ASSESSING INFLUENCE OF RAINFALL AND TEMPERATURE VARIABILITY ON PRODUCTIONPERFORMANCE OF SAHIWAL CATTLE IN SEMI-ARID REGION OF KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Master of Science Degree in Livestock Production Systems of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

This research thesis is my original work and to the best of my knowledge has not been presented for award of a degree at any other university.

Signature ________________________ Date 20/06/22

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Recommendation

This research thesis has been prepared with our supervision and submitted to graduate school with our approval as university supervisors.

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DEDICATION

I dedicate this thesis to my wife, Catherine Wanjiru, and siblings John Githinji, Denis Kubai Lillian Njeri, Racheal DamaWambui and Ian Gitonga.

Performance is a factor of genetics and environment subject to the production system

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ABSTRACT

For over 50 years, Sahiwal cattle breed at the National Stud Herd (NSH) has been bred on rain-fed pastures in a semi-arid ecosystem of Kenya. NSH is located in a hotspot of increasing climate change and variability where Sahiwal cattle herd grazed on rain fed pastures has had long exposure spanning over 50 years. It is hypothesized that Sahiwal has been exposed to large intra and inter annual variations in precipitation and temperatures, with significant influence on their survival rates and milk production. Therefore, the objectives of this study were to characterize the extent of variability in monthly rainfall and temperatures, and to determine their influence on survival rates and on milk production of Sahiwal cattle managed at the Naivasha NSH. Records of monthly herd inventory, deaths and milk yields, monthly minimum (Tmin), maximum (Tmax) and mean (Tmean) temperatures and rainfall for a period of 31 years were obtained from the Naivasha NSH. Variability trends in monthly rainfall and temperature were characterized using the coefficient of variation (CV), standardized anomalies, Precipitation Concentration Index (PCI) and moving averages. The trends were determined using Mann-Kendall (MK) trend test while the slope was computed from Sen's Slope test. The influence of rainfall and temperatures variations on cattle survival rates was determined using logistic regression while the influence on milk yield was determined using multiple regression analysis. Rainfall variability (CV) was larger in short seasons (CV 59.2%) than in long seasons (CV 48.2%) with a high rainfall concentration (PCI) observed in 34% of the years. The trend for mean annual, long and short season rain, Tmin, Tmax and Tmean were -36.5mm, -25.5 mm + 69 mm, 0.017^{o}C, -0.156^{o}C and -0.09^{o}C per decade, respectively. The range of standardized anomalies for annual rainfall and Tmean were -1.58 to +1.63 and -21.53 to 2.54. The Sen's slope for mean monthly rainfall, Tmin, Tmax and Tmean ranged from -1.36 to 0.76, -0.06 to 0.05, -0.07 to 0.07 and -0.05 to 0.05, respectively.Effects of temperature variability was insignificant on cattle survival, but rainfall variability had a discernable significant trend on the probability of an animal surviving. For every 1^{o}C increase in Tmin and Tmax, monthly milk yield decreased by 1.58kg and 1.17kg, respectively while for every 1 mm increase in monthly rainfall, monthly milk yield increased by 0.07kg. It is concluded that Naivasha NSH has experienced significant intra and inter annual variations in precipitation and temperatures, with significant influence on survival rates and milk production of Sahiwal cattle. It is advisable to implement adaptation strategies that will respond to effects of variability in precipitation and temperature on cattle survival and milk production. These include adjustments in animal husbandry, grazing management feed conservation to improve pasture quality and quantity all seasons.

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LIST OF ABBREVIATIONS AND ACRONYMS

AFC	Age at First Calving
AI	Artificial Insemination
AMY	Annual Milk Yield
ARV	Annual Rainfall Variation
ASAL	Arid and Semi-Arid Land
BW	Birth Weight
C.I	Calving Interval
CGRFA	Commission on Genetic Resources for Food and Agriculture
DMY	Daily Milk Yield
DG	Pre-Weaning Average Daily Gain
FAO	Food and Agriculture Organization of the United Nations
F1	First Filial Generation
GOK	Government of Kenya
GDP	Gross Domestic Product
GLM	Generalized Linear Model
IISD	International Institute for Sustainable Development
ICRAF	International Council for Research in Agro Forestry
IPCC	Intergovernmental Panel on Climate Change
KALRO	Kenya Agricultural & Livestock Research Organization
KMD	Kenya Meteorological Department
LL	Lactation Length
LMY	Lactation Milk Yield
MA	Millennium Ecosystem Assessment
MY	Milk Yield
WMO	World Meteorological Organization
NEAP	National Environmental Action Plan
NSC	Number of Services per Conception
NSS	National Sahiwal Stud
OECD	Organization for Economic Co-Operation and Development
PROC GLM	Procedures of Generalized Linear Model
PDG	Post Weaning Average Daily Gain
REML	Restricted Maximum Likelihood
ENSO	El Nino/ Southern Oscillation

SAS	Statistical Analysis System
SEAZ	Small East African Zebu
TD	Test Day
UNEP	United Nation Environmental Program
WW	Weaning Weight

CHAPTER ONE
INTRODUCTION

1.1 Background

The Kenya National Climate Change Action Plan for 2018-2022 period projected prevalent higher temperatures and more variable rainfall in the country. Climate change is expected to continue with more observed frequency and severity of drought events, pasture and water scarcity, flooding events and disease outbreaks (GOK, 2018). The arid and semi-arid lands (ASALs) ecosystems are projected to suffer the most, reflecting higher vulnerability status in these hotspots of an increasingly warming and variable climate. For livestock, changing and variable climate has direct and immediate negative effects. These will adversely impact on livestock yet the livelihoods in the ASALs are heavily reliant on livestock and the domestic beef supply is predominantly sourced from the ASALs (Imana *et al.*, 2023; Ndiritu *et al.,* 2020).

Temperature increases lead to heat stress which disrupt metabolic processes, cause oxidative stress and immune suppression. To the extreme, these can eventually lead to infections, morbidity and even death. Indirectly, the changing and variable climate triggers declines in quantity and quality of pastures and forages and drinking water as well as survival and redistribution of pathogens and or their vectors (Bett *et al.,* 2019; Lacetera *et al.,* 2019).

The severity of both the direct and indirect impacts of climate change induced hazards therefore manifest in cattle herd dynamics and production performance. The now increasingly more frequent and severe changing and variable climate necessitates an urgent search for adaptable cattle breeds. The indigenous Zebu cattle breed, though are low producing, demonstrates considerable resilience to impacts of changing and variable climate being experienced in the ASALs of Kenya (Maibam *et al.,* 2018; Upadhyay *et al.,* 2022).The Sahiwal cattle breed is one of the popular zebu cattle breeds of choice in up-grading programs of the indigenous zebu cattle in the ASALs. Relative to other zebu cattle breeds, Sahiwal cattle breed attracts high preference because of higher milk production and growth potential and better adaptability to impacts of variable precipitation and higher temperatures (Mwangi & Ilatsia, 2022).For over 50 years in Kenya, the source of Sahiwal breeding sires has been the Naivasha Sahiwal National Stud Herd (NSH).The Naivasha NSH has been supplying Sahiwal breeding stock to Maasai pastoralists and other leading Sahiwal ranches in the country and the region. The station also doubles as a research facility that develops appropriate animal husbandry and breeding practices for pastoral herd owners (Mwangi &

Ilatsia, 2022). Naivasha NSH is located in a semi-arid ecosystem, classified as a hotspot of increasing climate change and variability (Boutaj *et al.,* 2019). The stud herd is managed under field rain fed pasture grazing where variability is large in rainfall (average annual rainfall of 620mm), temperatures (range 8 to 26°C) and in humidity (range 60 to 75%). This raises the question of whether the performance of the Sahiwal cattle breed under long term exposure to the changing and variable climate has provided evidence for responsive management decisions.

To date, the Naivasha NSH has concentrated on Sahiwal breeding and husbandry practices without incorporation of the hazards of the now increasingly changing and variable climate to inform responsive management interventions. The breeding and husbandry interventions are planned and designed for implementation without adequate knowledge and evidence on the extent of sensitivity of the Sahiwal breed to impacts of variable and changing rainfall amounts and temperatures. This is despite overwhelming evidence of a trend of declining performance in herd size and milk production (Mwangi & Ilatsia, 2022).

Classifying seasons as fixed effects cannot quantify the actual changes on herd performance parameters in absolute terms. Lumping functional and production performance within season classes assume certain uniformity in the classification of the seasons and consequently assumes similar influence on population dynamics and individual functional and production performance over the years. However, there could be certain peculiarities in climatic factors associated with certain days or months within a given season, certain years and across years that would correspondingly reflect specific influences on population dynamics and functional and production performance. A more accurate approach is to regress herd dynamics and functional and production performance on the actual empirical precipitation data during a specific period under which a given animal performance is recorded. This is particularly important in assessing herd production and functional performance dynamics of the Sahiwal cattle genetic resources to changes in the intra and inter annual variation in rainfall and temperatures.

1.2 Statement of the Problem

Naivasha NSH is located in a hotspot of increasing climate change and variability. Cattle farming grazed on rain fed pastures in NSH area are continuously faced the threats of climate change especially high temperatures and poor precipitation. In particular Sahiwal cattle introduced to improve local Boran has been the most bred cattle breed in the NSH area. Nevertheless there is limited evidence on the relationship between herd dynamics and production performance of Sahiwal cattle at the Naivasha NSH given the changing and variable climate. Testing this hypothesis should provide empirical evidence base to inform responsive management interventions to secure the Sahiwal cattle assets. This study aims to provide empirical evidence to inform responsive management interventions to secure the Sahiwal cattle assets in the face of climate change extremes.

1.3 Objectives

1.3.1 General Objective

To contribute to food and nutrition security through identifying climate variability that negatively affect Sahiwal production in Kenya's arid and semi-arid lands.

1.3.2 Specific Objectives

i. To characterize the variability of monthly rainfall and temperature in in a semi-arid ecosystem where Sahiwal cattle have been grazed for long period

ii. To determine the influence of rainfall and temperature variability on survival rates of Sahiwal cattle grazed in a semi-arid ecosystem

iii. To determine the influence of rainfall and temperature variability on milk production of Sahiwal cattle grazed in a semi-arid ecosystem

1.4 Research Questions

i. How variable is the monthly rainfall and temperature in the semi-arid ecosystem where Sahiwal cattle have been grazed for long period?

ii. What is the influence of rainfall and temperature variability on survival rates of Sahiwal cattle grazed in a semi-arid ecosystem?

iii. How does rainfall and temperature variability in a semi-arid ecosystem influence the survival rates of Sahiwal cattle grazed over a long period?

iv. What is the influence of rainfall and temperature variability on milk production of Sahiwal cattle grazed in a semi-arid ecosystem?

v. What is the relationship between rainfall and temperature variability in a semi-arid ecosystem and the milk production of Sahiwal cattle?

1.5 Justification

Characterizing the variability of the monthly rainfall and temperature in a semi-arid ecosystem where Sahiwal cattle have been grazed for long period of time will provide evidence about the extent of the climate variability to which Sahiwal cattle are exposed to and their level of sensitivity. Determining the influence that rainfall and temperature variability has on survival rates and milk production of Sahiwal cattle will provide evidence to inform the designing of appropriate adaptation actions in the face of climate change extremes to secure Sahiwal cattle, which is a valuable genetic resource. The evidence on the extent of variability of the monthly rainfall and temperature and influence on survival rates and milk production of Sahiwal cattle will be useful in designing mitigating strategies to ameliorate climate change induced hazards and secure the livestock assets. The evidence obtained can be integrated within breeding and husbandry interventions.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Several studies have shown that annual rainfall variability (ARV) is a major driver of livestock population dynamics (He & Li, 2019; Longobardi & Boulariah, 2022; Marini *et al.,* 2019; Obwocha *et al.,* 2022). The impact of drought on livestock populations under different management systems is assumed to be comparable in terms of livestock survival (Lacetera, 2019; Mirzad *et al.,* 2018; Ronco *et al.,* 2017; Santos *et al.,* 2019). This is because of the strong connection between feed availability and ARV as animal numbers are indirectly controlled by forage availability (Rojas-Downing *et al.,* 2017). Some studies have used ARV as a proxy predictor of livestock population dynamics where long-term data series were used in the analysis (Maviza & Ahmed, 2021). Livestock systems based on grazing and mixed farming systems are more likely to be affected by fluctuation in rainfall, temperature and solar radiation (Descheemaeker *et al.,* 2018; Ochieng *et al.,* 2017).

2.2 Impact of Climate Change

2.2.1 Impact of Climate Change on Cattle

The ever-increasing demand for animal products in the tropics requires urgent improvements in herd productivity. Animal production in the tropics is mainly limited by feed availability (Godde *et al.,* 2019; Linstädter *et al.,* 2016; Sejian *et al.,* 2016). Livestock systems based on grazing and mixed farming systems will be more affected by global warming than those produced inthe industrialized system. This difference is mainly caused by the negative effects on crop and pasture growth due to lower rainfalls. These effects are more severe due to frequent droughts and direct effects of high temperatures and solar radiation on the animals (Maibam *et al.,* 2018; Sejian *et al.,* 2018).

Livestock grazing systems can broadly be categorized into two major systems. These grazing systems include the extensive grazing and pastoral systems (Kaufmann *et al.,* 2019). The systems utilize more than three billion hectares of arid pastures, where agriculture is not feasible. Pastoral systems are located mainly in Africa (Ouédraogo *et al.,* 2021), Asia, Australia and some parts of America and Europe**.** The second category includes the mixed crops livestock systems. These systems utilize about 2.5 billion hectares. Sere' and Stainfeld (1996) subdivided these systems into two sub-categories: a) rain fed mixed system and b) irrigated mixed systems. Ayana and Gufu (2012) reported that in Ethiopia, the mean annual precipitation for the Borana rangelands over the two decades was 500 mm, with a range of

238 to 896 mm. High fluctuations of forage and animal populations the Borana rangelands was strictly controlled by the amount and distribution of rainfall in space and time (Asfaw *et al.,* 2017). In addition, recent changes in land use patterns linked to the fragmentation of traditional grazing lands might increase the impact of ARV (Annual Rainfall Variation) on livestock population dynamics (Ratwan *et al*., 2022).

In Kenya, livestock is a fundamental asset for rural people especially in rangelands providing economic, social and risk management functions (Mwangi & Ilatsia, 2022). These rangelands are characterized with extreme erratic rainfall pattern and extended days of high temperatures and covers around 80% of the country .This exacerbates the vulnerability of cropping systems and leaves adaptable livestock species such as Sahiwal cattle as the most appropriate enterprise in those areas. The Sahiwal cattle breed was introduced in Kenya by the British colonial government from India and Pakistan for crossing with local Zebu breeds to improve milk and growth performance. The breed is usually has various shades of red to brown, with varying white markings (Topno *et al*., 2023).The Kenya Sahiwal is thus a product of several generations of crossing local East African Zebu (EAZ) cows with Sahiwal bulls (Mwangi & Ilatsia, 2022). The Sahiwal breed is well suited in arid area with a thermal neutral zone lying between 15˚C to 27˚C (Ahamad *et al*., 2022).

It is preferred to other breeds by pastoralists in Kajiado, Narok and Transmara counties among other parts of Kenya due to its high milk production, growth performance, and good reproductive ability. Since Sahiwal is a dual-purpose breed (provides both meat and milk), this puts it as the best alternative in rangelands over other livestock species (Mwangi & Ilatsia, 2022). Additionally, their ability to utilize low quality and feed resources to more than one product while growing very fast leaves them as the most appropriate livestock species in ASALs. The breed has a mean lactation milk yield of 1395 to 1400 Kg with a mean calving interval of 465 days.

The main aim of Sahiwal farmers in the different production systems is to increase milk yield, body size and mature weight. Good fertility and adaptation to local production conditions are also considered (Ratwan *et al*., 2022).

2.2.2 Impact of Climate Change on Livestock Feeds

Animal production parameters such as live weight gain, milk production, herd reproduction and mortality are strongly related to the availability of young, digestible plant material which in turn is strongly influenced by frequency of climate conditions (Dumont *et al.,* 2015). Some information exits on the likely impacts of climate change on forage quality, although little seems to be relevant to the tropics. Increased temperature leads to increased lignification of plant tissues, therefore, reducing the digestibility of plant spices (Thivierge *et al.,* 2016). This leads to reduced nutrients availability to the animals and ultimately reduced livestock production. Such reduction impacts on food security and incomes through diminished production of milk and meat.

2.2.3 Climate Change Impact on Heat Stress

Heat stress is a major source of production loss in dairy and beef industry (Summer *et al.,* 2019).Whereas new knowledge about animal responses to the environment continues to be developed, managing animals to reduce the impact of climate remains a challenge (Thornton *et al.,* 2021). Heat stress in livestock arises when the heat load from metabolic processes and the external environment is unable to be dissipated. Little is reported on assessment of the direct impacts of climate change on heat stress in animals, particularly in the tropics and subtropics. Increased thermal heat stress reduces livestock productivity through lower growth due to appetite suppression and decreased reproductive rates (Gonzalez-Rivas *et al.,* 2020; Rojas-Downing *et al.,* 2017).

There exists a number of methodological approaches to modeling heat stress in livestock. Some combine ambient temperature and relative humidity measurements to estimate thermal discomfort of the animals while others are based on measuring directly the temperature being experienced by the animal (Herbut *et al.,* 2018; Lees *et al.,* 2019). Out of these, a number of metrics have been developed to evaluate heat stress over time (Hammami *et al.,* 2013; Herbut *et al.,* 2018). Of these metrics, the most popular is the temperature humidity index (THI) (Mu *et al.,* 2013; Pinto *et al.,* 2020). It is, nevertheless, clear that the heat stress caused in livestock by hot and humid conditions leads to reduced feed intake thus causing declined productivity (Guo *et al.,* 2018). The vulnerability of livestock to heat stress varies according to species, physiological status, coat color and other factors (Godde *et al.,* 2021; Nguyen *et al.,* 2017; Rojas-Downing *et al.,* 2017). Smallholder dairy producers in the developing world, who have adopted high-yielding improved dairy cows bred for temperate regions, could be at greater risk (Bang *et al.,* 2021; Pezzopane *et al.,* 2018; York *et al.,* 2017). High temperatures also put a ceiling on milk yields irrespective of feed intake (Garner *et al.,* 2017).

2.2.4 Water Availability and Intake

Globally, freshwater resources are relatively scarce amounting to only 2.5% of all water resources, and of this, 70% is locked up in glaciers and permanent ice (Khilchevskyi *et* *al.,* 2021). Global renewable water supply estimates are imprecise, but lie between 33,500 and 47,000 cubic km per year and about one-third of this, is accessible to humans (Khilchevskyi *et al.,* 2021).

With global warming, water will probably be the main challenge in all livestock systems. With climate change, water availability is expected to be variable due to increased seasonal and annual variability in precipitation (Konapala *et al.,* 2020). The phenomenon of salination is spreading in many areas of the world. Apart from this phenomenon, water may contain chemical contaminants, either as organic or inorganic compounds, high concentration of heavy metals and biological contaminants (Benito *et al.,* 2022). Animals exposed to hot environments drink more water than those in thermo-neutral conditions (Fader *et al.,* 2016; Lacetera, 2019).With water shortages such livestock run into many risks including dehydration and hyper- ventilation that leads to metabolic failure (Serrano *et al.,* 2022). Water demand by livestock is strongly related to temperature and therefore likely to increase as temperatures rise. Such higher water requirements by livestock will mean that they will be unable to travel over long distance in search of water. This will limit the use of grazing resource in extensive grazing operations and tend to increase grazing pressure and increase risks of soil degradation near watering points.

2.2.5 Disease and Parasite Challenges and Climate Change

The effect of climate change on health of farm animals is a function of many factors. These include species, genotype (breed), geographical location, and characteristics of the disease (Lacetera, 2019; Rojas-Downing *et al.,* 2017). Climate change, in particular global warming, is likely to greatly affect the health of farm animals, both directly and indirectly (Cheng *et al.,* 2022). During extreme weather events, direct effects on animals include temperatures-related illnesses, increased morbidity and eventual death. Some studies carried out in dairy cows indicated higher incidences of mastitis during periods of hot weather (Dahl *et al.,* 2020). Currently, emerging and re-emerging diseases have significant impact on global economies and trade, public health and food contamination (Contosta *et al.,* 2019;Sipari *et al.,* 2022; Stoffel *et al.,* 2020).For instance, Sipari *et al.* (2022) has linked climate change to accelerated winter transmission of zoonotic pathogens in Northern Europe. The geographical distribution of parasites and their vectors as well as pests is also being affected by changes in climatic variables such as temperature and rainfall (Kjær *et al.,* 2019; Ma *et al.,* 2019; Ostfeld & Brunner, 2015). This then poses several challenges on understanding whether climate change increases prevalence of pathogens in reservoir hosts as well as the dynamics of the animal diseases given that the underlying mechanisms of the observed changes due to climate change are yet to be well understood.

2.2.6 Biodiversity and Climate Change

According to Hoban *et al.* (2020) loss of biodiversity is the loss of components of biodiversity which includes biomes, habitats and ecosystems, species, populations and genetic diversity. Climate change is one of the key drivers of loss of biodiversity (Guo *et al.,* 2017; WWF, 2020). Climate change affects biodiversity by changing life cycles and developing physical features and by changing or shifting habitat ranges, distribution of species, changes in abundance and migration patterns and changes in frequency and severity of pests and disease outbreaks (Sintayehu, 2018). Livestock genetic resources is the genetic diversity found within and across animal species and breeds which have socio-economic and cultural values (Kantanen *et al.,* 2015). According to Intergovernmental Panel on Climate Change (IPCC) report predicted that a 2 ^{o}C to 3 ^{o}C increase in temperature could lead to a 20 to 30% loss in livestock biodiversity (IPCC, 2014). Extreme weather events induced by climate change such as droughts, floods can have devastating effects on livestock genetic resources. Where breeds or populations are limited to a small geographical region, the populations can get wiped out (FAO, 2015)

2.2.7 Adaptive Capacity

The rural based nature of dairying makes it a suitable enterprise to contribute towards the government's strategy to meeting the millennium development goals and the Kenya Vision 2030.Adaptive capacity was defined by Walker *et al.* (2022) as the capacity of a system to respond to a change or shift in the environment to cope better with existing or anticipated external shocks.

Adaptation options to climate change have been summarized by Wulansari *et al.*(2022), who define a typology of adaptation options that include micro-level adaptation options, together with farm production adjustments such as diversification and intensification of crop and livestock production (Ali & Erenstein, 2017), changing land use and irrigation and altering the timing of operations. Income-related responses that are potentially effective adaptation measures to climate change, such as crop, livestock and flood insurance schemes, credit schemes, and income diversification opportunities (Antwi-Agyei *et al.,* 2018), technological developments, such as the development and promotion of new crop varieties and livestock feeds (Maltou & Bahta, 2019), improvements in water and soil management and improved animal health technology. Institutional changes, including pricing policy adjustments such as the removal or putting in place of subsidies, the development of income stabilization options, agricultural policy which includes agricultural support and insurance programs, improvements in agricultural markets, and the promotion of inter-regional trade in agriculture (Wulansari *et al.,* 2022).

2.2.8 Resilience

The IPCC (2022) defined resilience as the ability of a system (e.g. ecosystems, societies, corporations, nations and socio-ecological systems) to undergo a disturbance and still maintain its functions and control. They considered resilience as a measure of the magnitude of disturbance a system can tolerate and still persist. Another concept was advanced by Alexander (2013) defined resilience as a systems' ability to resist disturbance and the rate at which it returns to equilibrium following disturbance. The distinction between the two definitions of resilience has been useful in encouraging the managers of naturally variable systems (e.g. dry land pastoral systems) to move away from concentrating on management aimed at the unachievable goal of stability.

2.2.9 Livestock Systems Response to Climatic Change

In the extensive production systems, constraints caused by climate stress are substantial and aggravated by current degradation of natural resources, poor access to technologies and lack of investments in production (e.g. infrastructures). The animals are likely to experience heat stress for a prolonged period, especially in tropical zones (Rust, 2019). The rapid climatic variability will exert a strong influence on pastoral systems, despite their developed capability to cope and adapt to climate uncertainty. But for conditions that deviate from a "coping range" pastoral system will also became vulnerable if there is no adaptive capacity (Dong *et al.,* 2019). Pastoral systems will be exposed to climatic effects particularly in Africa, Australia, Central America and Southern Asia. In these areas, some studies forecast substantial loss of available biomasses (Godde *et al.,* 2020). However, since pastoral systems are totally dependent on availability of natural resources, the increase of inter-annual and seasonal variation of forage availability will contribute to reduce in overall sustainability, both from a social–economic and from an ecological perspective.

Solar radiation determines the major effect on thermoregulation of animals reared under extensive systems, usually grazing in areas where natural shade is not always available and provision of artificial shade is not always possible. In addition, for animals reared in extensive farming systems the mechanical work to explore grazing areas contributes to increasing the metabolic rate, consequently, the rate of heat production that must be dissipated to avoid heat stress. Commonly increased external parasites and vector-borne diseases occur (Grace *et al.,* 2015; Paul *et al.,* 2015). In tropical and subtropical regions an increased need of drinking water, as a consequence of prolonged exposure to high environmental temperature, is often coincident with a reduction of water availability and forage water content and quality (Rojas-Downing *et al.,* 2017). Fibrous forages reduce voluntary feed intake and can increase fermentative heat and the thermoregulatory demand for water (Reyad *et al.,* 2016; Summer *et al.,* 2019). An additional problem may derive from the quality of water available in hot arid or semi-arid areas. In such climatic areas, water is commonly characterized by high concentration of total dissolved solids. The reduction of vulnerability of pastoral systems to climate changes should be based on the analysis of specific characteristics of the systems adopting new technologies such as remote sensing to evaluate feed and water availability, movement of the flocks, to establish feeding strategies to adopt during exceptional events in connection with local decision-making processes (Cheng *et al.,* 2022).

2.2.10 Productivity and Sustainability of Cattle to Changes in Climate

Some studies have covered this topic but much needs to be done to fully understand the interactions of climate and increasing climate variability with other drivers of change in livestock systems and in broader development trends. First, much more clarity is needed concerning the benefits of livestock, the negative impacts they can have on greenhouse-gas emissions and the environment and the effects of climate change on livestock systems. Second, while much is known about how livestock keepers cope with climate variability, much more is needed concerning the nature and extent of tradeoffs possible between different crop and livestock enterprises and between on and off farm income sources, in different situations. Selection for efficient production has a clear benefit in mitigating emissions through selecting of high producing animals and feeding higher concentrate diets. However, this would lead to conflicts with other societal priorities, such as maximizing the availability of cereal crops for direct human consumption and hence affect the sustainability of livestock production (Martin *et al.,* 2020; Megera *et al.,* 2014)

2.3 Methodologies for Assessing Impacts of Climatic Change on Livestock Population Dynamics and Productivity

Several methodologies have been applied in numerous studies on climate change and some of them are discussed below:

2.3.1 Participatory Approaches

Participatory assessment of impacts of climate change uses tools such as key informant interviews and group discussions, house-based questionnaires and farmers' perceptions (Singh *et al.,* 2019).A key informant interview is a loosely structured conversation with people who have specialized knowledge about the topic you wish to understand. Key informant interviews were developed by ethnographers to help understand cultures other than their own. A good key informant can convey this specialized knowledge to you. The give and take of these interviews can result in the discovery of information that would not have been revealed in a survey. Household surveys can provide a wealth of information on many aspects of life. However, the usefulness of household survey data depends heavily on the quality of the survey, in terms of both questionnaire design and actual implementation in the field. In addition, the accuracy of the data being collected may affect the quality of your work (Singh *et al.,* 2019).

2.3.2 Use of Historical Empirical Data

The process of learning and understanding the background and growth of a chosen field of study or profession can offer insight into organizational culture, current trends and future possibilities. The historical method of research applies to all fields of study because it encompasses their origins, growth, theories, personalities, crisis among others. Both quantitative and qualitative variables can be used in the collection of historical information. Once the decision is made to conduct historical research, there are steps that should be followed to achieve reliable results.

Steps to followed and observed when acquiring and collecting historical empirical data include: identifying an idea, topic or research question, conducting a background literature review, refining the research idea and questions, determining that historical methods will be the method used. Further it involves identifying and locating primary and secondary data sources, evaluating the authenticity and accuracy of source materials, analyzing the data and developing a narrative exposition of the findings (Danto, 2008).

Ensuring not to repeat past mistakes is an important part of improving project performance. Mistakes can result in wasted money, delays, poor project quality, unmet objectives and tarnished reputation of the project team. Most studies on non-equilibrium dynamics have focused on livestock dynamics in Africa where frequent droughts occur (Adamson *et al.,* 2018; Gajjar *et al.,* 2018). With frequent droughts, often, the maximum livestock mortality reaches 50% (Saeed *et al.,* 2019; Vitali *et al.,* 2015). However, there is little research conducted in areas that experience long dry periods, where grazing systems are subject to droughts.

2.3.3 Simulations and Systems Modeling

Most studies have used process-based crop and pasture models to evaluate the impacts of climate change scenarios either at a local or global scale for crop and pasture species (Jones *et al.,* 2017; Silva *et al.,* 2022). However, substantial time, data, and expertise are needed to calibrate these models for particular locations (Pascquel *et al.,* 2022). Mechanistic models have recently been expanded in the context of climate change studies to cover an extended range of crop species. Considerable progress has been made in recent years in developing methods for modeling animal populations accurately (Jones *et al.,* 2017). Matrix models are useful tools in simulating possible effects of management interventions (Jones *et al.,* 2017). In the matrix models, discrete classes are used to represent the life cycles and reproductive cycles of livestock. All the individuals in a class are assumed to be identical and have similar transition probabilities.

There are many reasons to try to model an agricultural system including: assisting farmers in decision making, to try and predict the effect of a policy change, to evaluate the value of new technology and changes in production system such as building an irrigation scheme (Afokpe *et al.,* 2022). Agricultural systems models are diverse in focus, ranging from sub-molecular systems to global agro-climatic systems. Their character varies for example, ranging from the biophysical characteristics of plant nutrient transfer (Ehrhardt *et al.,* 2018) to simulating beef and sheep grazing systems (Wu *et al.,* 2022).Their duration also, varies ranging from a few hours in feed digestion and photosynthesis to centuries for soil erosion (Ehrhardt *et al.,* 2018). Vannier *et al.* (2022) reported two important components in agricultural systems: the biophysical consisted of the production system of crops, pasture, animals, soil and climate together with certain physical inputs and outputs. The second consisted of the management system which included people's values, goals, knowledge, resources, opportunities and decision-making ability. Utilizing these constructs, Vannier *et al.* (2022), defined five farming systems analysis and interventions that have evolved over time. These are economic decision analysis, dynamic simulation of production processes, economic analysis linked to biophysical simulation and decision support systems. The sixth farming systems analysis and intervention is the expert system and simulation aided discussion on management in an action research focus reported by Jarnevich *et al.* (2019).

2.3.4 Tools Used to Assess Trends in Rainfall and Temperature Variability

Over time climate change has attracted interest due to the impact caused by climate change. As a result of this, most research have focused on the magnitude of climatic variability at various geographical scales (Roshani *et al*., 2023). Several parametric (linear regression, F-test and T test) and non-parametric (Mann–Kendall test, modified Mann–Kendall, Sen’s slope estimator and Kruskal–Wallis test) approaches have been used in the past works for assessment of the magnitude of climatic variability (Swain *et al*., 2022). However, despite being more effective in analyzing climatic variability, parametric methods are only applicable to normally distributed time series data. On the contrary, non-parametric are more preferred over parametric methods for a variety of reasons, including the ability to handle missing data, the need for minimal assumptions, and the independence of data distribution. Mann–Kendall (MK) trend test and Sen Slope estimator are the most commonly used method for analyzing the trend of various climatic variables (Roshani *et al*., 2023).The Mann-Kendall (MK) trend test is a non-parametric statistical test used to detect trends in time series data. It assesses the presence and direction of trends without making assumptions about the distribution of the data. The MK test compares the ranks of data points over time to determine if there is a monotonic increasing or decreasing trend. In this study, the MK test was used to determine the trends in rainfall and temperature data. On the other hand Sen's Slope test, also known as the Sen's Estimator, is another non-parametric method used to estimate the magnitude of trends in time series data. It calculates the median of all possible slopes between data points, providing a robust measure of trend magnitude. Sen's Slope test is particularly useful when dealing with data that may contain outliers or non-linear trends (Roshani *et al*., 2023).

Other tools such as namely autoregressive (AR), moving average (MA), autoregressive and moving average (ARMA), integrated ARMA (ARIMA), decision tree algorithms (DT), exponential smoothing (ES), neural network and spectral analysis have been developed for forecasting variables (Roshani *et al*.,2023).

2.4 Presenting Climatic Data

Climate change and variability have been analysed across the world at all spatial scales. Such data provides significant information for sustainable development and effective management of the resources

2.4.1 Rainfall

Climatic data are often collected daily and it is important to have simple facilities to examine the raw data as well as summarized the observations. In some years the rains start early while in others they arrive late. Abrupt end of the growing season has been reported in some semi-arid parts of the sub-Saharan Africa (Zamudio, 2016). Semi-arid lands experience frequent droughts and dry spells during the growing season, making rainfed cropping risky (Alahacoon *et al.,* 2022). This annual variability makes the selection of crop or pastures types and varieties difficult. It makes planning of planting dates critical, yet also difficult, for successful cropping or pasture growth in rain fed production systems (Asfaw *et al.,* 2017; Faranda *et al.,* 2022). Crops or pastures yields are often reduced significantly due to the late start and early cessation of the growing season. This is further complicated by the occurrence of long dry spells during vegetative and reproductive growth stages of crops and pastures. Increases in dry spell lengths and reductions in wet day frequencies have been reported in Ethiopia, among other countries (Asfaw *et al.,* 2018).

2.4.3 Temperatures

Knowledge of how potential environmental stressors (ambient temperature, humidity, thermal radiation, air speed) can directly and adversely affect animal performance, health and well-being when coping capabilities of the livestock are exceeded is also required. Weather and climate can determine the efficiency of livestock production by direct and indirect influences (Lacetera, 2019; Rojas-Downing *et al.,* 2017). Direct influences affect the heat balance of the animal and include extreme meteorological events. Indirect influences are disease and parasites (Kimaro *et al.,* 2018). Excessive heat or cold increases the metabolic energy required to maintain the animal's body temperature, thus reducing the energy available for productivity (Thornton *et al.,* 2021). This energy imbalance is usually corrected by increased feed, which entails an additional cost to the farmer.

Table 2.1: Selected past studies on effects of climate change on animal production systems

Study	Country	Authors
Impact of climate variability on livelihoods of pastoral communities in Logondo District-Tanzania	Tanzania	Chamliho *et al.* *(*2017)
Perception of climate change and its impact by smallholders in pastoral/agro pastoral systems of Borana, South Ethiopia	Ethiopia	Debela *et al.* (2015)
The pastoralists' resilience and innovative adaptation strategies on impacts of climate change in rangelands of Longido District, Tanzania	Tanzania	Joseph *et al.* (2017)
The impact of climate change on extensive and intensive livestock production systems	Worldwide	Rust(2019)
Measuring household vulnerability to climate-induced stresses in pastoral rangelands of Kenya: Implications for resilience programming	Kenya	Opiyo *et al.* (2015)
Climate change perception and impacts on cattle production in pastoral communities of northern Tanzania	Tanzania	Kimaro *et al.*(2018)

CHAPTER THREE

CHARACTERIZATION OF VARIABILITY IN MONTHLY RAINFALL AND TEMPERATURE THAT SAHIWAL CATTLE HAVE BEEN EXPOSED TO IN A SEMI-ARID ECOSYSTEM OF KENYA

Abstract

This study characterized the variability of monthly rainfall and temperature in a semi-arid ecosystem. The objective was to determine the extent invariability and trends to which Sahiwal cattle have had a long period of exposure. Meteorological data on mean monthly rainfall and temperatures (minimum and maximum) of 31 years recording were extracted from the research center hosting the National Sahiwal Stud Herd in Kenya (Naivasha). The coefficient of variation (CV), percentage departure from the mean (Anomalies), Precipitation Concentration Index (PCI) and moving average were computed as proxies for the observed variability in monthly rainfall and temperatures. The trends were detected with Mann-Kendall (MK) and the Sen's Slope tests. The mean annual rainfall (578.5± 151.3 mm) was variable (CV 24.2%) with more variability in the short seasons (CV 59.2%) than in the long seasons (CV 49.2%).The PCI revealed moderate concentration of rainfall over the years with high rainfall concentration in 34% of the years (n=31). The rainfall anomalies depicted inter-annual variability, with the anomalies more varied in recent years. The decadal increase occurred in short season rains (69 mm) but decrease occurred in mean annual (36.5 mm) and long season rains (25.5 mm), corresponding to MK significant increasing trends in short rains and decreasing trends in long and annual rainfall. The mean monthly temperature (range 10.4 to 26.5^{o}C) recorded a decadal change at the rate of -0.09^{o}C, with maximum temperature (0.156 ^{o}C) being 9.18 times more relative to minimum temperatures (0.017^{o}C). Overall anomalies indicated inter annual variability trends with mean annual temperature significantly increasing and decreasing in April and July, respectively. The minimum temperature significantly increased in April and May, and declined in February, March and September while the maximum temperatures significantly increased in March and declined in June. The results reveal significant more inter-annual variability in short rains and maximum temperature, implying long term exposure of Sahiwal cattle to climate variability. This should necessitate urgent design and integration of adaptation actions in the Sahiwal cattle management and breeding programs towards enhancing adaptation.

3.1 Introduction

The changing and variable climate is a phenomenon being observed world over. Livestock production systems are exposed and vulnerable, but at disproportionate degrees. Pasture based livestock systems, particularly those in the tropics, suffer greatest exposure and vulnerability to hazards and risks of the changing and variable climate (Huang *et al.,* 2016; IPCC, 2015). Yet, these pasture-based livestock systems support livelihoods of those most exposed and vulnerable, who are dominating in the ASALs of sub-Saharan Africa (Adhikari *et al.,* 2015; IPCC, 2015).

In Kenya, the current understanding of climate change impact is that higher temperatures and more variable rainfall will likely continue being prevalent. Increased floods will be more likely with more precipitation in shorter periods, while droughts will be more frequent and severe with longer dry seasons (Asfaw *et al.,* 2018). The impacts of high temperatures and variable precipitation manifests as limited access to quality water and pastures, and as outbreaks of diseases and parasites of livestock and crops (Kimaro *et al.,* 2018; Thornton *et al.,* 2021). Through reduced quantity and quality of pastures, forages and water resource, and increased disease severity, these hazards and risks of the changing and variable climate ultimately impacts herd dynamics and production performance (Dantas-Torres, 2015; Magita & Sangeda, 2017; Rojas-Downing *et al.,* 2017). Climate change can be expected to have several impacts on feed crops and grazing systems. These manifest as changes in herbage growth brought about by changes in atmospheric CO_2 concentrations and temperature due to anthropogenic activities (Rahimi *et al.,* 2021; Rashamol *et al.,* 2019; Sejian *et al.,* 2018). This leads to changes in the composition of pastures, such as changes in the ratio of grasses to legumes, changes in herbage quality, with changing concentrations of water-soluble carbohydrates and N at given dry matter (DM) yields, and greater incidences of drought, which may offset any DM yield increases (Silva *et al.,* 2022).

Faced with the increasingly changing and variable precipitation and higher temperatures, pasture-based livestock systems are threatened. This calls for search for adaptable cattle breeds more urgently to secure livestock assets in the face of posed threats from the changing and variable climate (Godde *et al.,* 2021; Polsky & von Keyserlingk, 2017). Indigenous Zebu cattle breed, though perceived to be genetically inferior in productivity, demonstrates considerable resilient to the impacts of variable precipitation and higher temperatures under pasture-based production systems practiced in the ASALs

(Thornton *et al.,* 2021; Valente *et al.,* 2015). Sahiwal cattle breed is one of the popular breeds of choice used in up-grading programs of the local Zebu cattle for the ASALs due to its relatively high milk production and growth potential as well as adaptability to impacts of variable precipitation and higher temperatures (Mwang & Ilatsia, 2022).

Sahiwal cattle herd grazed on rainfed pastures has had long exposure spanning over 50 years at the Naivasha NSH located in a hotspot of increasing climate change and variability. An assumption follows therefore that Sahiwal cattle has had long period of exposure to the changing and variable climate. This assumption has informed the hypothesis of this study that the changing and variable climate in rainfall and temperatures is observable at the Naivasha NSH. The study objective was to characterize the variability of monthly rainfall and temperature in a semi-arid ecosystem to determine the extent in variability and trends to which Sahiwal cattle have had a long period of exposure.

3.2 Materials and Methods

3.2.1 Study Area

The study was carried out at the National Sahiwal Stud Herd (NSH) at Naivasha Dairy Research Institute (DRI). The Naivasha NSH is a research facility for breeding Sahiwal and developing appropriate animal husbandry and breeding practices for livestock keepers including those in the ASALs. The area is in agro-ecological zone IV which is classified as semi-arid with highly variable rainfall and temperature patterns and marked long periods of droughts (Shisanya *et al.,* 2009). The altitude is 1,829-2,330 m above sea-level.

The Naivasha NSH facility has an installed weather station which is under continuous supervision by the Kenya Meteorological Department. This weather station has been collecting data on basic weather variables including rainfall, temperature, wind direction and speed for over 35 years. Data extracted from the records was on daily rainfall (in millimeters), daily minimum and maximum temperature (in degree centigrade). The extracted data was processed in MS Excel spread sheets and aggregated into monthly rainfall and temperature for a period of 31 years, between 1981 and 2012.

According to the World Meteorological Organization (2017) it was recommended that the 30year standard should be used to identify a genuine climate trend. These years represent the period within which the climatic data was available. This chapter reports on the monthly rainfall and temperature variability

3.2.2 Data Analysis Techniques

The coefficient of variation (CV), percentage departure from the mean (Anomalies), Precipitation Concentration Index (PCI) and moving average were computed for the monthly rainfall and temperatures to evaluate their variability. The data was subjected to parametric and non-parametric tests to detect marked trends. Non-parametric tests were applied when the data was non-normally distributed, many outliers or is censored. This is a frequent feature in metrological time series data.

The coefficient of variation (CV) was computed as:

$$CV = \frac{\sigma}{\mu} * 100$$

Whereσ is the standard deviation and μ is the mean precipitation. With the CV, variability is classified (Hare, 2003): low when CV<20%; moderate when CV is between 20 and 30 and high when CV>30. The PCI used to assess variability of rainfall annually or seasonally was computed (De Luis *et al.,* 2011; Oliver, 1980) as:

$$PCI_{annual} = \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2} x\ 100$$

Where P_i is the rainfall recorded for the i^{th} month. PCI values of <10 indicate homogeneity of rainfall over all months i.e. uniform distribution of rainfall and therefore low concentration of precipitation. PCI values of between 11 and 15 indicate moderate concentration while values from 16 to 20 implies high concentration. PCI values ≥21 denote very high concentration (Oliver, 1980).

Standardized rainfall anomalies (Z) were calculated to determine the nature of trends, identify the recorded wet and dry years and to assess the frequency and severity of droughts (Eiste *et al.,* 2012; Gebre *et al.,* 2013) as:

$$Z = \frac{(X_i - \bar{X}_i)}{s}$$

Where Xi is the annual rainfall for the i^{th} year, $\bar{X}_i$ is the longterm mean for the study period and s is the standard deviation of annual rainfall over the study period.

Drought severity was classified according to Agnew and Chappel (1999) as extreme drought (Z<-1.65), severe drought (-1.28>Z>-1.65), moderate drought (-0.84>Z>-1.28) and no drought (Z>-0.84).

The non-parametric tests Mann-Kendall (MK) and the Sen's slope estimator were applied in detection of trends over time. The MK method test trends without testing for linearity or lack of it (Yue *et al.,* 2002). The MK trend test was used to detect monotonic (decreasing or increasing) trends in series of environmental data and to test the significance of the trends. The MK test statistic S was calculated (Yue *et al.,* 2002) as:

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

The trend test was applied to time series Xi ranked from i=1, 2 … n-1 and X_j which was ranked from j=i+1, 2 … n. Each X_i was taken as reference point and compared to the rest of the data points Xj such that:

$$sgn(X_j - X_i) = \begin{cases} + \; if \; (X_j - X_i) > 0 \\ 0 \; if \; (X_j - X_i) = 0 \\ - \; if \; (X_j - X_i) < 0 \end{cases}$$

Where Xi and Xj are the annual values in years I and j where j>I, respectively. The statistic S is approximately normally distributed if sample size, n≥10 with a mean and E(S) becomes 0 (Kendall, 1975). The variance of S, var(S) was calculated as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{t=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18}$$

Where n is the number of observations and ti are the ties of the sample time series. The $Z_c$test statistic was calculated as:

$$Z = \begin{cases} \frac{S-1}{\sigma} & if \; S > 0 \\ 0 & if \; S = 0 \\ \frac{S+1}{\sigma} & if \; S < 0 \end{cases}$$

Where Z_c follows a normal distribution and a positive Z_c depicts an upward trend and a negative Z_c meant a downward trend for the period.

The Sen's Slope estimation test was used to compute the slope (linear rate of change and intercept using Sen's method. The magnitude of the trend was predicted by Theil (1950) and Sen (1968) slope estimator methods. A positive β value indicated an upward trend while a negative β indicated decreasing values over time. The slope for N data pairs T_i, was computed according to Sen (1968) as:

$$T_i = \frac{x_j - x_i}{j - i}$$

Where x_j and x_k are data values at time j and k (j>i), respectively. The median of all the value of T_i represents Sen's estimator of slope and was computed as $Q_{med} = T_{(N+1)/2}$ if N was odd, it was considered as $Q_{med} = \left[T_{N/2} + T\left(_{(N+2)/2}\right)/2\right]$ if N was even. A positive Q_i indicated an increasing trend and a negative Q_i indicated a decreasing trend.

3.3 Results

Table 3.1 presents the descriptive statistics and Mann-Kendall trends for rainfall in Naivasha for the period 1981 to 2012. The normality test with Kolmogorov-Smirnov and Shapiro-Wilk tests indicated that the long and short season rainfall was nearly normally distributed. The mean annual rainfall during the 31 years study period was 578.5 mm with minimum of 324.8 mm and maximum of 810.4 mm. The rainfall patterns depict bimodal pattern with one peak in April (the long rains) and a lower peak occurring in November (short rains). The long rains accounted for more (33.2%) of the annual rainfall relative to short rains of October-November period (26.1%). The long rains of April to June season had less variability (CV of 49.2%) compared to the short rains occurring from October to December (CV of 59.2%). An examination of the Sens's slope (Table 3.1) shows that months in the intervening period between the two main rain seasons (January, February and March) and October had an increasing trend. Further, the Sen's slope indicated a significantly ($P<0.05$) decreasing trend for the short rains but an increasing trend for the long rains. However, the annual rainfall had a non-significant ($P>0.05$) increasing trend.

Table 3.1: Descriptive statistics, Mann-Kendall trends and Sen's slope for rainfall in Naivasha for the period 1981 to 2012

Month	Min	Max	Mean	%	SD	CV (%)	MK test	Sen's slope
January	0	180.6	35.3	6.1	47.5	134.4	0.7	0.4
February	0	108.9	24.9	4.3	29.6	119.0	0.8	0.3
March	0	148.6	59.5	10.3	48.8	82.0	0.6	0.4
April	23	211.8	93.9	16.2	58.5	62.3	-0.3	-0.3
May	0	146.4	64.6	11.2	48.3	74.7	-3.0	-1.4
June	0	148.9	47.5	8.2	38.5	80.9	-1.2	-0.8
July	0.5	104.7	34.8	6.0	27.8	79.8	-0.6	-0.2
August	0	89.9	34.6	6.0	24.9	71.9	-0.1	-0.0
September	0	78.5	32.4	5.6	20.0	61.5	0.8	0.3
October	11.3	111.1	45.1	7.8	25.9	57.4	1.6	0.8
November	0	165.6	53.7	9.3	39.6	73.9	-0.7	-0.3
December	0	214.8	52.1	9.0	48.6	93.3	-0.7	-0.6
Long rains	36.2	360.7	191.9	33.2	94.5	49.2	-34.4***	-2.9
Short rains	17.5	401.7	150.9	26.1	89.4	59.2	15.0**	0.1
Annual	324.8	810.4	578.5	100.0	151.3	24.2	1.1	-0.1

*** and ** values are statistically significant at 0.0001 and 0.05 levels of significance, respectively.

The MK tests reveal an increasing trend (P>0.05) for the months of the first dry season (January to march), September and October. In contrast, a non-significant decreasing trend (P>0.05) was observed for the months of April to August and November and December and June.

The high CV for long rain season (59.2%) compared to short rain season (49.2%) show that the long rains had higher inter annual variability than short rains. The inter-annual variability for annual rainfall was even lower, considering the CV% of 24.2%. The rate of annual change in minimum, maximum and mean annual rainfall are shown in Figure 3.1. Annual and long rainfall declined by -0.4 mm/year and -2.5 mm/year, respectively, whereas the rainfall for the short season increased by 0.7 mm/year.

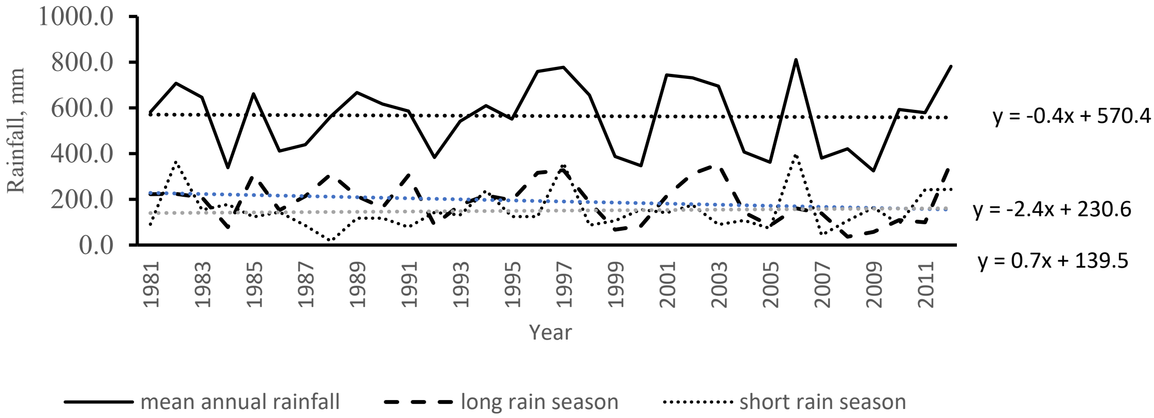


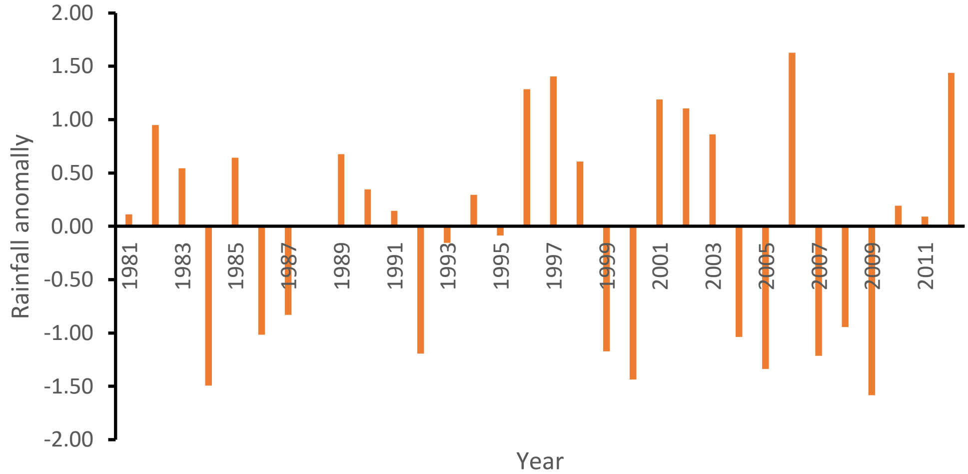
Figure 3 1:Patterns for mean annual, long and short season rainfall and their least squares regression lines for Naivasha from 1981 to 2012

Table 3.2: Linear regression coefficients for long rain and short rain season and annual rainfall on year from 1980 to 2012

Season	Change in rainfall (mm/year)	P-value	R^2	CV	% of total rainfall
Long rain	-2.4	0.2	0.05	48.7	33.2
Short rain	+0.7	0.7	0.01	60.1	26.1
Annual	-0.4	0.9	0.00	27.2	100.0

High values of rainfall anomalies corresponded to very dry years in the study area. The values for Naivasha ranged from +1.6 in 2006 to -1.6 in 2009 (Figure 3.2). Documented droughts following El nino were captured in the current study by a standardized anomaly of -

1.2 to -1.4 in 1999 and 2000, respectively. Other similar events were captured in 2009 with a



value of -1.6.

Figure 3.2: Standardized rainfall anomalies for Naivasha Sahiwal Stud relative to 1981 to 2012 period

The Precipitation Concentration Indices (PCI) is shown in Table 3.3. The PCI revealed that the study area has had rainfall with moderate concentration for about 67% of the years, with about 34% of the years having high rainfall concentration. This implies that majority of the years had rains falling more in some months than others. This is collaborated by the results presented in Table 3.2 where some months reported null amount of rainfall. Table 3.2also shows concentration of rains around the April to June and October to December periods.

Table 3.3: Precipitation concentration Index (PCI) for Naivasha for the years 1981 to 2012

Description	**Index**	**Number of years**
Low precipitation concentration (almost uniform	<10	0
Moderate concentration	11 to 15	21
High concentration	16 to 20	11
Very high concentration	≥21	0
Moderate concentration	Mean PCI	

The trend in temperature using linear regression is shown in Figure 3.3. The minimum and maximum temperatures for the study area were 10.4±0.52 and 26.5 ±0.91, respectively, while the mean temperature was 18.4±0.52. The rate of change for monthly minimum, maximum and mean temperature was 0.017°C, -0.156°C and -0.09°C per decade. The results indicate a decline in mean and maximum temperature and an increase in minimum temperature for the period of study.

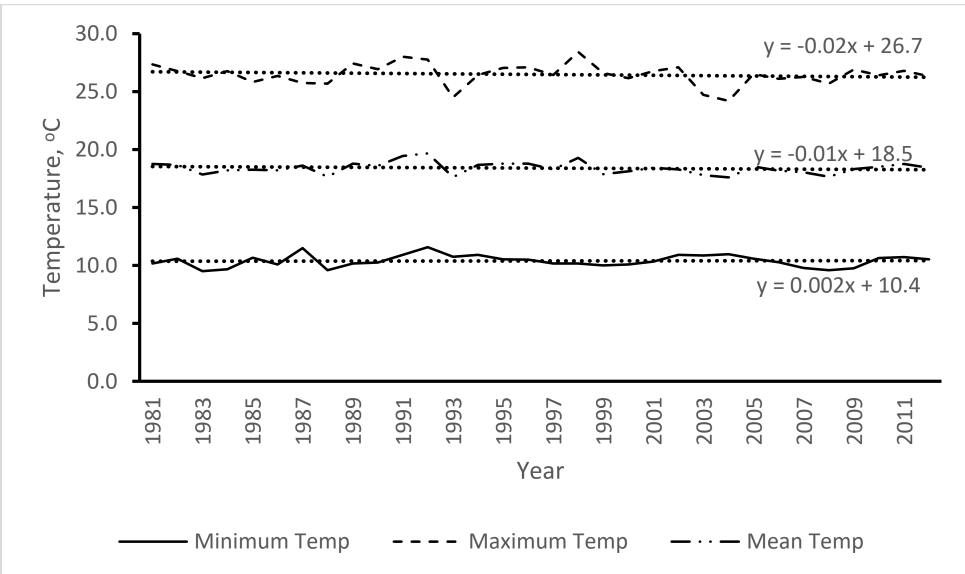


Figure 3.3: Patterns for mean, minimum and maximum temperature and their least squares regression lines for Naivasha for the period 1981 to 2012

The values reported in the current study are therefore lower than the global rate increase in temperature. Figure 3.4 shows a long range for standardized anomalies for temperature which depict inter-annual variability in temperature. The results of Figure 3.4 show an erratic pattern in the annual temperature trend with some years recording high temperatures while others recorded temperatures below the mean.

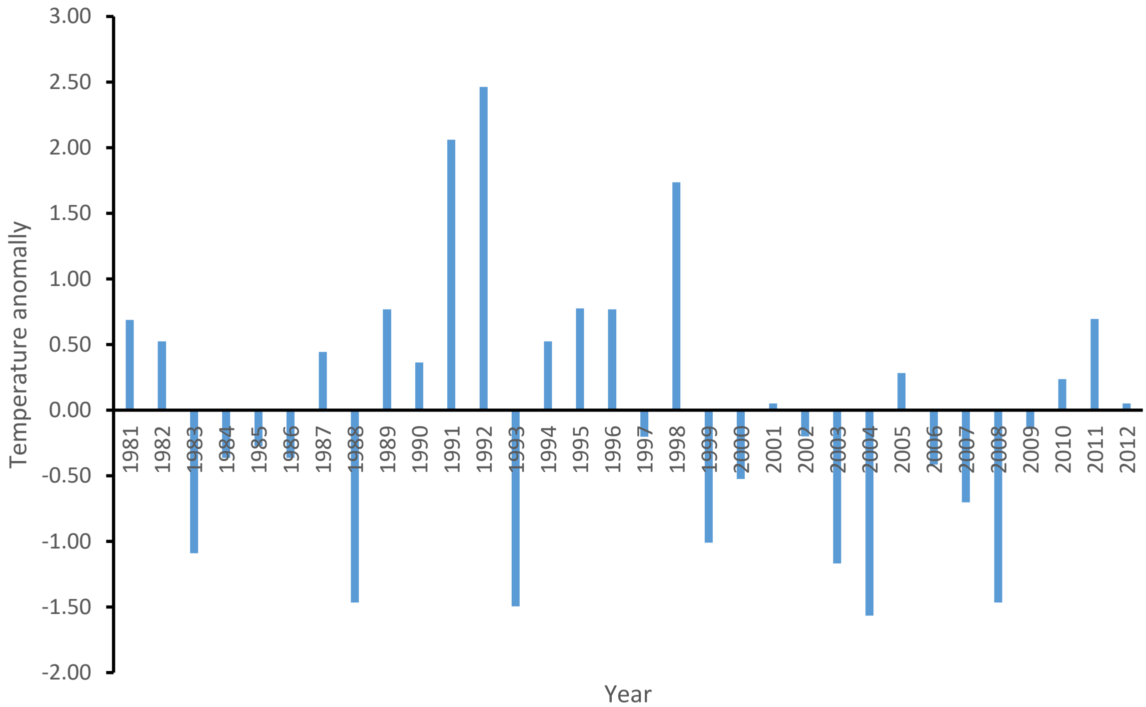


Figure 3.4: Temperature (°C) anomalies for Naivasha Sahiwal Stud relative to 1981 to 2012 period

Table 3.4 shows the minimum, maximum and mean annual temperature trend for the study area from 1981 to 2012. The MK trend test revealed that minimum monthly temperature increased while maximum and mean temperature declined non-significantly ($P>0.05$) throughout time. However, the months of April and May showed significant increase ($P<0.05$) while the months of February and September had significant declines in minimum temperature. According to the MK trend test, maximum temperature showed a general non-significant decline but with significant increase in the months of February and March and significant decline in June. For mean temperature, a significant increase and decrease was reported in the month of April and July, respectively.

Table 3.4: Mann-Kendall and Sen's slope test for monthly and annual minimum (Tmin), maximum (Tmax) and mean temperature (Tmean) for Naivasha, Kenya from 1981 to 2012

Month	Mean	T_{min}			T_{max}			T_{mean}		
		ZMK		Slope	ZMK		Slope	ZMK		Slope
Jan	19.2	-1.1		-0.01	1.28		0.05	0.60		0.01
Feb	18.8	-2.4	*	-0.06	2.39	*	0.09	0.59		0.01
Mar	19.2	-0.1		0.00	1.99	*	0.07	1.93		0.05
April	18.7	2.4	*	0.05	-0.56		0.00	1.78	**	0.03
May	18.2	2.0	*	0.05	-1.38		-0.05	0.16		0.00
June	17.6	0.7		0.00	-2.03	*	-0.07	-1.34		-0.03
July	17.5	-1.6		-0.03	-1.81		-0.06	-2.30	*	-0.05
Aug	17.5	1.0		0.01	-0.52		0.00	-0.28		0.00
Sept	18.3	-2.5	*	-0.03	-0.44		0.00	-1.20		-0.01
Oct	18.4	0.8		0.00	-0.81		-0.01	0.10		0.00
Nov	18.5	1.1		0.01	-1.89		-0.07	-1.85		-0.03
Dec	19.0	0.0		0.00	-1.05		-0.01	-1.09		-0.01
Av	18.4	0.0		0.00	-0.25		-0.01	-0.10		-0.01

*and ** values are statistically significant at 0.10 and 0.05 levels of significance, respectively.

3.4 Discussion

The mean had a standard deviation of 151.3 mm and a moderate variability with CV of 24.2%, basing on the variability classification by Hare (2003). This is evidence that a moderate rainfall variability was experienced in this semi-arid ecosystem where the national stud herd of Sahiwal cattle is managed and bred. This is evidence of a higher variability in the short rains than in the long rains. Further, there was evidence of more inter annual variability of the short rains than the long rains. Greater variability in short rains have also been observed in Ethiopia by Asfaw *et al.* (2018) and elsewhere by Arragaw and Woldeamlak (2017). The declining trend for long rains is similar to those reported by Negash *et al.* (2013) and Asfaw *et al.* (2018). These studies reported a significant and declining trend for the long rain season in various parts of Ethiopia. A non-significant increase has been reported for all seasons and annual rainfall in the central highlands of Ethiopia (Daniel *et al.,* 2014). Further a study by (Gebrechorkos *et al.* (2019) showed that long-term seasonal trend analysis showed a non-significant decreasing trend in rainfall in parts of Ethiopia and Kenya and a decreasing trend in large parts of Tanzania during the long rainy season. On the other hand the study also reported a non-significant increasing trend in large parts of the region was observed during the short rain season which collaborates with our study. On the contrary, Arragaw and Woldeamlak (2017) reported a significant decreasing trend for short rains, which deviates from a significant increasing trend observed in the current study. The results of the current study are contrary to those of Asfaw *et al.* (2018) for the Woleka basin in Ethiopia, which reported more variability for the main rain season in the Woleka basin of Ethiopia. Other studies which reported higher inter-annual variability for the short rain season are Viste *et al.* (2013) and Arragaw and Woldeamlak (2017) for most parts of Ethiopia. Other studies where the annual and long rains declined over time was reported by Asgaw *et al.* (2017) for the Woleka basin in Ethiopia.

These climate trends reveal a significantly modulating rainfall and temperatures over the years. The standardized anomalies have been shown to closely mirror occurrences of above and below normal events of rainfall in Ethiopia (Asfaw *et al.,* 2018). Asfaw *et al.* (2018) reported higher anomalies that ranged from +4.2 to -1.9 in different years for the Woleka sub-basin in Ethiopia. Other studies have reported high concentration of rainfall (Arragaw & Woldeamlak, 2017). The results of the current study are similar to some extend to those of Asfaw *et al.* (2018) which reported high to very high concentration of rainfall in 57.8% and 39.8% of the years.

A study by Asfaw *et al.* (2018) reported increasing trends for mean, minimum and maximum temperature of 0.05, 0.07 and 0.03 ^{o}C per decade, respectively for the Woleka sub-basin in Ethiopia. For the past century, a rate of increase of 0.6^{o}C in global temperature has been reported, which is higher than the rate reported in the current study. These results corroborates with (Gebrechorkos *et al.,* 2019) who reported significant increasing trends in T-max (up to 1.9 °C) and T-min (up to 1.2 °C) for virtually the whole east African region.

The increase in T-max and T-min has been associated with increased water losses by evapotranspiration and more severe droughts might occur given the decrease in rainfall. Further when high temperatures combines with a reducing rainfall, the combined effect can lead to more severe drought conditions that can affect agriculture production (Gebrechorkos *et al.,* 2019).

However, the trend for monthly maximum temperature from our study was the opposite of that reported for Woleka sub-basin in Ethiopia (Asfaw *et al.,* 2018). Studies which have reported increasing trends of monthly minimum temperature include Roy and Das (2013) and Daniel *et al.* (2014).

3.5 Conclusion

The study area has a bimodal rainfall pattern with two maxima, in the months of April to June and October to December. Rainfall is moderately to highly concentrated, with most of the rain falling in the October to December period. The rainfall anomalies found in the current study depict marked inter-annual variability with the trend in the anomalies being more varied in recent years. Mean annual and long season rain decreased by 36.5 and 25.5 mm per decade while short season rain increased by 69 mm per decade. The short season rain had higher inter-annual variability of the short rains. MK trend analysis test revealed significant decreasing trend for long and annual rainfall and a significant increase for short rains. The mean temperature for the study area ranged from 10.4 to 26.5^{o}C. The rate of change of minimum, maximum and mean monthly temperature was 0.017^{o}C, -0.156 ^{o}C and -0.09^{o}C per decade. The overall anomalies of mean annual temperature showed inter annual variability.

The MK trend analysis revealed non-significant increase and decline for minimum and mean temperature, respectively. Though the increase in minimum temperature was non-significant, the months of April and May showed significant increase while the months of February and September had significant decline, indicating inter-annual variability in minimum temperature. For maximum temperature there was significant increase in the months of February and March and significant decline in June. The trends provide evidence of a significantly modulating rainfall and temperature at Naivasha NSH over the years in this semi-arid ecosystem where Sahiwal cattle have been grazed for long period.

CHAPTER FOUR

INFLUENCE OF RAINFALL AND TEMPERATURE VARIABILITY ON SURVIVAL RATES OF SAHIWAL CATTLE IN SEMI-ARID KENYA

Abstract

This study determined the influence of rainfall and temperature variability on survival rates of Sahiwal cattle grazed in a semi-arid ecosystem in Kenya where Sahiwal has been bred for over 50 years. The analysis was to answer the research question of whether rainfall and temperature variability has significant influence on survival rates of cattle grazed on rainfed pastures in a semi-arid ecosystem experiencing intra and inter annual variations in precipitation and temperatures. Weather and cattle survival data were collected from the Naivasha National Sahiwal Stud Herd (NSH) center. Weather related data included monthly rainfall (in millimeters), daily minimum and maximum temperature (in degree centigrade) recorded from January 1979 to December of 2012. Survival was defined as a binary trait where an animal was alive (1) or dead (0) within a given month across years. A logistical regression model was fitted to determine the probability of an animal's survival as a result of rainfall and temperatures variations within a given month across the years. There was significant influence ($P<0.05$) of rainfall variation on survival, with discernable trends in changes in rainfall and the probability of an animal surviving in the herd. High precipitation was associated with increased probability of herd survival. However, there was no significant influence of temperature variations on probability of survival. Adaptation strategies are therefore necessary to respond to variability in precipitation that impact on survival of the cattle. These include adjustments in grazing management, pasture quality and feed conservation.

4.1 Introduction

In semi-arid ecosystems, increased intra and inter annual variations in precipitation and temperatures has implications on cattle production, mainly by decreasing grass and increasing shrub productivity accompanied by high inter and intra annual variability (Gherardi *et al.,* 2015). In East Africa, long-term trends in rainfall and temperature have shown decrease in rainfall and increase in temperature (Gebrechorkos *et al.,* 2019).Cattle population dynamics have been shown to be associated with mean annual rainfall

(Kgosikoma & Batisani, 2014). Using historical data, Ayugi *et al.* (2022) demonstrated that overtime modulating rainfall and temperature has influence on cattle population in Africa. In the period, droughts led to increased livestock mortality (World Bank, 2017). The sensitivity is greatest in the arid and semi-arid ecosystem (Spear *et al.,* 2021). The precipitation and temperature effects on cattle survival are through reduction in the quantity and quality of pasture and water available to cattle.

Many authors report the impacts of temperatures and variable precipitation manifested as change in amount of water resources, forage and pastures productivity, and livestock diseases outbreaks and parasites in arid and semi-arid ecosystems (Rojas-Downing *et al.,* 2017; Thornton & Herrero, 2014). These climatic variables influence the type of livestock production systems, breeds choices and number of livestock units that farmers may manage in a sustainable manner (Spear *et al.,* 2021). The Sahiwal cattle breed is a popular breed of choice for up-grading the East African Zebu in the southern rangelands. The breed popularity is due to its relatively high milk production and growth potential as well as its perceived better adaption to the stresses of water scarcity, nutritional inadequacy and heat load in rangelands (Mwangi & Ilatsia, 2022).

In chapter three of this thesis, evidence was presented of a significantly modulating rainfall and temperature at Naivasha NSH where Sahiwal cattle have been produced for over five decades. The modulating rainfall and temperature can be hypothesized to have had influence on survival rates of Sahiwal cattle. Studies on Sahiwal cattle at the Naivasha NSH are yet to present such evidence to inform any needed adjustments in cattle husbandry and breeding program that can enhance adaptive capacity and resilience to the changing and variable climate. The objective of study was to determine the influence of rainfall and temperature variability on survival rates of Sahiwal cattle grazed in a semi-arid ecosystem in Kenya. This was to answer the research question of whether rainfall and temperature variability has had significant influence on survival rates of Sahiwal cattle grazed on rainfed pastures in a semi-arid ecosystem experiencing intra and inter annual variations in precipitation and temperatures.

4.2 Material and Methods

4.2.1 Study Site, Data Collection and Analysis

Monthly rainfall and temperatures data birth and death records were collected from the National Sahiwal Stud (NSH) at Naivasha, Kenya. The NSH is a research facility used for development of appropriate husbandry and breeding practices that target livestock keepers mainly in the semi-arid southern rangelands of Kenya. The Naivasha Sahiwal NSH is well suited to the objectives of this study for two reasons. One, it is located in semi-arid regions that experience highly variable rainfall and temperature conditions and therefore represent the realities of climate variability in semi-arid rangelands. Two, the Naivasha Sahiwal NSH has maintained reliable herd performance, survival and weather-related data over a relatively long period of time to demonstrate evidence of intra and inter annual variations in precipitation and temperatures.

Daily rainfall and temperature data was extracted from the existing herd management records. The data included daily rainfall (in millimeters), daily minimum and maximum temperature (in degree centigrade) recorded from January 1979 to December of 2012. For ease of handling, data analysis and interpretation of the results, the data was aggregated into monthly rainfall and temperature across the 33 years. Data on herd survival was collected from the main animal registers that indicate the dates of birth of each individual animal, its sire and dam, date of disposal/death and their reasons. Individual animal dates of birth and death were then used to extract the month and year when an animal was alive or dead, respectively from January 1979 to December 2012. The final database constituted the herd population dynamics data, where death was defined as binary trait i.e. the individual was either alive (1) or dead (0) at any given month across the years.

Herd population dynamics was defined as the probability of an animal surviving through particular months across the years. Survival was considered as a discrete variable and denoted as either alive (1) or dead (0) within each month of the years. A simple logistical regression model was therefore fitted to the data to discern the probability of an animal's survival as a result of quantitative monthly precipitation and temperatures variations within each given month across the years. Given that survival of an animal can be influenced by age and gender disparities, the regression model allowed for the estimation of these two explanatory variables as shown in the equation:

$$Log\left[\frac{p_i}{1-p_i}\right] = \beta_0 + \alpha_1 SEX_{1i} + \beta_2 AGE_{2i} + \beta_{3i} RAIN_{3i}$$

Where P_i is the probability the i^{th}animal is alive or dead within a given month across the years as result of variation in rainfall, α_1, β_2, and β_3 are regression parameters associated with gender (*SEX*), age of the animal (AGE), and amount of rainfall (RAIN), respectively. To discern the influence of temperature on survival a similar model was used, however in this case the temperature (TEMP) was fitted instead of RAIN.

Trends in the probability of survival over the years, expressed as probability estimates of the main explanatory variable i.e. RAIN and TEMP, were plotted against month nested within years. This was to allow for a simultaneously association of changes in climate variables (rain and temperature) with probabilities of survival of an individual. Scatter plots were generated to determine the association of rainfall and temperature on overall herd mortality in the 33 years. In this case, mortality counts were plotted versus monthly rainfall and average temperature over the years.

4.3 Results

4.3.1 Effect of Rainfall and Temperature Variability on Herd Survival

The trends in the probability of an individual animal being alive in particular month across the years as influenced by amount of rainfall and temperature, respectively, are presented in the Figure 4.1a and b.

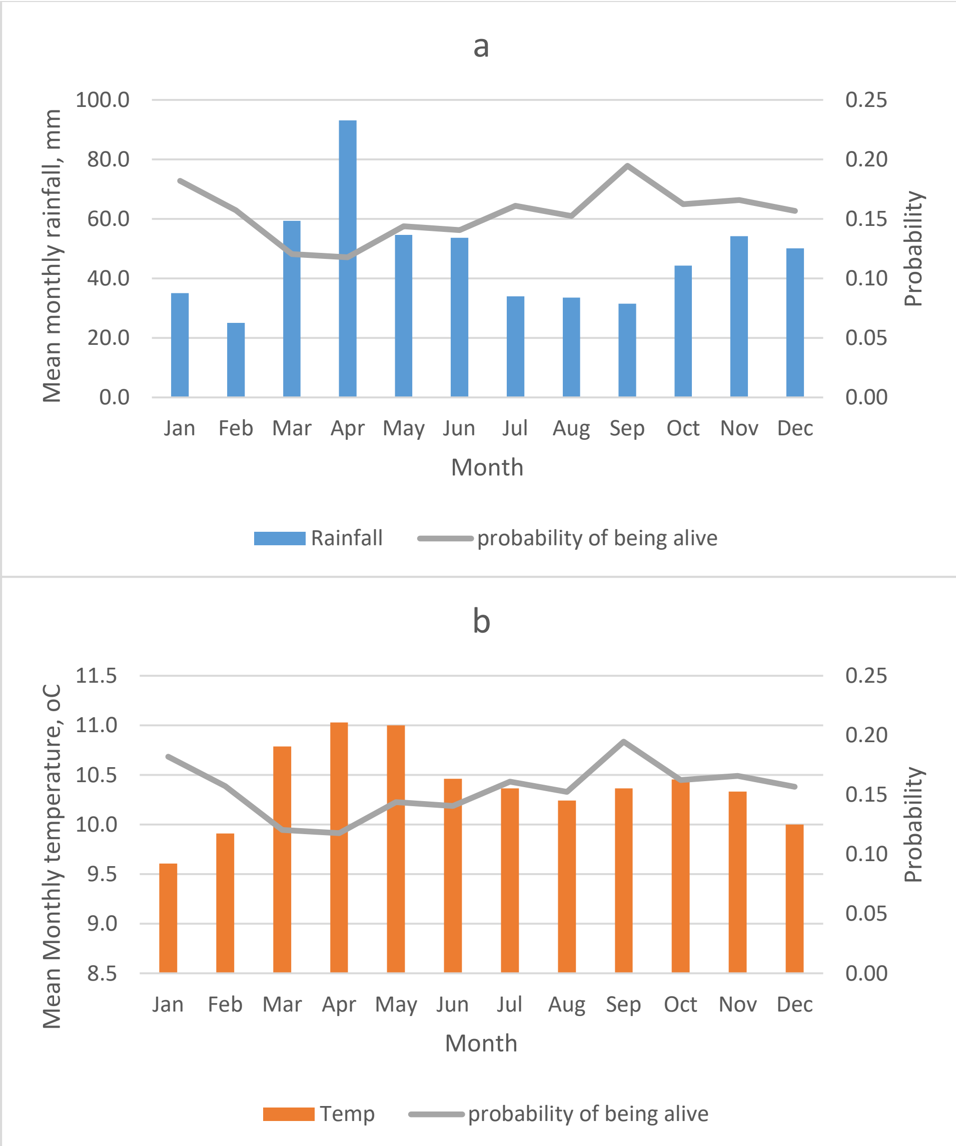


Figure 4 1:a and b. Trends in the probability of an individual being alive in particular month across the years as influenced by changes in precipitation (a) and temperature (b)

There were pronounced fluctuations in rainfall over the study period with resultant different responses in the probability of animal survival over time. For example, the conspicuous high spikes in January and September coincide with the low precipitation and temperature. These months were characterized by low quality and quantity if feed as well as low temperature, hence the high probability of an animal dying. On the contrary the conspicuous low spike in the month of April was associated with high precipitation and high temperature, implying that the animals were more thermos-comfortable and had access to better quality and quantity of feed.

Trends in monthly rainfall and temperature over the years show an inverse association between rainfall and temperature patterns on the one hand and herd survival as presented in scatter plot (Figure 4.2). The scatter plot underpins the strong and inverse association between amount of precipitation received and the likelihood of death occurring in the herd, though the R^2 was low **(**0.29%).

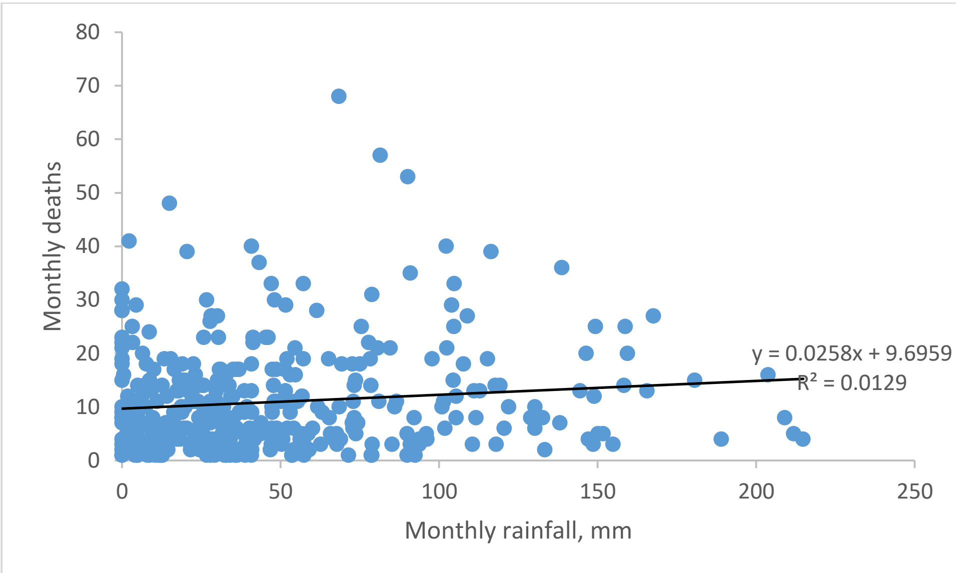


Figure 4.2: Scatter gram of association of animal mortality and amount of rainfall

4.4 Discussion

The influence of monthly rainfall variations over the years resulted in differentials in herd survival and consequently population dynamics. With more rainfall in certain months of the years, an increase in the probability of survival occurred compared to instances where low precipitation was associated with low probability of an individual remaining alive. Variability in rainfall is identified as major driver of livestock population dynamics (Leweri *et al.,* 2021) and this is more likely due to the strong positive association observed between precipitation and the supply in quantity and quality feed and water available to animals.

There were pronounced fluctuations in rainfall over the study period with resultant different responses in the probability of animal survival over time. For example, the conspicuous high spikes in January and September coincide with the low precipitation and temperature. These months were characterized by low quality and quantity if feed as well as low temperature, hence the high probability of an animal dying. On the contrary the conspicuous low spike in the month of April was associated with high precipitation and high temperature, implying that the animals were more thermos-comfortable and had access to better quality and quantity of feed.

In the presence of different production and management systems, depressed rainfall and high temperatures is bound to have a major influence on livestock population dynamics where forage availability may indirectly influence the animal numbers (Alemayehu & Getu, 2016; Hidosa & Guyo, 2017). Rainfall variability influences herd dynamics through herd die offs and lower birth rate due to fluctuation of fodder. This could explain the effect of rainfall variability on survivability of the herd (Alemayehu & Getu, 2016). It is for this reason that some of these studies (Nkondze *et al.,* 2014) used annual rainfall variability as a proxy predictor of livestock population dynamics using historical empirical performance data as is the case in this study. As reported by Ayugi *et al.* (2022), rain fed livestock grazing systems are more likely to be affected by fluctuation in rainfall and temperature as shown by results of this study. Rainfall variability greatly influenced herd dynamics under the communal and ranch management in terms of herd die-offs and lower birth rates, which also considerably affected milk production for household consumption

From the current study, temperature variations showed no significant influence on probability of survival. Owing to their long time adaptation with tropical climates, Sahiwal cows are more adapted to regulate body temperature in response to heat stress than European breeds (*B. taurus*) (Deb *et al*., 2014). It is therefore possible that the temperature increase recorded were not beyond the thermal neutral zone of Sahiwal, which could explain the lack of significant effect of temperatures on survival rate. The Sahiwal breed is well suited in arid area with a thermal neutral zone lying between 15˚C to 27˚C (Ahamad *et al*., 2022).A study conducted on the effect of heat stress on the expression profile of Hsp90 among Sahiwal showed that Sahiwal may express higher levels of Hsp90 at higher temperatures of 45 °C (Deb *et al*., 2014). "Heat shock proteins" (hsp) or Hsp90 are a set of proteins that are released under heat stress conditions, to allow the animal to overcome heat stress transcriptional activation and accumulation of a set of proteins called "heat shock proteins" (hsp) is well known regulate their body temperature and increase cell survivability under heat stressed (Deb *et al*., 2014). Further temperature increases between 1°C and 5°C above average have been suggested to give rise to higher mortality in grazing livestock (Zulfekar *et al*., 2020).

Compared to this study the rate of change of minimum, maximum and mean monthly temperature was 0.017°C, -0.156 °C and -0.09°C per decade which was not adequate to cause or increase mortality in cows.

Some studies reported direct association between rainfall variability and cattle populations in communal rangelands and state owned farms in Ethiopia (Alemayehu & Getu, 2016). These generally show direct associations of changes in annual precipitation with the changes in range-fed livestock (Ogandi *et al*.,2020).The implications of these is that rainfall and temperature variability expose to higher risks geographically restricted breeds such as the Sahiwal cattle populations in Kenya.

4.5 Conclusion

While high precipitation was associated with increased probability of herd survival, temperature variations showed no significant influence on probability of survival. The adaptation strategies therefore need to respond to variability in precipitation that impact on survival of the Sahiwal cattle.

CHAPTER FIVE

EFFECT OF VARIABILITY IN MONTHLY RAINFALL AND TEMPERATURE ON MONTHLY MILK PRODUCTION IN SAHIWAL COWS IN KENYA

Abstract

Climate change leads to alteration of environmental conditions directly or indirectly through anthropogenic activities. The consequences include fluctuations in the mean as well as variability of recognizable environmental variables with the changes persisting for longer than normal periods. Climate change poses numerous serious threats to livestock production through increased temperature, changes and shifts in rainfall distribution and increased frequency of extreme weather events. Grazing systems that are dependent on the natural cycle of climatic conditions are expected to be more seriously impacted by climate change. The consequences of climate change include increased heat stress, reduced water and feed quality and availability, increased cases of diseases and pests and or emergence of new ones. As livestock farmers in the tropics continue to bear the brunt of climate change, there is need to understand how the variability of identifiable environmental variables influence livestock performance. The objective of this study was to determine the influence of rainfall and temperature on milk yield of Sahiwal cattle in Kenya. Monthly milk yield records of Sahiwal cows and meteorological data for monthly minimum and maximum temperature and rainfall for a period of 32 years were extracted from records at the national Sahiwal stud, Naivasha, Kenya. The relationship between the variables was studied by multiple regression analysis. Minimum and maximum temperature and monthly rainfall significantly ($P<0.05$) affected monthly milk yield. The proportion of total variation accounted for by climatic variables was small (0.5%) but significant. Each individual weather variable accounted for a small proportion of total variation. Minimum and maximum temperature had a negative effect on monthly milk yield. For every 1^{o}C increase temperature, in monthly milk yield decreased by -1.58kg and -1.17kg, respectively. A 1 mm increase in monthly rainfall of monthly caused monthly milk yield to increase by 0.07kg. Mitigating strategies are required to alleviate the negative effects of temperature on monthly milk yield. Sound grazing management and feed conservation could harness the advantage of the positive effect of rainfall on milk yield.

5.1 Introduction

The consequences of climate change include increased heat stress, reduced water and feed quality and availability increased cases of diseases and pests and or emergence of new ones (Ogandi *et al*., 2020). The greatest adverse effects of climate change will be felt by crop and livestock farmers in developing countries who are dependent on natural systems (UNDP, 2014).

Grazing systems that depend on the natural cycle of climatic conditions are expected to be more seriously impacted by climate change (Ghahramani *et al.,* 2019).Among grazing systems across the world those found in low altitude arid and semi-arid areas will be affected most severely as higher temperatures and reduced rainfall reduce feed yields and increased land degradation (Bardgett *et al*., 2021).On the other hand, non-grazing systems are expected to be less affected by climate change because housing and other structures allow for greater control of production conditions (Bardgett *et al*., 2021)

Heat stress is one of the components of climate change with the most significant direct impact on livestock production. Recent studies have reported on the temporal and spatial variability of rainfall and temperature in different countries and ecosystems across the world (Nonaceur *et al.,* 2017; Rustum *et al.,* 2017). Most these studies have reported either increase or decrease in intensity of rainfall, increased incidences of drought and rising ambient temperatures (Kumar *et al.,* 2017; Nonaceur *et al.,* 2017). Heat stress decreases feed intake, feed conversion efficiency leading to reduced milk production, growth, reproduction and increased incidences of diseases and mortality (Lacetera, 2019; Santos *et al.,* 2019). Poor feed conversion efficiency leads to increased methane gas emissions (Kumari *et al*., 2020), further fueling global warming.

In Africa, drought and dry seasons are becoming more common, higher intensity, and longer in duration, resulting in heat stress for dairy cattle. There is therefore the possibility of increased climate change will result to a negative effect on milk yield in Kenya and many other countries (Niyonzima *et al*., 2022).The objective of this study was to determine the influence of rainfall and temperature of milk yield in Sahiwal cattle in Kenya.

5.2 Materials and Methods

Data of this study were collected at the National Sahiwal Stud, Naivasha, Kenya from 1981 to 2012. The stud is located at 0^{o} 43'1.8408" S, 36^{o} 25' 51.6936"E on the floor of the Great Rift Valley at about 600 m above sea level. The climate of this location is semi-arid with an annual average rainfall of 600 mm. The rainfall pattern of the area is bimodal, with two distinct peaks occurring in May and the other one in November. However, the rainfall distribution varies from year to year. The average minimum and maximum temperatures are 8^{o}C and 30^{o}C, respectively. The breed reared at the Stud is the Sahiwal cattle. The breed was brought into the country from India and Pakistan in the first half of the 20th century. Since then, it has been systematically bred for milk and growth. The Stud is run as a closed nucleus, in which performance and pedigree recording and genetic evaluation is carried out. The improved germplasm is distributed to commercial herds mainly breeding bulls and sometimes semen and surplus heifers (Ilatsia *et al.,* 2011). The cows at the stud are mainly raised on natural pastures dominated by star grass (*Cynodondactylon*) with mineral salts being provided. The pasture land is dotted by acacia trees with the main genus being the *Acacia xanthophloea*. The cows are milk twice a day by hand. Average milk yield has been reported to be 4.5±1.5kg per day per cow. Climatic was collected routinely by neighboring flower farm and included ambient temperatures and rainfall. The climatic variable recorded were minimum and maximum temperatures and monthly rainfall. Milk yields for each cow were recorded at milking and added to daily and weekly totals. From the weekly totals monthly totals were summed up. The monthly milk yield yields were then related to minimum and maximum temperature and rainfall for the same period.

5.3 Results

The effect of fixed factors on monthly milk yield is presented in Table 5.1. Parity, month of milking and year were significant at $P<0.001$. As monthly rainfall increased milk yield increased significantly ($P<0.001$) but decreased as minimum and maximum temperature increased. Mean monthly rainfall and maximum temperature significantly ($P<0.001$) influenced monthly milk yield.

Table 5 1: Effect of independent variables, partial sums of squares for monthly milk yield and coefficients of regression of monthly milk yield on weather variables

Source	Degrees of freedom	Sums of squares	Partial regression coefficients
Parity	5	1,356,776.2***	
Month	11	237,527.3***	
Year	31	3,126,052.4***	
Minimum temperature	1	21,520.3*	-1.58±0.57**
Maximum temperature	1	101,775.5**	-1.17±0.32***
Rainfall	1	43458.9**	0.07±0.02***
Model	50	46,534,615.6	
Residual	8,635	41,674,546.7	
R^2	0.10		

***P<0.001, **P<0.01, *P<0.05.

The effect of minimum temperature was significant at P<0.05. For every increase in monthly rainfall of 1 mm, monthly milk yield increased by 0.07kg. A 1^{o}C increase in minimum and maximum temperature lead to a decrease in monthly milk yield of 1.58kg and 1.17kg, respectively. The model accounted for 43% of the total sum of squares for monthly milk yield. Year of calving accounted for 6.7% of the total variation in monthly milk yield followed by parity (2.7%), month of milking (0.5%) and maximum temperature (0.2%). Variables associated with weather accounted for a small proportion of the total variation (0.4%), thought significant.

Least square means for monthly milk yield for the fixed effects are shown in Table 5.2. Monthly milk yield generally increased significantly (P<0.05) from parity 1 to a peak between parity 3 and thereafter decreased, with monthly milk yield in parity 2, 3 and 5; 5 and 6; and 3 and 4 being similar (P>0.05). Monthly milk yield, rainfall, minimum and maximum temperature generally remained constant (P>0.05) across the months from January to December (Figure 5.1).

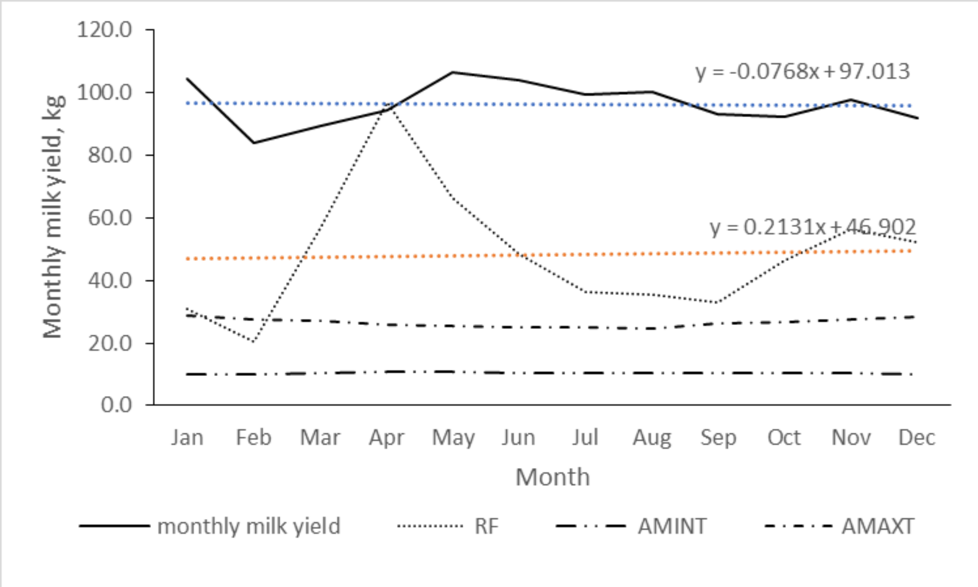


Figure 5.1: Trends of mean monthly rainfall (RF), minimum (AMINT) and maximum (AMAXT) temperature and milk yield for Sahiwal cattle in Kenya.

The correlations between monthly milk yield and rainfall, average minimum temperature, average temperature and maximum temperature are shown in Table 5.2. The correlations between monthly milk yield and monthly rainfall were positive and low and significantly different from 0 (P<0.0001). Monthly milk yield was negatively correlated with average minimum (P>0.05), average (P<0.05) and maximum temperature (P<0.05). This implies that months receiving high amounts of rain were generally cooler.

Table 5 2: Correlations between mean monthly milk yield, rainfall, minimum and maximum temperature at the National Sahiwal Stud, Naivasha, Kenya.

Variable	Monthly milk yield	Monthly rainfall	Minimum temperature	Maximum temperature
Monthly milk yield	-	0.042***	-0.017	-0.046***
Monthly rainfall		-	0.123***	-0.047***
Minimum temperature			-	-0.112***
Maximum temperature				-

*** Values are statistically significant at 0.0001 and 0.05 levels of significance, respectively.

Mean monthly rainfall was positively and significantly correlated (P<0.001) with mean monthly minimum and negatively and significantly correlated with mean monthly maximum temperature (P<0.001). The hottest months were also the coldest as indicated by the negative and significant correlation (P<0.001) maximum and minimum temperatures. This means that the study area has a wide diurnal temperature range.

5.4 Discussion

Monthly milk yield was positively associated with rainfall as shown by the positive correlation and regression coefficient. Many studies have reported a significant effect of rainfall on milk yield (Shaheen *et al.,* 2022). The high environmental temperatures expressed as thermal stress cause reduced feed intake and impaired metabolism, which consequently translate to low milk yield, and suboptimal fertility and health performances (Rana *et al*., 2014).

The effect of climate change is complex. However, studies have reported either upward or downward trend in monthly or seasonal rainfall (Rustum *et al.,* 2017). For the NSS at Naivasha Kenya, monthly rainfall increased leading to a concomitant increase in milk yield. The regression coefficient of monthly milk yield on rainfall (0.07±0.02kg/mm) reflects the effect of rainfall on pasture growth feed availability, palatability and nutritive value. From the study, it was observed that production per month peaked at 110 Kg during the months of April and May. Similarly Ongadi *et al*. (2020) reported an increase of milk production during these months that were characterized with long rains. The study also reported increase in green grass, legume forage and green crop residues which were more nutritionally superior. This could also explain the increased milk production within the current study.

On the other hand, dry seasons saw a reduced in the amount of monthly milk production. Typically the dry months are characterized with grasses and fodder of poor quality. For instance during the wet season it has reported that dry matter, crude protein and fiber content in grasses ranged from 25%,10% and 35% respectively. However during the dry period the crude protein reduced to almost 2%. Further, Energy and protein intakes from roughages fed to dairy cows in Eastern Africa during the dry season is insufficient to meet the requirements due to the high levels of fibre concentration (ADF-acid detergent fibre and NDF-neutral detergent fiber), lignin. The elevated levels of fiber in the diets of cows is associated with a reduced voluntarily intake due to the bulky characteristics associated with fibrous diets (Kahyani *et al*., 2019). It is therefore possible that the reducing nutrients profile of grasses could explain the low milk production (Ogandi *et al*., 2020).

The time lag from onset of rains to the maximal response in pasture value was also displayed in the current study. However, shorter periods may have been more sensitive in measuring this time lag.

The partial regression coefficients of milk yield on temperature indicate the importance of ambient temperature on the welfare of animals. The loss of 1.58±0.57 and 1.17±0.32kg milk yield for every 1^{o}C increase in minimum and maximum temperature is related to the negative effect of high ambient temperatures on animal behavior and physiological responses of animals. Similarly, according to Imrich *et al*. (2021) study, there was a negative correlation between both THI (Temperature Humidity Index) and milk yield ($r = -0.641$; $p <0.01$) and temperature and milk yield ($r = -0.637$; $p <0.01$). These results suggest that heat exerts considerable negative effects on milk production and its composition, especially during summer months.

As ambient temperatures increase metabolic heat production increases (Rhoads *et al.,* 2013) as a result, animals respond by altering their behavior and physiological processes. The changes include changes in feeding and water seeking behavior, increase in respiration rate, heart rate and rectal temperature (Wangui *et al*., 2018). For instance a study by Niyonzima *et al*. (2022) showed heat-stressed cows had lower voluntary feed intake and lower milk yield than control cows in a temperate climate. The consequence of the behavioral and physiological changes is often reduced milk yield and growth (Wangui *et al*., 2018).

The widest monthly temperature range of the study site of about 17.9^{o}C occurred in January, February, March, and September to December, which were also associated with significantly lower milk production. As a consequence of climate change, a number of studies have reported significant increase in mean and minimum average temperature (Asfaw *et al.,* 2018; Javari, 2017). When exposed to high temperature cows tend to adjust their physiological responses to increase heat dissipation to the environment. As a result the cow repartition its nutrient use from milk production in attempt to reduce thermal stress (Wangui *et al*., 2018). This may explain the greater influence of mean minimum temperature on milk yield found in the current study.

The results of the current study call for identification of mitigating strategies for pasture-based beef and milk production systems. Some of the strategies suggested include modifications in the management systems, breeding strategies, policy changes and a change in farmer perception and adaptive capacity to climate change (Rojas-Downing *et al.,* 2017; USDA, 2013). Specifically, the mitigation strategies will involve improvement of feeding strategies in terms of modifying diet composition, feeding time and frequency incorporation of agroforestry to modify micro-climates in grazing lands (Mostafa *et al.,* 2020).

However even when farmers employ heat stress mitigation strategies, losses of more than 50% of production per cow have been reported for dairy cattle (Lakew, 2017). In most production systems, animals are rarely exposed to a single environmental stressor. It is likely that the cows at the NSS were exposed to more stressors than were captured in the current study. Other stressors include wind speed, poor nutrition, diseases, pests and humidity. Seijan *et al*. (2013) reported that production and reproduction was further compromised by poor nutrition, long distances to feeding areas water sources. Although the Sahiwal cattle are reared within a demarcated area at the NSS, it is likely that animals walk longer seeking feed and spend more time under shade during hot months, further affecting production.

5.5 Conclusion

Climatic variables, minimum and maximum temperature and monthly rainfall significantly ($P<0.05$) affected monthly milk yield but for a small proportion of total variation (0.5%) through significant. A 1^{o}C increase in minimum and maximum temperature led to a 1.58kg and 1.17kg decrease in monthly milk yield, respectively. A 1 mm increase in monthly rainfall of monthly caused monthly milk yield to increase by 0.07kg.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The objective of this study was to establish evidence of rainfall and temperature variability and their influence on survival rates and milk production of Sahiwal cattle in a semi-arid ecosystem of Kenya. For over 50 years, Sahiwal cattle breed at the National Stud Herd (NSH) has been bred on rain-fed pastures in a semi-arid ecosystem of Kenya. It was thus hypothesized that Sahiwal cattle has been exposed to large intra and inter annual variations in precipitation and temperatures, with significant influence on their survival rates and milk production. Historical data was obtained from NSH on monthly animal inventory and deaths, milk yields, rainfall and temperatures. Analysis of the data was directed to answering the research questions of:

i. How variable is the monthly rainfall and temperature in the semi-arid ecosystem where Sahiwal cattle have been grazed for long period?
ii. Is there a significant influence of rainfall and temperature variability on survival rates of Sahiwal cattle grazed in a semi-arid ecosystem?
iii. Is there a significant influence of rainfall and temperature variability on milk production of Sahiwal cattle grazed in a semi-arid ecosystem?

6.2 Variability of Rainfall and Temperature

The current study showed that there is a general decline of rainfall over the study period. This is exemplified by the total amount of rains received by the study area showed that only the months of April and May had received rains above 100 mm in recent years (from 2005), while all the other months had an average rainfall of less than 100 mm. This decline will have greater influence on selection of livestock types and breeds in the coming decades (Lamy*et al.,* 2012). Climate affects animal production through impact of changes in livestock feed (grain) availability and price, impacts on pastures and forage crop production and quality, direct effects of weather and extreme events on animal health, growth and reproduction and lastly on the changes in the distribution of livestock diseases and pests. Typically, climate change is described in terms of average changes in temperature or precipitation, but most of the social and economic costs associated with climate change will result from shifts in the frequency and severity of extreme events. Climate change and global warming are the major concerns that define livestock production systems. Climate affects animal production through the impact of changes in livestock feed availability and price, impacts on pastures and forage crop production and quality, direct effects of weather and extreme events on animal health, growth and reproduction and lastly on the changes in the distribution of livestock diseases and pests. An increase in rainfall variability for months with average rainfall more than or equal to the year mean. This applies to January, March, April, May, June, November and December. The year mean was about 39 mm of rainfall. In the current study, rainfall variability was higher in the months with higher rainfall, namely January, March, April, May, June, November, and December, while months with low rainfall had lower rainfall variability (February, July, August, September and October).

6.3 Effect of Rainfall and Temperature Variability on Cattle Survival and Milk Production

The highest number of deaths reported was in July when we had temperatures dropping in June and in July. Temperatures were low than the mean line and this could be cause of death to young ones. Mortality is more by rainfall variability than temperature variability. Cattle populations in pastoral production systems are strongly influenced by rainfall variability and trends similar to the present study has been reported. According to IPCC (2014) report, changes in range-fed livestock numbers in any African region will be directly proportional to changes in annual precipitation. Calving rate was highest in July and June while it was lowest in February, September, November and December. Management of different livestock farms could use the result of this study in mitigating the interventions that could be put in place to see to it that mortality does not occur during the reported periods.

Specifically, variability in precipitation leads to unpredictable changes in production and quality of feed crop and forage (Polley *et al.,* 2013), water availability. The consequences are reduced animal growth and milk production disease and reproduction. These outcomes are primarily due to reduced water quality and availability, decreased forage quantity and quality and changes in grazing/feeding patterns due to increased ambient temperatures.

The potential effect of variability of climatic variables on livestock include changes in production and quality of feed crop and forage (Polley *et al.,* 2013), water availability reduced animal growth and milk production disease reproduction These outcomes are primarily due to reduced water quality and availability, decreased forage quantity and quality and changes in grazing/feeding patterns due to increased ambient temperatures (Polley *et al.,*

2013) As ambient temperatures increase the quantity and quality of feeds will be affected due to increase in atmospheric carbon dioxide which will lead to partial closure of stomata leading to improvement in the water use efficiency of some plants (Polley *et al.,* 2013).Thermal stress decreases feed intake, and feed conversion efficiency. Reduced feed intake in turn leads to negative energy balance and reduced weight gain. Reduced water intake due to thermal stress may also lead to decreased feed intake.

The current study found a negative association between the declining rainfall and increasing maximum temperature trends at the NSS and monthly milk yield as well as survival. Elsewhere, huge losses have been reported in the dairy industry due to heat stress. Heat stress has been shown to affect milk production in does, ewes and Buffaloes as well as milk composition. Olsson and Dahlborn (1989) found that during periods of water and heat stress, water loss reduction mechanism is activated, reducing water loss in urine in favor of milk production in goats. When exposed to elevated temperatures, larger animals reduce milk production as they are forced to deal with increased pulse, respiration rate and rectal temperature. The Sahiwal is a dual-purpose breed being reared for meat apart from milk. It is worth noting that increasing trend of maximum temperature is likely to have negative effects on body size, carcass weight and fat thickness in ruminants. Beef cattle with high body weights, thick coats and dark coat colors are more vulnerable to elevated ambient temperature (Seerapu *et al.,* 2015).

The decreased survival of animals at the NSS is in agreement with previous studies which reported reduction in survival due to the combined effects of declining rainfall and elevated temperatures. An increase in temperature of between 1 and 5^{o}C has been shown to induce high mortality in grazing cattle. The decreased survival is also partly due to deteriorating health of the animals due to effects of prolonged heat stress on metabolic rate, endocrine status, oxidative status glucose, and protein and lipid metabolism. All these effects interact to not only cause mortality but also reduce cow fitness and longevity. In the current study rainfall variability significantly influenced the probability of survival of animals in the Sahiwal herd in Kenya. High rainfall was associated with high chances of survival and vice versa. Rainfall is associated with a number of aspects that influence performance of animals under extensive grassland systems. Foremost is the availability of feed resources and their quality. Insufficient amounts of rainfall will lead to poor nutrition and hence poor growth and increased susceptibility to diseases, leading to increased morbidity and even deaths

6.4 Ameliorating Effects of Rainfall and Temperature Variability on Cattle Survival and Milk Production

A number of strategies have been put forward to deal with the unpredictability of climatic variables with regard to livestock production. Foremost, the immediate strategies of alleviating the negative effects of elevated temperatures include sprinkling, provision of shade or any other management strategy that can lead to cooling of animals (Rojas-Downing *et al*., 2017). For the case of the Sahiwal cattle that are extensively grazed, provision of shade can be achieved through planting of adapted tree species which could also provide supplemental feed. Agroforestry or establishment of trees and pastures in a mix apart from providing shade and supplemental feed can help to improve the quality of the air, soil, water as well as nutrient cycling (Rojas-Downing *et al*., 2017)..

Breeding for adaptability to climate change is another viable albeit long term strategy to ameliorate the negative effects of the variability of climatic variables (Ahmed *et al.,* 2015).Where possible, this process can be hastened by replacing more vulnerable breeds with more adapted genotypes (De Campos *et al.,* 2013). In the long term, adaptability should become an integral part of breeding objectives in cattle breeding. Studies have shown differences between and with cattle breeds with regards to adaptation to climate change (De Campos *et al.,* 2013; Uttarani *et al.,* 2014). Attention should be paid to the color and type of coat (Ahmed *et al.,* 2015).

6.5 Conclusions

i. The study indicates high variability in rainfall and temperature at Naivasha NSH, with notable differences between months and years. While mean temperature showed a decline and minimum temperature showed a non-significant increase, specific months exhibited significant changes. The long-term trends suggest a decrease in annual and long season rainfall but an increase in short season rainfall.

ii. The current study showed that there was a significant influence of rainfall variation on survival, with discernable trends in changes in rainfall and the probability of an animal surviving in the herd. High precipitation was associated with increased probability of herd survival. However, there was no significant influence of temperature variations on probability of survival.

iii. The study showed that higher temperatures have led to a decrease in milk production, with each 1°C rise causing a reduction in yield by around 1.58 kg and 1.17 kg.

However, increased monthly rainfall has had a positive impact, resulting in a boost of approximately 0.07 kg in milk yield for every 1 mm rise in rainfall.

6.6 Recommendations

i. There is need to adjust herd management activities in accordance with the variability occurrences in order to increase the adaptive capacity of grazing systems.

ii. Mitigating strategies are required to alleviate the negative effects the inter-annual variability of temperature and rainfall on monthly milk yield and survival. These include sound grazing management and feed conservation as well as establishment of tree-pasture mixes.

iii. Data from several metrological stations should be analyzed together in order have a clearer picture of the behavior of climatic variables in semi-arid pasture-based production systems

6.7 Areas of Further Research

i. To assess the genetic diversity and resilience of the Sahiwal cattle at the Naivasha NSH and identify potential traits for selection and improvement under changing climatic conditions.

ii. To evaluate the economic and environmental impacts of different adaptation strategies on the sustainability and profitability of the Sahiwal cattle production system at the Naivasha-NSH.

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APPENDICES

Appendix A: Calculation of Mann-Kendall's test maximum temperature for Objective One

	27.3	26.8	26.2	26.8	25.8	26.3	25.8	25.7	27.4	26.9	28.0	27.8	24.5	26.4	27.1	27.1	26.4	28.4	26.6	26.2	26.8	27.1	24.7	24.2	26.5	26.1	26.3	25.7	26.9	26.4	26.8	26.3			
27.3																																		n	32
26.8	-0.58																																	alpha	0.05
26.2	-0.58	-0.58																																	
26.8	-0.19	0.00	0.58																															MK-stat	-7.48
25.8	-0.37	-0.30	-0.17	-0.91																														s.e.	25.71
26.3	-0.20	-0.10	0.06	-0.21	0.50																													z-stat	-0.25
25.8	-0.26	-0.20	-0.10	-0.33	-0.04	-0.58																												p-value	0.80
25.7	-0.24	-0.18	-0.10	-0.27	-0.05	-0.32	-0.07																											trend	NO
27.4	0.01	0.10	0.21	0.13	0.40	0.36	0.83	1.73																											
26.9	-0.05	0.02	0.11	0.03	0.22	0.15	0.39	0.62	-0.50																										
28.0	0.07	0.14	0.23	0.18	0.36	0.33	0.56	0.77	0.29	1.08																									
27.8	0.04	0.10	0.18	0.13	0.27	0.24	0.40	0.52	0.11	0.42	-0.25																								
24.5	-0.24	-0.20	-0.17	-0.25	-0.17	-0.26	-0.21	-0.24	-0.73	-0.81	-1.75	-3.25																							
26.4	-0.07	-0.03	0.02	-0.03	0.06	0.01	0.10	0.12	-0.20	-0.13	-0.53	-0.67	1.92																						
27.1	-0.02	0.02	0.07	0.03	0.12	0.08	0.16	0.20	-0.06	0.03	-0.24	-0.23	1.28	0.63																					
27.1	-0.02	0.02	0.07	0.03	0.11	0.08	0.15	0.18	-0.05	0.03	-0.18	-0.17	0.86	0.33	0.03																				
26.4	-0.06	-0.02	0.02	-0.03	0.05	0.01	0.07	0.08	-0.13	-0.07	-0.26	-0.27	0.48	0.00	-0.32	-0.67																			
28.4	0.06	0.10	0.15	0.12	0.20	0.17	0.24	0.27	0.11	0.19	0.06	0.11	0.78	0.50	0.46	0.67	2.00																		
26.6	-0.04	-0.01	0.03	-0.01	0.05	0.02	0.07	0.08	-0.08	-0.04	-0.18	-0.17	0.35	0.03	-0.12	-0.17	0.08	-1.83																	
26.2	-0.06	-0.03	0.00	-0.04	0.02	-0.01	0.03	0.04	-0.11	-0.08	-0.20	-0.20	0.24	-0.04	-0.18	-0.23	-0.08	-1.13	-0.42																
26.8	-0.03	0.00	0.03	0.00	0.06	0.03	0.07	0.08	-0.06	-0.02	-0.13	-0.11	0.28	0.05	-0.05	-0.07	0.08	-0.56	0.08	0.58															
27.1	-0.01	0.02	0.05	0.02	0.07	0.05	0.09	0.10	-0.03	0.01	-0.08	-0.07	0.29	0.08	0.00	0.00	0.13	-0.33	0.17	0.46	0.33														
24.7	-0.12	-0.10	-0.07	-0.11	-0.06	-0.09	-0.06	-0.06	-0.19	-0.17	-0.27	-0.28	0.02	-0.19	-0.29	-0.34	-0.28	-0.74	-0.47	-0.48	-1.01	-2.36													
24.2	-0.14	-0.12	-0.09	-0.13	-0.09	-0.12	-0.09	-0.09	-0.22	-0.19	-0.29	-0.30	-0.03	-0.22	-0.32	-0.36	-0.32	-0.70	-0.48	-0.49	-0.85	-1.45	-0.53												
26.5	-0.03	-0.01	0.02	-0.01	0.03	0.01	0.04	0.05	-0.06	-0.03	-0.11	-0.10	0.17	0.01	-0.05	-0.06	0.01	-0.27	-0.01	0.07	-0.06	-0.19	0.89	2.32											
26.1	-0.05	-0.03	0.00	-0.03	0.01	-0.01	0.02	0.02	-0.08	-0.05	-0.13	-0.12	0.12	-0.03	-0.09	-0.10	-0.04	-0.29	-0.07	-0.01	-0.13	-0.25	0.46	0.95	-0.42										
26.3	-0.04	-0.02	0.00	-0.02	0.02	0.00	0.03	0.03	-0.06	-0.04	-0.11	-0.10	0.13	-0.01	-0.06	-0.07	-0.01	-0.24	-0.04	0.02	-0.08	-0.16	0.39	0.69	-0.12	0.18									
25.7	-0.06	-0.04	-0.02	-0.04	-0.01	-0.03	0.00	0.00	-0.09	-0.07	-0.14	-0.13	0.08	-0.05	-0.11	-0.12	-0.07	-0.27	-0.10	-0.06	-0.15	-0.23	0.19	0.37	-0.27	-0.20	-0.59								
26.9	-0.02	0.01	0.03	0.01	0.04	0.02	0.05	0.06	-0.03	0.00	-0.06	-0.05	0.15	0.03	-0.01	-0.01	0.04	-0.14	0.03	0.08	0.02	-0.03	0.36	0.54	0.10	0.27	0.31	1.21							
26.4	-0.03	-0.01	0.01	-0.01	0.02	0.00	0.03	0.03	-0.05	-0.03	-0.08	-0.08	0.11	0.00	-0.04	-0.05	0.00	-0.17	-0.02	0.02	-0.04	-0.09	0.24	0.37	-0.02	0.08	0.04	0.35	-0.50						
26.8	-0.02	0.00	0.02	0.00	0.04	0.02	0.04	0.05	-0.03	-0.01	-0.06	-0.05	0.13	0.02	-0.02	-0.02	0.03	-0.13	0.02	0.06	0.00	-0.03	0.26	0.37	0.05	0.14	0.13	0.37	-0.05	0.39					
26.3	-0.03	-0.01	0.00	-0.02	0.02	0.00	0.02	0.03	-0.05	-0.03	-0.08	-0.07	0.10	-0.01	-0.04	-0.05	-0.01	-0.15	-0.02	0.01	-0.04	-0.08	0.18	0.26	-0.03	0.04	0.01	0.16	-0.19	-0.04	-0.47				
	0	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	2				
	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
freg	56550	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		56550		

Appendix B: Calculation of Sen's slope for maximum temperature for Objective One

	27.3	26.75	26.17	26.75	25.84	26.33	25.75	25.68	27.42	26.92	28	27.75	24.5	26.42	27.05	27.08	26.42	28.42	26.58	26.17	26.75	27.08	24.72	24.19	26.51	26.09	26.28	25.68	26.89	26.39	26.78	26.31
27.3																																
26.8	-0.58																															
26.2	-0.58	-0.58																									alpha		0.05			
26.8	-0.19	0.00	0.58																								No. pai		496			
25.8	-0.37	-0.30	-0.17	-0.91																							se		25.71			
26.3	-0.20	-0.10	0.06	-0.21	0.50																						k		50.39			
25.8	-0.26	-0.20	-0.10	-0.33	-0.04	-0.58																					lower		222.80			
25.7	-0.24	-0.18	-0.10	-0.27	-0.05	-0.32	-0.07																				upper		273.20			
27.4	0.01	0.10	0.21	0.13	0.40	0.36	0.83	1.73																								
26.9	-0.05	0.02	0.11	0.03	0.22	0.15	0.39	0.62	-0.50																		slope		-0.014			
28.0	0.07	0.14	0.23	0.18	0.36	0.33	0.56	0.77	0.29	1.08																	lower		-0.028			
27.8	0.04	0.10	0.18	0.13	0.27	0.24	0.40	0.52	0.11	0.42	-0.25																upper		0			
24.5	-0.24	-0.20	-0.17	-0.25	-0.17	-0.26	-0.21	-0.24	-0.73	-0.81	-1.75	-3.25																				
26.4	-0.07	-0.03	0.02	-0.03	0.06	0.01	0.10	0.12	-0.20	-0.13	-0.53	-0.67	1.92																			
27.1	-0.02	0.02	0.07	0.03	0.12	0.08	0.16	0.20	-0.06	0.03	-0.24	-0.23	1.28	0.63																		
27.1	-0.02	0.02	0.07	0.03	0.11	0.08	0.15	0.18	-0.05	0.03	-0.18	-0.17	0.86	0.33	0.03																	
26.4	-0.06	-0.02	0.02	-0.03	0.05	0.01	0.07	0.08	-0.13	-0.07	-0.26	-0.27	0.48	0.00	-0.32	-0.67																
28.4	0.06	0.10	0.15	0.12	0.20	0.17	0.24	0.27	0.11	0.19	0.06	0.11	0.78	0.50	0.46	0.67	2.00															
26.6	-0.04	-0.01	0.03	-0.01	0.05	0.02	0.07	0.08	-0.08	-0.04	-0.18	-0.17	0.35	0.03	-0.12	-0.17	0.08	-1.83														
26.2	-0.06	-0.03	0.00	-0.04	0.02	-0.01	0.03	0.04	-0.11	-0.08	-0.20	-0.20	0.24	-0.04	-0.18	-0.23	-0.08	-1.13	-0.42													
26.8	-0.03	0.00	0.03	0.00	0.06	0.03	0.07	0.08	-0.06	-0.02	-0.13	-0.11	0.28	0.05	-0.05	-0.07	0.08	-0.56	0.08	0.58												
27.1	-0.01	0.02	0.05	0.02	0.07	0.05	0.09	0.10	-0.03	0.01	-0.08	-0.07	0.29	0.08	0.00	0.00	0.13	-0.33	0.17	0.46	0.33											
24.7	-0.12	-0.10	-0.07	-0.11	-0.06	-0.09	-0.06	-0.06	-0.19	-0.17	-0.27	-0.28	0.02	-0.19	-0.29	-0.34	-0.28	-0.74	-0.47	-0.48	-1.01	-2.36										
24.2	-0.14	-0.12	-0.09	-0.13	-0.09	-0.12	-0.09	-0.09	-0.22	-0.19	-0.29	-0.30	-0.03	-0.22	-0.32	-0.36	-0.32	-0.70	-0.48	-0.49	-0.85	-1.45	-0.53									
26.5	-0.03	-0.01	0.02	-0.01	0.03	0.01	0.04	0.05	-0.06	-0.03	-0.11	-0.10	0.17	0.01	-0.05	-0.06	0.01	-0.27	-0.01	0.07	-0.06	-0.19	0.89	2.32								
26.1	-0.05	-0.03	0.00	-0.03	0.01	-0.01	0.02	0.02	-0.08	-0.05	-0.13	-0.12	0.12	-0.03	-0.09	-0.10	-0.04	-0.29	-0.07	-0.01	-0.13	-0.25	0.46	0.95	-0.42							
26.3	-0.04	-0.02	0.00	-0.02	0.02	0.00	0.03	0.03	-0.06	-0.04	-0.11	-0.10	0.13	-0.01	-0.06	-0.07	-0.01	-0.24	-0.04	0.02	-0.08	-0.16	0.39	0.69	-0.12	0.18						
25.7	-0.06	-0.04	-0.02	-0.04	-0.01	-0.03	0.00	0.00	-0.09	-0.07	-0.14	-0.13	0.08	-0.05	-0.11	-0.12	-0.07	-0.27	-0.10	-0.06	-0.15	-0.23	0.19	0.37	-0.27	-0.20	-0.59					
26.9	-0.02	0.01	0.03	0.01	0.04	0.02	0.05	0.06	-0.03	0.00	-0.06	-0.05	0.15	0.03	-0.01	-0.01	0.04	-0.14	0.03	0.08	0.02	-0.03	0.36	0.54	0.10	0.27	0.31	1.21				
26.4	-0.03	-0.01	0.01	-0.01	0.02	0.00	0.03	0.03	-0.05	-0.03	-0.08	-0.08	0.11	0.00	-0.04	-0.05	0.00	-0.17	-0.02	0.02	-0.04	-0.09	0.24	0.37	-0.02	0.08	0.04	0.35	-0.50			
26.8	-0.02	0.00	0.02	0.00	0.04	0.02	0.04	0.05	-0.03	-0.01	-0.06	-0.05	0.13	0.02	-0.02	-0.02	0.03	-0.13	0.02	0.06	0.00	-0.03	0.26	0.37	0.05	0.14	0.13	0.37	-0.05	0.39		
26.3	-0.03	-0.01	0.00	-0.02	0.02	0.00	0.02	0.03	-0.05	-0.03	-0.08	-0.07	0.10	-0.01	-0.04	-0.05	-0.01	-0.15	-0.02	0.01	-0.04	-0.08	0.18	0.26	-0.03	0.04	0.01	0.16	-0.19	-0.04	-0.47	

Appendix C: Analysis of variance using Proc GLM of SAS for fixed factors influencing monthly milk yield for Objective Three

The GLM Procedure

Class Level Information

Class	Levels	Values
Par	6	1 2 3 4 5 6
Mon	12	1 2 3 4 5 6 7 8 9 10 11 12
YG	6	1 2 3 4 5 6

Number of observations 9363

NOTE: Due to missing values, only 8686 observations can be used in this analysis.

The SAS System 09:36 Friday, June 4, 2020 1244

The GLM Procedure

Dependent Variable: MMY

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	80	3728110.09	46601.38	9.37	<.0001
Error	8605	42806505.46	4974.61		
Corrected Total	8685	46534615.56			

R-Square	CoeffVar	Root MSE	MMY Mean
0.080115	73.04458	70.53090	96.55872

Source	DF	Type III SS	Mean Square	F Value	Pr> F
Par	5	1309029.229	261805.846	52.63	<.0001
Mon	11	242406.525	22036.957	4.43	<.0001
YG	5	1170299.618	234059.924	47.05	<.0001
Mon*YG	55	673743.646	12249.884	2.46	<.0001
AMINT	1	205.875	205.875	0.04	0.8388

AMAXT	1	286.774	286.774	0.06	0.8103
AVT	1	3737.036	3737.036	0.75	0.3861
RF	1	42782.231	42782.231	8.60	0.0034

The SAS System 09:36 Friday, June 4, 2020 1245

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|
Intercept	1	153.01400	11.09345	13.79	<.0001
AMINT	1	0.20124	0.84652	0.24	0.8121
AMAXT	1	0.26663	0.86224	0.31	0.7572
AVT	1	-3.61965	1.69705	-2.13	0.0330

The SAS System 09:36 Friday, June 4, 2020 1251

The REG Procedure

Model: MODEL1

Dependent Variable: MMY

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	4	224655	56164	10.53	<.0001
Error	8681	46309961	5334.63432		
Corrected Total	8685	46534616			

Root MSE	73.03858	R-Square	0.0048
Dependent Mean	96.55872	Adj R-Sq	0.0044
CoeffVar	75.64162		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|

Intercept	1	149.18648	11.43423	13.05	<.0001
AMINT	1	0.13626	0.85562	0.16	0.8735
AMAXT	1	1.04344	0.88045	1.19	0.2360
AVT	1	-4.66811	1.72942	-2.70	0.0070
RF	1	0.08290	0.01868	4.44	<.0001

The SAS System 09:36 Friday, June 4, 2020 1252

Appendix D: Regression of minimum, maximum and average temperature on year for Objective Three

The REG Procedure

Model: MODEL1

Dependent Variable: AMINT

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	7.13612	7.13612	3.69	0.0546
Error	8684	16772	1.93142		
Corrected Total	8685	16780			

Root MSE	1.38975	R-Square	0.0004
Dependent Mean	10.39595	Adj R-Sq	0.0003
CoeffVar	13.36823		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|
Intercept	1	10.43376	0.02468	422.68	<.0001
MMY	1	-0.00039160	0.00020373	-1.92	0.0546

The SAS System 09:36 Friday, June 4, 2020 1253

The REG Procedure

Model: MODEL1

Dependent Variable: AMAXT

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	74.16733	74.16733	12.51	0.0004
Error	8684	51470	5.92704		
Corrected Total	8685	51545			

Root MSE	2.43455	R-Square	0.0014
Dependent Mean	26.40113	Adj R-Sq	0.0013
CoeffVar	9.22139		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|
Intercept	1	26.52303	0.04324	613.36	<.0001
MMY	1	-0.00126	0.00035689	-3.54	0.0004

The SAS System 09:36 Friday, June 4, 2020 1254

The REG Procedure

Model: MODEL1

Dependent Variable: AVT

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	36.50238	36.50238	21.76	<.0001
Error	8684	14564	1.67716		

Corrected Total	8685	14601

Root MSE	1.29505	R-Square	0.0025
Dependent Mean	18.39328	Adj R-Sq	0.0024
CoeffVar	7.04090		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|
Intercept	1	18.47880	0.02300	803.33	<.0001
MMY	1	-0.00088567	0.00018985	-4.67	<.0001

The SAS System 09:36 Friday, June 4, 2020 1255

The REG Procedure

Model: MODEL1

Dependent Variable: RF

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	28842	28842	15.86	<.0001
Error	8684	15791943	1818.51029		
Corrected Total	8685	15820785			

Root MSE	42.64399	R-Square	0.0018
Dependent Mean	51.50079	Adj R-Sq	0.0017
CoeffVar	82.80260		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|

Intercept	1	49.09691	0.75744	64.82	<.0001
MMY	1	0.02490	0.00625	3.98	<.0001

The REG Procedure

Model: MODEL1

Dependent Variable: MMY

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	14212	14212	2.69	0.1010
Error	9328	49292830	5284.39432		
Corrected Total	9329	49307043			

Root MSE	72.69384	R-Square	0.0003
Dependent Mean	95.47106	Adj R-Sq	0.0002
CoeffVar	76.14228		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|
Intercept	1	104.75419	5.71035	18.34	<.0001
AMINT	1	-0.89265	0.54430	-1.64	0.1010

The REG Procedure

Model: MODEL1

Dependent Variable: MMY

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F

Model	1	103492	103492	19.64	<.0001
Error	9361	49333851	5270.14748		
Corrected Total	9362	49437342			

Root MSE	72.59578	R-Square	0.0021
Dependent Mean	95.50668	Adj R-Sq	0.0020
CoeffVar	76.01121		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|
Intercept	1	131.96694	8.26183	15.97	<.0001
AMAXT	1	-1.37825	0.31102	-4.43	<.0001

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The REG Procedure

Model: MODEL1

Dependent Variable: MMY

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	151332	151332	28.74	<.0001
Error	9361	49286011	5265.03693		
Corrected Total	9362	49437342			

Root MSE	72.56057	R-Square	0.0031
Dependent Mean	95.50668	Adj R-Sq	0.0030
CoeffVar	75.97435		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|

Intercept	1	151.24172	10.42296	14.51	<.0001
AVT	1	-3.02847	0.56488	-5.36	<.0001

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The REG Procedure

Model: MODEL1

Dependent Variable: MMY

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	82705	82705	15.48	<.0001
Error	8717	46581525	5343.75648		
Corrected Total	8718	46664231			

Root MSE	73.10100	R-Square	0.0018
Dependent Mean	96.59284	Adj R-Sq	0.0017
CoeffVar	75.67952		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr> |t|
Intercept	1	92.88761	1.22472	75.84	<.0001
RF	1	0.07217	0.01834	3.93	<.0001

Appendix E: Abstract of published paper on Objective Three

Journal of Animal and Veterinary Sciences
2020; 7(2): 8-12
http://www.openscienceonline.com/journal/javs

Open Science

Variability in Monthly Rainfall and Temperature Has an Influence on Daily Milk Production in Sahiwal Cows in Kenya

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Abstract

Climate change leads to alteration of environmental conditions directly or indirectly through anthropogenic activities. The consequences include fluctuations in the mean as well as variability of recognizable environmental variables with the changes persisting for longer than normal periods. Climate change poses numerous serious threats to livestock production through increased temperature, changes and shifts in rainfall distribution and increased frequency of extreme weather events. Grazing systems that are dependent on the natural cycle of climatic conditions are expected to be more seriously impacted by climate change. The consequences of climate change include increased heat stress, reduced water and feed quality and availability, increased cases of diseases and pests and or emergence of new ones. As livestock farmers in the tropics continue to bear the brunt of climate change, there is need to understand how the variability of identifiable environmental variables influence livestock performance. The objective of this study was to determine the influence of rainfall and temperature of milk yield in Sahiwal cattle in Kenya. Monthly milk yield records of Sahiwal cows and meteorological data for monthly minimum and maximum temperature and rainfall for a period of 32 years were extracted from records at the national Sahiwal stud, Naivasha, Kenya. The relationship between the variables was studied by multiple regression analysis. Minimum and maximum temperature and monthly rainfall significantly ($P<0.05$) affected monthly milk yield. The proportion of total variation accounted for by climatic variables was small (0.5%) but significant. Each individual weather variable accounted for a small proportion of total variation. Minimum and maximum temperature had a negative effect on monthly milk yield. For every 1°C increase temperature, in monthly milk yield decreased by -1.58kg and -1.17kg, respectively. A 1 mm increase in monthly rainfall of monthly caused monthly milk yield to increase by 0.07kg. Mitigating strategies are required to alleviate the negative effects of temperature on monthly milk yield. Sound grazing management and feed conservation could harness the advantage of the positive effect of rainfall on milk yield.

Keywords

Climate Change, Heat Stress, Mitigation, Rainfall Variability

Appendix F: Abstract of conference paper on Objective One

Tropentag, September 15 - 17, 2021, hybrid conference

"Towards shifting paradigms in agriculture for a healthy and sustainable future"

Characterisation of the Variability in Monthly Rainfall and Temperature in Grazing Ecosystem Supporting Sahiwal National Stud Herd in Naivasha, Kenya

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Abstract

Abstract
The present study evaluated the trends of rainfall and temperature at the national Sahiwal stud, Nakuru, kenya. Data on climatic variables comprising monthly rainfall (mm), minimum and maximum temperatures were obtained from the meteorological weather station within the Stud. The coefficient of variation (CV), percentage departure from the mean (Anomalies), Precipitation Concentration Index (PCI) and moving average were computed to evaluate the variability of rainfall and temperature. The detection of trends and their analysis were performed using parametric and non-parametric tests. The Mann-Kendall (MK) trend test was used to detect trends while the Sen's Slope test was used to compute the slope using Sen's method. The mean annual rainfall was 578.5± 151.3 mm and a CV of 24.2%. The PCI revealed that the study area has had rainfall with moderate concentration over the years, with about 34% of the years having high rainfall concentration. The rainfall anomalies found in the current study depict inter-annual variability with the trend in the anomalies being more varied in recent years. Mean annual and long season rain decreased by 38.5 and 25.5 mm per decade while short season rain increased by 69 mm per decade. The short season rain had higher CV (59.2%) than long season rain (49.2%). MK trend analysis test revealed found as statistically significant decreasing trend for long and annual rainfall and a significant increase for short rains. The mean temperature for the study area ranged from 10.4 to 28.5oC. The rate of change of minimum, maximum and mean monthly temperature was found to be was 0.017oC, -0.158 oC and -0.09oC per decade. The overall anomalies of mean annual temperature showed inter annual variability. The MK trend analysis revealed non-significant increase and decline for minimum and mean temperature, respectively. The months of April and May showed significant increase while the months of February and September had significant decline, indicating inter-annual variability in minimum temperature. The results of the current study point towards the need to adjust farming activities with the variability occurrence and design mitigation strategies to enhance adaptive capacity and resilience to climate change for livestock production systems.

Keywords: Mann-Kendall trend test, Rainfall, Sen's Slope estimator, trends

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