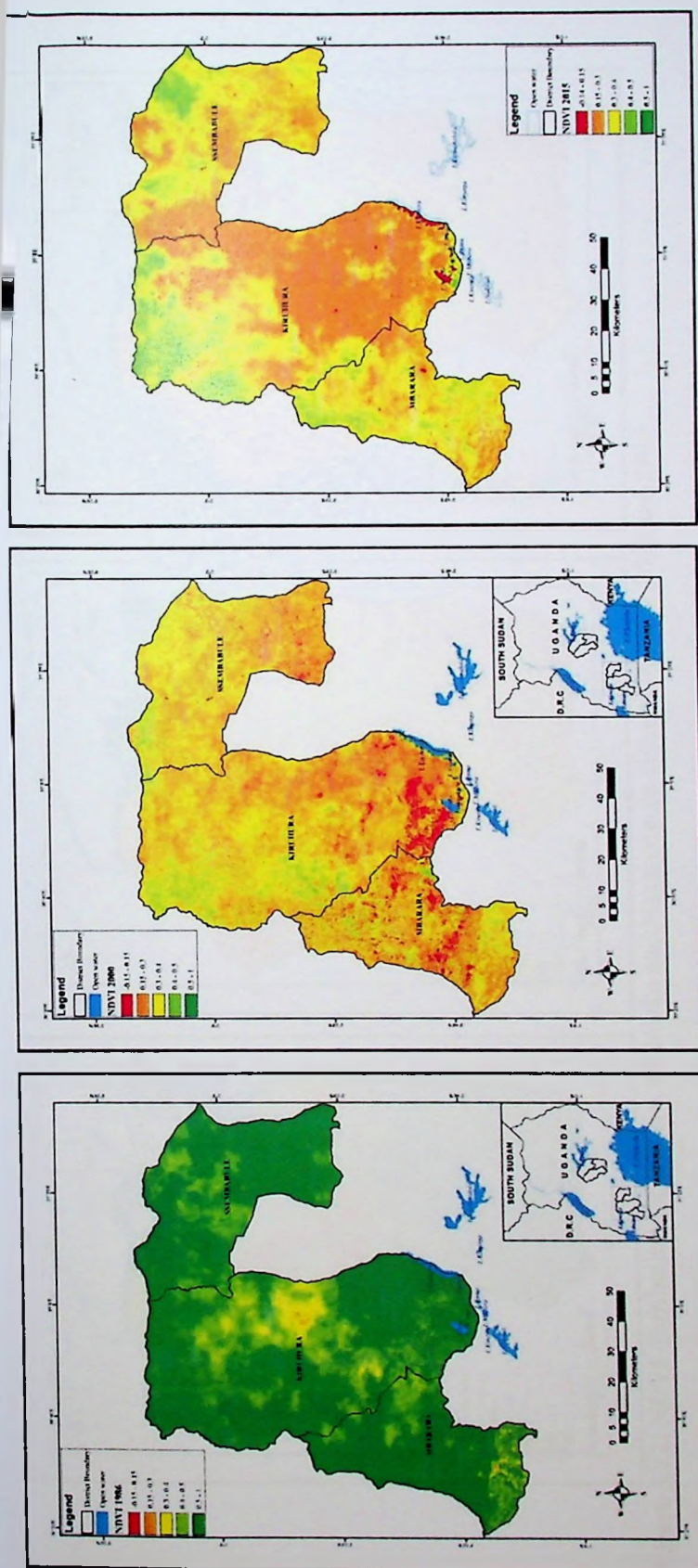
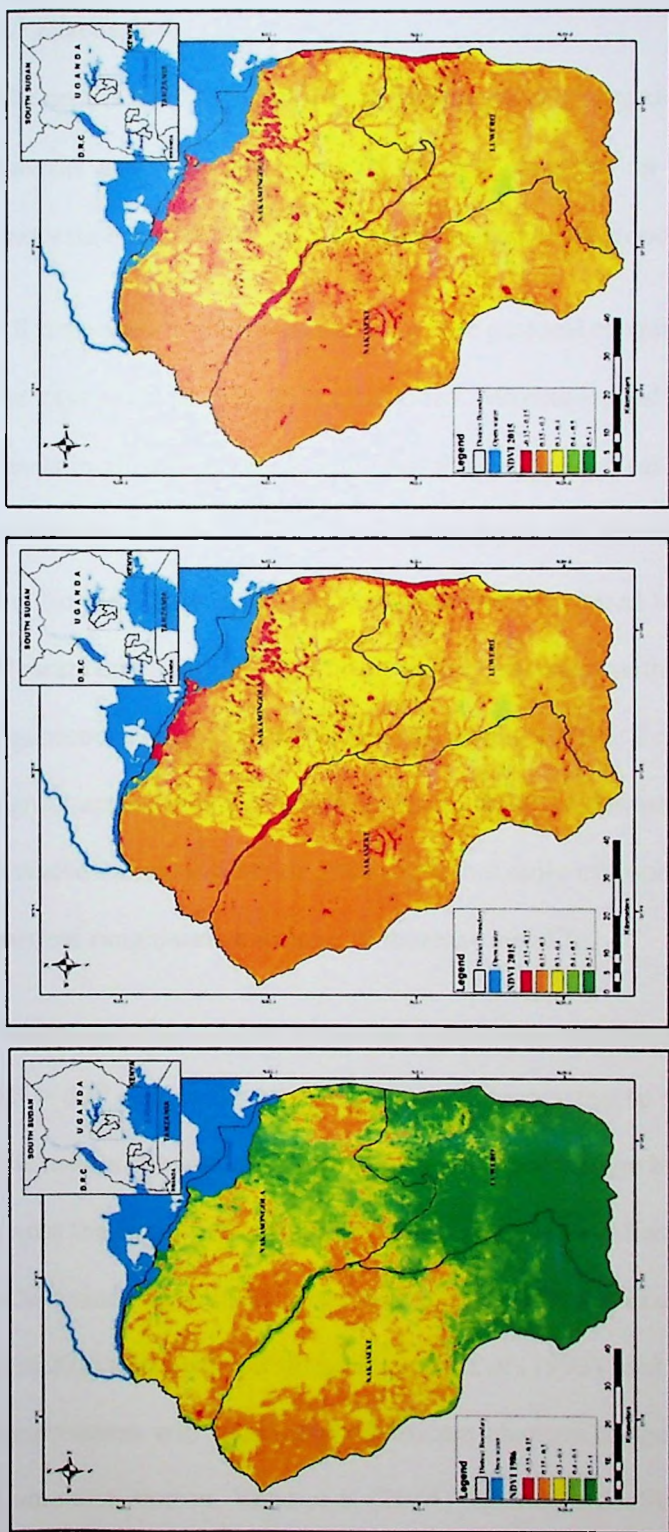


Figure 3.21: NDVI distribution for Mbarara, Kiruhura and Sembabule districts in 1986, 2000 and 2015



3.7 Discussion

The results from this study showed that pastoral rangelands are experiencing very unstable rainfall patterns and high frequency of climate extremes as perceived by the pastoralists. Majority of pastoralists perceived climate extremes as severe floods and prolonged dry season.

All temperature indices indicate that the pastoral rangelands will continue to experience increasing hot days and warm night's conditions. Maximum and minimum temperatures showed increasing trends in all stations indicating that the entire pastoral rangelands continues to experience raising temperatures. However, maximum temperatures showed significant trends ($p < 0.05$) in Mbarara and Soroti. Daily minimum temperatures continued to rise and were significantly increasing in Mbarara and Masindi. Our findings are consistent with global projections elsewhere (IPCC, 2007; Oguntunde, *et al.*, 2011; Narayanan *et al.*, 2013;). Temperature extreme indices revealed strong significant increasing trends in mean daily maximum temperatures. Most temperature indices revealed increasing trends, indicating that daily minimum and maximum temperatures in the entire pastoral rangelands continue to increase steadily.

Percentage of days/time when daily maximum temperatures, T_x and daily minimum temperatures, $T_N > 90^{\text{th}}$ percentile were significantly increasing ($p < 0.05$) throughout the pastoral rangelands. The results showed an increasing trend in percentage hot days ($TX90p$) and warm nights ($TX90p$) across the region. Our results support previous studies that reported a shift in higher temperature values since the middle of the 21st century (Hansen *et al.*, 2012; Donat and Alexander 2012; Donat *et al.* 2013). In a related study, Hanson *et al.* (1993) further observed that sustained increase in mean temperatures will result into significant changes in species distribution, composition patterns and biome distribution. Yano *et al.* (2014) reported a decline in livestock productivity parameters like

conception rates as result of increased temperatures. Further still, Rowlinson (2008) observed a reduction in feed intake of farm animals because of heat distress as a result of increased temperatures. Reduced feed intake directly results into poor growth performance of animals.

DTR which is the monthly mean difference between daily maximum and minimum temperature was significantly decreasing in Masindi and Mbarara. This indicates that daily maximum and minimum temperatures in Mbarara and Masindi continue to rise steadily. However, daily minimum temperatures were rising faster compared to daily maximum temperatures (Figure 3.20) while in the north east pastoral rangelands, DTR showed a significant increasing trend ($p < 0.05$).

The highest temperature increases were observed in Soroti-North east of the pastoral rangelands (Figure 3.17) indicating that there are variations of temperature extremes being experienced in the region. These temperature variations present unique challenges and opportunities for livestock production. For example raising temperatures result into increased heat stress to livestock and consequently increases maintenance energy requirements and respiration rates. In addition increased heat stress decreases dry matter intake, milk production and reproductive performance especially in dairy animals. Similarly, studies by Stem *et al.*, 1989 observed that climatic restrictions on vectors, environmental habitats, and disease causing agents are important for keeping many animal diseases in check. Therefore, the observed significant changes /increases in temperature extremes are most likely to result into uncontrolled prolific disease outbreaks for both human and livestock in the pastoral rangelands.

Results from NDVI revealed that most areas in Mbarara, Kiruhura and sembabule districts had higher greenness in 1986 as compared in 2015 (Figure 3.20). In Luwero, Nakaseke and Nakasongola districts the entire northern areas had higher NDVI values as compared to the

southern parts (Figure 3.21). This indicates that the proportion of land under vegetation biomass (grasslands, shrubs and forest woodlots) was progressively reducing. For example by 2015 NDVI values in all districts showed less values ($p < 0.15$) confirming that most of the dense vegetation cover had disappeared leaving only sparse vegetation and short grasslands. The results from satellite images are consistent with observed rainfall and temperature extremes. Moreover consecutive wet days (CWDs) were more frequent in 1986 as compared to 2000. In addition, annual rainfall variability showed strong positive deviations in 1986 as compared to 2000. The reduction in dense vegetation cover perhaps can be attributed to increased human population pressure and increasing forest destruction activities like charcoal burning. Burning forest wood for charcoal has been on the increasing in all the cattle corridor districts thus reducing the vegetation biomass. These results are consistent with Zziwa et al (2012) who observed that grasslands in Nakasongola district had reduced by 23.3% in 2004 as compared to 25.6% in 1986. The same authors further reported that in Nakasongola district wetland and water bodies had increased by 5 and 7.81% respectively by 2000 as compared to 1986.

The observed NDVI values > 0.3 (Figure 3.20) corresponds well with peaks when consecutive wet days and maximum precipitation days were highest. Topp and Doyle (1996), affirms that changes in rainfall are most likely to influence the quality and quantity of forage produced and consequently altering the productivity of grazing livestock. Moreover, Nandozi et al (2012) and Magsar (2004) reported that areas with high rainfall are likely to have high vegetation biomass. Egeru et al (2014) reported a 59.6, 62.9, 68.2 and 72.1% reduction between wet and dry seasons in above ground biomass in woodlands, grasslands, bush lands, thickets and shrub lands in Karamoja sub regions. The differences between wet and dry season forage quantity were attributable to variations in rainfall over the seasons.

In a related study, Awa et al. (2002) noted that forage quantity is directly related to rainfall in semi-arid areas of Chad and Cameroon. Hopkins and Del Prado (2007) further observed that climate change will lead to changes in pasture composition such as changes in the ratio of grasses to legumes. For example farmers acknowledged that some pasture species like *Hyparrhenia spp* were disappearing at the expense of *Lantana camara* an invasive pasture weed in the rangelands. Therefore trends of increasing rainfall patterns observed in Mbarara-southwest of the pastoral rangelands may favour increased pasture production and by implication enhance livestock production for improved livelihoods in the region. However, in North east of the pastoral rangelands in areas of Nakasongola and parts of Luwero the frequency of CDDs showed significant increasing trends ($p < 0.05$) indicating that these areas within Soroti climatological zone are progressively becoming drier. This result compares well with Basalirwa *et al.* (1995) who reported that the cattle corridor of Uganda is most likely to become drier. Furthermore, the observed changes in vegetation (Figure 3.21) in 2015 indicated more land being under cultivation and less water resource as compared to 1986. Increased areas under cultivation together with declining grasslands can be attributed to increased human population which exerts pressure on opening up more land to grow crops and increase food production.

3.8 Conclusion and recommendations

In all study areas the amount of rainfall received annually varied highly. In addition, increasing temperatures coupled with unstable rainfall patterns will negatively impact on livestock production in the pastoral rangelands. Therefore pastoralists need to adopt strategies that minimize the negative impact on livestock production like: (i) promoting pasture species tolerant to hot and warming conditions, (ii) widen use of pasture conservation techniques like hay, increase utilization

of alternative livestock feeds like crop residues and (iii) promotion of water harvesting and conservation interventions may offer an excellent adaptation package in improving productivity of pastoral rangelands under varying rainfall and increasing warmer and hotter temperature conditions.

CHAPTER FOUR

PASTORALISTS' PERCEPTIONS OF CLIMATE EXTREMES AND ADAPTATION STRATEGIES DEVELOPED TO ENHANCE LIVESTOCK PRODUCTIVITY IN THE PASTORAL RANGELANDS

ABSTRACT

Understanding farmers' perceptions and their knowledge to climate extremes provides useful information in developing appropriate adaptation strategies. This study was conducted to establish farmers' knowledge and perceptions to trends of climate extremes in the pastoral rangelands of Uganda. Climate extremes were derived by analyzing rainfall and temperature data sets from 1970 to 2013 using RClimdex software. Data to establish farmer's knowledge were collected through face to face household interviews and analyzed using descriptive statistics and multinomial logistic regression models using SPSS software. Percentage hot days were positively increasing while warm nights revealed a declining trend. Pastoralists' perceived changes in rainfall and temperature extremes compared well with the observed climatological trends. CDDs and heavy precipitation days were the most perceived extremes. Key adaptation strategies included; fencing of grazeable land, use of drought tolerant pasture species, utilization of crop residues and feed conservation, water harvesting and change of grazing time. Limited access to climate information and insecure land ownership rights were key barriers constraining adaptation. Therefore policies that ensure secure land ownership rights while improving farmers' access to early warning information on climate events can effectively facilitate adaptation to climate change.

Key words: *Trends, precipitation, temperature, extremes and adaptation*

4.1 Introduction

Climate change will continue to stress and increase the vulnerability of agricultural systems especially those in semi-arid regions in supporting livelihoods (IPCC, 2007). The pastoral rangelands in Uganda are characterized as semi-arid and are considered among the most fragile regions in the country (NEMA, 2001). Livestock production is the main agricultural activity that sustains livelihoods in the pastoral rangelands of Uganda. Most common livestock species kept include cattle, goats, and sheep. These livestock species depend chiefly on grazing natural pastures in the rangelands. Availability of pastures and water resources in the rangelands of the cattle corridor is directly influenced by the amount of rainfall received and the surrounding ambient temperatures (MLWE, 2003). Climate change has affected the rainfall patterns and consequently the frequency of rainfall extremes are rapidly changing. Donat *et al.* (2013) reported that changes in rainfall and temperature extremes are among the key indicators of climate change and must therefore be carefully understood.

Climate change will affect all dimensions of food security through reduced availability of water and increased environmental temperatures (Beddington, *et al.* 2011). However, CCSP (2008) observes that changes in extreme climatic events result in severe socio-economic impacts which can have both positive and negative effects. Most systems have adapted to their historical range of events of extremes implying that the majority of events outside the desired and tolerable range quite often have negative impacts to society. Reducing negative impacts of climate change which are a result of changing extremes events can be achieved through enhanced adaptation (Kurukulasuriya and Rosenthal, 2003). Adaptation to climate change takes on many definitions (Burton *et al.* 2005; Thornton *et al.* 2008). However, IPCC (2001) defines adaptation to climate change as an adjustment in natural or human systems in response to actual or expected climatic

stimuli or their effects, which moderates harm or exploits beneficial opportunities. Thornton *et al.* (2007) argues that adaptation can be influenced by management of resources at household level. However, variability in rainfall and temperature together with changes in extremes events directly influences natural and human systems much more than average climate (Peterson *et al.* 2008). Most organisms and life processes can always adapt to changes in climate means. However, changes in climate extremes usually result into serious devastating impacts. Climate extremes are unusual weather events in their occurrence which always lie in the upper or lower ten percentile of the distribution and have destructive potential like hurricanes, tornadoes, hailstorms, very heavy rainfall and heat waves for long period of time (CCSP, 2008).

Studies on climate extremes generate information which is vital for stakeholders in making policy and management decisions for better adaptation to climate change (Manton *et al.* 2000; Donat & Alexander, 2012). Although, Manton *et al.* (2000) reports that fewer studies have examined trends in climate extremes. Studies elsewhere on changes in temperature and precipitation extremes have generated information vital for adaptation processes (Anguilar *et al.* 2009). However, information concerning how farmers perceive and respond to changes in climate variability and extreme events in Uganda is not available. Yet, such information is necessary in developing appropriate adaptation strategies to a changing climate. This study was therefore conducted to establish farmers knowledge and perceptions of climate variability and extremes in order to inform the process of developing appropriate adaptation strategies to climate extremes for sustainable livelihoods in the pastoral rangelands of Uganda.

4.2. Materials and methods

4.2.1 Description of the study sites

This study was conducted in six pastoral rangeland districts (Figure 4.1). These districts included; Mbarara, Kiruhura, Sembabule, Nakaseke, Luwero and Nakasongola. These districts were purposively selected as they are entirely located in the pastoral rangelands agro-ecological zone of Uganda (MAAIF, 2018) and had the highest concentration of pastoralists. Mbarara and Kiruhura districts are located in the southwestern Uganda along Masaka- Kabale highway about 210 km south west of Kampala. It's located on latitude $00^{\circ}15''$ to $00^{\circ}24''$ and longitude $031^{\circ}34''$ to $031^{\circ}44''$. Nakaseke, Luwero and Nakasongola districts are located in central region of Uganda along the Bombo -Gulu Road 60 Km North of capital Kampala (Figure 4.1). It's located on the equator at latitude $0^{\circ}55'N$ to $1^{\circ}40'N$ and longitude $31^{\circ}55'E$ and $32^{\circ}50'E$.

In Nakaseke, Luwero and Nakasongola districts the vegetation is described as dominantly open savannah woodland with tall grasses as characterized by Wortmann and Eledu, (1999). The total area of Luwero district is approximately 2,577.5 sq km. Luwero district is bordered by Mukono and Wakiso districts in the south, Nakaseke in the west, Nakasongola in the North and in the East is Kayunga district. The present topography in Luwero is as a result of a number of ancient denudation processes of the rock systems leaving a series of old erosion levels. Most parts of the district ranges between 1,219 and 1,524 meters above sea level. The long term average annual rainfall for Luwero is 1,300mm. The mean annual maximum temperature falls between $27.5^{\circ}C$ and $30^{\circ}C$, whereas the mean annual minimum temperature is between $15^{\circ}C$ and $17.5^{\circ}C$.

The soils are generally red sandy loam, while in the southern part are relatively fertile and can support all kinds of crops. Unlike other areas in the pastoral rangelands of Uganda, in Luwero a

wide range of food crops are grown in the district such as cassava, sweet potatoes, maize, bananas and horticultural crops among others. In all districts, generally key grass species included: *Hyparrhenia rufa*, *Themeda triandra*, *Brachiaria spp*, *Panicum maximum*, *Chloris gayana* and *Laudetia kagerensis*. Woody plants included: *Combretum terminalia*, *Acacia brevispica*, *Canthium lactescens*, *Grevia mollis*, *Teclea nobilis* and *Vernonia brachycalyx*.

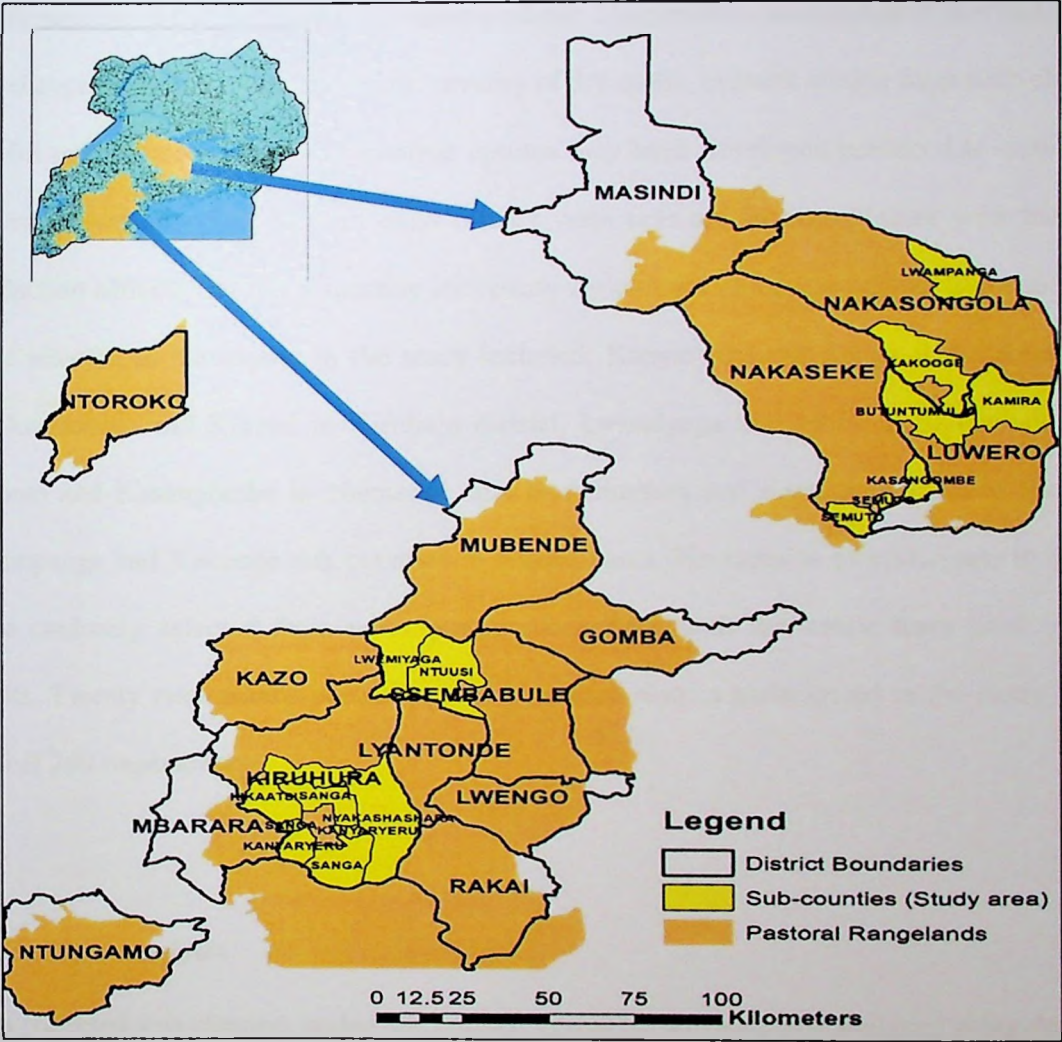


Figure 4. 1: Map of Uganda showing districts covered by Pastoral Rangelands and the selected sub-counties where the study was conducted

4.2.2 Data collection

Data to establish farmers' perceptions on rainfall trends, adaptation strategies, and barriers to adaptation were collected through face to face household interviews using pre-tested semi-structured questionnaires. The survey questionnaire was also used to collect data on socio-economic household characteristics like age of the household head, marital status, education level, family size, household land holdings among others. Respondents were asked if they had observed any changes in heavy rainfall patterns, severity of dry spells, impacts arising from such changes in rainfall patterns and possible adaptation options they have developed/practiced to ensure better survival. Two subcounties from each district were selected in consultation with the district production officers and the respective subcounty agricultural extension agents. Sub counties that were selected to participate in the study included: Kanyaryeru and Sanga in Mbarara district, Nyakashashara and Kikatsi in Kiruhura district, Lwemiyaga and Ntusi in Sembabule district, Semuto and Kasangombe in Nakaseke, and Butuntumura and Kamira in Luwero district and Lwampanga and Kakooge sub counties in Nakasongola. Households to participate in the study were randomly selected from participating subcounties with assistance from local extension agents. Twenty respondents per subcounty from each district participated in the study raising a total of 240 respondents.

4.2.3 Data Analysis

Data collected was cleaned, coded and entered into SPSS software and analyzed using descriptive statistics and multinomial logistic regression models. McConnell et al (2009) confirmed that for a farmer to make a decision on whether or not to adapt to a particular technology or innovation, he

does not only consider how to maximize profit from that innovation but on how to attain the highest level of utility otherwise referred to as utility maximization. It is observed that farmers have a level of utility they want to meet and therefore make choices based to achieve it. Gbetibouo, 2009 asserts that any adaptation option could fall under the general framework of utility and profit maximization. The utility of a farmer is given as U_{ij} , from choosing alternative j . Livestock farmers will choose whether or not to adapt to impacts of climate change depending on the relative utility levels associated with the two choices. In this case, choice models were used to analyze a farmer's decision to adapt or not to adapt to climate change. The choice models are used based on the dependent variable which takes the form of 0 or 1 (dummy variable). Two models for this analysis were the logit and probit models. Logit and probit models were derived from an underlying latent variable model:

$$y^* = \beta_0 + \beta_1 x_1 + \dots + \beta_k x_k + \varepsilon \text{ and}$$

$y = 1[y^* > 0]$. Where y^* denotes the unobserved, or latent variable; x denotes the set of explanatory variables, ε denotes the error term and $1[y^* > 0]$ defines the binary outcome. The main difference between the probit and logit models lies in the assumption of the distribution of the error term, ε . The error term is assumed to have the standard logistic distribution in the case of the logit, and the standard normal distribution in the case of the probit model (Deressa *et al.*, 2009).

To determine factors affecting farmers' adaptation strategies to climate change a logistic regression model was used which was specified as;

$$\text{Logit}P(x) = \alpha + \sum_{i=1}^n \beta_i x_i$$

Where α denotes a constant and β the regression coefficient.

Finally the regression model for this study was specified as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \varepsilon$$

where Y denotes whether to adapt or not, X_1 Age of the household head, X_2 Gender of the household head, X_3 Marital status, X_4 Education level of the household head, X_5 Family size, X_6 Cattle number per household, X_7 Land size available per household, and X_8 Farming experience of the household head (Table 4.1).

Table 4. 1: Description of explanatory variables used in the model

Predictors	Explanations	Measurement	<i>A priori</i> expectation
X_1	Age of the household head	Years	—
X_2	Gender of the household head	1 if male; 0 otherwise	+/-
X_3	Marital status	1 if married, 0 otherwise	+
X_4	Education level of the household head	0=Never, 1=Primary, 2=Secondary, 3=Post-secondary	+
X_5	Family size	Number	+
X_6	Cattle number per household	Number	+
X_7	Land size under per household	Hectares	+
X_8	Farming experience	Years spent in the village	+

Gender of the household head was expected to have a positive or negative effect on adaptation to climate change. This is because male farmers are more likely to have access to information about

new technologies and undertake risky businesses than female farmers (Asfaw & Admassie, 2004). Furthermore, male farmers are well endowed with production resources such as land than their female counterparts and would take initiatives to adapt to climate change. Age of the farmer was measured in years and was expected to have a negative effect on adaptation to climate change. Due to the fact that young farmers are agile, can take risk and quickly learn of the new interventions than old livestock farmers. Educational level was expected to have a positive effect on adaptation to climate change. This is because educated farmers are more likely to obtain information, perceive and adapt to climate change (Maddison, 2006). Household family size was hypothesized to have a positive relationship with adaptation to climate change since Deressa et al., (2009) reported that larger family sizes were more likely to adapt as they can contribute to labour demands.

4.2.4 Analysis of pastoralists' choice of adaptation strategies

To identify factors that affect farmers' choice of adaptation strategies to climate change, a multinomial logistic regression model was used. Mabe et al. (2014) employed a logistic regression model to analyse factors that affect the choice of climate change adaptation strategies of farmers in Northern Ghana. Using the logit model the factors that significantly influenced the choice of adaptation strategies to climate change were estimated. Okoffo et al. (2016) also used LRM to analyze factors influencing operational habits exhibited by cocoa farmers during and after pesticides application. The advantage of logit regression model is that it allows for analysis of decisions and determines the associated probabilities for the choice of a particular adaptation strategy. A LR model also allows for each adaptation strategy to be analyzed separately and independently, unlike the use of multinomial logit model (Deressa, *et al.*, 2009). This is to eliminate the effects of the choice of one adaptation strategy on the other. Six adaptation strategies namely; fencing, integration of crop into livestock, stocking rate control, change of grazing time,

use of crop residues and drought tolerant pasture species which were used by the livestock farmers. Additional data was got from district production offices and Non-governmental organizations. Data from district production offices included time when extreme events such as hailstorms occurred and the impacts/ consequences from such events.

4.3. Results

4.3.1 Socio-economic characteristics of the surveyed households

Respondents from Sembabule district were older (56 ± 11 years) compared with other districts while Kiruhura district had respondents with least age of 46 ± 13 years (Table 4.2). Households in Nakasongola district had relatively the largest family sizes of 14 persons as compared to other districts. Most of the household heads were married although other cases of those which were single and widows/widowers were also evident. Most of the respondents had attained formal education at different levels which included primary, secondary and post-secondary (Table 4.2). Although some reported that they could not complete and as such never attained equivalent respective academic certificates. Household heads that had never attained or enrolled for any formal of education also existed in all the districts. Respondents' who had never gone to school to attain any form of formal education were highest in Kiruhura and Nakasongola districts. Luwero and Mbarara districts had the least number of people who had never gone to school.

Table 4. 2: General demographic characteristics' of the households

Household characteristics	District					
	Mbarara	Kiruhura	Sembabule	Nakaseke	Luwero	Nakasongola
Age of the household head (years)	48±14	46±13	56±11	51±9	49±5	54 ± 10
Family size	10.8	12	11	10	8	14.2
Marital status of household head (%)						
Married	98	95	86	95	91	90
Widow/widower	2	5	10	3	8	10
Separated	0	0	3	0	0	0
Single	0	0	1	2	1	0
Education level of the household head (%)						
Primary	50	35	44	37.5	49	32
Secondary	30	17	26	31	21	29
Post-secondary	0	7	5	8.5	12	2
Never	20	41	25	23	18	37
Time spent in village						
Duration stayed in village (years)	31	36	39	34	30	33.5

4.3.2 Livestock herd size

Cattle and goats were the most important livestock species kept (Figure 4.2). Households in Kiruhura district kept larger cattle herd size as compared to other districts. Perhaps this could be attributed to improved management practices such as breeding, feeding of high quality pastures and increased availability of water. In Sembabule district the number of goats kept per household was higher compared to other districts (Figure 4.2).

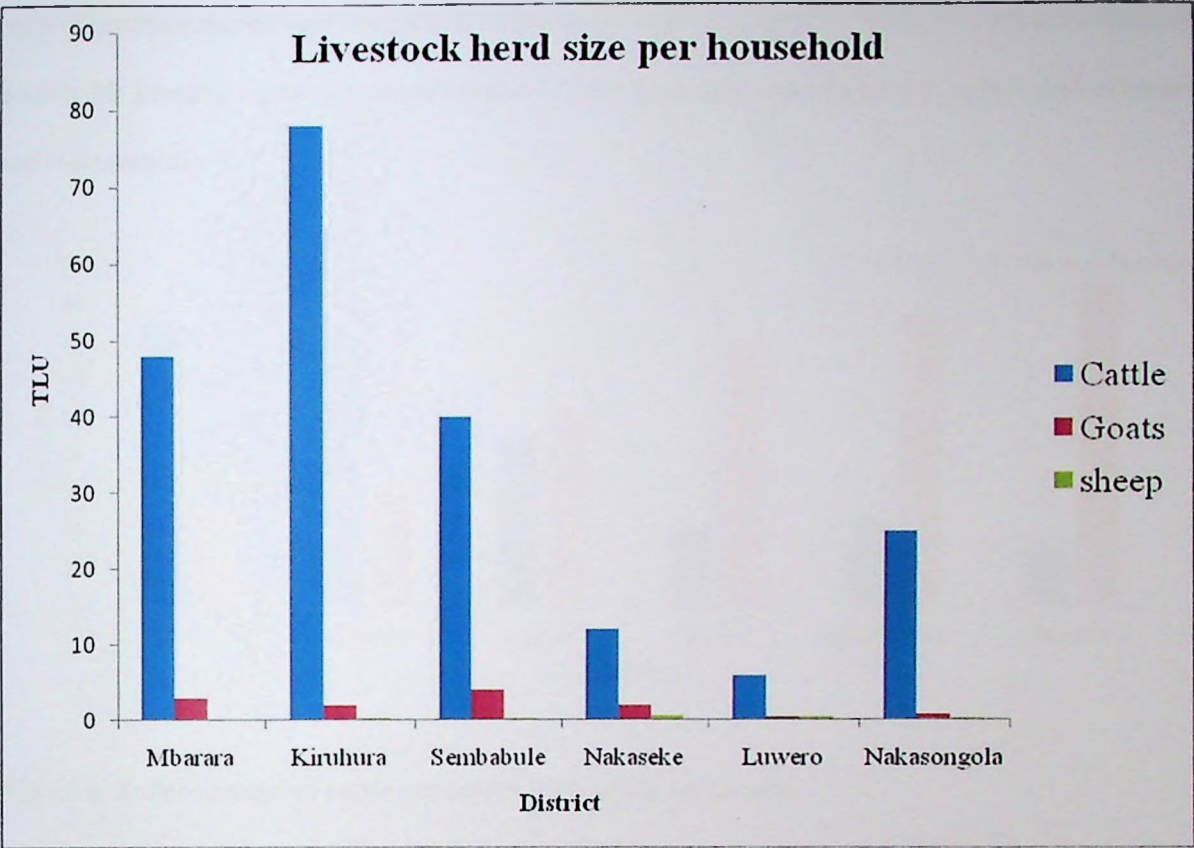


Figure 4. 2: Livestock herd size per household in Total Livestock Units (TLU)

Most of the households kept indigenous cattle genotypes (Figure 4.3). However, the percentage of households keeping exotic genotypes especially the Friesians were high in Kiruhura and Mbarara and Nakaseke districts.

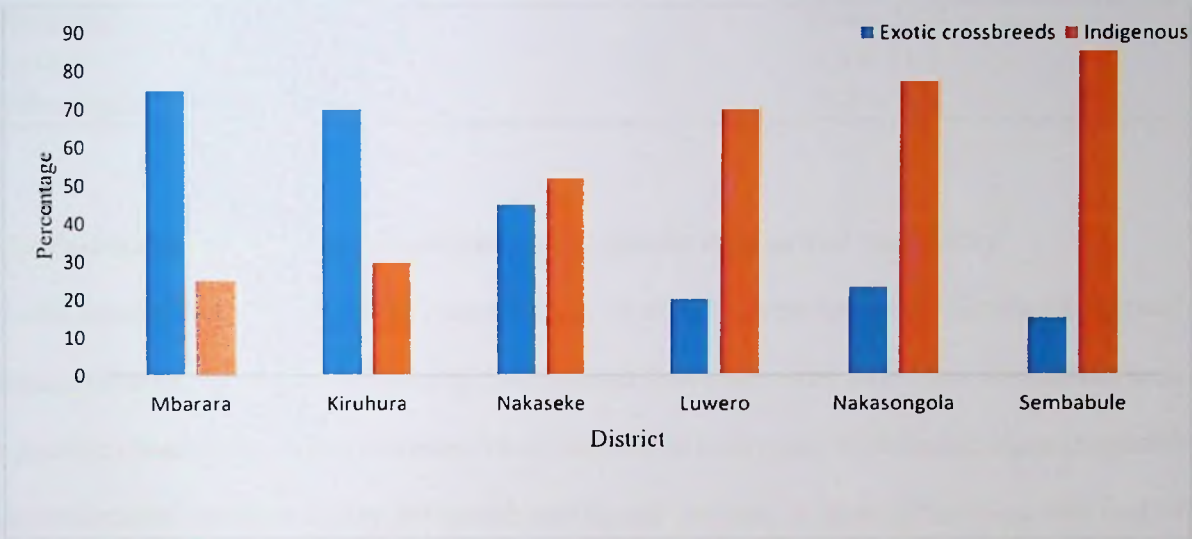


Figure 4. 3: Percentage of cattle genotypes kept in the study area

4.3.3 Land holdings

The study revealed that households in Kiruhura, Mbarara and Sembabule districts owned more land as compared to other districts (Table 4.3). Households in Luwero district had the smallest land sizes available per household. However, the variations between individual households in the size of land owned were high in all the districts.

Table 4. 3.Average land holdings per household in hectares (mean±SD)

District	Hectares
Mbarara	20.0 ± 22.4
Kiruhura	22.1 ± 23.6
Sembabule	17.2 ± 19.9
Nakaseke	13.4 ± 18.4
Luwero	4.6 ± 11.3
Nakasongola	8.5 ± 7.7

4.3.4 Pastoralists awareness and perceptions to climate change and variability

Results showed that majority of the pastoralists in all districts were aware of climate change and increased climate variability. Severity of droughts and floods were key indicators pastoralists used to perceive climate change and increased variability. Other indicators' included changes in rainfall patterns/seasons, increase in day hot temperatures, and changes in start of the rains and end of rains among others. Pastoralists perceptions on the amount of rainfall received annually revealed mixed results (Figure 4.5). Over 80% of the pastoralists in the districts of Nakasongola, Nakaseke and Sembabule perceived that the amount of rainfall received annually was decreasing (Figure 4.4). Most of the farmers perceived the amount of rainfall received as decreasing except in Mbarara, Kiruhura and Luwero districts who perceived changes in the amount of rainfall received as increasing (Figure 4.4). In Nakasongola, Luwero, Nakaseke, Sembabule, Kiruhura and Mbarara district 86%, 44%, 51%, 91%, 37% and 38% respectively perceived changes in rainfall events have decreased (Figure 4.4). This is in agreement with precipitation trends. On the contrary, about 86 and 84 percent of the households in Sembabule and Nakasongola districts reported the amount of rainfall received was decreasing (Figure 4.4).

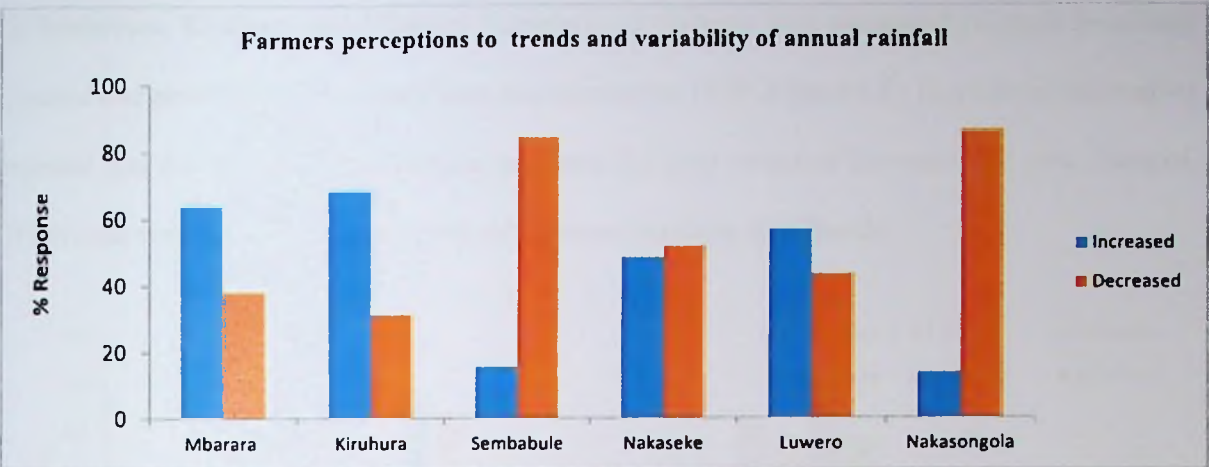


Figure 4. 4: Pastoralists perceptions to trends and variability of annual rainfall

Further investigation of farmers' perceptions regarding weather and climate extremes revealed that severe droughts and floods were the most perceived climate extremes in the pastoral rangelands. Most farmers who had perceived changes in rainfall, reported that severe drought periods were increasing and 1980 was the year when the rangelands in Nakasongola, Luwero and Nakaseke experienced severe droughts (Figure 4.5).

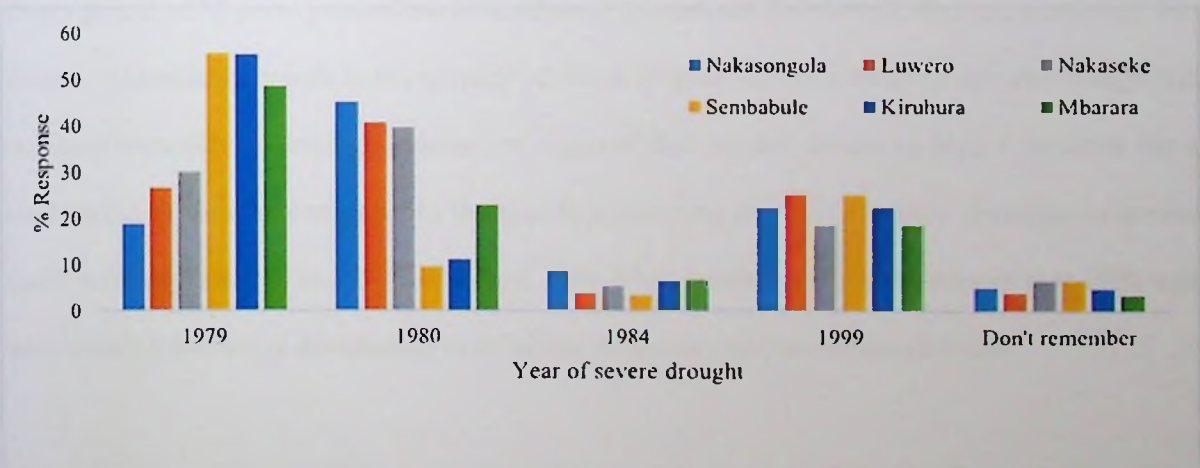


Figure 4. 5: Pastoralists' perceptions on the year when severe droughts occurred over 30 years ago

In Sembabule, Kiruhura and Mbarara districts most farmers who perceived changes in rainfall reported that severe drought periods were experienced in 1979 (Figure 4.6). In addition pastoralists reported that due to changes in climate extremes the start /onset of the rains had also changed. When rains start they are always heavy with storms resulting into floods.

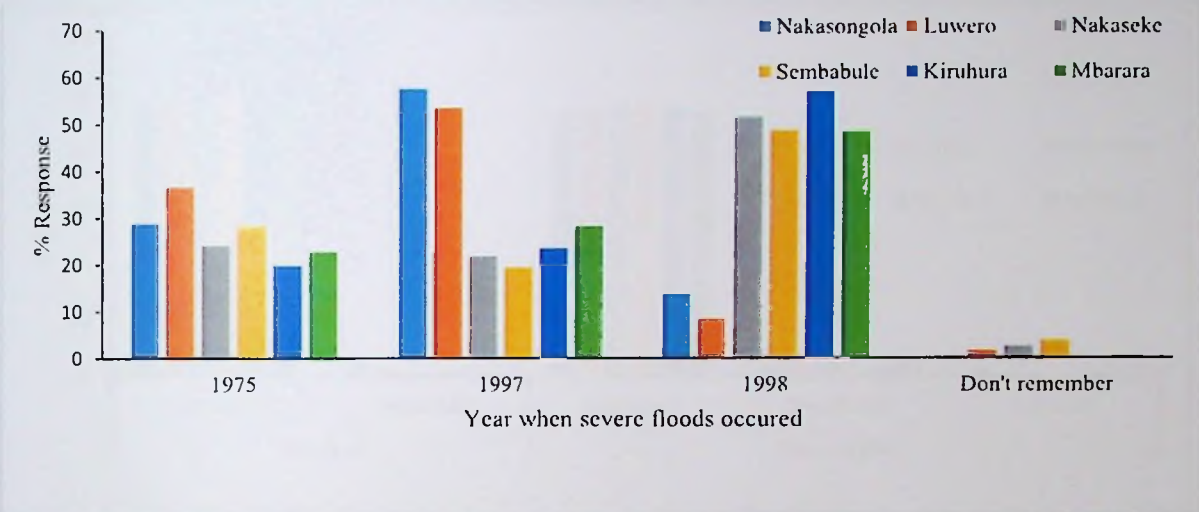


Figure 4. 6: Pastoralists perceptions on the year when severe floods occurred over 30 years ago

Over a period of 30 years pastoralists in Kiruhura, Mbarara and Sembabule districts perceived that there were increasing trends in the severity of floods (Figure 4.6) as a result of climate change and increased variability. Although pastoralists reported that rainfall comes in high intensities for a short period of time as compared to the past thus resulting into floods, three episodes of severe floods were experienced in 19975, 1997 and 1998. Most farmers were in agreement that 1998 was when floods were worst devastating in Kiruhura, Mbarara and Sembabule districts.

4.3.5 Pastoralists’ perceptions of changes and trends in daily day and night temperatures

Over 95% of the pastoralists perceived that in the last 30 years, extreme hot days and warm nights have increased (Figure 4.7). Percentage of pastoralists who perceived that day hot temperatures and warm nights were decreasing were less than 5% in all the districts.

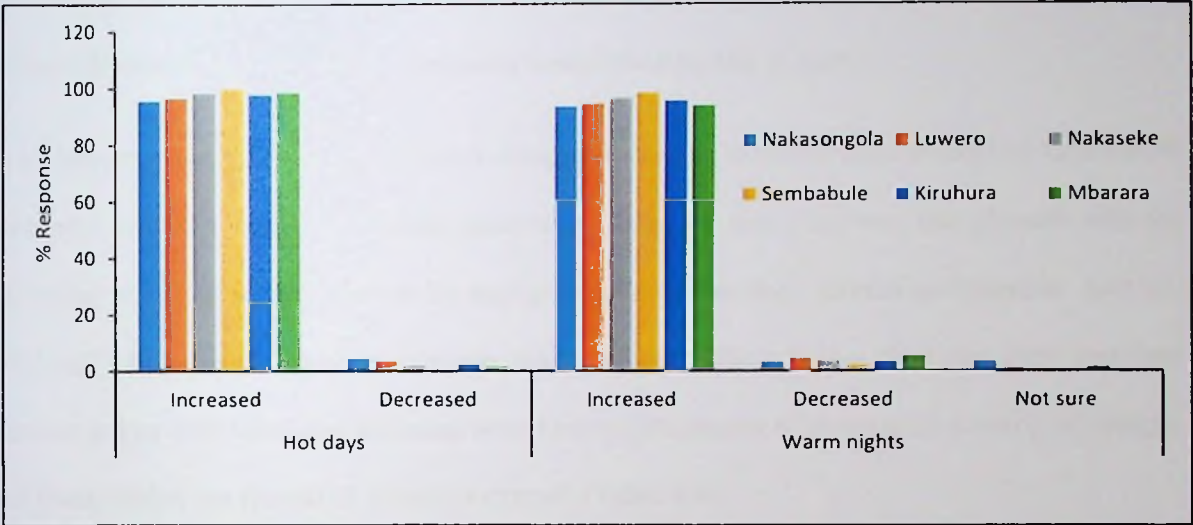


Figure 4. 7: Pastoralists perceptions on the changes of day and night temperatures over 30years ago

In Kiruhura, Mbarara and Sembabule districts farmers reported that day temperatures were increasingly becoming hotter while night temperatures warmer (Figure 4.7). In Sembabule district all respondents perceived that hot day temperatures were increasing while about 2% held a perception of night temperatures to be decreasing as compared to 30 years ago.

4.3.6 Pastoralists’ perceptions of causes of climate extremes and variability

Investigating the pastoralists’ perceptions of causes of changes in rainfall variability and increasing environmental day hot temperatures revealed different responses. Majority of pastoralists believed that climate extremes which were majorly perceived as changes in severity of drought and floods

were caused by various human-environmental related activities such as bad farming practices (Table 4.4). Bad farming practices included increased bush/thicket burning, tree harvesting for burning charcoal, overgrazing and poor crop farming practices among others. Others perceived climate change being caused by natural phenomenon which occur overtime. Those who perceived that climate change was caused by natural environmental changes further believed and hoped that events will revert back to normal after some unspecified period of time.

In all districts, pastoralists who perceived changes in climate extremes to be caused by God's wish were also evident (Table 4.4). These pastoralists believed that God was not pleased with the prevailing man's lifestyle/behavior by engaging in activities they termed undesirable" like bewitching" fellow people, theft and jealous among others. Others held a view that their ancestors were not happy with them and pollution were responsible causes of changes in severity of drought and floods which are typical of climate extremes (Table 4.4).

Table 4. 4: Drivers of perceived changes in rainfall and temperature in percentages

District	God's wish	Pollution	Bad farming practices	Changes are natural	Ancestors not happy	Don't know
Mbarara	22.5	2.5	50.0	12.5	5.0	7.5
Kiruhura	27.5	0	37.5	20.0	12.5	2.5
Sembabule	12.5	2.5	57.5	12.5	2.5	12.5
Nakaseke	20	7.5	45.0	15	2.5	10.0
Luwero	12.5	10	62.5	7.5	2.5	5.0
Nakasongola	26.1	0	69.2	1.5	3.2	0

4.3.7 Pastoralists perceptions to trends of increasing of consecutive dry days (CDDs)

CDDs were the most perceived precipitation (rainfall) extremes by pastoralists. Table 4.5 showed that most respondents generally accepted that the dry periods were becoming more frequent and

consequently water and pastures for livestock were increasingly scarce. The study revealed that majority of pastoralists attributed scarcity of water to increased drought periods (Table 4.5). However a proportion of farmers who reported that scarcity of water were attributed to having few water sources especially the valley tanks and dams and lack of labour for fetching/sourcing water even for long distances was also evident (Table 4.5).

Table 4. 5: Pastoralists’ response for causes of scarcity of water in percentages

Causes	District					
	Mbarara	Kiruhura	Sembabule	Nakaseke	Luwero	Nakasongola
Few water sources	18.4	12.0	21.0	32.8	16.4	27.2
Increased drought periods	62.2	59.5	68.0	54.2	65.1	56.1
Lack of labour	19.4	28.5	11.0	13.0	18.5	16.7

Lack of pastures and water for livestock were the most common effects resulting from increased number of consecutive dry days and rainfall variability. During the dry periods, livestock especially cattle lose weight, milk production reduces due to lack of pastures and water and in extreme cases die due to starvation. Figure 4.9 shows percentage households who lost cattle due to starvation because of extreme scarcity of pastures as a result of increasing consecutive dry days (CDD). In all districts, farmers who had lost cattle due to starvation as a result of lack of pastures were evident. Sembabule district had the highest percentage (73.6%) while Nakaseke had the least number of households (45.5%) who had lost cattle due to starvation (Figure 4.8).

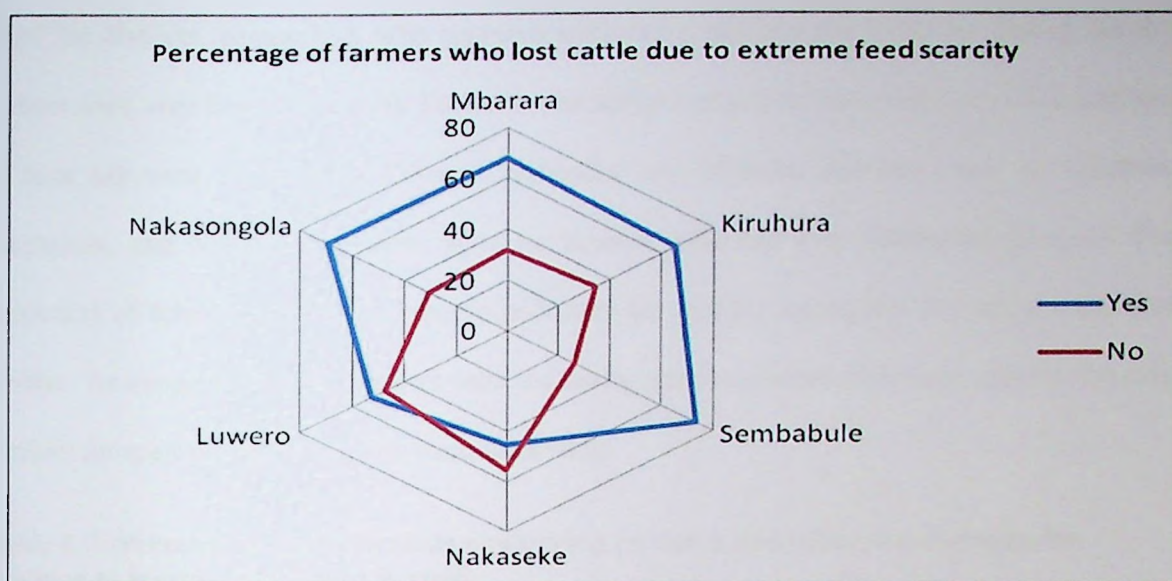


Figure 4. 8: Percentage of households who lost cattle due to extreme starvation
Results further indicated that increased drought periods were reported as the most cause of scarcity of pastures in all districts (Table 4.6). However other causes of scarcity of pastures were reported including high livestock numbers, small land acreages under pasture and increased termite action which was mostly reported in Nakasongola, Nakaseke and Sembabule districts.

Table 4. 6: Pastoralists' response to causes of scarcity of pastures/feeds for livestock in percentages

District	Increased droughts	High livestock numbers	Small grazing area	Increased termite action
Mbarara	79.8	10.8	8.2	1.2
Kiruhura	81	9.4	9.1	0.5
Sembabule	89	4.1	5.2	1.7
Nakaseke	75.4	4.1	18.3	2.2
Luwero	72.1	4.5	23.2	0.2
Nakasongola	82	4.3	8.5	5.2

In all the districts, pastoralists who reported conserving pastures for livestock during the dry seasons were very low (Table 4.6). Farmers who acknowledged to have ever conserved pastures in form hay were reported in Luwero, Nakaseke and Mbarara districts while in Kiruhura, Sembabule, and Nakasongola there were no farmers who had ever conserved pastures. The proportion of farmers who could reserve paddocks for grazing during the dry season was also evident. As a coping strategy, farmers were increasing the use of alternative feed options like crop residues for example maize stovers were increasing.

Table 4. 7: Percentage of pastoralists conserving pastures and other technologies for adaption to increased drought periods

District	Making Silage	Hay making	Utilization of crop residues	Reserve paddocks	None
Mbarara	1.5	2.5	12.5	26.5	57
Kiruhura	0	1.5	8.4	25.4	64.7
Sembabule	0	0	5.1	3.5	91.4
Nakaseke	1.8	1.2	4.6	6.2	86.2
Luwero	1.5	0	5	4.5	89
Nakasongola	0	0	3	5	92

4.3.8 Pastoralists adaptation strategies to climate extremes and variability

Fencing off grazing land, integration of crop into livestock production systems, diversification of livestock species kept, control of stocking rates and changing grazing time were among the major adaption strategies used by pastoralists to overcome impacts of increased climate extremes. (Figure 4.9). On the contrary, irrigation, acquisition of agricultural loans and conservation of forage were among the least adaptation strategies employed by pastoralists. . Pastoralists who acknowledged using other strategies like use of crop residues as alternatives to pastures, planting improved pastures that are drought torelant and conserving pastures were also evident. The results further indicated the proportion of farmers who often migrate in cases of extreme dry or flood

periods exist although very small. Sembabule district had the highest number of farmers who could migrate to less dry stressed neighbouring areas especially in Kiruhura and Mubende districts. Other farmers reported acquiring agricultural loans and starting irrigation to increase crop production in emerging crop-livestock systems as among the strategies used to adapt to extreme dry days. Nakasongola had the highest number of famers who reported to have aquired loans to improve livestock production and ensure survival. Farmers further reported that such loans are acquired to enable farmers buy household food items especially maize flour to enable them cope with extreme dry periods.

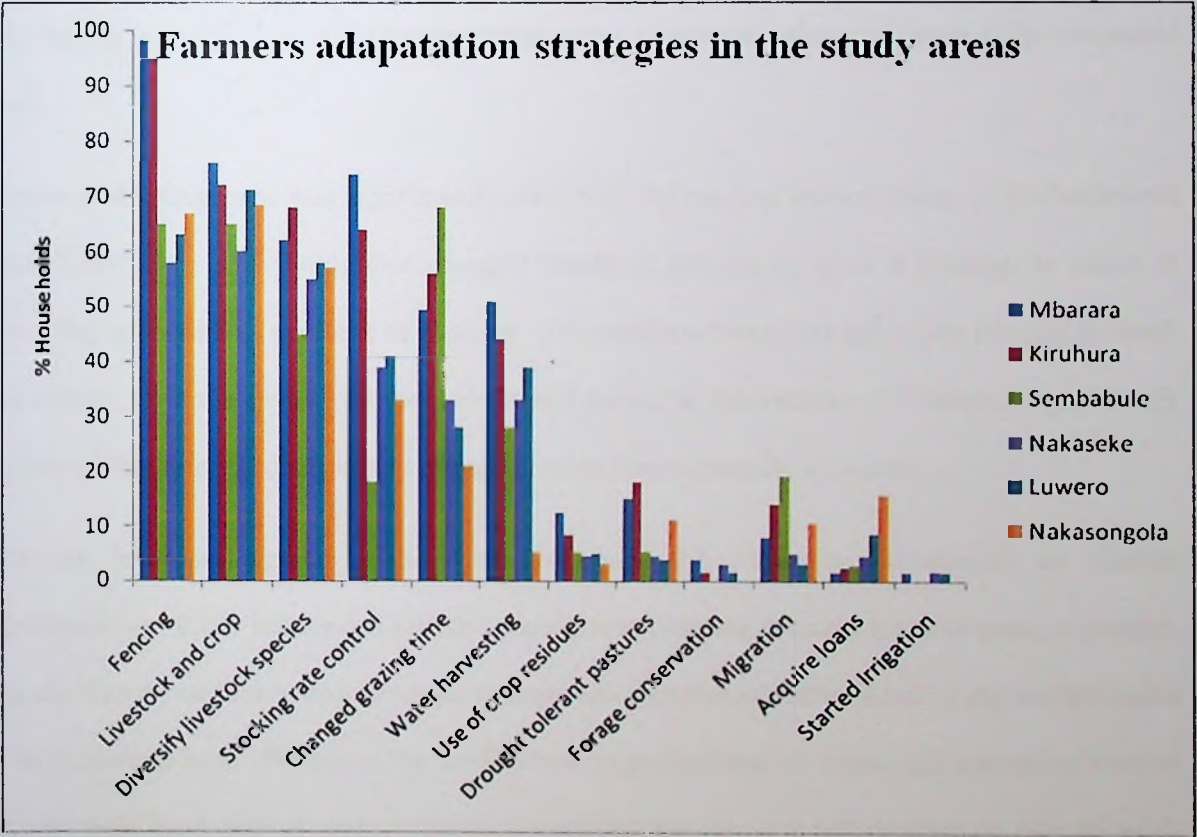


Figure 4. 9: Pastoralists’ adaptation strategies to alleviate feed scarcity challenges

4.3.9 Factors influencing pastoralists' choice of adaptation strategies

Table 4.8 showed the factors influencing farmers' choice of adaptation strategies to climate change. Pastoralists farming experience in their respective communities/village significantly influenced fencing off the grazing land as an adaptation strategy to increase the availability of pastures during the severe drought periods.

Gender of the household head, marital status, education level, household land size and farming experience significantly ($p < 0.05$) influenced farmers' choice in deciding whether to integrate crops in livestock production systems. Diversification of livestock species kept per household was significantly influenced ($p < 0.05$) by the marital status, gender and education level of the household head,

Control of stocking rates was significantly influenced by age and marital status of the household head. There were households that changed livestock grazing time as a strategy to adapt to increasing temperatures and lack of pastures. The results showed that age of the household head, and number of cattle owned per household and access to information on climate significantly influenced the farmers' decisions to change grazing time especially for cattle.

Education level and gender of the household head and access to information on climate significantly ($p < 0.05$) influenced farmer' decisions in planting drought tolerant pasture species. The use of crop residues as an adaptation strategy was significantly influenced by the marital status of the household head. However, the coefficients on gender, marital status and education level of the household head, size of land owned per household and access to information on climate in all adaptation strategies/measures were positively loading confirming that male households heads

who are married, educated and have access to information of climate were more likely to adapt to impacts as a result climate extremes.

Table 4. 8: Parameter estimates of the multinomial logit climate change adaptation model.

Variables	Fencing		Integration of crop and livestock		Diversity livestock species		Stocking rate control		Changed grazing time		Drought tolerant pasture species		Crop residues	
	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level
Age of HHd	-0.002	0.890	0.063	0.270	0.019	0.367	0.035	0.042**	0.008	0.002**	0.984	0.566	0.019	0.307
Gender of HHd	0.557	0.285	1.201	0.003**	1.545	0.002**	1.265	0.121	1.277	0.133	1.238	0.003**	0.008	0.341
Marital status	0.432	0.388	0.056	0.045**	0.023	0.055*	0.075	0.044**	0.024	0.194	0.017	0.143	0.018	0.005**
Education level	0.309	0.504	0.114	0.017**	0.214	0.002**	0.018	0.581	0.032	0.244	0.223	0.001**	0.065	0.421
Household size	-0.030	0.417	0.053	0.222	0.055	0.350	0.032	0.462	0.301	0.545	0.016	0.855	0.055	0.350
Livestock herd size	0.001	0.531	-0.143	0.683	-0.001	0.330	0.000	0.794	0.231	0.048**	0.000	0.985	-0.001	0.330
Household land size	0.001	0.386	0.487	0.002**	0.002	0.275	0.001	0.498	0.342	0.412	0.001	0.587	0.002	0.275
Farming experience	-0.023	0.084*	0.217	0.011**	-0.019	0.313	-0.019	0.313	0.485	0.671	-0.02	0.479	-0.019	0.313
Information on climate	0.156	0.605	0.221	0.342	0.421	0.556	0.333	0.450	0.084	0.072*	0.348	0.048**	0.468	0.543

*Significant at 10% level

**Significant at 5% level

4.3.10 Barriers constraining pastoralists adaptation strategies

Pastoralist's failure to adapt to climate extremes was being influenced largely by insecure land ownership rights and lack of information/early awareness concerning severe and extreme climatic events such as floods, dry spells, start and end of the rains among others (Figure 4.10). The proportion of households not secure with their land ownership rights was highest in Nakaseke, Luwero and Nakasongola and least in Mbarara and Kiruhura districts. Respondents also reported lack of resources for investment especially the start-up funds which could be used to facilitate adaptation to extreme rainfall events or consecutive dry days. Results further revealed that there were a proportion of farmers who reported shortage of labour for use especially in construction of water harvesting channels and fencing of paddocks among others. In all districts, respondents who acknowledged failure to adapt due to lack of will/interest existed and such farmers thought that changes in climatic events/extremes of rainfall events were natural and consequently deserved less attention.

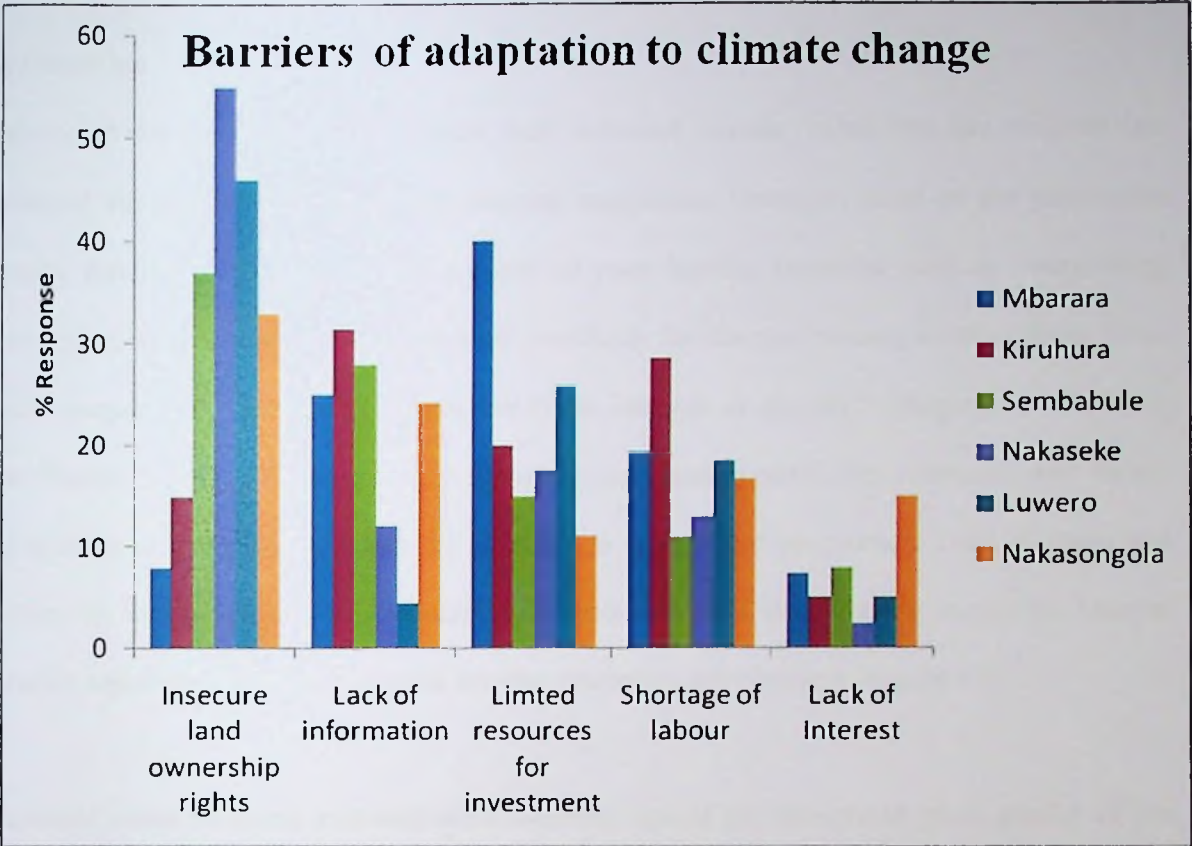


Figure 4. 10. Barriers of adaptation to climate extremes and variability

4.4 Discussion

Majority of the pastoralists were aware that increased climate variability has resulted into prolonged droughts and floods in the pastoral rangelands. However, most of the pastoralists reported that these changes were as a result of poor farming practices such as overgrazing, uncontrolled bush burning and destruction of woodlands for charcoal burning among others. These results compare well with studies elsewhere (Fosu-Mensah, *et al.*, 2012; Megersa, *et al.*, 2014; Zake Hauser., 2014). Severe prolonged droughts consequently result into increased crop failure and shortage of water and pastures for livestock in the pastoral rangelands. Lack of water and pastures for livestock leads into reduced milk production and loss of body condition. Loss of livestock especially cattle as a result of extreme starvation were evident (Figure 4.8).

Household socio-economic characteristics including age of the household head, gender of the household head, education level and household family size influenced adaptation to climate change. Age of the household head, which represents pastoralists' experience, affected adaptation to climate extremes. This can be attributed to the fact that the longer a farmer stays in the village, the better he/she understands the climate and weather changes for that particular locality.

Gender of the household head positively influenced choice of adaptation strategies to climate extremes and variability. Households that are male headed were more likely to adapt to climate extremes. This can be attributed to differential perceptions of men and women to climate variability. Moreover Awiti, (2022) reported that increased climate variability reduces agricultural productivity often with unequal impacts on women's and men's assets. In the Sahel for example, Goh, (2012) observed that women believe they would lose access to rangeland and other livestock production resources due to increased climate variability. Marital status of the household heads

also significantly influenced adaptation to climate extremes indicating that households heads who are married were more likely to adapt to climate change as they will be more able to source and practice adaptation strategies. Education level of the household heads significantly influenced adaptation to climate change. This can be explained by the fact that education comes with exposure and awareness of adaptation strategies to climate change. When household heads are informed of the adaptation strategy then the more likely they will be adopted at the household level. These results are consistent with Maddison (2006) who reported a positive relationship between the education level of the household head and adoption of improved technologies.

Household family size positively significantly influenced choice of adaptation strategies to climate extremes and variability. These results are consistent with Deressa et al (2009) who observed that family size positively influenced farmers' choice of adaptation methods in Ethiopia. Results further confirmed that larger families are more likely to adapt to climate change than families with less people. Perhaps this can be explained by the fact that larger families have more labour units available to implement the adaptation strategies. For example larger families could easily fence off the grazing land and practice rotational grazing as opposed to smaller families. On the contrary, household family size did not significantly increase the farmers' choices to adaptation to climate change.

Livestock ownership especially cattle herd size owned per household significantly affected adaptation strategies. Households with relatively high numbers of cattle were most likely to fencing off grazing land as opposed to others. The number of livestock owned per household showed positive relationship in most of the adaptation strategies although the marginal impacts were not significant. The pastoral production system is undergoing transformation and is slowly changing into an agro-pastoral system. For example in Mbarara and Kiruhura districts, most

pastoralists have crossbred the indigenous herd to improve milk production and the cattle herd composition was 75 and 70 % of mainly Friesian crossbreeds. On the contrary, in the districts of Nakaseke, Luwero, Sembabule and Nakasongola the main objective of pastoralists crossbreeding was to improve the indigenous herd for beef production. The genotypes involved were mainly of beef composite breeds of Boran, Bosmara and a few farms specializing in dairy using Friesian crosses.

Household land size positively influenced adaptation to climate extremes. This indicates that households owning high acreages of land were most likely to adapt to climate change. This means that the smaller the size of land owned per household, the more vulnerable such farmer will be to impacts of climate change. These findings are consistent with Oluwatusin (2014) who reported that cocoa farmers owning large acres of land were more likely to adapt to climate change.

Farming experience denoted as the number of years the household head had spent in the village rearing livestock significantly affected farmers decisions to adapt to climate change. This means that as the experience of a farmer increase, the more likely such farmer will adapt to climate change. A number of arguments have been advanced for example Yirga (2007) reported that households with large families may be forced to divert part of the labor force to off-farm activities in an attempt to earn income in order to ease the consumption pressure imposed by a large family. In a related study Croppenstedt *et al.*, 2003 argued that households with a larger pool of labor are more likely to adopt agricultural technology and use it more intensively because they have fewer labor shortages at peak times.

Pastoralists adaptation strategies in response to extreme droughts as a result of increasing CDD included: fencing off grazeable pastures/land, integration of crops into livestock production

systems, diversification of livestock species kept, use of drought tolerant pasture species, control of stocking rates, utilization of crop residues and water harvesting among others. However, most important adaptation strategies livestock farmers used were those that increased availability of pastures and water for livestock. These adaptation strategies included; fencing of available grazing land, diversification of livestock species, control of stocking rates, planting drought tolerant pasture species, change of grazing time among others.

Most farmers acknowledged fencing off grazing land as the key adaptation strategy to control movement of stock and be able to practice rotational grazing and preserve some paddocks for standing hay which can guarantee availability of pastures for increased livestock production throughout the year. These results are consistent with Dixon et al. (2001) who reported that adaptation technologies that farmers adopt depend mostly on the type of crop or system involved. Other studies for example Deressa *et al.* (2009) reports soil conservation, tree planting early and late planting as adaptation strategies to climate change in Ethiopia. However, according to Mabe *et al.* (2012) farmers have different adaptive capacities which directly affect the rate of adaptation to climate change.

Pastoralists' acknowledged diversifying livestock species/ breeds as one of the adaptation strategies to climate extremes. Losses of livestock especially cattle as a result of extreme starvation were evident in all districts (Figure 4.8). Death of livestock due to starvation increases the vulnerability of people's livelihoods in the pastoral rangelands. Interestingly no household reported losing small stock like goats as a result of scarcity of pastures/natural browse. As noted by Busajja Livingstone aged 63 years one of the farmers from Nakalikinya village, Nakasongola district: "...throughout my life time I have never seen a goat that died of starvation (lack of browse) it's only cattle especially those which are old that are vulnerable". Occurrences of severe dry days

are not a new phenomenon in Uganda for example a related study by Stampone *et al.* (2011), revealed that there has been an increase in the occurrence of droughts of which 1991-2000 decade recorded the highest frequency of droughts.

The relationship between vegetation production and rainfall is positively correlated (Mduma *et al.*, 1999) implying that increased frequency of drought periods will negatively affect pasture production which compromises survival of livestock thus constraining livelihoods in the rangelands. Perhaps this can be explained by the fact that different livestock species have unique environmental stress levels and as such can cope differently in various agro-ecological conditions. By keeping different livestock species for example goats and chicken farmers were able to spread the risk and guarantee production thus reducing the vulnerability of their individual households to increased climate variability and changes in extreme climatic events.

Marital status and age of the household head significantly influenced farmers' decisions to control stocking rates at household level. This means that household heads that were married and were above mean age of 45 years were most likely to reduce and control the stocking rates especially of the cattle owned. Reduction in stocking rates were practiced in events of anticipation of future severe drought conditions, livestock farmers significantly reduce their herds to remain only with those purported manageable herds by selling them off at good premium prices before such animals could lose condition due to starvation arising from lack of pastures during severe drought periods.

The study further revealed that pastoralists changed the grazing time (Figure 4.9). The normal grazing time often started around 6:30 a.m. However, as an adaptation strategy during severe dry periods livestock farmers have drastically changed the grazing time to begin as early as 3:00 a.m. This is because during this time the dry standing hay has some moisture and the prevailing

temperatures are very conducive for grazing animals as opposed to during the day time when temperatures are abnormally high and consequently livestock can't graze. Moreover, Lyons (2014) reports that increasing time on pasture have a potential impact of animal behavior and environmental benefits.

Planting of drought tolerant pasture species was also reported among the adaptation strategies farmers were using to alleviate impacts of climate change. Although all the factors showed a positive influence on the planting of drought tolerant pasture species none was significant. Perhaps this can be attributed to the low levels of adoption of new improved varieties in Uganda. The number of consecutive dry days, CDDs were increasing, resulting into high incidences of prolonged droughts. Prolonged droughts usually result into scarcity of pastures/feeds for livestock, lack of water for both domestic and livestock and increased crop failures/poor harvests.

Scarcity of pastures often results into; reductions in both quality and quantity of products like milk, retarded growth especially in young animals, loss in body condition and in extreme scarcity death. However, 19.8 and 18.2% of the farmers in Nakasongola and Mbarara districts respectively reported to have planted drought tolerant pasture species like *Brachiaria spp* as an adaptation strategy to improve pasture availability during drought periods. Elsewhere technological advancements like use of drought tolerant pasture species have proven an effective adaptation strategy to increasing frequency of dry spells (Kurukulasuriya and Rosenthal, 2003; Thornton *et al.*, 2009). Therefore more pastoralists are encouraged to adopt and plant drought tolerant pasture species in order to ensure availability of pastures for livestock throughout the year and seasons.

Technological adaptation strategies /options such as forage conservation in form of hay and silage and feeding crop residues remain rarely used by farmers to offset dry season feeding challenges.

However very few farmers acknowledged to have conserved feeds during the dry season citing lack of start-up funds and lack of awareness as key barriers hindering them to adopt such useful innovations. Majority of farmers who had never conserved forage for feeding livestock during drought periods cited lack of information and necessary skills to make hay and silage.

Results also showed that some livestock herders migrate with their livestock herds to wet riparian areas anticipating fresh pasture and water resources (Figure 4.9). However, these lowland riparian areas are often degraded, livestock disease outbreaks usually occur as a result of mixing herds from different households and locations. In a related study Makuma-massa *et al* (2010) noted that the cattle corridor experienced outbreaks of FMD and contagious Bovine during the severe droughts of 1980 to 1983, 1990 to 1992 and 1996 to 2000.

The study in addition revealed that pastoralists encounter barriers to adaptation such as insecure land ownership rights, lack of climatic information, shortage of labour and lack of start-up funds among others. Traditionally, most of the land in the pastoral rangelands was owned communally. The communal land ownership system is slowly changing into private individual ownership with increased individual rights to land. However, this transition comes with a number of challenges. For example farmers acknowledged that it's almost impossible to fence off grazing pastures for livestock and plant drought tolerant pastures species when land is owned by the entire community or landlord. The study further revealed that fencing off communal land in most cases was interpreted as land theft and could attract attention from the public and criminal charges preferred to the concerned individuals/persons for trespassing. Studies conducted elsewhere for example in Ethiopia, have reported that farmers who encountered barriers such as lack of information and shortage of labour among others usually fail to adapt to climate change (Deressa *et al*, 2009).

Therefore policies that promote secure land ownership rights should be encouraged to facilitate increased adaptation to extreme climatic events in the pastoral rangelands.

4.5 Conclusions and recommendations

In conclusion majority of pastoralists perceived climate extremes as increasing. Severe droughts and floods, increase in day hot temperatures and warm nights were the most perceived climate extremes. Changes in rainfall patterns, start and cessation of rains, changes in day hot temperatures and night temperatures were the most perceived by pastoralists as a result of increased climate variability and extremes. In order to increase their resilience to climate extremes and variability, pastoralists devise adaptation strategies to ensure survival of livestock. Most adaptation strategies aimed at increasing availability of pastures for livestock. Most socio-economic household characteristics positively influenced farmer's choice of adaptation strategies. Results from the study further revealed that most of the socio-economic household characteristics like age of the household head, marital status, and education level of the household head, family size, land ownership and number of cattle owned per household positively influenced farmers' choice of adaptation strategies adaptation to climate change. Most of these household socio-economic characteristics can be enhanced through government policy interventions and as such can have significant improvement of adaptation to climate extremes. Limited access to climate information and insecure rights to land ownership were key barriers constraining adaptation.

Therefore policies that can promote and ensure secure individual land ownership rights in communal settings while improving farmers' access to early warning climate information can effectively facilitate adaptation to climate extremes and increased variability. Therefore it is further recommended to encourage efforts aimed at enhancing pastoralists adaptation to impacts of climate variability and extremes and sensitize household heads on adaptation strategies such as

control of stocking rates, changing planting time, diversifying livestock species kept, planting improved pasture species

CHAPTER FIVE

PREDICTION OF FUTURE LIVESTOCK PRODUCTIVITY UNDER HEAT STRESS CONDITIONS AND ITS IMPLICATIONS ON MILK PRODUCTION

ABSTRACT

Heat stress is considered among the most important impacts of climate change on livestock production. The main objective of the study was to predict future heat stress and derive implications on milk production for cattle reared in the pastoral rangelands of Uganda. Temperature Humidity Index (THI) was used as an indicator of heat stress. Daily temperature and relative humidity data from 1960-2013 were used for computation of THI values. ARIMA models in SPSS Expert modeller were used to predict futuristic trends of heat stress. Best ARIMA model selection was made using Akaike information criterion (AIC) and Bayesian information criterion (BIC). ARIMA (1, 1, 0) (0, 0, 0)¹² was found the best fit model as it could perfectly produce an excellent match with THI values. Predicted THI values revealed increasing trends of heat stress at a rate of 0.032 per year. By 2030 the predicted THI will be above 72 maximum threshold beyond which lactating cows begin to suffer heat stress. This will most likely impact negatively on milk production especially for cattle in open grazing lands. Therefore the current drive of improving genotypes to high grade animals like pure Friesians is most likely not to be sustainable unless appropriate interventions are adopted. Therefore, there is need to keep livestock genotypes that are tolerant to increasing heat stress like indigenous long horned Ankole or their F1 crossbreds. There is also a need to adapt strategies like planting of trees (silvopastoralism) to provide shade in open grazing lands and construction of shades to effectively minimize heat stress in the pastoral rangelands.

Key words: *Heat stress, Temperature humidity index, rangelands*

5.1 Introduction

Global estimates indicate that over 768 million people live under starvation and 2.5 million children face acute starvation (FAO, 2021). Projections further indicate worsening situation of malnutrition and hunger in sub-Saharan Africa. In Uganda, hunger and starvation are both a function of poverty and limited resources. Key interventions for fighting malnutrition especially in children and poverty stricken areas is to improve protein consumption. Livestock products especially milk provide an excellent source of protein and incomes for poverty stricken households. The pastoral rangelands of Uganda accounts for over 90% national livestock herd and 95% of milk production in the country (UBOS, 2019). Livestock production entirely depends on existence of rainfed natural pastures and available surface water sources. However, during the dry seasons these two resources reduce significantly to very minimal levels and consequently the rangelands resources cannot support any meaningful livestock production. Livestock productivity (Lo) as described by Peden et al (2007) is the total beneficial out from livestock enterprise. In pastoral production systems, benefits from livestock go beyond economic values to include social benefits. However, this study only considered the quantifiable beneficial outputs from livestock such as milk, meat, hides and skins, manure and traction power. In this study only beneficial outputs from milk were used since it is the only easily quantifiable output in the pastoral rangelands. Milk production records from Mbarara district were only used since data sets from other datasets had a lot of missing entries.

Studies on milk production especially in cattle indicate positive association with very many factors including; the amount of available forage, the genotype of the livestock species involved and climatic factors like relative humidity, temperature, solar radiation, and rainfall among others (Gantner *et al.*, 2011). In the tropics, milk production usually follows a seasonal pattern with peak

yields during the rainy seasons. However, seasons and other climatic conditions are changing due to global climate change (Nimusiima *et al.*, 2013; Nkuba *et al.*, 2019) which will consequently affect pasture availability (Ogutu *et al.*, 2007; Sloat, *et al.*, 2018) thus constraining livestock productivity through reduction in milk production among others.

Climate change increases severity and frequency of drought periods which ultimately affect livestock production (IPCC, 2007). All animals have a thermal neutral zone which is the range of temperatures that are conducive for optimum health and performance. However, among the impacts of climate change is unprecedented increase in temperatures. Increase in ambient temperatures is most likely to reach upper critical temperatures which is the point at which heat stress effects begins to affect animal performance. For example, heat stress begins to occur in dairy cattle when $THI > 72$ (Todorović *et al.*, 2011). Climate change manifests in increased rainfall and temperature extremes. Occurance of extreme rainfall and temperature events result into severe consequences for the environment and society (CCSP, 2008; Manton *et al.*, 2000).

While the past can be understood because we have already observed and experienced it, the future will always be uncertain. However, this uncertainty has been demystified with the new advances in technology. Several methods have been developed using models for predicting future production with high levels of certainty (Yano *et al.*, 2014; Aborass *et al.*, 2022). The use of Box-Jenkins and autoregressive moving averages (ARIMA) modeling approach is the most popular (Babazadeh and Shamsnia, 2014; Kumar *et al.*, 2014) in deriving predictions for the future. For example Babzadeh and Shamsnia (2014) derived rainfall and temperature forecast for Shiraz station in Iran and concluded that rainfall and temperature were increasing. Yurekli *et al.* (2005) used ARIMA modelling to simulate with accuracy the monthly flow of Kelkit stream in Turkey. Shamsnai *et al.* (2009) also used ARIMA models to forecast drought. Yurekli and Kurunc (2004) used ARIMA

models to simulate drought periods in hydrologically homogeneous regions and reported that predicted data represented the actual data very well for each region. Suresh et al. (2012) made a forecast of livestock feeds till 2030 and highlights that the models can be used for forecasting agricultural production in the country. Furthermore, Ramachandra et al. (2007) provided a forecast of availability of dry fodder, concentrates and green fodder in India by 2020. Sustainability of any agricultural system will always depend on reliable planning processes. However, effective planning must be guided by accurate and reliable information of what the future will most likely be in order to design appropriate and suitable interventions to ensure sustainable livelihoods. Moreover Jain (1996) suggests that the quality of decisions largely depends on the quality of the forecast. This study was therefore conducted to develop suitable ARIMA models for predicting rainfall, temperature and THI values on milk production in the pastoral rangelands of Uganda. The results could inform both pastoralists and policy in making appropriate decisions aimed at sustaining improved milk production in the pastoral rangelands of Uganda.

5.2. Materials and methods

To predict future heat stress and its implications on milk production, required data sets of temperature, relative humidity, rainfall and milk yields from the past records.

5.2.1 Data collection

Data sets on climate variables (rainfall, temperature and relative humidity) for Mbarara station from 1963-2013 were used. Data on monthly milk production from Mbarara district was obtained from the district production records in Mbarara and milk collecting centres. Additional data sets on milk production were obtained from Dairy development Authority (DDA) offices in Mbarara.

5.2.3 Statistical analysis and ARIMA model fitting

Monthly time series datasets of rainfall, relative humidity, maximum and minimum temperatures and milk production were used. and temperature –humidity index (THI) were entered into SPSS spreadsheet and subjected to ARIMA modeling following procedures as in Liang et al., (2009). ARIMA models are sometimes referred to as Box-Jenkins models (Box and Jenkins, 1970). Fitting ARIMA models involved three stages/steps (i) model identification (ii) parameter estimation and (iii) diagnostic checking (Box and Jenkins, 1970; Zakaria *et al.*, 2012; Murat, 2018). The identification stage determines the level of differencing (p,d and q) of the AR is required and the moving average (MA) components of the model. Parameter estimation was done using nonlinear optimization procedure as in Yano et al (2014). The trend ARIMA procedure estimates the coefficients of the model which have been identified (Murat *et al.*, 2018). ARIMA modelling automatically performs iterative calculations needed to determine maximum likelihood coefficients and adds new series representing fit or predicted values, the error (residual) and the

confidence limits for the fit values (Murat, *et al.*, 2018; Nyatuame and Agodzo, 2018). Therefore ARIMA models are a combination of an autoregressive (AR) process and moving average (MA) process applied to a non-stationary data series (Box, 2013). In a non-seasonal ARIMA (p,d,q) model, AR-(p) refers to order of the autoregressive part, I-(d) refers to degree of differencing involved and MA-(q) refers to order of the moving average part. An ARIMA (p,d,q) model was therefore described as;

$$X_t = \mu + [\beta_1 * (Z_{t-1} - \mu)] + \beta_2 * (Z_{t-2} - \mu) + \epsilon_t$$

Where X_t is the stationary time series, μ is the mean of time series X_t , β_1 and β_2 parameters to be estimated. However, Yurekli et al., (2007) highlights that ARIMA models predict future values as products of several past observations and random errors.

Model diagnostics

The third stage which involved diagnostic checking was conducted to determine whether residuals were independent, homoscedastic and normally distributed. Diagnostic information helps to suggest alternatives if necessary during model building (Murat, *et al.*, 2018; Shumway and Stoffer, 2006). This procedure was repeated several times until models satisfying rainfall, temperature, milk production and temperature-humidity Index (THI) data sets were finally identified following procedures used by Khadr (2011) and Box (2015). Ljung-Box test was used to determine if the model was correctly specified. The best fitting models were assessed based on minimum value of mean square error (MSE), Bayesian Information Criterion (BIC), Akaike Information Criterion (AIC), Schwartz’s Bayesian Criterion (SBC) and the maximum value of R^2 . Stationary R-squared values were preferred compared to ordinary R-squared since they clearly provide an estimate of the proportion of the total variation in the time series that can be explained by the model especially

those with a trend or seasonal components. The final selected model was then used to predict and forecast the future values.

The AIC model was specified as:

$$AIC(p, q, P, Q) = N \ln(\sigma_a^2) + \frac{2(p+q+P+Q+1)N}{(N-p-q-P-Q-2)}$$

$$SBC = -2 \log(L) + (p+q+P+Q+2) \ln(N)$$

Where L = the likelihood function of the ARIMA models, σ_a^2 is the residual variance, p is the non-seasonal Autoregressive order, q is the non-seasonal moving average, P is the seasonal autoregressive order, Q is the seasonal moving average order and N is the number of observations. The model that gave the minimum Akaike Information Criterion, AIC was selected as a *parsimonious* model. While running ARIMA models, the following assumptions were critical; there should be no known/suspected predictor variables, level shifts, deterministic time trends of the form . . . , t , no seasonal dummies, one time anomalies, model parameters are constant over time and the error process is homoscedastic (constant) over time (Box, 2013; Nyatuame and Agodzo, 2018). Therefore when fitting ARIMA models, the time series data sets must ensure stationarity. Stationarity of the data sets is necessary to ensure that statistical parameters like mean and auto correlation are constant over time. In order to ensure stationarity in the datasets; autocorrelation function plot (ACF) and partial auto correlation function (PACF) were performed to detect the presence of autocorrelation in the milk, and THI data sets and identify the order of time lag to account for it in the modeling.

To determine the effect of changing climatic (rainfall and temperature) conditions on livestock productivity, temperature–humidity index (THI) was used (Polsky and Keyserlingk, 2017; Herbut *et al.*, 2018; M'Hamdi *et al.*, 2021). THI is a measure that relates the combined effects of prevailing

air temperature and humidity associated with the level of thermal stress (Marciniak, 2014). Therefore, temperature –humidity index (THI) was used since it's a true indicator of heat stress (Kadzere *et al.*, 2013) which directly affects milk production in lactating animals (Gantner *et al.*, 2011; Atrian and Shahryar, 2012; Marciniak, 2014). Temperature-humidity index (THI) values on a monthly basis were calculated using the equation as in Kibler (1964) which was specified as:

$$THI = 1.8T_a - (1 - RH) (T_a - 14.3) + 32$$

Where: T_a was the measured ambient temperature in °C and RH the relative humidity expressed as a percentage. Temperature-humidity index (THI) of ≤ 72 was considered ideal as in Gantner *et al* (2011). Future THI values were then predicted using ARIMA Expert modeler following Box-Jenkins modeling approach (Box and Jenkins, 1970; Box 2015) as described in the previous section. For non-seasonal components of seasonal ARIMA model, the MA operator was written as:

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \dots - \theta_q B^q$$

Where: q =the order of non-seasonal MA operator; $\theta_j, j= 1, 2, \dots,$

q = the MA parameters, B =the back-ward shift operator such that $BZ_t = Z_{t-1}$

The AR operator is written as

$$\Phi(B) = 1 - \Phi_1 B - \Phi_2 B^2 - \dots - \Phi_p B^p$$

Where: p =the order of non-seasonal AR operator, $\Phi_i, i=1, 2, \dots, p$ =the non-seasonal AR paramcters.

The non-seasonal ARIMA model for a set of equidistant measurements $Z=[Z_1, Z_1, \dots, Z_n]$ was derived as: $\Phi(B)(1-B)^d(Z_t) = \Phi(B) - \Phi_2 B^2 - \dots - \Phi_p B^p$

5.3 Results

5.3.1 Trends for rainfall, temperature and milk production in the pastoral rangelands

5.3.1.1 Rainfall and temperature trends over a period of 50years

The amount of rainfall received annually showed an increasing trend since 1963 with considerable variations (Figure 5.1). However, the driest years throughout the 50 year period were 1979 and 2007 while the current decade has been largely characterized by increasing amounts of rainfall compared to past decades.

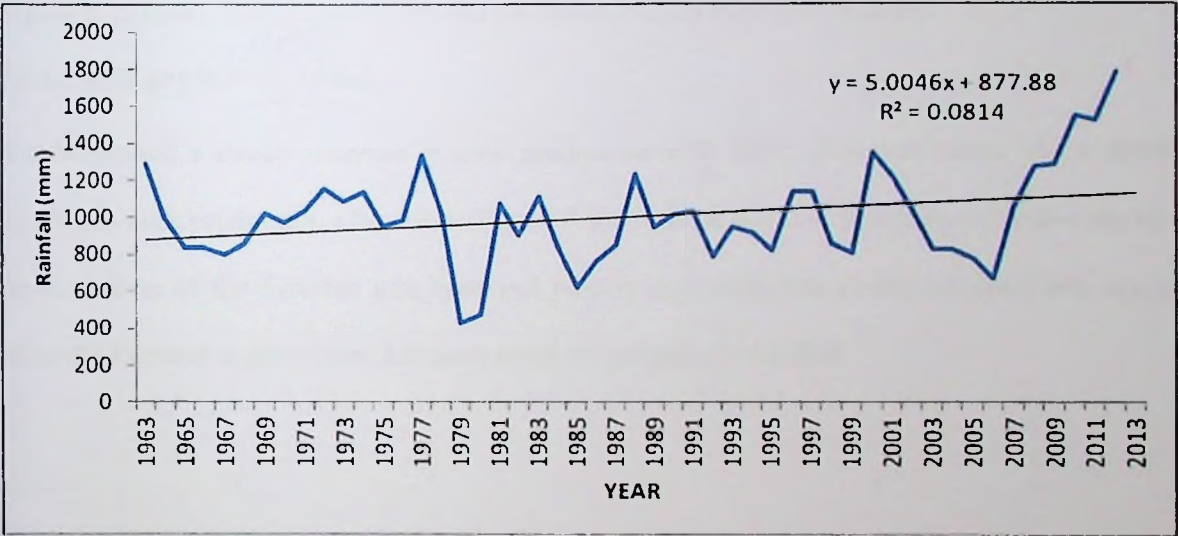


Figure 5. 1: Time series of annual rainfall for Mbarara for 50 years

5.3.1.2 Temperature trends

Mean daily maximum and minimum temperatures have been rising since 1963 (Figure 5.2). However, the rates of increase of mean annual minimum temperatures were high as compared to maximum temperatures.

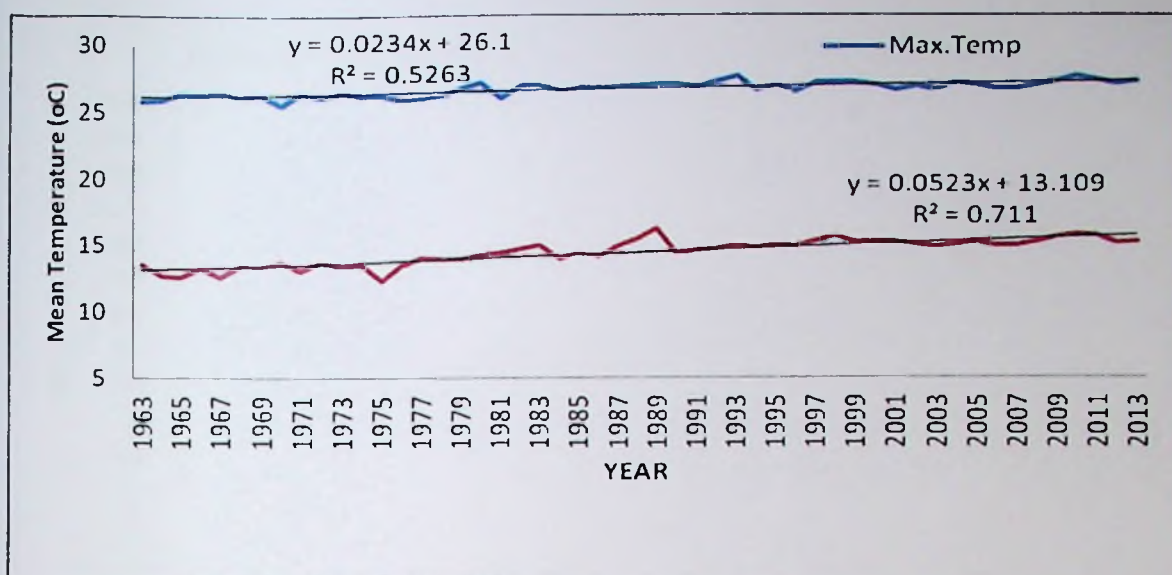


Figure 5. 2: Mean annual maximum and minimum temperatures in Mbarara

5.3.1.3 Milk production trends

Results showed a steady increase in milk production until 2001. However, there was a drastic increase in milk production after 2001 (Figure 5.3). Perhaps this can be attributed to the massive popularization of the Friesian genotype and pasture improvements in the southwestern region under the National Agricultural Advisory services program (NAADS).

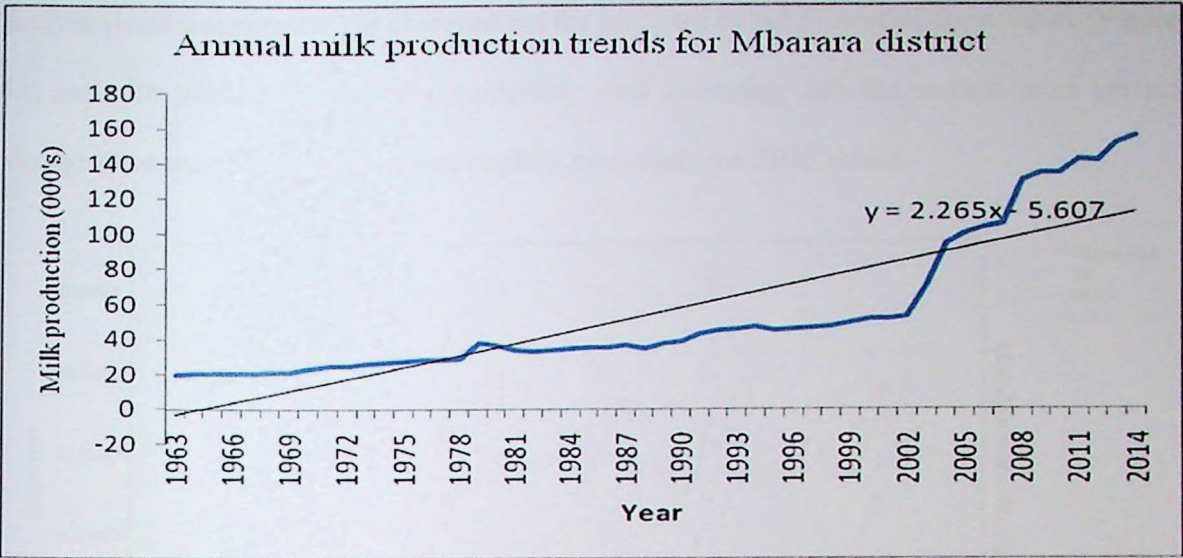


Figure 5. 3: Annual milk production trend for Mbarara district

5.3.2 Best model identification and fitting

Table 5.1 showed the best fit statistical ARIMA models for estimation of milk production, Temperature Humidity Index, rainfall and temperature. Results further showed that rainfall and maximum temperatures were significant predictors of milk production. Mean minimum temperature does not significantly predict milk production.

Table 5. 1: ARIMA model statistics

Model parameter	Stationary R^2	Ljung-Box statistic			ARIMA Model type
		Statisti cs	DF	P- value	
Milk production	0.825	6.852	17	0.985	(1,1,0) (0,0,0) ¹²
Temperature Humidity Index	0.712	8.336	17	0.959	(1,1,0) (0,0,0) ¹²
Maximum temperature	0.607	19.241	15	0.203	(1,1,0) (0,0,0) ¹²
Minimum temperature	0.635	24.690	16	0.705	(1,2,1) (0,0,0) ¹²
Rainfall	0.730	15.437	17	0.564	(1,1,0) (0,0,0) ¹²

Based on visual assessments, the observed and the predicted values of rainfall, temperature (Figure 5.4) and milk produced matched considerably well indicating that the models were perfect although there were some observations slightly away from the fitted values.

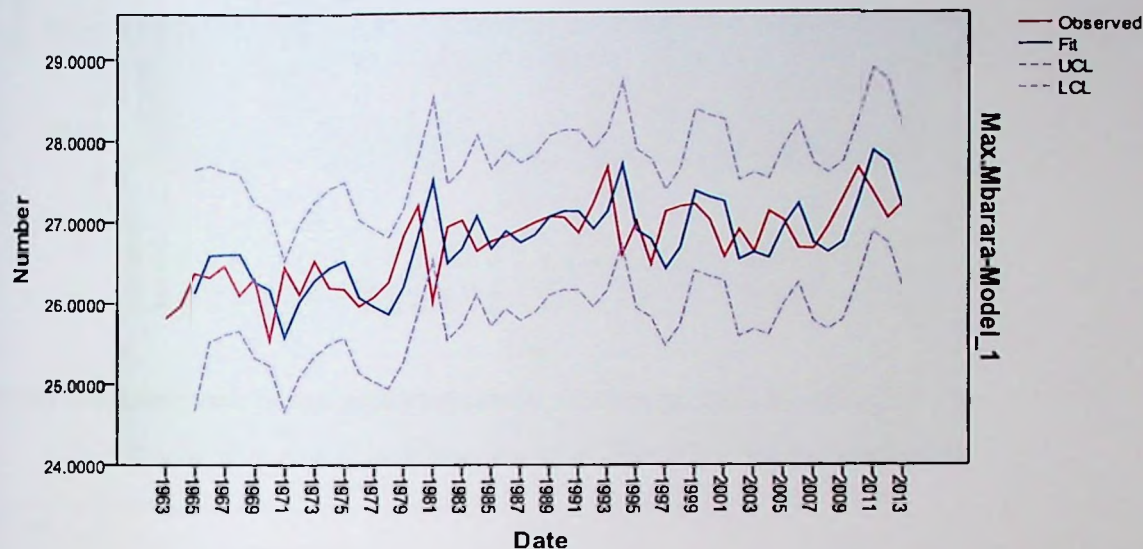


Figure 5. 4. Actual (Observed) and predicted (fit) values of maximum temperature in Mbarara

5.3.3 Predictions of future heat stress conditions and their implications

5.3.3.1 Predictions of rainfall and temperature

The ARIMA model (1,1,0) (0,0,0)¹² showed that the amount of rainfall received annually will continue to increase steadily for example in 2030 the amount of rainfall received is estimated annually at 1365.5 mm indicating 1.4% increase compared with 2014 values (Figure 5.5). The ARIMA model results produced were in excellent agreement with observed values as evident from Figure. 5.5. The mean values of the predicted rainfall, minimum and maximum temperatures (Figure 5.7) are parsimonious in matching the actual values.

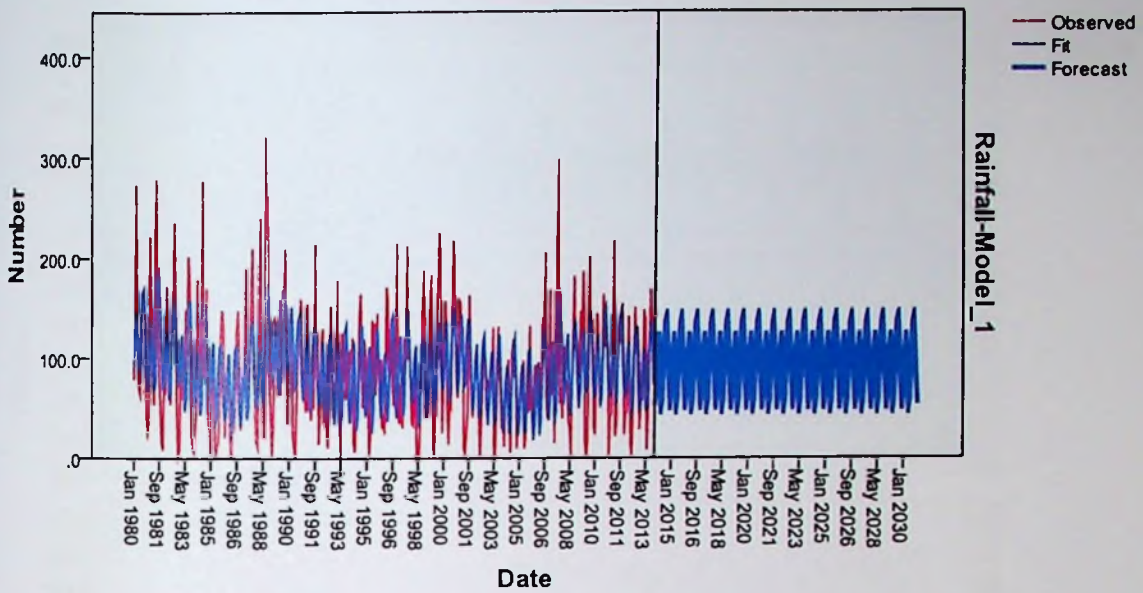


Figure 5. 5. Observed, fit and predicted annual rainfall for Mbarara by 2030

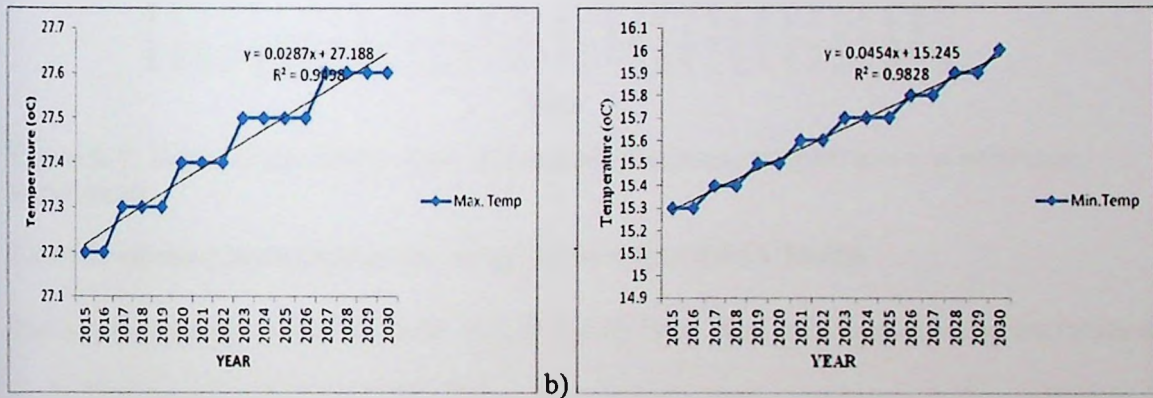


Figure 5. 6: Maximum and minimum temperature forecasts till 2030

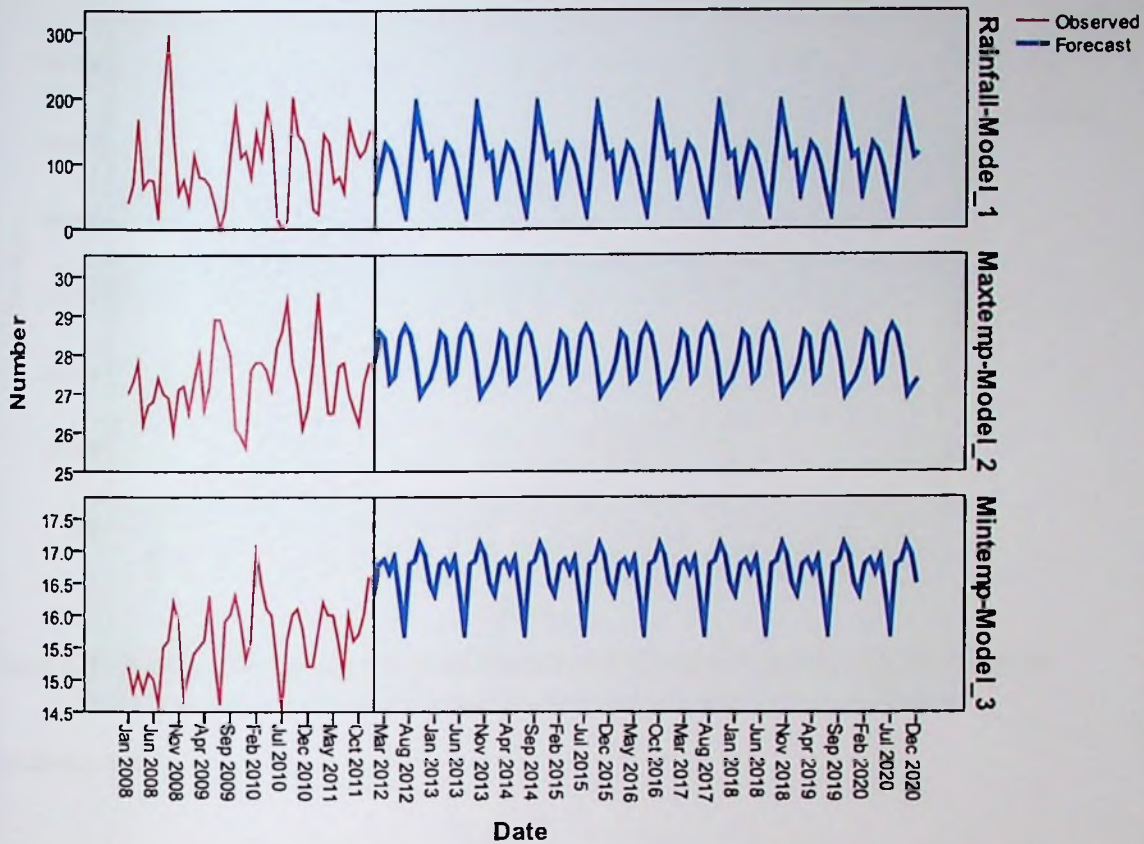


Figure 5. 7: Real and predicted values for rainfall, maximum temperature and minimum temperatures

5.3.3.2 Predicting milk production using the best fit ARIMA Model

The identified best fit ARIMA model $(1,1,0) (0,0,0)^{12}$ was then used in predicting the future milk trends from January 2015 till 2030. The model revealed a steady increase in milk production. The predicted milk production values revealed that milk production will increase at a steady rate of 6.77% per year and by 2030, the region will be producing close to 287.2 million litres (Table 5.2). The predicted milk production values also showed a seasonal pattern with significant peaks during the rainy season as confirmed by results from ACF and PACF plots (Figure 5.9)

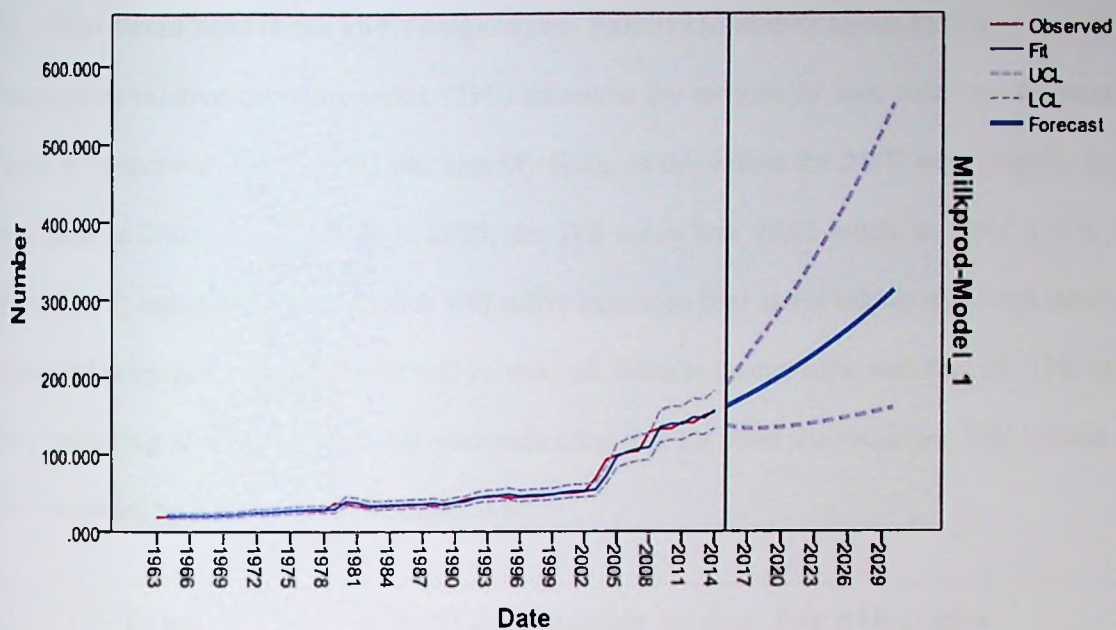


Figure 5. 8: Actual (Observed) and predicted (fit) values of milk production in Mbarara

Residual plots

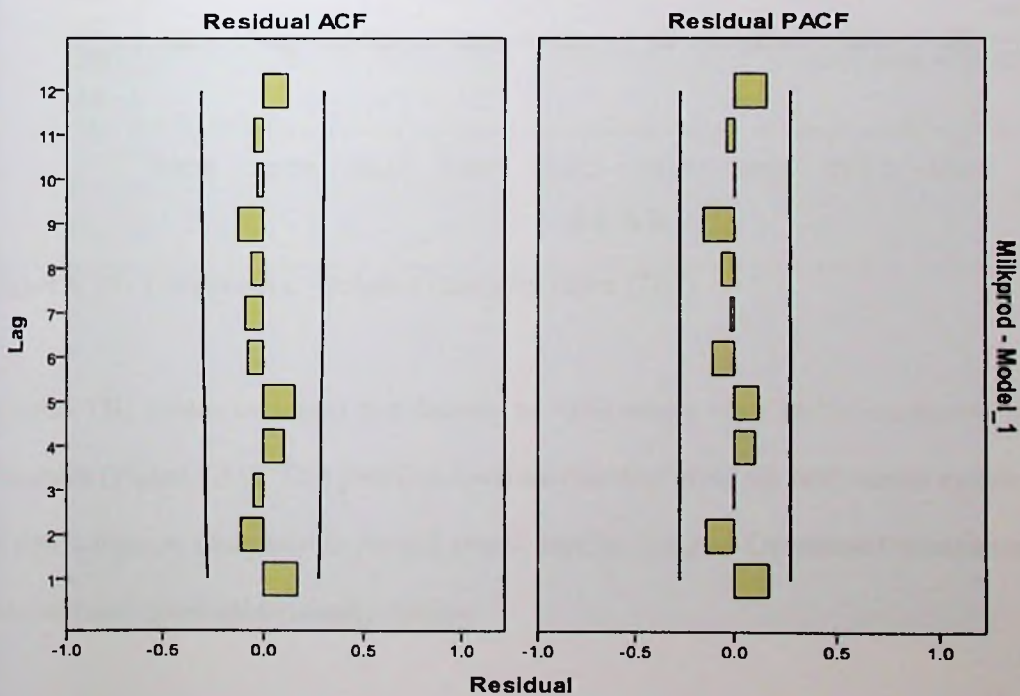


Figure 5. 9: Residual Auto Correlation function (ACF) and Partial auto correlation plots

5.3.3.3 Predicted heat stress and Temperature- Relative humidity Index (THI)

Temperature relative humidity index (THI) measures the amount of heat stress to the animals. Figure 5.10 showed that the THI was steadily rising as the values for 2017 were slightly higher than those in 2008. For example in 2008, the THI index was 76.01 while in 2017 it was 76.3 (Figure 5.10) indicating that livestock will suffer increased heat stress which will limit their feed intake and consequently production will be reduced. Results further indicated that the THI values were increasing at a rate of 0.12 per year indicating that by 2040 the projected THI values will have increased by 3.97 and will be close to 80.

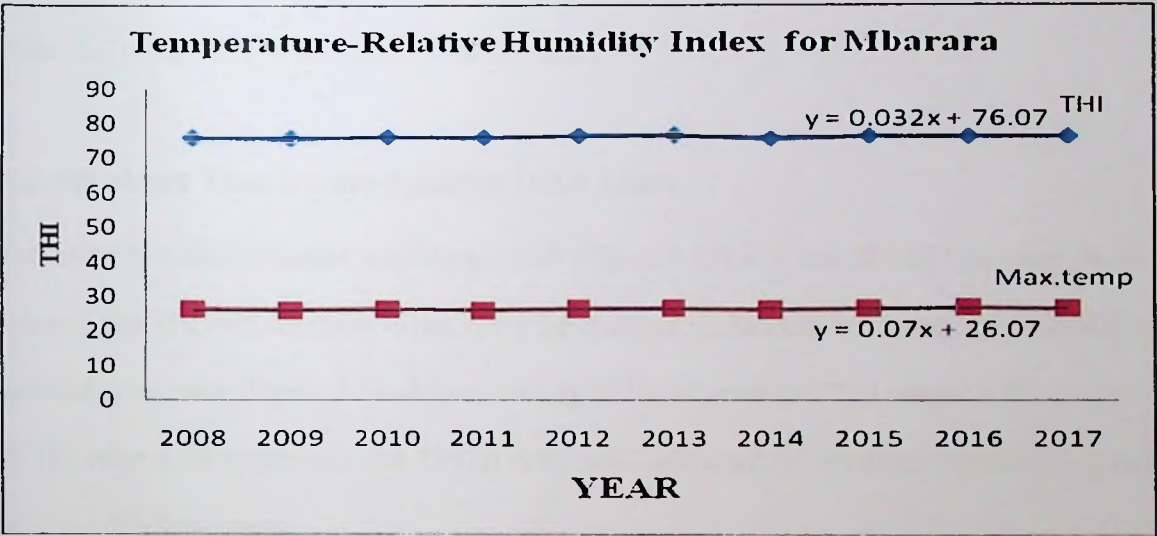


Figure 5. 10. Temperature –Relative Humidity Index (THI)

Monthly THI values indicated that January to April values were higher compared to August to December (Figure 5.11). This provides evidence that the during the first season months heat stress is always high as compared to second season months (August-December) consequently fertility rates and milk production usually decline.

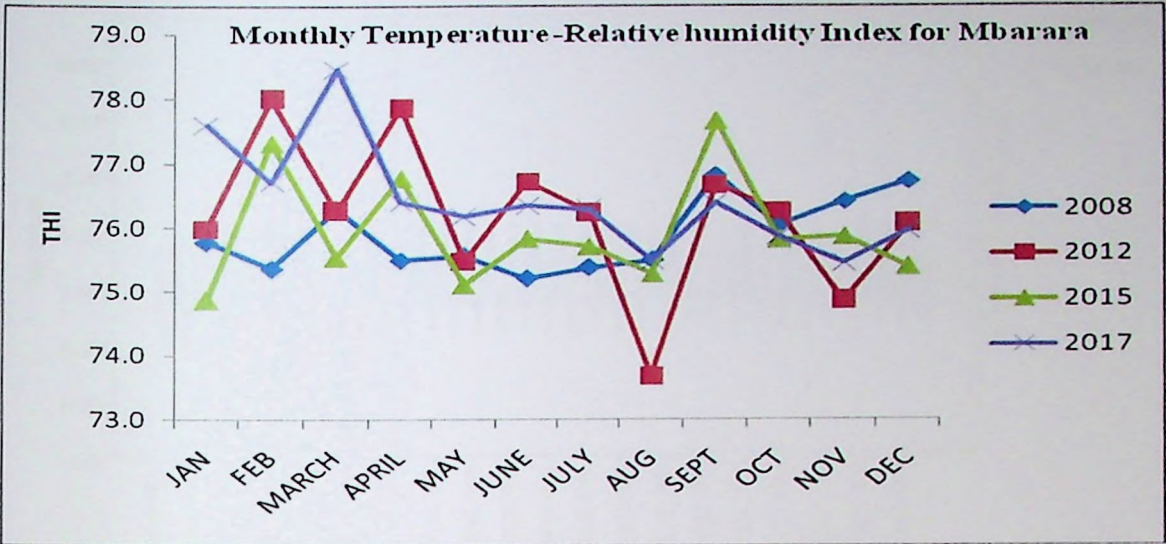


Figure 5. 11: Monthly temperature-humidity index

5.3.3.4 Predicted Temperature-Humidity Index values

Predicted THI values revealed increasing trends (Figure 5.12) at a rate of 0.032 per year. Results indicated that THI will continue to rise since the daily maximum and minimum temperatures are predicted to increase. Figure 5.12 showed that by 2030 the predicted THI values will be close to 78. This value is far greater than the 72 THI threshold (Lallo *et al.*, 2018) when high lactating cows begin to suffer heat stress.

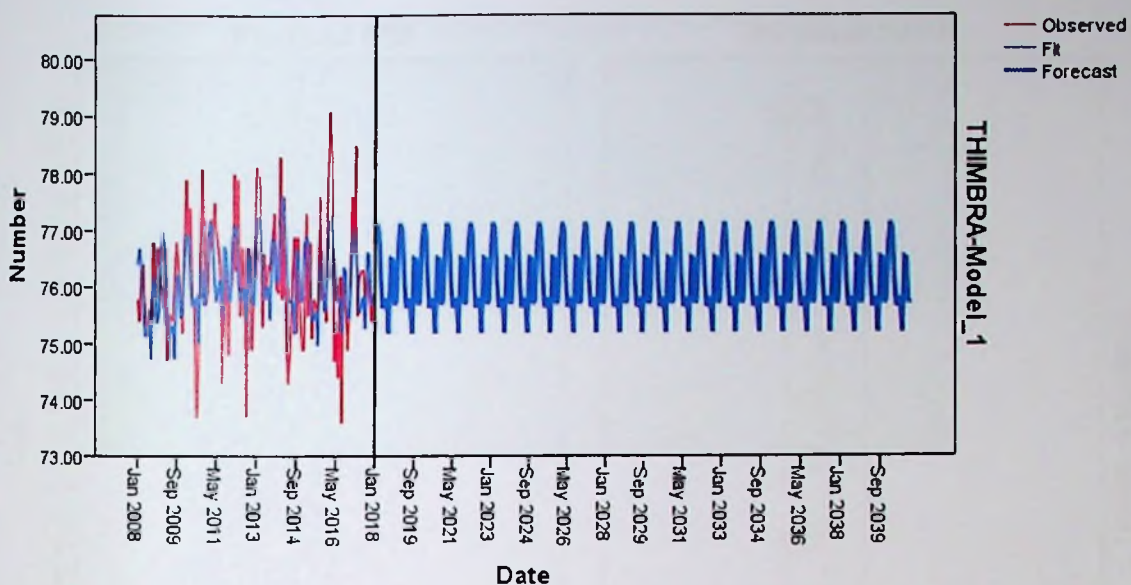


Figure 5. 12: Predicted Temperature-Humidity Index (THI) 2019-2040

The residual ACF and PACF plots were close to zero (Figure 5.13) confirming stationarity and a seasonal component in the forecast.

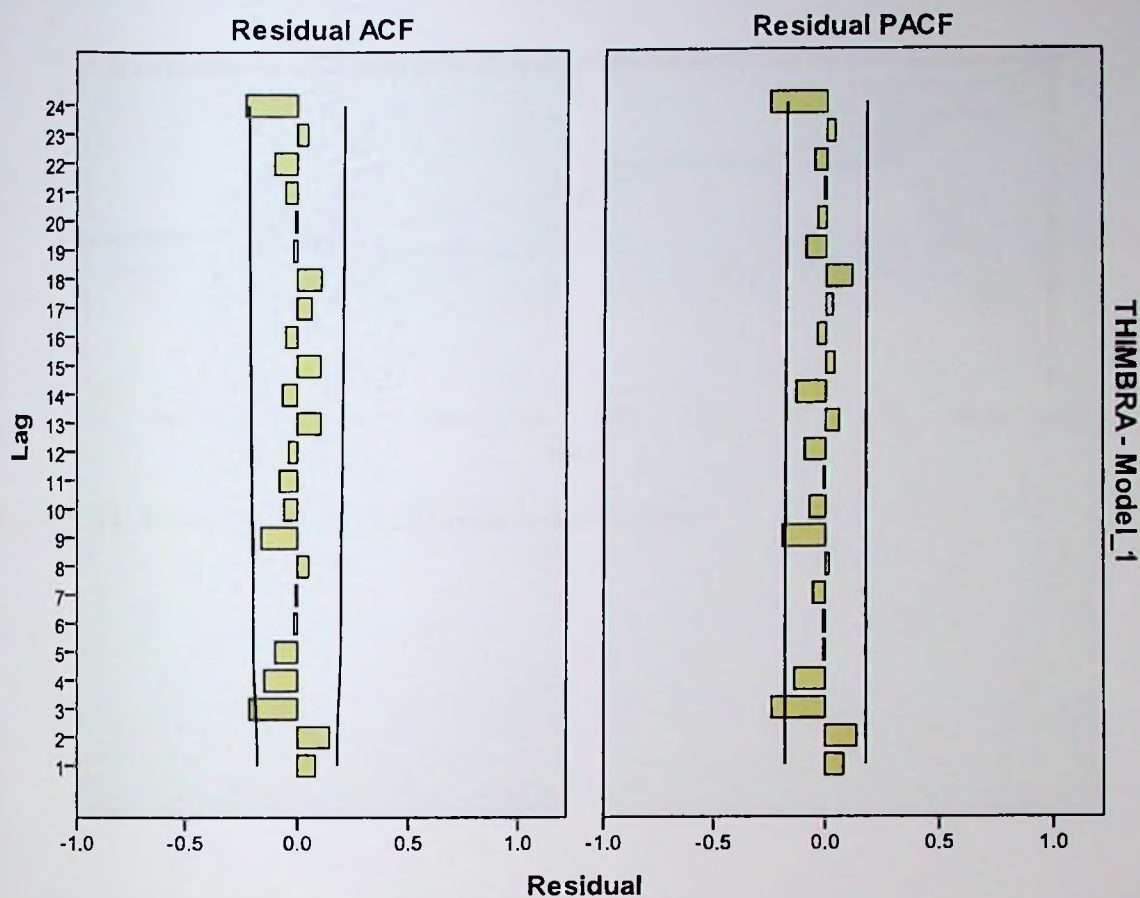


Figure 5. 13: Residual ACF and PACF plots for temperature-humidity

THI forecasts revealed an increasing trend (Figure 5.14). Currently the THI levels of about 73.6 indicates very mild heat stress to livestock. However ARIMA model $(1, 1, 0) (0, 0, 0)^{12}$ predictions indicated increasing THI values and by implication this will impact negatively on milk production.

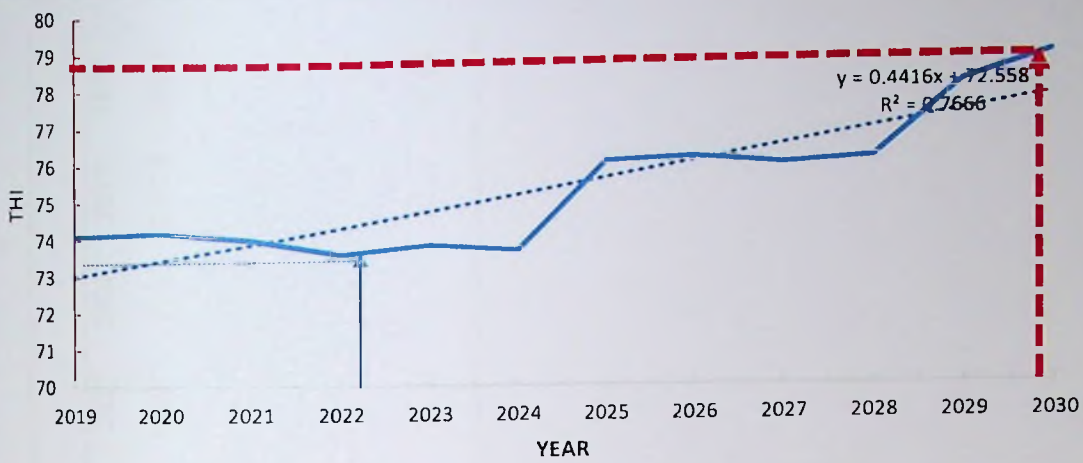


Figure 5. 14: Temperature –humidity index values by 2030

Table 5. 2: Predicted estimates of rainfall, temperature and milk production by 2030

Parameters	YEAR											
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Rainfall (mm)	1348.9	1349.5	1351.1	1352.7	1354.3	1355.9	1357.5	1359.1	1360.7	1362.3	1363.9	1365.5
Maximum temperature (°C)	27.3	27.4	27.4	27.4	27.5	27.5	27.5	27.5	27.6	27.6	27.8	27.9
Minimum temperatures (°C)	15.5	15.5	15.6	15.6	15.7	15.7	15.7	15.8	15.8	15.9	15.9	16.0
Milk production (M Lts)	192.7	201.3	210.3	219.6	229.4	239.4	250.3	261.5	273.1	285.3	287.9	287.2
Temperature Humidity Index (THI)	74.10	74.20	74.02	73.61	73.85	73.70	76.10	76.20	76.01	76.16	78.21	78.99

5.4 Discussion

Predicted THI values revealed increasing trends. These predicted THI values are greater than 72 beyond which lactating animals begin to experiencing heat stress. For example it's predicted that by 2030 THI values will be 79.99 (Table 5.2) and this indicates high heat stress levels especially to high lactating genotypes. Kadzere et al (2013) reported that THI values of less than 70 were comfortable while 75-78 stressful and lactating dairy cattle could not maintain the body heat balance in values greater than 78. Further still, studies conducted by Lallo et al (2018) and Kadzere et al (2013) showed that beyond the THI threshold of 72 for the pure Friesian genotype will begin to suffer heat stress and consequently milk production will reduce. However, overtime the long horned indigenous Ankole genotype has been tolerant to harsh tropical conditions including high temperatures as opposed to the exotic genotypes. This means that the raising THI will as a result lead to a negative performance of the exotic genotypes which are not tolerant to increased heat stress conditions.

Milk production followed linear trend until 2004 and thereafter there was a drastic increase of 34.6% in milk production from 5.2 million litres to 7.0 million litres (Figure 5.3). This can be greatly attributed to increased availability of grazeable pastures due to high incidences of rainfall patterns in Mbarara district south west of the pastoral rangelands. There was a positive decadal deviation (2000-2009) only in Mbarara indicating that the region experienced increased amounts of rainfall. In addition total heavy precipitation days $R > 10$ mm and CWDs were more frequent during the 2000 decade. Already rainfall has got a positive direct influence on the vegetation/pasture growth. Increased pasture availability translated into higher milk production levels in cattle. In addition, the government under the National Advisory services (NAADS) program in 2000 promoted the introduction of the highly lactating Friesian genotypes and coupled with series

of trainings to model progressive farmers in improved livestock husbandry practices these interventions could explain the drastic increase in milk production. ACF and PACF results confirmed a seasonal component in the time series data of milk production following a rainfall gradient. The ARIMA model results further indicated that rainfall will continue to increase at 1.4 % per annum. Perhaps this increase in rainfall may favour increased rainfed pasture production in the pastoral rangelands and by implication could translate into increased milk production in the area. Furthermore, both maximum and minimum temperatures showed increasing trends (Figure 5.2). The ARIMA (1, 1, 0) (0, 0, 0)¹² model forecasts that minimum temperatures and maximum temperatures will increase at rate of 0.045 and 0.03°C per year respectively. This indicated that by 2030, average maximum and minimum temperatures will be 27.9 and 16.1°C respectively. These figures will be considerably higher compared with the current average maximum and minimum temperatures of about 26 and 14.5°C respectively. These results are consistent with FEWS NET (2010) which reports that temperatures have increased by up to 1.5°C across much of Uganda with typical rates of warming around 0.2°C per decade. Also a related study by Nimusiima et al. (2014) reports that Nakasongola and other areas in the pastoral rangelands are experiencing increased high temperatures.

The amount of milk production annually was slightly increasing since 1960's until 2003 (Figure 5.3). However, there was a very drastic increase in milk produced since 2004. This increase in milk production could be attributed to the wide spread promotion of the Ankole X Friesian cattle genotypes specifically under the government NAADS program. The exotic Friesian genotype was specifically introduced to improve the genetic potential of the indigenous long horned Ankole in milk production and has widely been adopted by farmers in the pastoral agro-ecological zone. In addition, the region has increased cattle population and farmers have been trained on improved

livestock practices such as use of high quality forages and alternative feeds such as brewers' waste which are all geared to increasing milk production.

The ARIMA model (1,1,0) (0,0,0)¹² further revealed that milk production will continue to increase at a rate of 6.77 % and by 2030 the amount of milk production will be close to 287.2 million litres (Table 5.2) compared to the current production at 155 million litres of milk (UBOS, 2019). The results are consistent with Deshmukh and Paramasivam (2016) indicating that suitable ARIMA models are most suited for forecasting milk production. This projected increase in milk production could be partly attributed to increasing temperatures in the region. Moreover Yano et al. (2014), observed that some individual dairy cows increase milk production as the temperature increases up to a threshold. Similarly, Dash et al., (2016) reported that cows producing high quantities of milk are sensitive to heat and tend to decrease milk production as the temperatures increase. The same authors indicated that the physiological conditions of dairy animals are greatly affected by increased temperatures.

The ideal ambient temperatures for a dairy cow are between 5°C to 25°C (40°F to 77°F). At temperatures above 25°C (77°F) cows show signs of heat stress as they have to use energy to cool themselves. However, the primary means of cooling is by heat loss through surface skin and the respiratory tract. As the ambient temperatures and relative humidity continue to increase, it becomes more difficult for a cow to cool herself. Consequently, cows that suffer from heat stress have reduced feed intake and milk production. However, temperature alone may not severely affect the performance of lactating animals but an effect arising from a combination of temperature and relative humidity.

The temperature-humidity index (THI) is widely used (Du Preez *et al.*, 1990, Salem & Bouraoui, 2009) to determine the effect of heat stress on lactating animals. Figure 38 showed that the predicted temperature–humidity index values will be high as compared to the current values due to increased precipitation and raising temperatures. The severity of heat stress is correlated to both ambient temperature and humidity level. The bovine thermal comfort zone is -13°C to $+25^{\circ}\text{C}$. Within this temperature range, the animal comfort is optimal, with a body temperature between 38.4°C and 39.1°C (Berman *et al.*, 1985). Above 25°C , the cow suffers from heat stress: its health status and production performance are affected. For example in lactating dairy cows the ambient temperatures above 25°C are associated with lower feed intake, drops in milk production and reduced metabolic rate.

In a related study, Rowlinson (2008) observed a reduction in feed intake of farm animals because of heat distress as a result of increased temperatures which directly results into poor growth and performance of animals. Barash *et al.* (2001) explained these observations that ambient temperatures will continue to favour increased milk production and beyond temperature–Humidity index (THI) of 72, feed intake and milk production begin to decrease. Wheelock *et al.* (2010) observed that heat stressed dairy cows in one chamber experiments consumed less feed (13.6 vs. 19.4 kg/day), more water (86.0 vs. 81.9 l/day) and produced less milk (16.5 vs. 20.0 kg/day) than cows in a thermal neutral environment respectively. Ravagnolo *et al.* (2000) reported that milk yield declined by 0.2 kg per unit increase in THI after THI exceeded 72. The same authors explained that the reduction in milk production during heat stress could be attributed to decreased nutrient intake and decreased nutrient uptake by the portal drained viscera of the cow. Blood flow

limited to peripheral tissues for cooling purposes may alter nutrient metabolism and contribute to lower milk yield during hot weather. However, Legrand et al. (2009) reported that during the daytime when the THI was high, the cows spent more time indoors, which they were likely using for shade. Langbein and Nichelmann (1993) found that cattle on pasture exposed to temperatures up to 28°C spent 85% of each hour in shade. Moreover Prgana et al (2017) reported that Holstein-Friesian cows are known to be the most susceptible dairy cow breed to heat stress.

Berman et al. (1985) noticed that the upper limit of ambient temperatures at which Holstein cattle may maintain a stable body temperature is 25 to 26°C, and that above 25°C practices should be instituted to minimize the rise in body temperature. This means that relying on the Friesian genotype for milk production in the pastoral rangelands may not be sustainable under increasing temperatures as observed. The projected average temperatures in Mbarara by 2030 will be close to 28°C (Table 5.2) and the temperature-relative humidity index will be 76.8 (Figure 5.12) which is far beyond the 72 the desirable index where animals begin to suffer heat stress (Todorović *et al.*, 2011). These values indicate that heat stress will be high and consequently the improved crosses of the Friesian genotype will be constrained to sustain high milk production levels. This means that the raising warm nights and hot days coupled with over reliance on the exotic Friesian genotypes may not sustain high milk production levels in the future as the temperatures continue to raise unprecedented. Calle et al., (2017) reports that silvopastoral systems increase efficiency and mitigate production of greenhouse gases while reducing the environmental burdens of extensive ranching systems. In a related study Pezo et al (2018) observed that silvopastoral systems were very effective at providing more favorable conditions for livestock with increased survival and body weight of the animals. Silvopastoral systems help to increase the milk production due to the microclimate created by the trees and provide to the animals a thermal comfort of decreasing

temperature in events of heat stress. Therefore sustaining increased milk production for pastoral rangelands in the future will call for; (i) inclusion of trees (silvo-pastoral agroforestry) with good canopies in the pasture development initiatives especially for open grazing grasslands to provide shade for cooling animals and for carbon sequestration (ii) adoption and promotion of genotypes that are more resilient to warming conditions and (iii) change in production systems to include and cater for shade/housing of the exotic and crossbreds of the Friesian genotypes.

5.5 Conclusions and recommendations

The study has revealed that future THI values will increase steadily indicating heat stress in the pastoral rangelands. Consequently, livestock will suffer increased heat stress which is more likely to impact negatively on milk production especially for cattle in open grazing lands. This is because milk production will gradually reduce following the heat stress gradient. However, the negative effects of heat stress on performance of lactating cows particularly the Friesian genotypes on milk production may be reduced by encouraging pastoralists to keep livestock genotypes that are tolerant to increasing heat stress like indigenous long horned Ankole or their F1 crossbreds. Therefore the current drive of pastoralists improving to high grade animals (Pure Friesian) is likely not to be sustainable in the pastoral rangelands unless appropriate interventions are adopted. In addition, pastoralists also need to adapt strategies that minimize heat stress like planting of trees (silvo-pastoral) to provide shade in open grazing lands and construction of shades.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

General Discussion

Pastoralists' perceptions to changes in rainfall trends varied from one district to another in the pastoral rangelands. In the south western part of the pastoral rangelands in the districts of Mbarara and Kiruhura, farmers acknowledged that the amount of rainfall received was increasing while those in Nakaseke, Mbabule and Luwero reported decreasing rainfall receipts. These results are in agreement with observed rainfall trends from meteorological data (Chapter 3). In addition, pastoralists across the entire study area acknowledged that temperatures were drastically increasing. This was consistent with results from analysis of meteorological data that revealed increasing hot days and warm nights. Farmers further highlighted that the nights are becoming increasingly hot unlike in the past years. Pastoralists also acknowledged that the frequency of droughts were increasing and more severe. Changes in rainfall patterns coupled with raising temperatures were slowly changing the pasture species available for livestock. Farmers also reported that the rising temperatures were favouring the action of termites which were foraging all the available pasture species which would be available for livestock. Consequently, there is reduced forage for livestock which ultimately leads to a reduction in livestock productivity. Unfortunately, each household reported to have lost cattle due to extreme starvation during the prolonged extreme dry season.

Most of adaptation strategies aimed at increasing availability of pastures to sustain livestock production throughout the year. Key adaptation strategies included: fencing grazeable land, diversification of livestock species, stocking rate control, use of crop residues as livestock feeds, planting drought tolerant pasture species and conservation of pastures/feeds during the wet season for feeding livestock in the dry season. Zake and Hauser (2014) reported similar results however, the report further cautions that effective implementation of disaster preparedness strategies are needed to avert the current negative

Climate change disasters that impacts on community livelihoods. The study further revealed that there were barriers to these adaptation strategies which included; insecure land ownership rights, shortage of labour and lack of start-up funds. Insecure land ownership rights and lack of information concerning climate changes were among the most barriers encountered. Most of the land in the study area was owned communally a system which evolved traditionally. However, this system of land ownership may not match the recent trends because most of the current developments on land are individual initiatives that require individual land ownership rights. Majority of the farmers acknowledged that implementing climate smart practices for example fencing/paddock of grazeable land to encourage rotational grazing cannot be done on land that is communally owned.

Control of stocking rates in cattle was significantly ($p < 0.05$) influenced by the age of the household head and marital status. This could be explained by the fact that pastoralist who are of age had experience to decipher the climate situation and as such could sell off some of their cattle when the body condition scores are still good thus earning meaningful incomes. Integrating crops and livestock production was significantly ($p < 0.05$) influenced by gender of the household head, marital status, household land size, and farming experience. In events of severe scarcity of fresh water sources and pastures, some pastoralists diversify by rearing other livestock species apart from cattle such as goats, swine and poultry. This was because such livestock species were seen to have less demands for pasture and water resources. Diversification of livestock species as an adaptive strategy was significantly ($p < 0.05$) influenced by gender of the household head, marital status ($p < 0.01$) and education level of the household head. Change of grazing time as an adaptive strategy was significantly influenced age of household, cattle herd size, access to climate information ($p < 0.01$). Climate change increases frequencies of consecutive dry days that culminate into sever prolonged dry periods and consequently livestock lack pastures for grazing. Some pastoralist adapt by planting drought tolerant pasture species. Planting of drought tolerant pastures species as an adaptive strategy was influenced by gender of the household

and, education level of the household head and access to climate information. These results are consistent with Nkuba et al (2019) who revealed that non-farm assets and education level tend to promote engagement in non-weather related livelihood activities and enhance sedentary pastoralism.

2. Trends in variability of rainfall and temperature extremes

The study focused on understanding of behavior and trends of variability in rainfall and temperature extremes in the pastoral rangelands of Uganda. Annual rainfall received varied highly in all stations (Chapter 3). Decadal rainfall variability showed that in 1970's all stations had positive deviations. However, in the decade of 2000s only Mbarara showed positive decadal deviations (Chapter 3). The results are in close agreement with global rainfall projections which highlights increasing rainfall patterns in most parts of East Africa (Nicholson, 1996; Ogutu *et al.*, 2007). However, results from Masindi indicated decreasing rainfall trends. East African rainfall is directly influenced by inter-tropical convergence zone, the Zaire air boundary and El Niño – Southern Oscillation (ENSO) with teleconnections to Pacific and surface sea temperatures (Nicholson, 1996).

Results also showed increasing trends in the occurrence of precipitation extremes in all stations (Chapter 3). Although there was a general increase in the annual rainfall received in most stations, total annual wet days (PRCPTOT) were not significantly increasing across all stations. CWDs were only increasing in Mbarara while SDII was only increasing in Mbarara and Soroti areas. On the contrary, CDDs were significantly increasing in Soroti, not significantly increasing in Mbarara and significantly decreasing in Masindi (Table 3.6).

Furthermore, analysis of temperature extremes revealed strong significant increasing trends in both mean daily maximum and minimum temperatures (Chapter 3). Maximum and minimum temperatures

showed increasing trends in all stations (Table 3.6). Percentage of days/time when daily maximum temperatures, TX and daily minimum temperatures, TN > 90th percentile were significantly increasing ($p < 0.05$). DTR was significantly increasing in Soroti while in Masindi was decreasing though not significant. Daily minimum temperatures were warming faster at an average of 0.9°C per year than daily maximum temperatures at an average of about 0.4°C per year.

6.3 Prediction of future livestock productivity under heat stress conditions

Results of the best fit ARIMA models showed positive increasing trends in rainfall at a rate of 1.4% per year (Chapter 5). The model showed that by 2030 areas surrounding Mbarara district will receive about 1365 mm of rainfall as compared to 1281 mm received in 2013. This could be attributed to the influence of inter tropical convergence zone (ITCZ), the Zaire westerly winds and the interaction with the natural water bodies and streams. The predicted increasing rainfall trends may favour increased rainfed pasture production in the rangelands and by implication increase milk production. The results from the forecast also revealed increasing temperatures at a rate of 0.045 and 0.03°C per year for minimum and maximum temperatures respectively. This increase in temperatures perhaps can be explained by a general increase in surface sea temperatures (SSTs) and raising sea level of the Indian Ocean (IPCC, 2007).

Milk production is projected to increase from the current 155 million litres to 287.2million litres by 2030. This projected increase in milk production could be attributed to increasing warmer tendencies of minimum temperatures (warm nights) especially during the wet seasons. Temperature-humidity index (THI) which measures the level of heat stress to animals was also increasing at a rate of 0.032 per year. This means that livestock will continue to suffer high heat levels and consequently feed intake will reduce and this will result into declining milk production levels. The improved crosses of the Friesian X indigenous long horned Ankole genotypes were becoming popular because of high lactation yields which are higher compared to the indigenous. However, such improved genotypes may not tolerate

future high levels of heat that will prevail in the pastoral rangelands and consequently this will ultimately lead into a reduction in milk production per lactating dairy cow as heat stress increases. Moreover, Barash et al. (2001) reported that milk production will increase with an increase in ambient temperatures until a threshold is reached ($THI > 72$) and the animal begins to be heat stressed and consequently milk production declines. Therefore, the predicted future heat stress levels will not favour increased milk production from the high grade crosses of Friesian X indigenous since they will not be able to tolerate high stress levels at THI beyond THI maximum threshold of 72.

6.4 Conclusion

In the entire pastoral rangelands the amount of rainfall received annually varied highly with both positive and negative deviations from the long term means. Annual rainfall trends showed increasing rainfall in Mbarara (south-west) while in areas of Nakasongola and those adjacent districts rainfall revealed decreasing trends. Frequency of extreme precipitation events showed weak increasing trends for Mbarara which is located in the southwest of the pastoral rangelands. Frequency of extreme dry days showed a significant increase in Nakasongola and Soroti North east of the pastoral rangelands. All extreme temperature indices (percentage hot days and warm nights, frequency of hot hottest and warm days) indicate that the pastoral rangelands have continued to experience increasing hot conditions and drier conditions. The observed increasing warm night temperatures, coupled with increasing CDDs and temperature-humidity index values in Mbarara which is in southwest of the pastoral rangelands will most likely result into decreased milk production provided the thermal neutral tolerable zone is not exceeded.

5.5 Recommendations and future work

The amount of rainfall in the south western part of the pastoral rangelands are projected to increase while in central districts of Nakasongola and Luwero projections indicate decreasing rainfall amounts. Maximum and minimum temperatures continue to increase steadily indicating that the pastoral rangelands are getting hotter. Therefore pastoralists are encouraged to promote cattle genotypes that are tolerant to increasing heat stress like indigenous long horned Ankole or their F1 crosses (Friesian X indigenous). The following are key policy recommendations;

1. There is need to ensure secure ownership rights to land by streamlining and increasing individual entitlements/rights of land ownership in a communal setting.
2. There is need for formulation of policies that guide and ensure free and easy access of timely climate information to both male and female farmers in order to help them devise better and appropriate strategies are urgently needed. Platforms/channels like use of mobile public announcements among others could be used while delivering information across pastoral communities.

In this study, I have been able to establish the behaviour of trends of rainfall and temperature extremes in the pastoral rangelands of Uganda. In addition, the study revealed increasing THI values and by 2040 will be 80 far higher than 72 THI maximum threshold beyond which lactating cows begin to suffer heat stress. The THI threshold of 72 used in this study at which lactating dairy cattle begin to experience heat stress was based on studies involving high grade crossbreds or pure Friesians because of lack of THI thresholds for the breeds in Uganda. There is therefore need to conduct detailed studies to determine THI thresholds for pure Ankole and their crossbreds to ascertain whether they can withstand the predicted increasing future heat stress in the pastoral rangelands.

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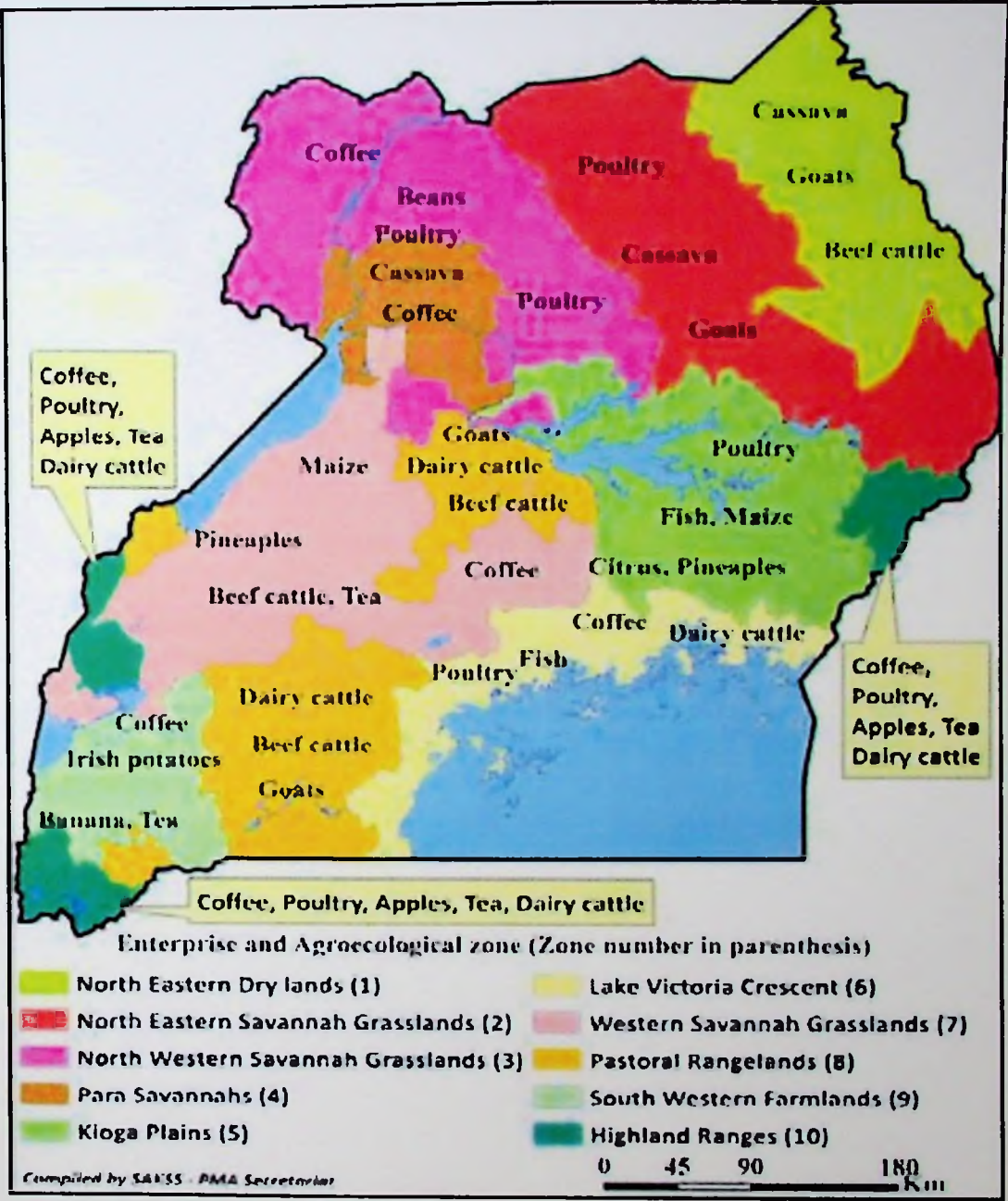
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Appendix 1: Map of Uganda showing AEZs and the key Agricultural products



Source: MAAIF, 2018.