TEMPORAL CHARACTERIZATION OF DAILY RAINFALL TRENDS IN ZAMBIA FROM 1983 TO 2019: A CROP GROWING SEASON PERSPECTIVE.

By

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Declaration

I Kapila Liteta Biggie, declare that this dissertation is a presentation of my original research work and has not been submitted for any degree or examination at any other university. This dissertation does not contain other person's data, pictures, graphs or other information unless specifically acknowledged as being sourced from other persons. Except where states otherwise by reference or acknowledgment, the work presented is entirely my own.

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Kapila Liteta Biggie Date

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Certificate of Approval

The dissertation of Kapila Liteta Biggie is approved as fulfilling the requirements for the award of the Degree of Master of Science in Geography of the University of Zambia. Signed:

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Abstract

Daily rainfall amounts and distribution are known to be highly variable leading to either low crop yields or total crop failure in some parts of Zambia because many small scale farmers depend on it as a main source of moisture to support the growth of crops. Therefore, this study aims to provide improved knowledge and evidence on current (1983-2019) rainfall trends in Zambia using CHIRPS data with the aim of drawing inferences of their implications on the length of crop growing seasons. The study adopted an explanatory sequential embedded mixed-method research design that allowed approaching the study problems from different perspectives. Stratified random sampling and purposive sampling methods were utilized to reach the saturation point. Objective one was analyzed with The Mann-Kendall (MK) test, a statistical non-parametric test widely used for trend analysis in climatological and hydrological time series data. Mann-Kendall test is advantageous because it does not require the data to be normally distributed. The Standard Precipitation Index technique was employed in determining the characteristics of intra-annual rainfall variability. Furthermore, qualitative data analysis was performed by utilising a rainfall-based criterion which was earlier used by the Famine and Early Warning System (FEWS). Results show that the average rain season onset dates are 19th, 17th, and 16th of November for agro-ecological regions 1, 2, and 3 respectively. Further, with an average withdraw date of 19th March; agro-ecological region 3 experiences the latest cessation of the rainy season. Trends in rainy season length were found to be declining across all agro-ecological regions with the steepest slope on the Sen's estimator (-0.11) being observed over agro-ecological region 2, followed by region 1 (-0.08) and region 3 (-0.06) respectively. The observation that rainy seasons are getting shorter reflects the late onset that has been found across all agro-ecological regions. In conclusion, the observed decrease in the length of the rainy season translates into shorter crop growing seasons. This is likely to affect the choice of crops to be grown in each of the three agro-ecological regions. Therefore, the research recommends farmers in AER 3 potentially to have multiple harvests in any given season or could easily diversify. However, in the case of the Agro ecological Regions 1 and 2 early maturity crops and establishment of irrigation systems are possible solutions to the observed decrease in rainy season length.

Keywords: Rain season onset, rain season cessation, rain season length, CHIRPS dataset

Dedication

I dedicate this dissertation to my parents Adam Kapila (late), Media Chipungu, and all my relatives. All of you have given me the spirit of perseverance.

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List of Abbreviations and Acronyms

AERs	:	Agro-Ecological Regions
AEZs	:	Agro-Ecological Zones
FEWS	:	Famine and Early Warning System
ANU	:	Australian National University
CSO	:	Central Statistical Office
CHIRPS-V1	:	Climate Hazard Group InfraRed Precipitation with Station Data
°C	:	Degree Celsius
DFID	:	Department for International Development
ECA	:	Economic Commission for Africa
ENSO	:	El Niño Southern Oscillation
FAO	:	Food and Agriculture Organization
GDP	:	Gross Domestic Product
GHGs	:	Greenhouse Gases
GRZ	:	Government Republic of Zambia
IAPRI	:	Indaba Agricultural Policy Research Institute
IPCC	:	Intergovernmental Panel on Climate Change
ITCZ	:	Inter-tropical Convergence Zone
IUCN	:	International Union for Conservation of Nature
km^2	:	Kilometre Squared
KNMI	:	The Royal Dutch Meteorological Institute
LDC	:	Least Developed Country
MAP	:	Minimum Average Precipitation
MOA	:	Ministry of Agriculture
MK	:	Mann-Kendall
Mm	:	Millimeter
MTENR	:	Ministry of Tourism, Environment and Natural Resources
NAPA	:	Nationl Policy for Adaptation
SASSCAL	:	Southern African Science Service Centre for Climate Change and Adaptive Land Management
SPSS	:	Statistical Package for Social Sciences

SPI	:	Standard Precipitation Index
SDG	:	Sustainable Development Goals
WMO	:	World Meteorological Organisation
WFP	:	World Food Programme
UNFCCC	:	United Nations Framework Convention on Climate Change
UNDP	:	United Nations Development Programme
UNEP	:	United Nations Environment Programme
USDA	:	United States Department of Agriculture
USGS	:	United States Geological Survey

CHAPTER ONE

INTRODUCTION

1.1. Background to the study

The economies of Africa largely depend on rain fed agriculture (FAO, 2004). According to the Seventh National Development Plan (2017-2021), the agriculture sector in Zambia is the fourth largest contributor to national GDP (8.7 percent) and the largest contributor to employment. Zambia's agricultural sector is said to be key to the development of the Zambian economy and provides livelihood for more than 60% of the population (Jain, 2007). Agriculture is also the major national employer with 85% of the labour force working as subsistence farmers (DFID, 1999) while 90% is established in informal farming (CSO, 2010). The importance of the agricultural sector is clearly outlined in national development plans and is backed up by national policy and commitments made towards this.

Further, the agriculture sector is critical for achieving diversification, economic growth and poverty reduction in Zambia (CSO, 2019). It covers 98% small scale farmers whose agricultural activities are entirely dependent on rainfall (FAO, 2004). This makes it extremely vulnerable to rainfall variability and impacts of climate change (NAPA 2007; Phiri et al, 2013). In the agriculture sector, rainfall is the most important weather factor particularly among small scale farmers. Existence of increased rainfall variability will likely affect Zambia's set national development goal of attaining strengthened agricultural and income growth (Hachingota et al., 2013).

Over time, Zambia has experienced variations involving both increasing and decreasing trends in the rainfall quantities as well as differing periods of onset and offset of rainfall (Mubanga and Umar, 2014; Mbewe and Mubanga, 2019). Further, the country has experienced delays in start of rainfall, number of rain days and cessation of rainfall, length of growing season and distribution of extreme rainfall events over parts of Zambia(Mulenga and Wineman, 2014; Chabala et al., 2013).

Like most developing countries, Zambia's small-scale agriculture is largely rain fed with a distinct production season running from October to April. Rain fed agriculture is vulnerable to weather shocks, in the recent times small scale farmers have been experiencing variations and rainfall performance particularly relating to dry spells during December, January, and February (Hachingonta and Reason, 2006). During La Nina years, Zambia tends to see decreased dry-spell frequency and increased wet-spell frequency (Hachingota and Reason, 2006). In this context, a dry spell is a five-day period with less than 5mm of rainfall and a wet spell as a five-day period with more than 20mm of rainfall.

Extreme rainfall variability can have devastating socio-economic impacts. Impacts associated with climate extremes include floods and droughts resulting in loss of life and property, food insecurity, water scarcity, power and communication interruptions, poor infrastructure, and other socio-economic disruptions (Chabala et al., 2013). Detailed characterization of spatial and temporal trends of daily rainfall in Zambia is therefore essential for effective adaptation to all rainfall dependent activities such as farming. The IPCC (2007) estimated that climate change will lead to increases in the frequency and intensity of natural disasters and extreme weather events, such as floods and droughts, changes in rainfall patterns with an expected reduction in agricultural productivity in marginal areas, especially in sub-Saharan Africa. In Zambia, researchers have reported increased rainfall variability and a season of epic wet and dry periods with increased frequencies and intensities in floods and droughts (Sichingabula, 1998; Mubanga and Umar, 2014; Mubanga et al., 2015; Mubanga and Ferguson, 2017). Further, food security has been highly threatened because of these climatic variations (WFP, 2011).

The occurrence of wet and dry spells within the rainfall season determines the water availability for rain-fed agriculture. Very limited efforts have been made to understand their characteristics well and predict the interannual variability of the intra-seasonal characteristics of the wet and dry spells in Zambia (Kampata et al., 2008; Huang et al., 2013).

The importance of understanding rainfall characteristics is the key environmental constraint for hydrological, biogeochemical, agronomical and ecological processes (Dunkerley, 2008). While rainfall amount, expressed as an annual, monthly, or less frequently daily precipitation depth is a key variable, other characteristics of rainfall, including rainfall intensity and duration can significantly influence the partitioning of water among canopy interception, surface ponding, evapotranspiration, shallow, and deep soil infiltration (Wang et al., 2005; de Wit and Stankiewiciz, 2006).

Moreover, properties of single rain events such as intensity and duration directly affect runoff mechanisms and related processes (Haile et al., 2011). For instance, intra-event variability of intensity within a rain event can significantly impact on runoff processes and flood generation (Kusumastuti et al., 2007), while runoff strongly controls water available for plant growth and soil biogeochemical processes in water limited environments (Sun et al., 2006). A thorough understanding of rain properties and their changes in time is essential to correctly characterize the earth system and is of particular importance for models of land surface hydrology, biogeochemistry, and ecology that are used to simulate human systems in a context of global and environmental changes. This is important especially in Zambia where most farmers depend on rain-fed agriculture and rangelands for their livelihoods (Cooper et al., 2008).

Droughts or dry spells and floods are extreme climate events that are likely to change more rapidly than the mean climate. Wilhite and Buchanan-Smith (2005) described these extreme climate events to be among the Worlds costliest natural disasters. Davis (2011) indicates that with over 70% of farmers in sub-Saharan Africa relying on rain fed agriculture, any changes in rainfall distribution are disastrous for crop production. Sivakumar (1991) reported that the success or failure of a crop depends more on the distribution of the total rainfall in that period. Hence, many scholars have attributed long dry spells within a growing season and shorter rain seasons as the major contributing factors to low yields. Although it is not possible to influence timing and amount of rainfall, knowledge of their frequency for a variety of duration is imperative, if they are to be well managed (Chabala et al., 2013).

Rainfall is the most important limiting factor in rain-fed farming systems in Africa (Niles et al. 2015) since it determines availability of soil moisture required for potential productivity. The amount and distribution of rainfall determines suitability of crop varieties and related agronomic management at different locations (Muthoni et al. 2017). Low or sub-optimal rainfall contribute to agricultural droughts that retard plant growth and reduce yields (Zampieri et al., 2017; Zipper et al., 2016) while extremely high rainfall events could destroy crops.

Generally, the analysis of extreme trends and variability in annual daily rainfall and temperature has been carried out in recent years by several researchers in various parts of the World at varying spatial and temporal scales. However, in Zambia, few studies have characterized the behaviour of daily rainfall trends for purposes of determining the effects on the length of crop growing season for the country. Despite the perceived and actual damaging effects of rainfall variability in Zambia, studies on long term changes in seasonal rainfall accompanying extreme events such as floods and dry spells are limited(Chabala et al.,2013 This study aimed at analysing the characteristics of daily rainfall trends with the intention of drawing inferences to the length of crop growing season.

1.2 Statement of the problem

The climate in Zambia is characterized by uncertainties; erratic weather patterns such as heat stress, droughts, longer or prolonged dry seasons, and uncertainty in rainfall adds pressure on already stressed systems (Mulenga et al., 2017). Further, change the in climate variables such as rainfall and temperature have drastic consequences on subsistence rain-fed crops that results into yield decline and vulnerability in the form of food insecurity (Chisanga, 2017).

Rainfall is reportedly unreliable and highly variable in terms of its onset, cessation, amount and distribution, leading to either low crop yields or total crop failure in some parts of Zambia (Mulenga at al., 2017). In addition, poor crop husbandry practices and a lack of precise information on rainfall onset, duration, amount, cessation and pattern make farming a risky venture. In most instances in Zambia, farmers start tilling land after the onset of rainfall as a result, optimal potential crop productivity is never attained because of the mismatch between the timing of optimum moisture conditions and the crop's peak water requirements (Mbewe and Mubanga, 2019).

In Zambia, farming patterns are gradually changing as they are faced with perceived climate change and its negative consequences on agriculture (Chabala et al., 2013). Agriculture is affected in terms of low yields and increase in animal diseases due to reduced precipitation, increasing warming conditions, increased evapotranspiration, shortened crop growing season due to late onset and early cessation of rainfall (FAO, 2012). The fluctuations in rainfall patterns have led to a reduction in crop yields as most of the crops die before reaching maturity stage. As a result of these variations in the rainy season Mbewe and Mubanga (2019) reported that farmers in Chongwe have resorted to change in farming systems, preferring early maturing maize seeds that do not require a long growing season that is not high yielding, practising of intercropping, crop rotation and legume technology. It is therefore essential to generate and characterize daily rainfall trends to maximize available rainfall for purposes of optimum agricultural production.

Induced impacts of climatic changes, such as decrease of early-rainy season rainfall and a high number of extreme events (Christine et al., 2007; Kotir, 2011), increase the risk of low yields or even yield losses. Although a seasonal forecast system exist in Zambia to support the agricultural sector, this information is not precise enough as it only provides approximate rainfall statistics. Even these statistics are often not easily accessible to small scale farmers in rural areas. As a consequence, rain-fed agriculture especially in remote areas is still based on the trial-and-error principle. As such, researchers have suggested the need for a more detailed analysis of rainfall trends (Usman and Reason, 2004; Tadross et al. 2005; Hachingota and Reason, 2006; Hachingota et al. 2008)

Though much research on various aspects of climate change has been done in Zambia by some scholars such as Chabala et al,(2013), Mubanga and Umar (2014), Sichingabula (1998) and Mbewe and Mubanga (2019), research in the characteristics of daily rainfall trends to determine how it has affected the length of crop growing season for each agro-ecological region limited (Jadadheesha et al., 2003; Usman and Reason, 2004). Hence, this research tried to address these gaps by characterising rainfall trends for Zambia and investigated its implications on the length of crop growing season using accurately measured CHIRPS data sets.

1.3. Aim

The aim of this study was to characterize the trends in daily rainfall in Zambia's agro ecologica4l regions using CHIRPS data sets for purposes of drawing inferences on how the trends have affected its crop growing season.

1.4.Objectives

The study pursued the following specific objectives:

(i)To generate annual temporal rainfall trends for Zambia, from 1983- 2019.

(ii)To determine the characteristics of annual rainfall in Zambia's AERs.

(iii) To assess the implications of the rainfall trend on the length of crop growing season of Zambia over the period 1983 to 2019.

1.5.Research Hypotheses:

(i) There is a significant trend in daily rainfall for Zambia from 1983 to 2019.

1.6.Research Questions

Objectives two and three were studied using the following research questions.

(i) What are the characteristics of rainfall trends over Zambia from 1983 to 2019?
(ii) What are the implications of rainfall trends on the length crop growing season in Zambia from 1983 to 2019?

1.7.Justification of the study

The trends in precipitation have been investigated in many regions of the world. However, in Zambia only a few studies are available as part of global studies or at much localized levels, have assessed trends in crop growing season. Among the reasons that could explain this deficit, the limited access to data seems to be one of the most important.

Furthermore, the general requirement allowing for the collection of a sufficiently large number of long-term rainfall time series, for detecting meaningful changes over the past decades, is especially difficult to meet in Zambia. This is due to several difficulties that emerge in accessing daily meteorological data (Recha et al. 2016). The difficulties related to meteorological data may range from "a limited capacity of meteorological services in getting observational datasets, and human and informatics resources" as mentioned in (Funk et al, 2015).

Since rain fed agriculture is the mainstay for majority of Zambia's population (FAO, 2004; Mubanga and Ferguson 2017; Kabisa et al., 2019) but most rainfall studies have concentrated largely in-situ data (Recha et al. 2016; Guan et al. 2014). Therefore, it was imperative to understand daily characteristics of rainfall trends based on CHIRPS data sets because of its accuracy to enable farmers in planning effectively (Funk et al, 2015).

Rainfall, like many other environmental variables, may have increasing or decreasing tendency through time. Defining this increasing or decreasing trend in rainfall values is very important for agricultural purposes. Also exploring changes in rainfall over long period of time can be very helpful for future studies related to climate change (Funk et al. 2015).

Better understanding of rainfall totals and intra-seasonal statistics of wet and dry spells is of paramount importance in the policy planning and management of agriculture and other rainfall dependent sectors of the economy. This is in line with the Sustainable Development Goals that were formulated in the year 2015 by the member states of the United Nations. Availability of information on the characteristic in terms of trends in rainfall which this study aims to derive may contribute significantly towards the achievement of sustainable development goals of eradicating hunger and extreme poverty.

Findings of this research provides accurate spatial evidence to support agronomic and crop breeding programmes to setup empirical experiments aimed at developing cultivars and management practices adapted to climatic trends in each agriculture region in Zambia. Crop breeders could target regions that exhibit significant increase or decrease in rainfall to set up multi-location trials for developing cultivars adapted to specific climatic regimes.

Besides, the United Nations Sustainable Development Goal number one prefers eradicating poverty and hunger to other SDGs (UNDP, 2015) of which climatologically trends in terms of rainfall are major contributors in achieving this goal. Rainfall trends have continued affecting people's agricultural productivity and if there are no location specific investigation and realization of its negative effects then mitigation and adaptation would be delayed and the future effects on yields would be disastrous (Zambia Country Climate Risk Assessment Report, 2018).

1.8.Scope and Limitations of the Study

The research focused on one climatic element rainfall because it is the main element of weather that influence arable farming agriculture.

Preliminary surveys indicated the following limitations were accosted with;

(i) The study focused on arable agriculture crop excluding other forms of agriculture undertaken in the AERs since mixed farming is predominantly practiced by subsistence farmers in all AERs of Zambia.

(ii) The study focused on only one climatic element rainfall while excluding the others, since rainfall is the main elements required for plant growth to occur. Secondly due to data limitations in undertaking key informative interviews because of corona virus pandemic the study focused on Climate Hazard Group Infrared Precipitation with Station Data only because the data sets are valid and reliable to reduce compromise in the quality of the results.

1.9.Operational Definitions of Key Terms and Concepts

Climate Variability: Variations in the statistical distribution of weather patterns on a temporal and spatial scale.

Climate Change: Is any change in climate over time that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere in addition to natural climate variability observed over comparable time periods.

Crop growing season: is the period of the year when crops and other plants grow successfully.

Rainfall trends: is defined as the general movement of a series over an extended period or it is the long-term change in the dependent variable over a long period of time

1.10. Structure of the dissertation

Chapter One outlines the background of the study, the problem statement, objectives of the study, the hypothesis and research questions and the justification of the study. Chapter Two reviews the literature on climate change, rainfall trends and the length of crop growing season in Zambia Chapter Three outlines the study area in terms of location and the physical characteristics. Chapter Four presents the methodology used in data collection and further outlines the analytical techniques used. Chapter Five presents the results of the study based on the objectives. Chapter Six discusses the results of the study and highlight the implications of rainfall trends on the length of crop growing season. Chapter Seven gives the conclusion of the study; and recommendations.

CHAPTER TWO

REVIEW OF LITERATURE

2.0. Introduction

This chapter covers the previous studies related to climate change and rainfall trends highlighting the knowledge gaps the proposed research study intends to fill.

2.1. Climate Change

Climate change is a global concern with significant current and future impacts to society and ecological systems. Anthropogenic GHG emissions, which have been steadily increasing since the 1970s, are identified as the primary driver of climate change (IPCC, 2014). The largest increase in emissions has occurred since 2000, despite worldwide mitigation efforts, with 78% of those emissions caused by fossil fuel combustion and industrial processes (McSweeney et al., 2010). Although impoverished countries, especially those in warm climates, have borne the brunt of climate change effects so far, no areas of the globe have been immune to climate change effects (IPCC, 2007). The most direct and obvious impacts include increased frequency and intensity of droughts, wildfires, precipitation, extreme weather events, floods, and heat waves.

The IPCC (IPCC, 2014:117) defines climate change as a "state of the climate that can be identified using statistical test, by changes in the mean and or the variability of its properties, and that persist for an extended period, for decades or longer. The changes in climate may be because of natural internal processes or external forcing such as modulations of the water cycle, volcanic eruption, and persistent anthropogenic changes in the consumption of the atmosphere or land". The variability of the daily temperature and precipitation extremes are considered as a signature of climate change in a region (IPCC, 2007; Zhang et al., 2011).

2.2. Climate trends in Europe

Colombo et al. (2007) studied the climatic behaviour of two principal observables, temperature and rainfall as obtained from 50 meteorological stations located in Italy for 1961-2000. Stations were classified to different classes according to their geographic location. They checked for trends in temperature and rainfall during a period of 10 years (1991-2000), using a reference World Meteorological Organisations (WMO) standard data set. This reference data set is the climatic normal that contains the long-term means for the period 1961-1990 for Italy. Summer temperatures showed a sharp significant increase starting from 1980, especially for mountain stations. The trend analysis of precipitation showed evident increase during autumn and winter for mountain stations, but for the rest of Italy, precipitation had decreased during early spring.

Cannarozzo et al. (2006) studied the temporal trends and spatial distribution of annual, seasonal and monthly rainfall in Sicily, Italy for 1921-2000. To determine the possible trend in rainfall, the Mann-Kendal test was applied to data from 250 meteorological stations. Local significance levels of each meteorological station were interpolated using the inverse distance weighting method to analyze trend variation over the Sicily Island. According to their results, increasing precipitation trend was less clear and was found out only at few stations in summer period. A significant decreasing precipitation trend was more frequently found annually and in the winter seasons.

2.3. Climate trends in Asia

Jiang et al. (2007) studied the effects of climate warming on precipitation variation in the Yangtze River Basin, China. Their primary data sources are daily precipitation observations measured at 147 stations for 1961-2000. They analyzed the trend in precipitation with the Mann-Kendal test, and the spatial trend with simple regression. They found out significant increasing trend on precipitation and rainstorm frequency during the summer season. Additionally, they found out significant increasing trend in flood discharges for the time period of the study. They concluded that trends in precipitation and rainstorm are probably caused by climate warming. The seasonality, amount, distribution and the timing of the rainfall is of particular importance to the population that depends on rain-fed agriculture for the livelihoods. But due to climate change, the reliability of the rain for agricultural purposes has reduced in the recent years.

2.4. Revelation of new trends in Australian Temperatures

Researchers have developed Australia’s longest daily temperature record, identifying a decrease in cold extremes and an increase in heatwaves since 1838. Joelle (2020) from the Australian National University (ANU) says the study examined daily records from around Adelaide and the analysis shows that snow was once a regular feature of Southern Australian climate. As Australia continues to warm, they also observed a decrease in cold extremes and an increase in heat waves. While most other historical studies of Australia's climate have looked at annual or monthly values, the new record means it is possible to look at daily extremes. This is important as the impact of global temperatures increases on human health; agriculture and the environment are most keenly felt through extreme events like heat waves (Joelle, 2020).

2.5. Historical Global Temperature Trends

Global temperatures rose significantly throughout the 20th Century (IPCC, 2004). The impacts of increased temperatures due to greenhouse gases can be felt almost uniformly over the Earth. As energy from the sun hits the surface of the earth, it gets absorbed and then emitted back out into the atmosphere as infrared light. This infrared light is what keeps the surface of the Earth warm as it naturally gets kept in the atmosphere by various greenhouse gases. Much of it eventually escapes the atmosphere, keeping the Earth's temperature at a level suitable for sustaining life. In 2011, carbon dioxide concentrations were up by 40% since 1750 while methane concentrations were up by 150% in the same time frame (Ciais et al., 2013). With the current increases in greenhouse gas concentrations in the atmosphere, too much heat is being trapped causing temperatures to rise steadily (IPCC, 2014).

2.6. Significance of Temperature to Agriculture

All crops have minimum, maximum, and optimum temperatures for growth (USDA, 2013; IPCC, 2014). An increase in temperatures will likely lead to reduced growth, reduced yields by increasing evapotranspiration, which would reduce water availability for crops. Temperature has major effects on photosynthesis and respiration, plant growth and phonological development. Phonology is particularly important in cooler regions and at higher altitudes. As a rough guide, atmospheric temperatures experienced by crops decrease by about 1°C for each 2°C in latitude, for each 100m increase in altitude. Temperature is important in controlling phonological changes in development from germination and seedling emergence, through vegetative growth to floral initiation and reproductive growth. Of course, variation in temperature tolerance is evident both within populations of single plants and between genotype. Temperature within a plant, particularly at the growing points, may differ from prevailing air temperatures for several reasons, including plant structure and density, distance from the soil surface, and shade.

Temperature also has a major influence on the rate of evaporative loss from soils and leaf surfaces (Easterling et al., 2007). The warming of the global climate is an irrefutably observed trend over the last century. Global temperatures have risen 0.13°C per decade over the past fifty years which is double the decadal rise over the last 100 years (Solomon, 2007). In addition to global rising temperatures, observations have revealed significant variability in temperature trends within decades and even within individual years, leading to extreme swings in regional temperatures (Stocker, 2014). This increase of global temperatures has led to several adverse effects such as melting of polar ice caps, increased droughts, rising ocean temperatures, and degradation of ecological systems as vegetation and animal life struggles to adapt at the rate temperatures rise.

As temperature rise, several positive feedback loops can emerge which create conditions that result in further temperature increases. Rising temperatures impact the exchange of greenhouse gases, such as carbon dioxide and methane between land and ocean ecosystems (Raynaud et al., 1993). These gas cycles are heavily influenced by temperature. Rising temperatures tend to cause these cycles to output more gas into the atmosphere than the surface takes back, resulting in higher greenhouse gas concentrations which in turn continue to raise temperature (IPCC, 2007).

2.7. Historical Global Precipitation Trends

The steady warming of the Earth's surface can have varying impacts over time. Increased temperatures lead to an increase in evaporation of water from the Earth's surface. Higher evaporations rates will lead to higher atmospheric moisture in several parts of the world. Rainfall rates rely heavily on convergence rates so as the rate moisture increases, the rate of rainfall will increase with it (Trenberth et al., 2003).

A general pattern emerges of wet areas receiving more rainfall and dry areas receiving less rainfall. Overall, rainfall rates will decrease in the drier subtropics and rise in the wetter subpolar regions (GFDL, 2007). Several large areas across the globe have observed increased precipitation trends such as the eastern Americas, and northern Europe and Asia, while the Mediterranean, Southern Africa, and Southern Asia is experiencing declining rainfall amounts (Solomon, 2007).

Ogallo et al (1988) investigated the persistence of the monthly rainfall over East Africa and found out that the rainfall patterns vary from each month persistently. Further works of Ogallo (1979) postulated that rainfall over Africa is oscillatory in time. Chabala et al, (2013) in their study on characterization of temporal changes in rainfall and temperature in Zambia found that the trends in seasonal rainfall were variable while temperatures generally showed an increasing trend.

Rainfall amount, distribution and variability is one of the most important aspects that determine the day-to-day socioeconomic activities in any given region or country. High variations have been observed in the monthly distribution of the rainfall globally. Trends in rainfall distribution have been studied and researched by many authors in different aspects (Chabala et al, 2013, Mubanga, 2014, Sichingabula 1998). The studies have shown that changes in rainfall are typically harder to detect because rainfall varies so much from place to place from year to year.

2.8. Precipitation and its effects on crops

The effects of precipitation on crop yields are more difficult to predict than those of carbon dioxide concentration and temperature because the connection between precipitation and soil moisture is relatively indirect. An increase in mean annual and summer precipitation would not necessarily lead to greater water availability to crops when they need it because of improper timing, increased evapotranspiration, and more intense rainfall events leading to greater runoff (USDA, 2013). Heavier rainfall events could also increase erosion, which selectively remove organic matter, fine soil particles, and nutrients from the soil, thus reducing soil fertility (Brady and Weil, 2008). For crops, more important than the total amount of rainfall during the growing season is its distribution throughout the season. For example, maize is more sensitive to excess water at its early stages and to insufficient water during grain-filling (Mulenga and Wineman, 2017).

2.9. Climate change and crop yields

Substantial literature converges on the notion that climate change will variously impact on agriculture, notably on crop yields under rain fed agriculture systems (Parry et al., 2004, Mathew and Reynolds, 2010 and Jawoo, 2013). The impact will be felt through reduction of suitable areas for agriculture, altering the length of growing season and reducing the yield potential (Cline, 2007, Vreiling et al, 2013). Generally, a 4°C warming is expected to reduce crop yields by 15-80% (IPCC, 2010). Although some regions may benefit from climate change because of increase in the length of the growing season, expansion of agriculture land and increase in warm temperatures (Parry et al., 1999), most areas and Africa especially is projected to be negatively affected (Mearns et al., 1997. This implies that adverse shifts in climate will cause devastating effects on agriculture necessitating increased attention to be paid to assessing risk to African agriculture under climate change. Some research have projected moderate to severe effects on agricultural productivity occurring in as early as two decades depending on weather adaptation to climate changes is taken into consideration (Lobel et al., 2013).

The impact of rainfall on crop production can be related to its total seasonal amount or its intra seasonal distribution. In the extreme cases of droughts, with very low total seasonal amounts of rainfall, crop production suffers the most. But more subtle intra-seasonal variations in rainfall distribution during crop growing periods, without a change in total seasonal amount, can also cause substantial reductions in yields. This means that the number of rainy days during the growing period is as important, if not more, as that of the seasonal total (Worishima and Akasaka, 2010).

Periods of extreme heat are predicted to cause crop failures, physical fatigue, hunger, loss of income and more diseases to both humans and animals. Droughts are expected to have similar impacts. Flooding is also expected to increase, resulting in damage to crops (IUCN, 2007).

The Fourth Assessment of the Intergovernmental Panel on Climate Change states that the impacts of human induced climate change are likely to be felt in poor countries and poor communities first. The UN Framework Convention on Climate Change (UNFCCC) also recognizes Africa as being particularly vulnerable,and adds to this the Least Developed Countries (LDCs). Africa is among the most vulnerable regions of the world to climate change (IPCC, 2007).

The Intergovernmental Panel on Climate Change (IPCC, 2014) stated that there are high economic losses from weather and climate related disasters which have increased during the last 60 years and will have greater impacts on sectors with closer links to climate, such as water, agriculture and food security; while the largest fatality rates and economic losses caused by hydro meteorological induced disasters are registered in developing countries.. According to the IPCC (2012) increasing evidence indicates that global warming has resulted in a growing frequency and severity of extreme climate events in the past decades, such as heat wave, high temperature, and multi-region heavy rainfall and flood.

Extreme precipitation events have been increasing since the late 20th century in the mid-latitude and high latitude land areas of the Northern hemisphere (IPCC, 2007). Climatic precipitation extremes aggravate the frequency, intensity, and duration of disasters, such as droughts and floods, and cause catastrophic damage to agriculture, ecology and life (You et al., 2008; Penalba and Robledo, 2010; Fu et al., 2013). Extreme events have received worldwide attention due to their large-scale impacts and have been studied in many regions of the world (Deng et al., 2014; Song et al., 2015 and Yan et al., 2015).

Africa is considered highly vulnerable to climate change (FAO, 2004), largely because many socio-economic activities in Africa, particularly agriculture, depend on climate and especially rainfall. Consequently, climatic variations and change have an impact on the productivity of many socio-economic activities (Obasi, 2005). Within the agriculture sector drought is arguably the most important climatic challenge and has major impacts on agriculture. (Sichingabula 1998; Mubanga 2014).

Further, projections of future change place southern Africa's agriculture sector at the forefront of climate change vulnerability with potential negative impacts on revenue from dryland farming (Kurukulasuriya, et al., 2006). Therefore, rainfall is a major determinant of agricultural production in any agro-ecological zone globally (Cooper et al., 2008). The reliance of the agricultural sector on natural rainfall places it at a serious risk of shrinking due to the inter-annual rainfall variations. Nnyaladzi (2009) observed that with the declining rainfall trends in Southern Africa and most of the sub-Saharan African region, agricultural production and other economic activities are most likely to decline, raising concerns about issues of food security.

2.9.1. Rainfall trends in Africa

Rainfall in Africa is about 670 mm per year with greater variation in time and place. Temporal variability of rainfall is typically 40% around the mean, much higher than in temperate zones. At sub-regional level, the spatial distribution of rainfall is varied. The highest rainfall occurs in the Island countries (1,700 mm per year), the central African Countries (1,430 mm), and the Gulf of Guinea (1, 407 mm per year). The lowest rainfall occurs in the northern countries where average annual rainfall is only 71.4 mm per year (ECA, 2015).

Maidment et al. (2015) observed increasing rainfall trend in Southern Zambia (0.04 mm per day in a year) and the Lake Victoria Basin (<0.02mm per day in a year) using CHIRPS-v1 data from 1983 to 2008 that were resampled to march coarser 2.5 degrees grids (-275 km at equator). IPCC (2007) also reported that the increasing annual rainfall in Southern Africa was driven mainly by more December, January and February rains that are attributed to sea surface temperature patterns particularly the Pacific Walker Circulation.

Davis (2011) evidence for rainfall trends suggest moderate decreases in annual rainfall over parts of Southern Africa contrary to Fauchrean et al (2003) indicating inter-annual rainfall variability over Southern Africa has increased since the late 1960's and that droughts have become more intense and widespread in the region. But Fowler et al (2005) indicates that there have been concerns that with future climate changes, rainfall events will become more intense and frequent and therefore increase the risks of flooding. High rainfall events that also lead to flooding are determined by four main factors which include intensity, duration, antecedent and soil moisture and the response of the catchment (Hand et al, 2004).

Fauchereau et al., (2003) examined rainfall variability and change during the 20th century in the context of global warming. They reported that although there were no long-term trends of cumulative summertime rainfall anomalies in South Africa, rainfall variability in Southern Africa has experienced significant modulations, especially in recent decades. Droughts have become more intense and widespread. New et al. (2006) reported a decrease in average rainfall intensity and an increase in dry spell length from 1961 to 2000.

Furthermore, a report by the Intergovernmental Panel on Climate Change (IPCC, 2007) showed an increasing trend in rainfall amount from 1901 to 2005 from the equator to tropical eastern Africa but a decreasing trend South of 20 degrees south on the African continent. However, the report also noted that these tendencies were obscure during 1979 and 2005. These studies and reports suggest that annual rainfall has not had a clear tendency in the last 20 or 30 years, but dry periods in Southern Africa have become longer and more intense.

2.9.2. Agriculture and climate change in Sub-Saharan Africa

Since early 21st century, Sub-Saharan Africa has failed to keep pace with the rest of the World in terms of development where a total of 330 million people live in extreme poverty (Hellmuth et al., 2007). In rural areas, about 80 percent of the people depend on agriculture and even those not living in rural areas also depend on it to lift them out of poverty (Haggblade et al., 2004).

However, despite being a very important sector to Africans, production is primarily subsistence oriented and rain-fed (Hellmuth et al., 2007). This means that any change in climatic pattern would affect the production of different crops in the region. So far, Africa follows global trends of recent increase in temperature and records show that it has been warming through 20th century at the rate of about 0.05°C per decade (UNEP, 2002) and in the case of rainfall, mentioned that for many decades now, rainfall pattern has been changing in South Africa, Zimbabwe, Western Mozambique, Southern Malawi and Zambia during 20th Century and 21st Century with the general trend being a dry trend. In fact, rainfall season has been short by one month in that rainfall delay by one month but no change in rainfall cessation month (IPCC, 2014).

2.9.3. Effects of climate change on crop growing season.

The rain season duration is one of the primary factors affecting crop production prospects. Within a specific location, rain season onset and final rain date are varying greatly from one cropping season to another. The variation of onset explains the significant variations in season duration since the onset date is more variable than the end date of the rains. Early onset of rains, relative to the mean date of onset for a given location, results in a longer growing season (Sivakumar, 1988). However, the relationship between onset date and seasonal rainfall duration is not always linear as rainy season characteristics are uncertain.

The effects of climate change on the length of the rain season may vary due to geographical factors, level of preparedness, institutional set up, technological development and financial capabilities (Hepworth, and Gouden, 2007; Wasige, 2009. Higher temperatures in spring and fall would not only cause crops to grow more during those months, but would allow farmers to plant earlier and harvest later if soil conditions are appropriate (e.g., not too wet), thereby increasing the amount of time for crops to grow (USDA, 2013).

In addition to seasonal rainfall variability, higher growing season temperatures can have dramatic impacts on agricultural productivity, farm incomes and food security (Battisti and Naylor, 2009). Barron et al., (2003) also indicates that temperature during the cropping season often exceeds the optimum for physiological processes such as phenology, leaf area development, assimilate accumulation and grain filling. High air temperature around flowering can reduce pollen viability and grain set in major cereals of the tropics (rice, maize, sorghum etc.). The incidence of high soil temperature during crop establishment is also a threat in semi-arid environments. Soil surface temperature greater than 60°C is common in Africa, India and Australia semi-arid tropics, and seedling mortality or thermal injuries are frequent (Stewart and Harsh, 1982).

Intra-seasonal variability leads to extreme climate events that have direct impact on crop production and livelihood opportunities in the agriculture sector. For example, an unprecedented deficit of 49 percent in the all-India average rainfall in July 2002 led to a major drought, while rainfall was close to normal during all the other months of the rainy season (Vreiling, 2013). This led to a decline in farm-level crop productivity especially due to mid-season breaks in the monsoon activity. Global information and early warning systems on food and agriculture indicates that sudden-onset disasters especially floods have increased from 14 percent of all natural disasters in the 1980s to 20 percent in the 1990s and 27 percent since 2000 (FAO, 2008).

2.9.4. Climate Trends in Zambia

Zambia has a tropical climate where temperatures remain relatively cool throughout the year due to the high altitudes of the East African Plateau. The highest seasonal temperatures are reached in the hot, dry season, September to November (22-27°C), and coolest in the winter, June to August (15-20°C). The hot summer months are very dry, receiving almost no rainfall between June and August. Rainfall in Zambia is also strongly influenced by the El Nino Southern Oscillation (ENSO), which causes further inter-annual variability. El Nino brings drier than average conditions in the wet summer months in the Southern half of the country, whilst the north of the country simultaneously experiences significant wetter than average conditions (Zambia Climate Action Report, 2016).

According to Zambia Climate Action Report, (2016) there was a continuous reduction in rainfall amounts and number of rainy days especially over the Southern half of Zambia. The reduction was caused by a deep low-pressure system in the Mozambique Channel that was inducing moist Congo airflow over the Northern parts of Zambia leaving much of the country under relatively dry south-easterly.

Mulenga and Wineman (2014) in their study found that total rainfall over the crop growing season had increased in Chipata. It must be noted however, that the coefficients on rainfall seem quite small, and rainfall levels exhibit a high level of inter-annual variations even when this does not take the form of a trend. Further, the study showed that rainy season onset and offset has shifted resulting into a decrease of the rainy season in Mbala, and Chipata.Another study that was conducted in Chipepo Areas of Southern Zambia by Mubanga and Umar (2014) found that despite the area being an agricultural community, the agricultural sector in the region has been in doldrums for several years. This is due to the inadequate and intermittent rainfall received in the area which fails to sustain crop growth during the farming.

In addition, World Bank (2019) postulated that the performance of Zambia's 2018/2019 agricultural season was one that was filled with challenges that negatively affected production. The season brought to light the seriousness of the impact of climate variability and change on the sector's growth rate from 9.8% in the 2017/2018 season, to minus 21.2% in the 2018/2019 season. This is because the continued rain-fed nature of production left the sector vulnerable to crop failure in the Southern and Western parts of the country from prolonged dry spells (CSO, 2019).

Chabala et al., (2017) indicated that the mean annual maximum temperature for Choma had an increasing trend which was not statistically significant. However, mean annual minimum temperatures for Choma had an increasing trend which was statistically significant. This means that the district has been experiencing significant warmer temperatures with time. The mean and annual maximum and minimum temperatures in Mpika had an increasing upward trend which was not statistically significant. In Serenje, the mean maximum and minimum temperatures had an increasing upward trend that was not statistically significant.

Fauchereau et al., (2003) opined that some parts of Southern Africa which includes Angola, Zambia, Namibia, Mozambique and Malawi are expected to record significant increases in heavy rainfall events which were predicted as a manifestation of rainfall variability. Mubanga (2014) further found that rainfall records show that Southern Zambia experienced below and above average rainfall in the periods 1886-1925 and 1926-1970. After 1970, there was a general decrease in rainfall.

De Wit (2006) reported that climate trends in Zambia exhibit rising temperatures, declining rainfall and increasing frequency of drought. More generally, future climate change and variability in Eastern and Southern Africa is expected to lead to an increase in the severity of extreme weather events like droughts and flooding, and reduced length and regularity of rainfall seasons (Dinar et al., 2008). These changes are likely to have widespread effects on agriculture production.

2.9.5. Climate Change in Zambia

McSweeney et al., (2010) reported that in Zambia average yearly temperatures increased by 1.3°C from the 1960 to 2003, at a mean rate of 0.2°C per decade. Also, the number of hot days (temperature above 25°C) increased by 43 days per year between the years 1960 to 2003. Additionally, Zambia's mean annual rainfall decreased by 1.9mm per month per 10 years from the year 1960 to 2003. The change is most notable in the months of December, January, and February. This has resulted in the reduction of the crop growing season (Tadros et al., 2009).

The evidence from climate scientists on future climate change of Zambia shows a likely increase in the mean annual temperatures of 1.2 to 3.4°C by the year 2060 (McSweeney et al., 2010). Additionally, the following trends are expected: decrease in the mean annual rainfall, increases in the daily rainfall intensity and increase in the frequency of dry spell length (Hulme et al., 2001; Jury, 2013).

2.9.6. Local Farmers' Observations of Climate in Zambia

Farmers reported an increase in intra-seasonal variation, with less dependable rainfall particularly during the January-February period that is critical to maize growth. Maize crop is the most sensitive to drought during this period of silking and grain filling, when the flowers are pollinated and the grain begins to develop (Mubanga and Umar, 2014). Farmers in Northern Province note that hailstorms and other precipitation extremes have increased, and farmers in both Siavonga and Chipata note that rainfall has become more localized, such that one farmer's experience may vary from her neighbours.

2.9.7. Mitigation and Adaptation to climate trends

There are two main strategies to reduce the expected negative effects from climate change: mitigation and adaptation. Mitigation is the process of reducing emissions or increasing sequestration of greenhouse gases to reduce or reverse further global warming (IPCC, 2014). Adaptation is the process of making changes to human or natural systems to reduce the observed or expected negative effects of climate change and take advantage of climate change of the positive effects (IPCC, 2007). These two strategies are complimentary and equally necessary. Mitigation is necessary because even the most effective adaptation efforts will not be able to counteract all the negative effects of climate change if greenhouse gas concentrations increase beyond certain level (Easterling, 1996). Adaptation is necessary because the planet will continue to warm for centuries unless current net carbon dioxide is quickly replaced with net sequestration over a sustained period.

When describing adaptation in crop production, some authors have distinguished between long-term, major changes, which they define as adaptation, and short-term, minor ones, which they define as adjustments (IPCC, 2014). In this nomenclature system, adaptations are changes that transform crop production systems and require new research, technologies, market mechanisms, or government policies, including the introduction of new crops, the translocation of crops, and resource substation (Easterling, 1996). Adjustments, on the other hand, are changes that maintain the basic structure of crop production systems while making them more resilient to future disturbances and are immediately available to producers, such as changes in timing of operations (Mulenga and Winneman; 2014).

Overall, though much research on various aspects of climate change has been done in Zambia by some scholars there was still a research gap in the characteristics of daily rainfall trends and how it has affected the length of crop growing season for each agro-ecological region.

CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

3.0. Introduction

In this chapter, the background information of the study area is given. The background information includes country size and location, population, climate, Topography, soils, climate and vegetation.

3.1. Country size and location

Zambia is a landlocked country covering an area of 752,614 km² (Saasa, 2003) and lies between latitudes 8 and 18° south and longitude 22 and 34° east of Greenwich Meridian. Zambia is divided into ten provinces; each province is subdivided into several districts with a grand total of 73 districts (CSO, 2013). It is centrally located in the Southern region of Africa. The Country shares boarders with eight countries namely Angola, Botswana, Democratic Republic of Congo, Malawi, Mozambique, Namibia, Tanzania and Zimbabwe. Zambia lies on a plateau with an altitude of between 300 and 1800 meters (CSO, 2013).

Figure 1: Map of Zambia

Source: Nations Online Project (2008).

3.2. Population

In the last census in 2022, the population was estimated at 19,610 769 million (Zambia Statistics Agency, 2022). The rural population is estimated at 11.8 million of the total population, whereas the urban population accounts for 7.8 Million. The gender distribution reflects 10,007,713 million women and 9,603,056 men (Zambia Statistics Agency,, 2022).

3.3. Topography

Aregheore (2006) indicated that Zambia has three main topographical features such as mountains with an altitude of at least 1500m; plateau with altitude ranging from 900 to 1500m; and lowlands with altitude ranging 400m and 900m. In fact, the same author postulated that the country is on the great plateau of central Africa at an average altitude of 1200m and most of the landmass lies between 910m and 1370m above sea level. In the North-East, Muchinga Mountains exceed 1800m in height though most rivers and valleys are found in areas.

3.4. Soils

The Zambezi and Luangwa escarpments are mountainous and rocky, while the rest of the country is mainly a level to gently undulating plateau with slopes rarely exceeding 3 to 5 percent (Saasa, 2003). Interfluves mostly comprise deep weathered soils, which occupy tracts of land in the main drainage systems consisting of the Zambezi, Luangwa, Luapula/Chambeshi and Kafue rivers. Major soil types include the black clays and sand clays commonly found in the Kafue basin and the dambo areas. Red clays, sand veld and clay loam soils are common in plateau areas. These soils are generally of moderate fertility status with no salinity problems (Saasa, 2003; 2006 Jain, 2007).

3.5. Vegetation

Zambia has three major vegetation formations namely closed forests, open woodland forests and grasslands. The closed forests are limited in extent, covering only about 6 percent of the country. The most extensive closed forests are the *Cryptosepalum* and *Baikiaea* forests covering parts of North-Western provinces (MTENR, 2003).

Open forests/woodlands are the dominant vegetation formation in Zambia, covering 66% of the forested area (MTENR, 2003). There are four types of woodlands in the country, of which the most extensive is miombo. Miombo woodland covers 42% of the country and is characterized by the following genera: *Brachystegia, Julbernadia and Isoberlina*. This is followed by Kalahari woodlands, characterized by *Mopane, Munga and Termitaria* (MTENR, 2003). Termitaria, or antihill vegetation, covers 3 percent of land, and is present in all regions of the country, except in areas of pure stands. It is classified according to its association with other vegetation types, as in: *Miombo Termitaria, Kalahari Termitaria, Mopane Termitaria, Munga Termitaria*, Riparian *Termitaria* and Grassland *Termitaria* (MTENR, 2003).

3.6. Climate and Agro-ecological regions

According to Mumba (2002) Zambia's climatic conditions are influenced by the following factors:

3.6.1. Inter-tropical convergence Zone

Inter-tropical convergence zone (ITCZ); which results in Northern part of the country receiving more rainfall than the southern part. The Inter-Tropical Convergence Zone (ITCZ) may be defined as a narrow zone into which low-level tropical equatorward moving air masses from both hemispheres generally converge (Okoola, 1999). It may be summarized as a zone marked with maximum cloudiness, humidity, and precipitation, and minimum wind and pressure.

Rainfall is unimodal and mainly influenced by the Inter-Tropical Convergence Zone (ITCZ) with variations due to altitude, latitude, temperature, relative humidity and control of air masses. The ITCZ is essentially a low-air pressure zone or belt that attracts the moist north-easterly/westerly winds, which in effect bring rainfall to the area (Ngoma, 2008). This low-pressure zone lies mostly over the Democratic Republic of Congo and the Northern parts of Zambia for much of wet season, bringing about the rainy season between the months of November and April. Mean annual rainfall is 1020 mm. Zambia's rainfall increases from the southern to northern parts of the country. It is lowest in agro-ecological region I (below 700 mm), while it is intermediate in the central parts of the country which is agro-ecological region II (between 700 and 1000mm/year) and highest in agro-ecological region III in the northern parts of the country (above 1000 mm) (Ngoma, 2008; Mumba, 2002).

3.6.2. El Niño and Agro-ecological regions of Zambia (AERs)

Rainfall in Zambia is also strongly influenced by the El Niño Southern Oscillation (ENSO), which causes further inter-annual variability. El Niño conditions (warm phase) bring drier than average conditions in the warm and wet winter months of December, January and February in the Southern part of the country, whilst the northern part of the country simultaneously experiences significant wetter than average conditions. The reverse pattern occurs with La Niña cold phase) episodes, with dry conditions in the north and wet conditions in the South. Zambia was one of the countries in Africa most severely affected by the 1997/1998 El Niño event, suffering flooding due to abnormally persistent and heavy rainfall in the north, as well as near-drought conditions in the South (McSweeney et al, 2010).

According to Mumba (2002) Zambia has three seasons namely; warm rainy season (November-April), with temperatures of 27-30ºC, Cool dry season (May-July), with temperatures of 16-27ºC and Hot dry season (August –October), with temperatures of 27-30ºC. Further, Zambia is divided three agro ecological regions and based on the amount of rainfall received; it is further grouped into three agro-ecological regions (Jain, 2007).

3.7. Agro-ecological Region I

It lies in Western and Southern Zambia accounting for 15% of the total land area of the country (Mumba, 2002). AER I is a low rainfall region that receives an average annual rainfall in the range of 400 to 800mm and average temperatures of 30 to 36˚C. The region has diverse and slightly acidic and eroded soil types that are frequently exposed to climatic events such as droughts and flash floods (World Bank, 2003). Due to precipitation or moisture stress and short plant growing season of 60 to 90 days, the region is characterised by drought tolerant and early maturing subsistence mixed cropping systems (Saasa, 2003).

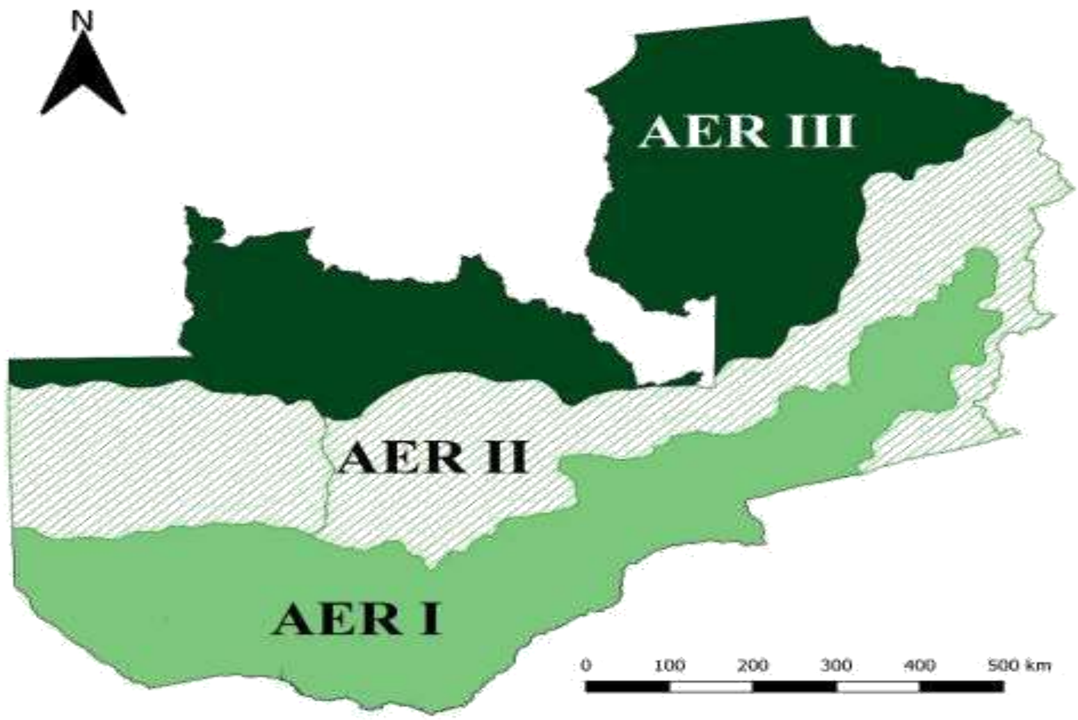
3.8. Agro-ecological region II

Agro-ecological region II: It consists of central part of Zambia extending East through Western and receives between 800 to 1000mm of rainfall annually (World Bank, 2006). AER IIa extends from the eastern to the central parts of the country and is known to have highly fertile soils (Mumba, 2002). Consequently, most of the crops grown in the region include maize, groundnuts, sunflower and horticultural crops (Ngoma, 2008). AER II b extends from the western part of the country and comprises unproductive soils for arable agriculture making it a priority for livestock rearing (Jain, 2007; Phiri et al., 2013).

The region has the most fertile soils with a plant growing season of 90 to 140 days which can support growth of a wide range of crops grown in Zambia. Much of the country's agriculture is in this region and comprises both mixed cropping subsistence to commercial farming (World Bank, 2006; Jain, 2007)

3.9. Agro-ecological region III

It consists of the northern part of the country and receives over 1000mm of rainfall annually (World Bank, 2006). Other characteristics include a long crop growing season of 140-200 days, low probability of drought, and cooler temperatures during the growing season (Saasa, 2003). The amount of rainfall received results in most of soils in the region being leached and acidic (Mumba, 2002). The main crops grown include maize, cassava, finger millet, and beans. Livestock rearing is not very common in this region (World Bank, 2006; Ngoma, 2008).



Source:

Figure 2: Study Area (Ecological Regions)

The map was created using SASSCAL Data available here:

https://data.sasscal.org//metadata//view.php?view=geodata&id=5722

CHAPTER FOUR

RESEARCH METHODOLOGY

4.0. Introduction

The chapter covers the research methodology that was employed in undertaking the study This includes; the research design, data collection methods, data processing and analysis techniques.

4.1. Research Design

The study adopted an explanatory sequential embedded mixed-method research design that allowed approaching the study problems from different perspectives for purposes of improving accuracy in data analysis (Taylor, 1999). The purpose of embedded design, as Creswell (2007) state to collect quantitative and qualitative data simultaneously or sequentially, but to have one form of data play a supportive role to the other form of data. The reason for collecting the second form of data is that it supports the other form of data. The supportive data may either be qualitative or quantitative. This allows enhancement of data quality and the improvement of quantitative data interpretation (Brewer and Hunter, 1989).

4.2. Ontological and Epistemological Consideration

Ontology is the study of 'being', concerned with the nature of existence and the structure of reality (Crotty 1998). In research, ontological issues relate to the nature of reality and its characteristics. Depending on the ontological position taken, reality may be seen as subjective and multiple or objective and singular (Creswell, 2007).

This research adopted the pragmatism research philosophy, according to pragmatism philosophy; research question is the most important determinant of the research philosophy. Pragmatics can combine both, positivists and interpretivsm positions within the scope of a single research according to the nature of the research question. Pragmatic positivist philosophical thought that was utilized in this research collected quantitative rainfall observed recorded data objectively that was used to test the hypothesis in an objectivity ontological perspective, determine the characteristics of daily rainfall trends and assess the implications on the length of crop growing season. Besides, interpretive ontological position that was used in this research considered interpreting the effects of rainfall trends on the length of crop growing season using published reviewed journals and books on rainfall trends and crop growing season (Creswel, 2007).

Epistemology deals with the relationship of the researcher and the researched. This research utilized the positivistic ontology position because rainfall data is recorded in an objective manner and an interpretive epistemology that is based on the assumption that social reality is not singular or objective but is rather shaped by human experiences and social contexts (ontology) especially on the implications of the length of crop growing season, and its therefore best studied within its socio-historic context by reconciling the subjective interpretations of its various participants (Bird, 1998). Interpretive epistemology asserts that social reality is constructed. It argues that knowledge is a product of society, and it cannot be studied independently, thus, a research cannot be free from the researcher's influence and that knowledge is acquired.

Therefore, in this research, both epistemological position namely positivism was used to achieve objective one and two. Interpretive was employed to accomplish objective three. This was essential because it helped the researcher to compare quantitative rainfall trends with the interpretation of findings on the standard precipitation index and the implications on the length of crop growing season.

Pragmatism research philosophy was based on the epistemology perspective that there is no single way to learning but many ways of understanding hence this research adopting a mixed method research design (Creswell, 2007). Knowledge of multiple realities of climate trends on cop growing season was gained through an integration of multiple research methods encompassing both qualitative and quantitative research methods. Through this the researcher gained a better understanding of the manifestation of the problem being investigated from literature and testing of the hypothesis. This mixed method approach enhanced a more detailed understanding of the research hypothesis and questions that led to balanced conclusions and recommendations.

4.3. Axiological Position

This research undertook a value free axiological position with the objective and subjective ontological positions of positivism. The positivistic paradigm argues that there is one reality out there which can be captured using objective, value free research. It assumed that reality is accessible through the sensory experience, is measurable and unambiguous; and that there is independence between the reality, the researcher and the instruments of research (Sumner and Tribe 2008). Therefore, the methodological question in this research was answered by adherents of the positivistic paradigm by assessing that inquiry must be based on methods that strip the context of possible contaminating influences. Structuring the inquiry to be able to discover or test presumptions about.

4.4. Research Strategy

A research strategy is the general orientation of the conduct of social research. It provides a framework for the collection and analysis of data (Bryman 2004). This study employed both quantitative and qualitative research strategies. A quantitative research strategy emphasizes quantification in the collection and analysis of data; it places an accent on the testing of theories and embodies a view of social reality as an external, objective reality.

In a quantitative inquiry, researchers have assumptions about testing theories deductively, and being able to generalize and replicate the findings (Creswell 2009). On the other hand, a qualitative research strategy emphasizes the multiple dimensions of a problem or issue and displays them in all of their complexity (Creswell 1998), including the ways in which individuals interpret their social world. It embodies a view of social reality as a constantly shifting, emergent property of individuals' creation (Bryman 2004) and provides an in-depth understanding of people's experiences, perspectives and histories in the context of their personal circumstances or settings (Spencer et al. 2003).

In this research both strategies were utilized sequentially to examine different aspects of the research topic for instance quantitative data of observed rainfall records was collected and tested to establish any possible trends. Thereafter, daily rainfall was analyzed to determine the implications of rainfall trends on the length of crop growing season. This was in line with Creswell (1998) who pointed out that qualitative research is appropriate to use where there is need for detailed and contextual understanding of the issue. By virtue of the data collection methods that were used for the rainfall trends and its implications on the crop growing season, it was necessary to adopt both quantitative and qualitative research strategies.

4.5. Sample size and sampling procedures

In this study, Daily precipitation satellite-based rainfall product (CHIRPS) blended with records of 35 meteorological ground stations to cover data-sparse regions of the country were used with single stage stratified sampling techniques for generalization purposes (Table 1).

Table 1: Point Based Meteorological stations

WMO No	Station	Latitude [°S]	Longitude [°E]	Elevation [m]	AER
67403	Kawambwa Met	− 9.793	29.076	1334	III
67413	Mbala Met	− 9.028	31.553	1665	III
67441	Mwinilunga Met	− 11.74	24.431	1365	III
67461	Mansa Met	− 10.173	28.942	1257	III
67463	Samfya Marine-Met	− 11.371	29.911	1194	III
67475	Kasama Met	− 10.224	31.14	1384	III
67476	Misamfu Agro-Met	− 10.171	31.225	1378	III
67477	Mpika Met	− 11.901	31.433	1399	III
67531	Zambezi Met	− 13.534	23.108	1065	III
67541	Kasempa Met	− 13.457	26	1334	III
67543	Kabompo Met	− 13.596	24.208	1090	III
67551	Solwezi Met	− 12.171	26.367	1384	III
67561	Ndola Met	− 12.994	28.659	1269	II
67563	Kafironda Agro-Met	− 12.614	28.148	1220	II
67571	Serenje Agro-Met	− 13.227	30.215	1390	II
67580	Msekera	− 13.646	32.563	1011	II
67581	Chipata	− 13.564	32.589	1025	II
67583	Lundazi	− 12.294	33.175	1138	II
67599	Mfuwe	− 13.255	31.931	557	II
67633	Mongu	− 15.254	23.151	1048	II
67641	Kaoma	− 14.795	24.804	1158	II
67655	Mumbwa	− 15.078	27.189	1209	II
67659	Kafue Polder	− 15.777	27.921	976	II
67662	Kabwe Agro-Met	− 14.395	28.828	1175	II
67663	Kabwe Met	− 14.448	28.302	1204	II
67665	Lusaka Int. Airport	− 15.324	28.448	1153	II
67666	Lusaka City Airport	− 15.417	28.321	1274	II
67667	Mt. Makulu	− 15.548	28.248	1221	II
67673	Petauke	− 14.251	31.339	1022	II
67731	Senanga	− 16.111	23.298	1012	I
67741	Sesheke	− 17.477	24.301	942	I
67743	Livingstone	− 17.823	25.82	991	I
67751	Magoye	− 15.998	27.617	1025	I
67753	Choma	− 16.838	27.07	1275	I
67754	Chipepo	− 16.795	27.879	488	I

Source: *Thurlowet al. (2008)*

4.6. Data Collection.

The lack of accurate ground-based observed daily rainfall data as discussed previously across Zambia; satellite rainfall estimates were used as an alternative to in-situ observations. The many satellite-based rainfall products with long-time series have coarse spatial and temporal resolutions and are not homogeneous. The rainfall data from the Climate Hazards Group Infrared Precipitation with Stations version 2 developed by the Climate Hazards Group of University of California was used for the 3 Agro ecological regions for the period 1983 – 2019, (CHIRPSv2.0: Funk et al., 2015).

Besides the period for the rainfall record was long enough to establish the patterns and trends in climatic conditions in Zambia as well as to generate climatic indices of interest. The CHIRPS dataset is a quasi-global rainfall dataset covering 50° S to 50° N and spanning from 1981 to near present. It incorporates 0.05° x 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series, freely available in netCDF format and suitable for trend analysis and seasonal drought monitoring. It is originally computed in a pentad (5 days), and all other time steps are either aggregated (decadal and monthly) or disaggregated (daily). It can be freely accessed at http://chg.geog.ucsb.edu/data/chirps/. It was developed by the University of California, Santa Barbara and the United States Geological Survey (USGS) by merging observed rain gauge data with satellite images from the Globally Gridded Satellite dataset of the National Climate Centre of NOAA (Yang et al, 2018; Funk et al., 2015).

According to previous studies by (Katsanos et al., 2016; Cavalcante et al., 2020; Libanda et al., 2020) Zambian mean precipitation from the CHIRPS dataset shows a similar performance to the commonly used satellite products CMORPH, TMPA, PERSIANN, and TRMM at the decadal, monthly, and seasonal time scales. As described by Funk et al. (2015), the CHIRPS algorithm is built around a 0.05° climatology that incorporates satellite information to represent sparsely gauged locations. According to Shresta et al (2017) this rainfall product uses a three-step development process. First, infrared precipitation (IRP) pentad (5-day) rainfall estimates are created from satellite data using cold cloud durations (CCD) lower than 235 K as a threshold value and calibrated in relation to the TRMM 3B42-based precipitation pentads by local regression. Then, the IRP pentads are divided by its long-term IRP mean values to present a percent of normal. Second, the percent of normal IRP pentad is multiplied by the corresponding Climate Hazards Precipitation Climatology (CHPclim) pentad to generate an unbiased rainfall estimate, with units of millimeters per pentad, called the CHG IR Precipitation (CHIRP). Third, pentadal CHIRP values are disaggregated to daily precipitation estimates based on daily NOAA

Climate Forecast System (CFS) fields rescaled to 0.05° resolution (Tapidor et al. 2017). The grid boxes that were used in this study are:

(i) AER 1: longitude 23.3° E – 30.3° E and latitudes 17.5° S and 15.6° S.

(ii) AER 2: longitude 22.1° E – 33.2° E and latitudes 15.6° S and 13.3° S

(iii) AER 2: longitude 22.1° E – 33.2° E and latitudes 15.6° S and 13.3° S

4.7. Data Analysis

4.7.1. *Mann* Kendall test

The M-K test is a statistical non-parametric test widely used for trend analysis in climatologically and hydrological time series data. The test was suggested by Mann (1945) and has been extensively used with environmental time series. There are two advantages to use this test. First, it is a nonparametric test and does not require the data to be normally distributed.

The Mann-Kendall test (Mann, 1945; Kendall, 1975), a rank-based non-parametric test, is particularly suitable for censored, missing and non-Gaussian distributed variables. It searches for a trend in a time series without stipulating whether the trend is linear or non-linear (Maidment, 1993). Data are assumed to consist of uniformly sampled time series, and the test indicates the direction and significance of any trend. Much research has been undertaken using the Mann-Kendall test to detect trends in climatological parameters (Rao, 1993; Kothyari and Singh, 1996; Brunetti et al., 2000; Yue and Hashino, 2003, Abdul and Burn, 2006; Jiang et al., 2007; Modarres and Silva, 2007), and this particular non-parametric test has been shown to be more powerful than some parametric tests when dealing with skewed data (Onoz and Bayazit, 2003).

The only underlying assumption of the MK test is that when no trend is present, the data is independent and identically distributed. The test procedure is also capable of dealing with missing data, which is a common occurrence in precipitation data. Because the MK test does not give the magnitude of the trend, the linear regression method a parametric test can be used to obtain the magnitude or the sen slope estimator.

According to MK test in this study, the null hypothesis (H_0) assumes that there is no trend (the data is independent and randomly ordered) and this was tested against the alternative hypothesis H_1, which assumes that there is a trend. The computational procedure for the Mann Kendall test considers the time series of n data points and T_i and $T_j$as two subsets of data where i = 1,2,3,…, n-1 and j = i+1, i+2, i+3, …, n. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic *S* is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, *S* is decremented by 1. The net result of all such increments and decrements yields the final value of *S*

The Mann-Kendall S Statistic is computed as follows:

Equation 1: Mann - Kendall S Statistic

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(\mathrm{Tj} - \mathrm{Ti}) \qquad \text{(Equation 1)}$$

$$sign(\mathrm{Tj} - \mathrm{Ti}) = \begin{cases} 1 \; if \; \mathrm{Tj} - \mathrm{Ti} > 0 \\ 0 \; if \mathrm{Tj} - \mathrm{Ti} = 0 \\ -1 \; if \; \mathrm{Tj} - \mathrm{Ti} < 0 \end{cases} \qquad \text{(Equation 2)}$$

whereTj and Ti are the annual maximum daily values in years j and i, j >i, respectively.

If n < 10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall. The two tailed test is used. At certain probability level H_0 is rejected in favour of H_1 if the absolute value of S equals or exceeds a specified value Sα/2, where Sα/2 is the smallest S which has the probability less than α/2 to appear in case of no trend. A positive value of S indicates an upward trend. For n ≥ 10, the statistic *S* is approximately normally distributed with the mean and variance as follows:

Equation 3: Mean for S statistic

E(S)=0

Equation 4: The Variaince for S-Statistic

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{n}$$

in which t_i denotes the number of ties to extent i. The summation term in the numerator is used only if the data series contains tied values. The standard test statistic Zs is calculated as follows:

Equation 5: Standard Z test statistic

$$Z_s = \begin{cases} \frac{s-1}{\sigma}\ forS > 0 \\ 0\ for\ S = 0 \\ \frac{s+1}{\sigma} forS < 0 \end{cases}$$

The test statistic Zs is used as a measure of significance of trend. In fact, this test statistic is used to test the null hypothesis, H_0. If | Zs| is greater than Zα/2, where α represents the chosen significance level (eg: 5% with Z 0.025 = 1.96) then the null hypothesis is invalid implying that the trend is significant.

While there are several methods for trend detection, in this study, the renowned Mann-Kendall test (Mann, 1945 and Kendall, 1975) improved by Hamed and Rao, (1998) was employed using the 'modifiedmk' Package in R programming Language (R Core Team, 2013). This approach was chosen because of its robustness in accounting for autocorrelation structures in time series. It follows the hypothesis:

- H_0 no monotonic trend detected;
- H_1 monotonic trend present

The modified Mann-Kendall test is mathematically expressed as follows:

Equation 6: Modified Mann-Kendall test Statistic

$$Z_i = \phi^{-1}\left(\frac{R_i}{n+1}\right) \text{for } i = 1 : n,$$

Where: $R_i$is the rank of the detrended series, *n* is the time series' length, and is the inverse standard normal distribution function with a mean of 0 and a standard deviation of 1.After computing trends, their magnitude were quantified using the non-parametric Sen's slope estimator (Sen 1968) which is mathematically expressed as:

Equation7:: Sen's slope estimator

$$Q = \frac{Y_{i'} - Y_i}{i' - i} \qquad [7]$$

Where: Q is a slope estimate. Y_I' areY_I the values at times I' and I, where I' is greater than I, N' is all data pairs for which I' is greater than i.

The 'pheno' package (Schaber, 2003) in R Programming Language was then used to run the sequential Mann-Kendall test (Sneyers, 1990) with the aim of detecting abrupt changes in the trend of the timeseries.

4.7.2. Data Analysis for objective two

The Standard Precipitation Index technique was employed in determining the characteristics of intra-annual rainfall variability. The SPI was developed by McKee et al. (1993) and it is defined as the number of standard deviations that the observed cumulative rainfall at a given time scales would deviate from the long-term mean.

The Standard Precipitation Index is the number of standard deviations that observed cumulative precipitation deviates from the climatological average (McKee et al. 1993). It can be calculated for any timescales. To compute the index, a long-term time series of precipitation accumulations over the desired timescales was used to estimate an appropriate probability density function.

SPI is based on precipitation data only, and it runs a comparative analysis of annual average precipitation and transforms the data to a normal distribution performed using an equal-probability transformation after fitting the precipitation data to a gamma distribution (Zargar et al., 2011). The average is then fitted to zero with above zero values denoting relatively high precipitation and below-zero values denoting drought.

Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way, and wet periods can also be monitored using SPI. McKee et al (1993) also defined the criteria for a drought event for any of the timescale. A drought event occurs at any time the SPI is continuously negative and reaches an intensity of-1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the droughts magnitude. However, the Meteorological Drought Monitoring software (Salehnia et al., 2017) was used to calculate the standardized precipitation index (SPI) as follows:

Equation 8: Used to Calculate the Standardised precipitation index (SPI)

$$g(x) = \frac{1}{\beta^{\alpha\Gamma(\alpha)}} x^{\alpha-1} e^{\frac{-x}{\beta}} \; (> 0)$$

where: *Γ(α)* represented the gamma function, x is the amount of precipitation in millimeters ($x>0$);□□ is the shape parameter, and β is the scale parameter *($\beta>0$).*

The classification of wet and dry years was subsequently done following McKee et al., (1993) and as given in Table 2. The SPI was calculated on an annual basis.

Table 2: Classification of the Wet and Dry Years on the SPI scale

Description	Magnitude
Extremely dry	≤ -2
Severely dry	-1.5 to -1.9
Moderately dry	-1.0 to -1.4
Near Normal	-0.9 to 0.9

Source: Barua et al., (2010)

4.7.3. Data analysis for objective three

Several methods for computing onset and cessation of the rainy season exist. Hachigonta et al., (2008) employed a rainfall-based criterion which was earlier used by the Famine and Early Warning System (FEWS) and documented in AGRHYMET, (1996). This approach requires the first dekad (10 days) of the rain season to accumulate a total of 25 mm followed by two dekads with a total of at least 20 mm. The onset date is then taken as the first day of the first dekad. In the work of Hachigonta et al., (2008), this method was used to calculate the onset date and rain season duration. Ryan et al. (2017) also used the same statistical approach to examine pre-rain green-up across tropical southern Africa and cautioned that this approach is designed to determine rainfall that allows the start of maize cultivation. Hence, the approach should be used conservatively with respect to other requirements e.g., ecological. For this reason, a method that is generally applicable to both agricultural and ecological fields was used in this study.

Specifically, an algorithm was developed in R Programming Language. To do this, each individual year was sectioned into an agro meteorological year beginning in September and ending in August the year that follows. The onset was then be considered as the first day of the agro meteorological year when 8% of precipitation was recorded across each agroecological region and the cessation as the day when less than 90% of precipitation was reported. The length of the rainy season was then taken as the difference between cessation and onset. Many researchers (e.g., Ilesanmi, 1972; Laux et al., 2008; Ndomba et al., 2010; Guenang and Kamga, 2012; Amekudzi et al., 2015) have utilized a similar approach in studies around the world.

Table 3: Summary of the objectives, Hypotheses, Research Questions, Data analysis and Sampling

Objectives	Hypotheses/Research Questions	Data collection	Data Analysis	Sampling
To generate daily temporal rainfall trends for selected districts in Zambia, from 1983 - 2019	There is a significant trend in the rainfall for Zambia from 1983 to 2019.	CHIRPS-v1 daily rainfall secondary data	Mann-Kendall Test	Stratified random
To determine the characteristics of the rainfall trends for AERs of Zambia.	What are the characteristics of rainfall trends over Zambia from 1983 to 2019.	Daily rainfall data, 1983 - 2019 Secondary Data	Standardized Precipitation Index (SPI)	Stratified
To assess the implications of the rainfall trends characteristics on the crop growing season of Zambia.	What are the implications of rainfall trends on the crop growing season in Zambia from 1983 to 2019?	Secondary daily rainfall data	Rainfall-based criterion/ Content	Purposive

Source: Author

4.8. Validity and Reliability

Validity is defined as the extent to which a concept is accurately measured in a quantitative study (Bryman, 2008). Quantitative research distinguishes between construct validity and external validity. Construct validity has to do with whether a measure that is devised for a concept really does reflect the concept that it is supposed to be denoting while external validity questions whether the results of a study can be generalized beyond the specific research context.

Furthermore, for the quantitative part of this study, validity and reliability concerns were addressed through correct application of tools and following recommended procedure. The second measure of quality in a quantitative study is reliability, or the accuracy of an instrument. In other words, the extent to which a research instrument consistently has the same results if it is used in the same situation on repeated occasions (Bryman 2008).

Reliability is concerned with the question of whether the results of a study are repeatable. Reliability of data reflects the consistency of results across different measurement activities. Any observed differences in the results should be due to a genuine difference in the sample and not because of unreliability of the data collection techniques (Hammersley, 1992). Reliability was ensured through the strict following of sampling techniques and procedures to ensure the sample is representative and the data collected from the sample was reliable (Kassu, 2019).

4.9. Ethical Considerations

Before undertaking this study, consent was sought from all participants who took part in this study. The research proposal was submitted to the natural science research ethical committee through the Directorate of Research and Graduate studies for approval. Thereafter, the researcher approached the Zambia Meteorological Department Headquarters in Lusaka for purposes of collecting quantitative rainfall data. However, it was discovered that the Zambia Meteorological Department relies heavily on point-based data sets only which were not satisfying the objectives of this study. Therefore, to ensure accuracy the researcher utilized high quality CHIRPS-VERSION 2 blended data sets. For qualitative objectives, consent was sought in person to potential key informants via emails and phone calls for their willingness to take part in the study. However, it was found that most potential key informants declined to be interviewed due to the fear of contracting Covid-19 virus through face-to-face interactions leading to reviewing of previous literature to interpret the implications of rainfall trends on the length of crop growing season.

CHAPTER FIVE
RESULTS

5.0 Introduction

This chapter presents results according to the specific objectives of the study. The first part presented the trends in mean annual rainfall over the three AERs, from 1983-2019. The second part analyses characteristics of mean annual rainfall in the three AERs of Zambia and trends on the length of crop growing season.

5.1 Trends in mean annual precipitation

The results of rainfall trends for AERs 1, 2 and 3 are presented in Tables 4-6. The tables show the trends calculated. Turning points (Abrupt charges) in precipitation trends over Agro-ecological Region 1) Agro-ecological Region 2) Agro-ecological Region 3 based on the sequential Mann-Kendall test statistic; where progressive indicates the forward sequential statistic and retrogressive indicates the backward sequential statistic.

Table 4: SkMk for AER 1

Year	Progressive	Retrogressive	Turning point
1983	0	-0.96775	FALSE
1984	0	-0.55316	FALSE
1985	1.044466	-0.35313	FALSE
1986	1.698416	-0.36776	FALSE
1987	0.734847	-0.39764	FALSE
1988	0.751469	-0.08895	FALSE
1989	1.501879	-0.04648	FALSE
1990	1.360897	-0.47028	FALSE
1991	0.7298	-0.4759	FALSE
1992	0	-0.21409	FALSE
1993	0.622799	0.168823	FALSE
1994	0.205718	0.05927	FALSE
1995	-0.30504	0.416938	TRUE
1996	-0.21898	0.925745	FALSE

Year	Progressive	Retrogressive	Turning point
1997	0.395897	1.097684	FALSE
1998	0.225113	0.669719	FALSE
1999	0.700275	1.109239	FALSE
2000	0.98482	0.902334	TRUE
2001	1.399423	1.056892	FALSE
2002	0.875996	0.811107	FALSE
2003	0.754923	1.399423	TRUE
2004	1.071521	1.96964	FALSE
2005	0.633851	1.936054	FALSE
2006	1.066589	2.656328	FALSE
2007	1.237813	2.375384	FALSE
2008	1.719241	2.518265	FALSE
2009	2.001303	2.013293	FALSE
2010	2.232487	1.577169	TRUE
2011	2.307242	1.089899	FALSE
2012	2.06956	0.715542	FALSE
2013	2.073563	1.146829	FALSE
2014	2.091922	1.113461	FALSE
2015	1.874824	0.901127	FALSE
2016	1.630689	1.127204	FALSE
2017	2.016603	1.714643	FALSE
2018	2.165722	1.019049	FALSE
2019	1.63486	0	FALSE

Source: Authors results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/)

Table 5: SkMk for AER 2

Year	Progressive	Retrogressive	Turning point
1983	0	-0.58065	FALSE
1984	0	-0.15086	FALSE
1985	1.044466	0.091552	FALSE
1986	1.019049	-0.0681	FALSE
1987	0.244949	-0.14201	FALSE
1988	0.375735	0.118596	FALSE
1989	1.201503	0.108461	FALSE
1990	0.866025	-0.17838	FALSE
1991	0.521286	-0.20396	FALSE
1992	0	0	TRUE
1993	0.622799	0.468952	TRUE
1994	0.068573	0.05927	FALSE
1995	-0.42706	0.54202	TRUE
1996	-0.32847	1.102078	FALSE
1997	0.098974	1.424653	FALSE
1998	0.135068	1.215416	FALSE
1999	0.700275	1.531806	FALSE
2000	0.681799	1.240709	FALSE
2001	1.259481	1.479649	FALSE
2002	0.811107	1.070661	FALSE
2003	0.996498	1.679307	FALSE
2004	1.184313	1.81813	FALSE
2005	0.792314	1.936054	FALSE
2006	1.016981	2.656328	FALSE
2007	1.284523	2.771281	FALSE
2008	1.675158	2.737245	FALSE
2009	1.834528	2.501364	FALSE

2010	2.272	2.400039	FALSE
2011	2.457306	2.024097	TRUE
2012	2.319334	1.609969	FALSE
2013	2.073563	1.355344	FALSE
2014	1.897325	1.360897	FALSE

Year	Progressive	Retrogressive	Turning point
2015	1.595925	1.201503	FALSE
2016	1.274902	1.127204	FALSE
2017	1.704172	1.714643	TRUE
2018	1.757095	1.019049	TRUE
2019	1.320967	0	FALSE

Source: Authors results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/)

Table 6: SkMk for AER 3

Year	Progressive	Retrogressive	Turning point
1983	0	-0.67742	FALSE
1984	0	-0.25144	FALSE
1985	1.044466	0.039237	FALSE
1986	1.698416	-0.2588	FALSE
1987	1.224745	-0.65327	FALSE
1988	0.751469	-0.62263	FALSE
1989	0.901127	-0.5423	FALSE
1990	0.866025	-0.63244	FALSE
1991	0.312772	-0.61187	FALSE
1992	-0.17889	-0.3925	FALSE
1993	0.3114	-0.01876	FALSE
1994	-0.20572	-0.41489	FALSE
1995	-0.79312	0	TRUE
1996	-0.76643	0.440831	FALSE
1997	-0.69282	0.817424	FALSE
1998	0	1.116198	FALSE

1999	0.288348	0.686672	FALSE
2000	0	0.733146	FALSE
2001	0.489798	1.298468	FALSE
2002	0.22711	0.875996	FALSE
2003	0.513348	1.469394	FALSE

Year	Progressive	Retrogressive	Turning point
2004	0.620354	1.287842	FALSE
2005	0.58103	1.441742	FALSE
2006	0.818545	1.845923	FALSE
2007	1.331233	2.078461	FALSE
2008	1.322493	1.532857	FALSE
2009	1.542671	1.769258	FALSE
2010	1.955895	1.440024	TRUE
2011	1.857048	0.778499	FALSE
2012	1.962513	0.894427	FALSE
2013	1.665649	0.521286	FALSE
2014	1.832459	0.61859	FALSE
2015	1.286036	0	FALSE
2016	1.037711	0.751469	FALSE
2017	1.164517	1.224745	TRUE
2018	1.402952	1.698416	FALSE
2019	1.504071	1.044466	TRUE

Source: Authors own processed results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/

The mean annual precipitation was increasing across all the AERs between 1983 and 2019 (Figure 4 and 5, Table, 3, 4 and 5). The rate of increase in mean annual rainfall has been highest in AER 1 at 2.1 mm/year ($p = 0.056$), while AER 2 (1.8 mm/year; $p = 0.065$) and AER 3 (1.1 mm/year; $p = 0.08$) as shown on figure 3 and 4 and recorded lower rates of rainfall increase over the same period. However, as indicated by the p-values, none of the increase was significant; implying that the overall quantity of rainfall received remained statistically the same over the study period.

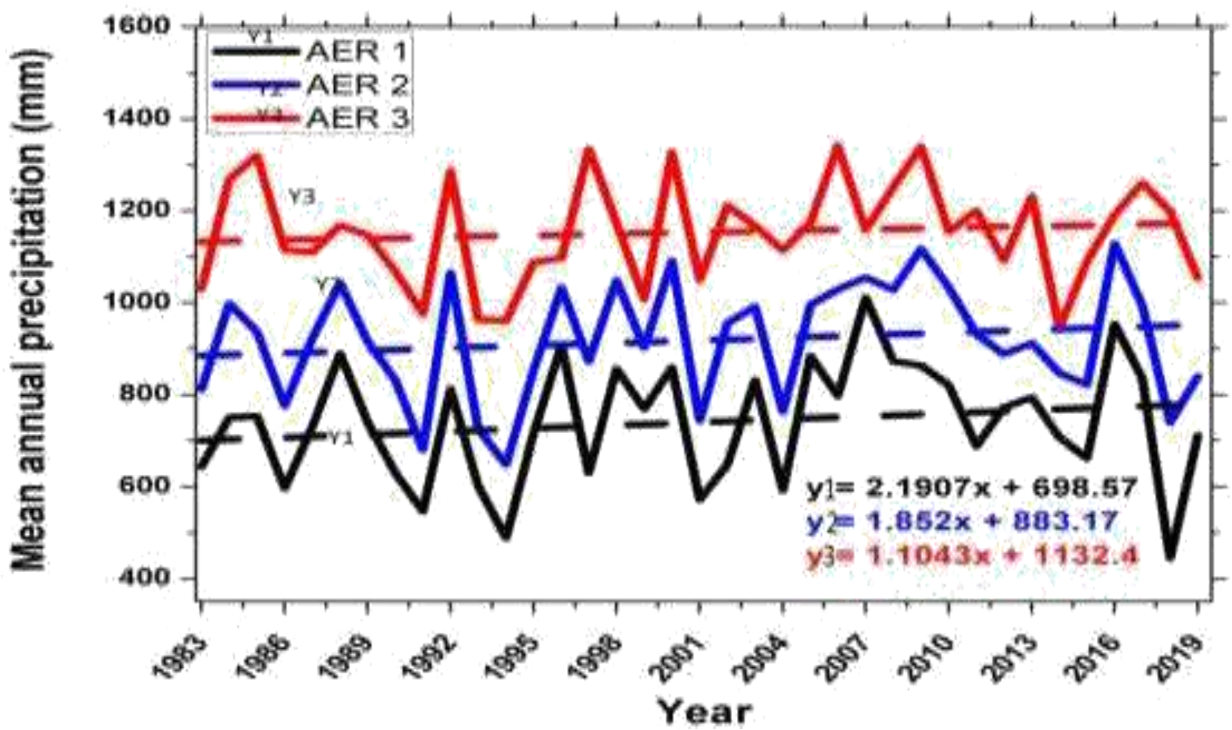


Figure 3 Trends in the Mean annual precipitation period 1983 - 2019. The black (y1) linear line is the trend for AER 1, blue (y2) AER 2 and red (y3) AER 3 fitted using the Sen's slope estimator. Source: Authors own processed results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/).

The observed trends in figure 4 and tables 3, 4 and 5 of mean annual precipitation were further explored for potential turning points. Results indicate that several significant abrupt changes occurred over all the three Agro-ecological Regions. AER 1 experienced a drought turning point in 1995, 2000, 2003, and 2010 (Figure 4a and Table 3). However, the change in magnitude was different with those that occurred in 1995, 2000 and 2003. AER 2 experienced abrupt changes in 1992, 1993, 1995, and 2011 experiencing some form of droughts (Figure 4b and Table 4). Further in 2017 and 2018, the forward and backward sequential statistics barely cross thus, these two years cannot be considered turning points although not statistically significant at the $\alpha = 0.95$ (*Onset:* Sen's slope = 0.02; P-value = 0.034; *Cessation:* Sen's slope = 0.3; P-value = 0.067. AER 3 experienced sudden changes in 1995, 2010, 2017, and 2019 (Figure 4c and Table 5) and all changes were not significant at the $\alpha = 0.95$ (*Onset:* Sen's slope = 0.062; P-value = 0.033; *Cessation:* Sen's slope = 0.1; P-value = 0.057).Trends in rainy season length were found to be declining across all Agro-ecological regions with the steepest slope on the Sen's estimator (-0.11) being observed over Agro-ecological region 2, followed by Region 1 (-0.08) and Region 3 (-0.06) respectively. Noteworthy, all the Agro-ecological regions experienced a statistically significant abrupt change in 1995 towards more drought

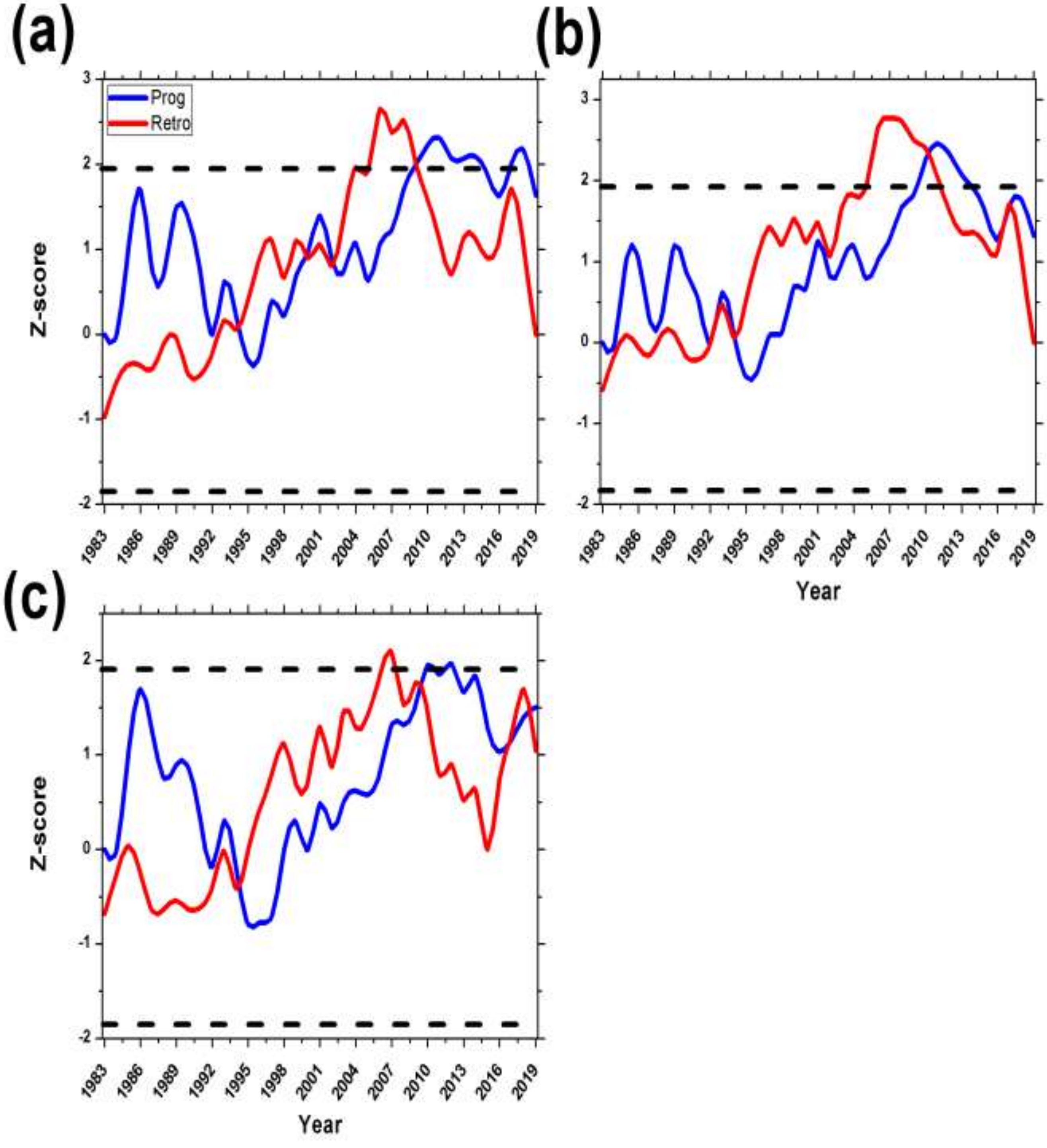


Figure 4: Turning points (Abrupt charges) in precipitation trends over; a) Agro-ecological Region 1, b) Agro-ecological Region 2, and c) Agro-ecological Region 3 based on the sequential Mann-Kendall test statistic; where prog *is the abbreviation of* progressive *and indicates the forward sequential statistic and* retro *or* retrogressive *in full indicates the backward sequential statistic. The dashed black lines indicate limits of statistical significance at* $\alpha = 0.95$. *The period 1983 – 2019.* Source: Authors results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/).

5.2 Variations in intra-annual rainfall characteristics

At the annual scale, SPI results (Figure 5) indicated that the occurrence of wet and dry events coincided across all agro-ecological regions for 27 of the 36-year study period (1983 – 2019). Differences were observed in 1987 when AER 2 experienced a slight positive value of 0.02 on the SPI scale whereas AERs 1 and 3 received below normal rainfall. Further, in 1989, AER 2 experienced a dry year while AER 1 and 3 received above average rainfall. The most recent differences were in 2018 when AER 1 and 2 experienced a generally dry year while AER 3 was characterized by above normal rainfall.

Overall, it was found that AER 3 experienced the highest number of wet events (21), followed by AER 1 with 20 and AER 2 with 19. This observed high number of wet compared to dry events across all agro-ecological regions, while rainy seasons are getting shorter implies that rainfall intensity was increasing across all the AERs (Figure 3). An increase in mean annual precipitation with reduced rainy season length translates into more intense precipitation events.

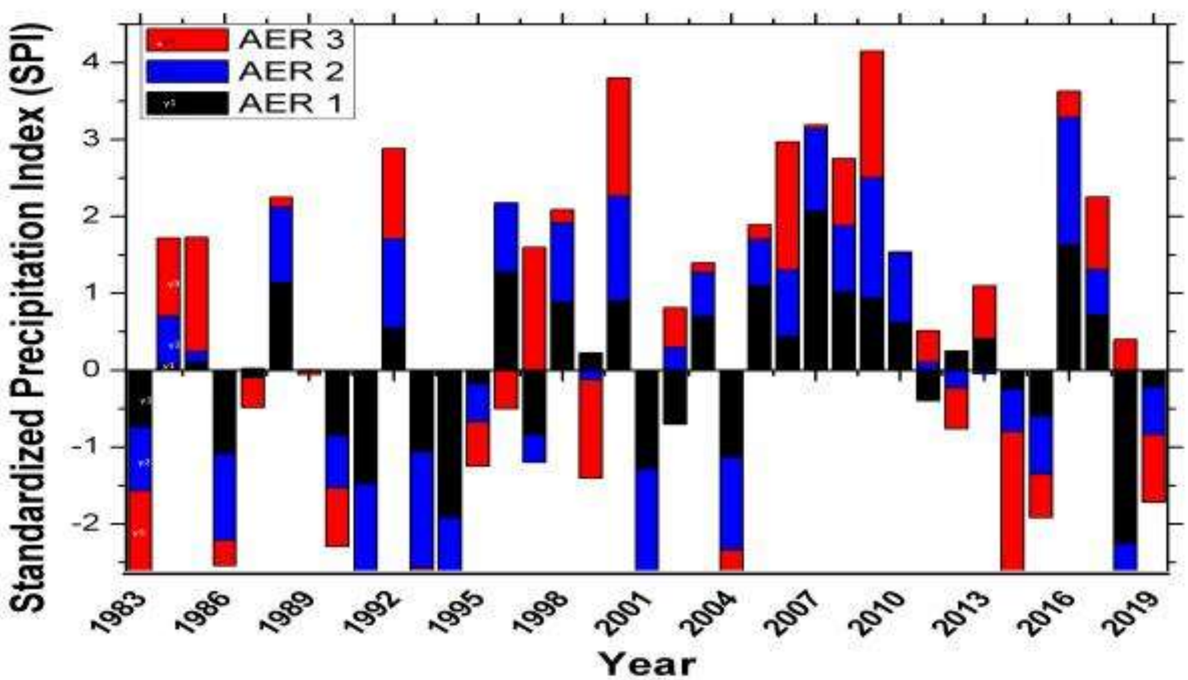


Figure 5 Standardized precipitation index (SPI) results for the period 1983 -2019. Source: Authors own processed results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/).

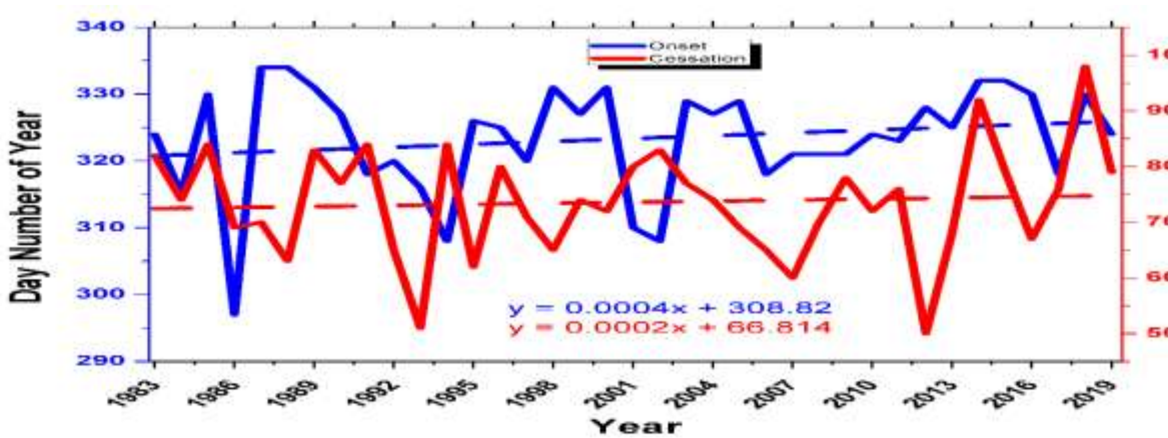
Table 7: Length of rain season for AER 1

Year	Start	End	Length	MAP
1983	20/11/1983	22/03/1984	123	643.825
1984	28//11/1984	15/03/1985	125	750.3625
1985	26/11/1985	25/03/1986	119	753.466
1986	24/10/1986	27/03/1987	137	597.2463
1987	30/11/1987	25/03/1988	101	727.8796
1988	29/11/1988	4/03/1989	95	889.3255
1989	27/11/1989	24/03/1990	117	741.0047
1990	23/11/1990	18/03/1991	115	628.9512
1991	14/11/1991	24/03/1992	131	546.8381
1992	15/11/1992	6/03/1993	111	812.0807
1993	26/11/1993	20/02/1994	100	600.8167
1994	13/11/1994	25/03/1995	141	489.521
1995	22/11/1995	2/03/1996	101	717.5669
1996	20/11/1996	21/03/1997	121	907.7766
1997	16/11/1997	10/03/1998	116	630.1839
1998	27/11/1998	6/03/1999	99	856.3579
1999	23/11/1999	14/03/2000	112	769.6043
2000	26/11/2000	13/03/2001	107	859.1679
2001	19/11/2001	21/03/2002	135	571.8101
2002	14/11/2002	24/03/2003	140	648.3457
2003	25/11/2003	17/03/2004	113	831.8206
2004	22/11/2004	15/03/2005	113	592.7145
2005	25/11/2005	01/03/2006	105	884.0523
2006	14/11/2006	6/03/2007	112	797.2832
2007	17/11/2007	29/02/2008	104	1011.254
2008	16/11/2008	18/03/2009	115	873.3375
2009	17/11/2009	19/03/2010	122	863.3867
2010	20/11/2010	13/03/2011	113	821.3075
2011	19/11/2011	16/03/2012	118	688.2887
2012	23/11/2012	19/02/2013	88	772.8974

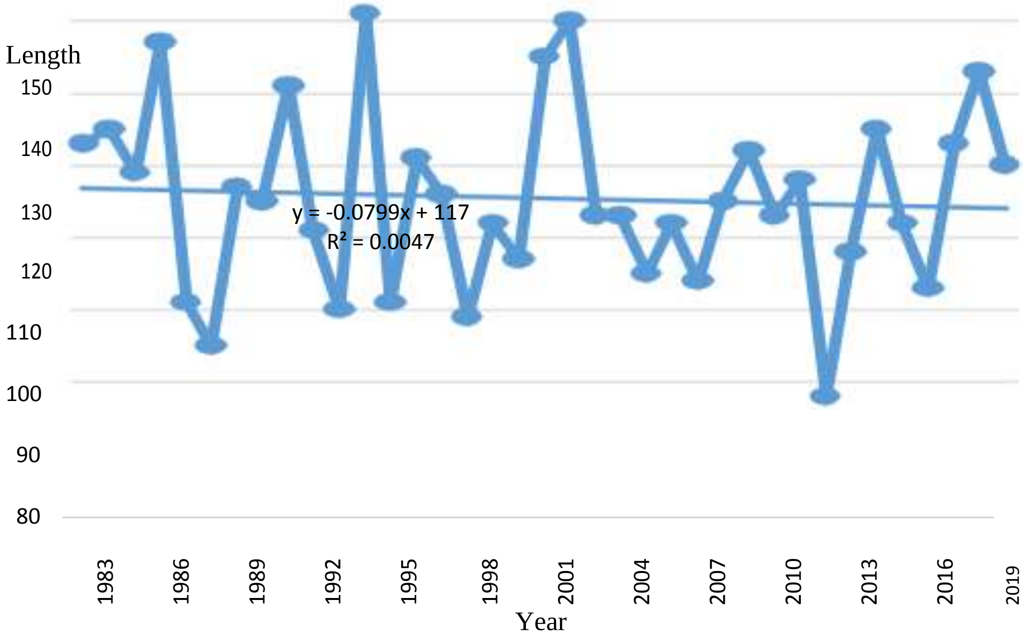
2013	21/11/2013	9/3/2014	108	793.8153
2014	28/11/2014	2/4/2015	125	707.5629
2015	28/11/2015	19/03/2016	112	662.5023
2016	25/11/2016	8/3/2017	103	953.8707
2017	14/11/2017	17/03/2018	123	834.6942
2018	26/11/2018	8/4/2019	133	444.8294
2019	20/11/2019	19/03/2020	120	711.2534

Source: Authors results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/)

Results indicated that the average onset date over AER 1 is 19th November while the cessation is on 14th March each year during the period 1983 to 2019. One other observation that emerged from the data was that the onset of the rainy season exhibits an increasing trend (*Onset:* Sen's slope = 0.07; P-value = 0.04) while the trend of cessation dates is statistically significant (*Cessation:* Sen's slope = 0; P-value = 0.056). Therefore, these results suggest that rainy seasons across AER 1 are generally starting late without much difference in their withdraw dates (Figure 6a and b) indicates the length of crop growing season averaged at 117 days respectively. This indicates that the period of the crop growing season has been reducing in length from the onset side rather than the withdraw side.



(a)



(b)

Figure 6: (a) Mean trend in onset and cessation of the rainy season over Agro ecological region 1 for the period 1983 – 2019. The blue (y1) dashed line is the trend for onset while the red (y2) dashed one represents cessation fitted using the Sen's slope estimator. Figure 6(b) Length of crop growing season over AER 1. Source: Authors own processed results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/).

Table 8 contains processed data indicating dates of onset and offset of rainfall in agro ecological region 2. These findings were analyzed further to determine the length of crop growing season which were illustrated in figure 6. The graphical output of this data in figure 9 showed that useful rainfall starts on 17th November and ended around 15th March for the period 1983 to 2019. Trends in the length of crop growing season as revealed from figure 6 clearly showed that crop growing season over AER 2 begin late with no changes in offset dates. Length of crop growing season was longest in 1991 with 135 days with mean annual precipitation of 680.8392mm, while the shortest crop growing season occurred in 1993 with 98 days with a mean annual precipitation of 725.4779mm. However the crop growing season trend in AER 2 has been reducing.

Table 8: Length of rain season for AER 2

Year	Start	End	Length	MAP
1983	17/11/1983	16/03/1984	120	812.5586

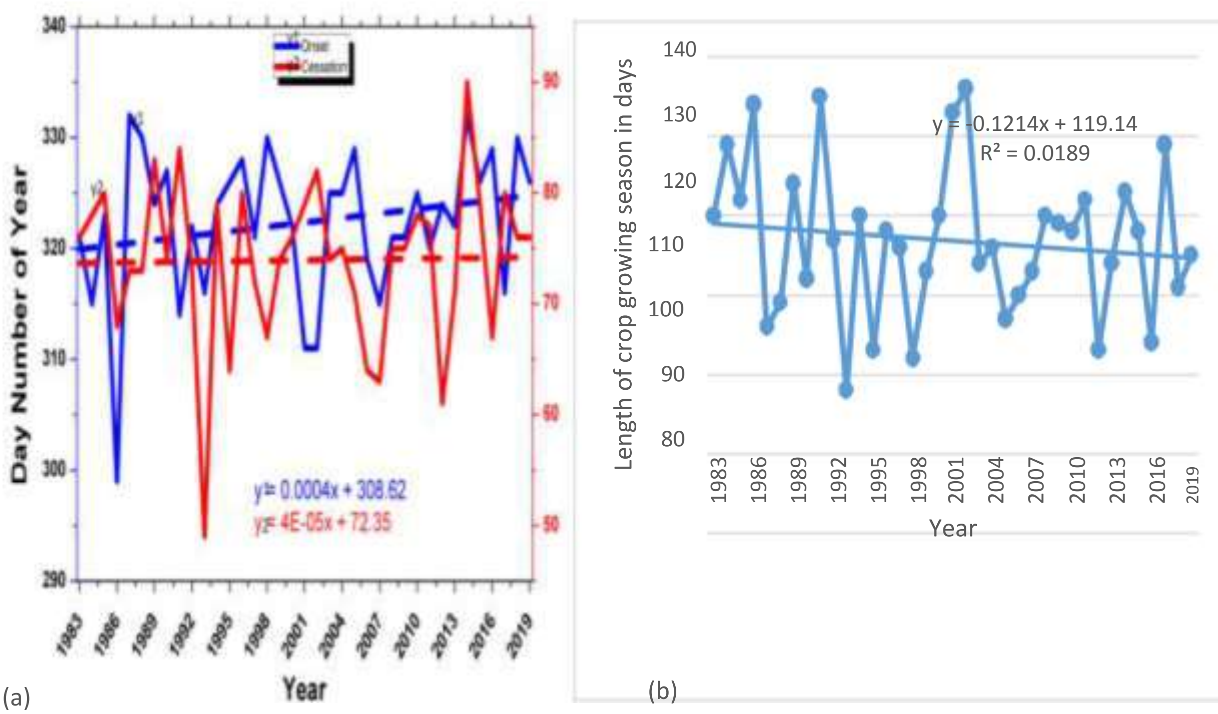
1984	15/11/1984	19/03/1985	129	997.6936
1985	19/11/1985	21/03/1986	122	936.9753
1986	26/10/1986	9/03/1987	134	776.1571
1987	28/11/1987	13/03/1988	106	921.3786
1988	25/11/1988	14/03/1989	109	1043.455
1989	20/11/1989	24/03/1990	124	917.0738
1990	23/11/1990	15/03/1991	112	831.1834
1991	03/11/1991	24/03/1992	135	680.8392
1992	17/11/1992	14/03/1993	117	1065.656
1993	21/11/1993	18/02/1994	98	725.4779
1994	20/11/1994	20/03/1995	120	648.5476
1995	22/11/1995	4/03/1996	103	854.73
1996	23/11/1996	21/03/1997	118	1032.944
1997	17/11/1997	13/03/1998	116	872.8828
1998	26/11/1998	8/03/1999	102	1049.334
1999	22/11/1999	14/03/2000	113	902.9337
2000	17/11/2000	17/03/2001	120	1091.171
2001	07/11/2001	20/03/2002	133	743.8947
2002	03/11/2002	23/03/2003	136	956.1709
2003	21/11/2003	14/03/2004	114	991.5207
2004	20/11/2004	16/03/2005	116	764.0761
2005	25/11/2005	14/03/2006	107	995.6091
2006	15/11/2006	5/03/2007	110	1028.906
2007	22/11/2007	3/03/2008	113	1054.713
2008	16/11/2008	16/03/2009	120	1028.26
2009	17/11/2009	16/03/2010	119	1117.36
2010	21/11/2010	19/03/2011	118	1033.328
2011	16/11/2011	17/03/2012	122	931.4944
2012	19/11/2012	2/03/2013	103	889.055
2013	18/11/2013	23/03/2014	114	912.175
2014	28/11/2014	31/03/2015	123	847.6137

2015	22/11/2015	19/03/2016	118	821.8081
2016	24/11/2016	8/03/2017	104	1128.946
2017	20/11/2017	21/03/2018	129	993.1359
2018	26/11/2018	17/03/2019	111	740.1345
2019	22/11/2019	16/03/2020	115	840.1421

Source: Authors results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/).

Across AER 2, rainy seasons were found to start two days earlier than in AER1 (i.e., 17th November). The average cessation date, in comparison to AER 1, was found to be a day later (15th March). Like AER 1, trends in onset dates over AER 2 were found to be upwards (*Onset:* Sen's slope = 0.08; P-value = 0.04). However, unlike over AER 1, the trends for AER 2 are statistically significant at $\alpha = 0.95$. Regarding cessation dates, the trend over AER 2 was found to be not statistically significant (*Cessation:* Sen's slope = 0; P-value = 0.9). Conclusively,

these results indicate that the rainy season over AER 2 starts late but there were no changes in the cessation during the period 1983 – 2019 (Figure 7*a*) while figure 7*b* showed the mean length of crop growing season of 119 days respectively.



(a) (b)

Figure 7: (a) Trend in onset cessation of the rainy season over Agro ecological Region 2 for the period 1983 – 2019, averaged over longitude 22.1° E – 33.2° E and latitudes 15.6° S and 13.3° S. The blue (y1) dashed line is the trend for onset while the red (y2) dashed one represents cessation fitted using the Sen's slope estimator. Figure 7 (b) Length of crop growing season over AER 2.

Source: Authors own processed results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/).

Table 9 showed the length of rain season for AER 3 covering the period 1983 to 2019 of which the generated graphical results in figure 9 indicated decreasing rainfall trends or shortening crop growing season despite this agro-ecological region 3 experiencing the longest crop growing season and receives highest amounts of rainfall for the period under investigation. The graphical output of this data in figure 7 indicated that useful rainfall starts on 17th November and ended around 15th March for the period 1983 to 2019. Trends in the length of crop growing season as revealed graphically on figure 6 clearly showed that crop growing season over AER 3 begin late with no discrepancy in withdraw dates. Length of crop growing season was longest in 1991 with 142 days with a mean annual precipitation of 975.7831mm, while the shortest crop growing season with the study period occurred in 1994 with 110 days with mean annual precipitation of 961.2754mm. However the crop growing season shows a decreasing trend. Overall, it was found that the mean rainy season length over AER 3 is 121 days with annual precipitation of 1153.355mm.

Table 10: Length of rain season for AER 3

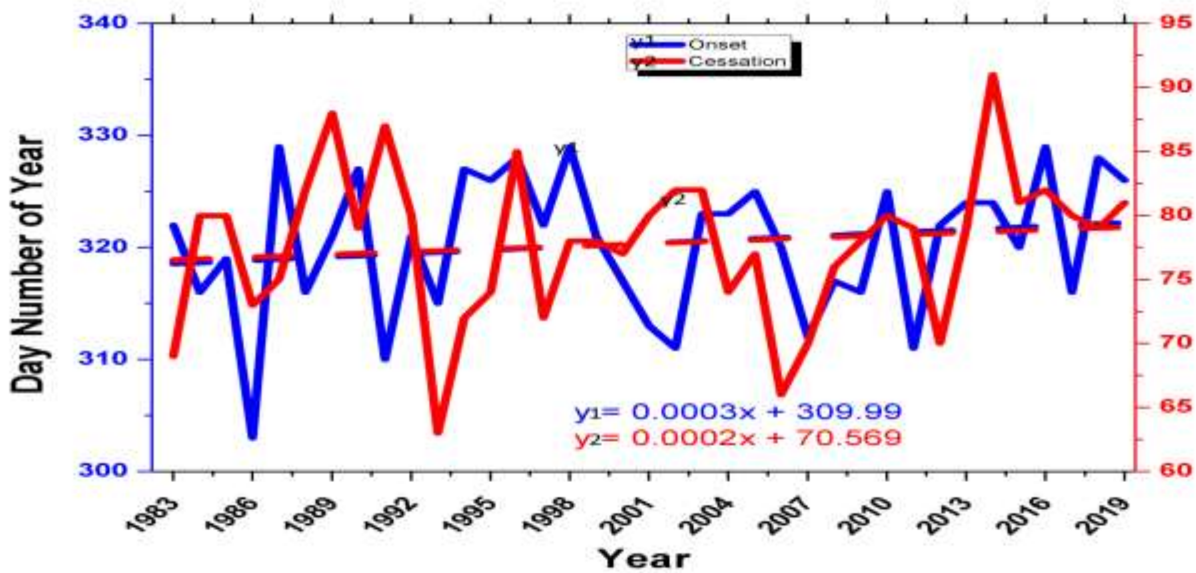
Year	Start	End	Length	MAP
1983	18/11/1983	9/3/1984	112	1030.453
1984	19/11/1984	21/03/1985	130	1268.637
1985	15/11/1985	21/03/1986	126	1320.893
1986	30/10/1986	14/03/1987	135	1115.73
1987	25/11/1987	15/03/1988	111	1109.395
1988	20/11/1988	23/03/1989	132	1167.947
1989	17/11/1989	29/03/1990	132	1147.921
1990	23/11/1990	20/03/1991	117	1067.593
1991	19/11/1991	27/03/1992	142	975.7831
1992	16/11/1992	21/03/1993	125	1286.719
1993	18/11/1993	4/3/1994	113	963.7664
1994	23/11/1994	13/03/1995	110	961.2754

Year	Start	End	Length	MAP
1995	22/11/1995	14/03/1996	113	1088.335
1996	23/11/1996	26/03/1997	123	1096.842
1997	18/11/1997	13/03/1998	115	1334.364
1998	25/11/1998	19/03/1999	114	1173.037
1999	17/11/1999	18/03/2000	122	1008.15
2000	19/11/2000	18/03/2001	126	1327.072
2001	22/11/2001	21/03/2002	132	1049.646
2002	20/11/2002	23/03/2003	136	1211.763
2003	19/11/2003	22/03/2004	124	1167.055
2004	18/11/2004	15/03/2005	117	1114.463
2005	21/11/2005	18/03/2006	117	1174.589
2006	16/11/2006	7/3/2007	111	1342.257
2007	17/11/2007	6/03/2008	123	1158.788
2008	20/11/2008	17/03/2009	125	1252.1
2009	19/11/2009	19/03/2010	127	1339.878
2010	21/11/2010	21/03/2011	120	1155.212
2011	22/11/2011	19/03/2012	133	1199.899
2012	17/11/2012	18/03/2013	114	1093.1
2013	20/11/2013	20/03/2014	120	1231.555
2014	20/11/2014	1/4/2015	132	945.5351
2015	16/11/2015	21/03/2016	126	1089.589
2016	24/11/2016	23/03/2017	119	1192.013
2017	24/11/2017	21/03/2018	129	1260.415
2018	24/11/2018	20/03/2019	116	1198.762
2019	22/11/2019	21/03/2020	120	1053.457

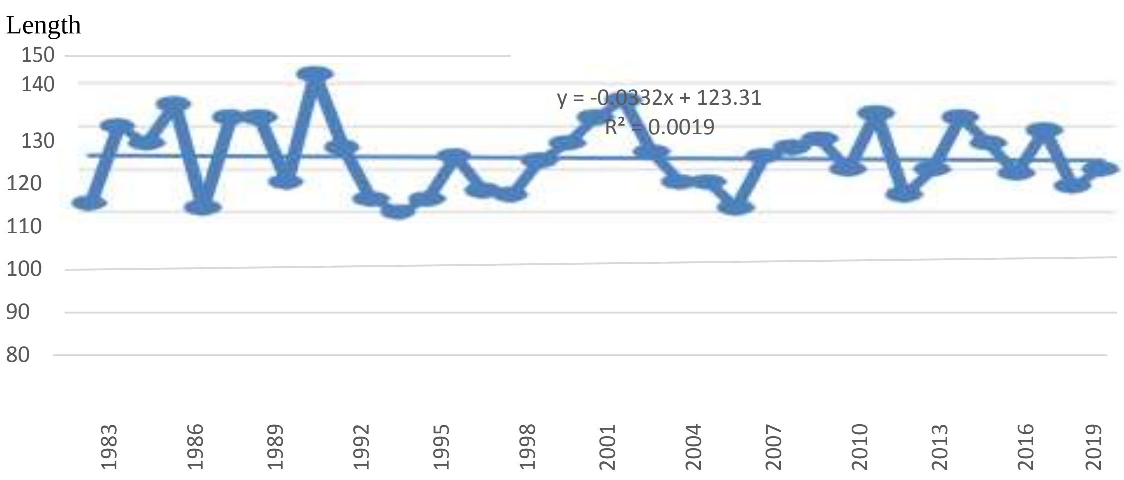
Source: Authors results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/).

When cessation and onset dates of the rainy season were analyzed over AER 3 using data in table 9, results showed that this AER experiences the earliest precipitation onset date (16^{th} November) among the 3 agro-ecological regions (Figure 8). Further, with an average withdraw date of 19th March; agro-ecological region 3 experiences the latest cessation of the rainy season. Against this background, it was hypothesized that AER 3 would, ordinarily, experience the longest rainy seasons of 123 days (Figure 8a and 8b). To be certain, this was interrogated further (See Figure 9).

Regarding trends, both onset and cessation dates were found to exhibit an upward orientation although all trends were not statistically significant at α = 0.95 (*Onset:* Sen's slope = 0.04; P-value = 0.035 *Cessation:* Sen's slope = 0.1; P-value = 0.06).



(a)



(b) Year

Figure 8 :(a) Trend in onset and cessation of the rainy season over Agro ecological region 3 for the period 1983 – 2019, averaged over longitude 22.1° E – 33.2° E and latitudes 15.6° S and 13.3° S. The blue (y1) dashed line is the trend for onset while the red (y2) dashed one represents cessation fitted using the Sen's slope estimator. Figure 8 (b) Length of crop growing seasons over AER 3.

Results presented in Figure 9 and table 9 confirm the set hypothesis that due to the observed differences in rainy season onset and cessation dates, agro-ecological region 3 experiences the longest rainy season. Overall, it was found that the mean rainy season length over AER 3 is 123 days (Fig 8b), while over AER 2 and 1, its 119 117, respectively (Figures 7b and 6b).

Trends in rainy season length were found to be declining across all agro-ecological regions with the steepest slope on the Sen's estimator (-0.11) being observed over agro-ecological region 2, followed by region I (-0.08) and region 3 (-0.06) respectively. However, these results were found not to be statistically significant at $\alpha = 0.95$. Although, they could be expressing trends of what could be expected. Taken together, these findings suggest that the rainy seasons are becoming shorter across all agro-ecological regions with the magnitude being largest across agro-ecological region 2. However, this should be taken to indicate a possible trend whose magnitude could become significant with time. As it is, the trends are not significant at $\alpha = 0.95$.

The observation that rainy seasons are potentially getting shorter reflects the late onset that has been found across all Agroecological regions (Figures 6, 7, 8 and table 6, 7 and 8) coupled with a near static cessation (apart from region 3).

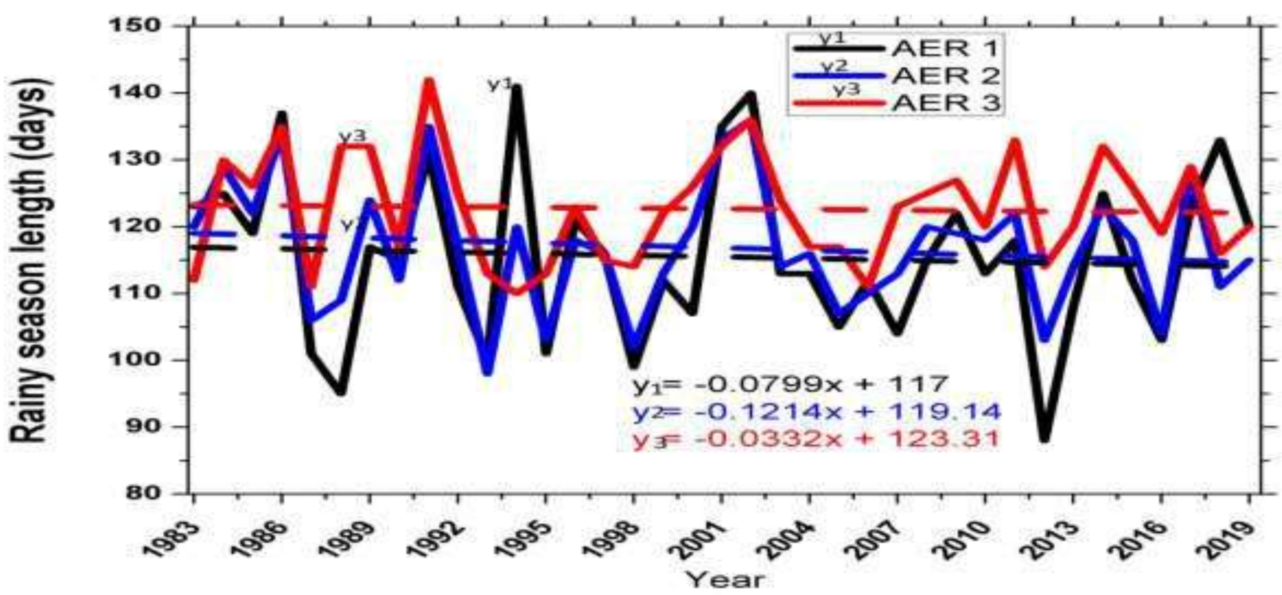


Figure 9: Trends in the length of the rainy season for the period 1983 – 2019 averaged over longitude 22.1° E – 33.2° E and latitudes 15.6° S and 13.3° S. The black (y1) linear line is the trend for AER 1, blue (y2) AER 2, and red (y3) AER 3 fitted using the Sen's slope estimation.

Source: Source: Authors own processed results with Data from CHIPS-v2 (https://www.chc.ucsb.edu/data/chirps/).

5.3 Implications on the crop growing season

The findings of this study showed that the rainy seasons are becoming shorter across all agro-ecological regions with the magnitude being largest across agro-ecological region 2. However, this should be taken to indicate a possible trend whose magnitude could become significant with time. The observation that rainy seasons are potentially getting shorter reflects the late onset that has been found across all agro ecological regions coupled with a near static cessation apart from region 3.

Overall results of this study indicate that the length of crop growing season is getting shorter in the last three decades. This follows a delaying trend in suitable onset dates. The results support the notion that the rainfall patterns, which are important for rain fed agriculture have shifted despite the seasonal amount of rainfall in the three AERs of Zambia remaining the same. An implication of this phenomenon is that farmers will have to adopt husbandry practices which can fit in this shortened growing season. However, this study has limitations as it only considered rainfall without analyzing possible trends and shifts in other climatic variables like temperature and other environmental parameters.

Table 10: Summarized characteristics of rainfall received in the three AER's over the period 1983 to 2019

Rainfall Characteristic	AER 1	AER 2	AER 3
Mean number of wet events	20	19	21
Mean number of dry events	16	17	15
Date of onset of rainfall	19th November	17th November	16th November
Onset shifted over time?	Yes	Yes	Yes
Date of offset of rainfall	14th March	15th March	19th March
Offset shifted over time?	No	No	No
Length of growing season	117 days	119 days	123 days
Trend in length of growing season(i.e.increasing, decreasing, constant)	Decreasing	Decreasing	Decreasing

Source: Author

CHAPTER SIX

DISCUSSION OF FINDINGS

6.0. Introduction

This chapter discussed the findings structured into three main sections with each section discussing findings based on the specific objectives. The first part discussed the trends in mean annual rainfall over the three AERs from 1983-2019. The second part discussed characteristics of mean annual rainfall in the three AERs of Zambia and implications of rainfall trends on the length of crop growing season.

6.1. Trends in mean annual rainfall over the three AERs of Zambia, 1983-2019.

The study revealed that the mean annual precipitation was showing increased trends across all the AERs between 1983 and 2019 with annual rates of 2.1 mm/year for AER 1, while AER 2 had 1.8 mm/year; and AER 3 recorded 1.1 mm/year. However, as indicated by the p-values, none of the increase was significant; implying that the overall quantity of rainfall received remained statistically the same over the study period contradicting findings of World Bank (2007). The observed increase can be explained in terms of rainfall variability, even though the observed trends should be of interest to policy makers as it could represent rainfall characteristics of the AERs in future. Further, the observation that the trend of mean annual precipitation was not significant can be attributed to the multiple abrupt changes that have been observed across all the Agro-ecological Regions resulting from general shifts in air currents aggravated by local and synoptic scale mechanisms that are known to induce changes in the trends of mean annual precipitation (Caloiero et al., 2010).

The findings of this study agreed with Maidment et al. (2015) who also observed increasing rainfall trend in Zambia (0.04 mm per day in a year) using CHIRPS-v1 data from 1983 to 2008 that were resampled to march coarser 2.5 degrees grids (-275 km at equator). Maidment et al. (2015) correlated with this research results because it was reported that the increasing annual rainfall in Southern Africa where Zambia is positioned was driven mainly by more DJF rains that are attributed to sea surface temperature patterns particularly the Pacific Walker Circulation.

Besides, since this research indicates that several significant abrupt changes in rainfall characteristics occurred over all the three Agro-ecological Regions. AER 1 experienced a drought turning point in 1995, 2000, 2003, and 2010 coinciding with reports of Sichingabula (1995) and other scholars. However, the change in magnitude was different with those that occurred in 1995, 2000 and 2003. AER 2 experienced abrupt changes in 1992, 1993, 1995, and 2011 experiencing some form of droughts. Further in 2017 and 2018, the forward and backward sequential statistics barely cross thus, these two years cannot be considered turning points although not statistically significant. Trends in rainy season length were found to be declining across all Agro-ecological regions being observed over Agro-ecological region 2, followed by Region 1 respectively. Noteworthy, all the Agro-ecological regions experienced a statistically significant abrupt change in 1995 towards more droughts coinciding with World Bank, (2007) and Sichingabula (1995).

The observation that all the Agro-ecological Regions experienced a statistically significant abrupt change in 1995 agree with previous studies which found that 1995 was a severely dry year across the whole country and was influenced by large-scale high-pressure systems (Libanda et al., 2019). In years where changes are not representative of the whole country, abrupt changes are generally a result of enhanced local precipitation triggering mechanisms. Davis (2011) confirmed that existing evidence for rainfall trends suggest moderate decreases in annual rainfall over parts of Southern Africa. Fauchrean et al (2003) showed that inter-annual rainfall variability over Southern Africa has increased since the late 1960's and that droughts have become more intense and widespread in the region.

In contrast to other scholar's findings, AER 3 experienced the highest number of wet events (21 years), followed by AER 1 with 20 and AER 2 with 19. This observed high number of wet compared to dry events across all agro-ecological regions, while rainy seasons are getting shorter implies that rainfall intensity was increasing across all the regions.

6.2. Characteristics of mean annual rainfall in the three AERs of Zambia

The findings of this study are not in agreement with those established in different models at both local and global level. For example, the rainfall projection from CMIP5 GCMs over the Southern African context suggests a decrease in rainfall by the end of the 21st century despite the occurrences of extremes (droughts and floods). These models further reveal that the whole Southern African region will experience more drought incidences than flood. In addition, the findings of the present study are also in contrary with those by (De Wit, 2006, and Muller and Shackleton (2014), just to mention a few. Drought incidences have adverse impacts on agriculture and the ecosystems of the locality, thus upsetting the sustainability of the peoples' livelihoods especially small scale farmers who heavily depend on rain fed farming (Mkonda, He, and Festin 2018).

On the other hand, the results of the study align well with those of Yanda and Mubaya (2011) who predicted the probability of increased frequency and intensity of extreme weather particularly in Southern Africa as a result of accelerated global warming. Further, GRZ 2020 further agrees with the results of this study as it reported increased mean annual rainfall in all the AERs with AER 3 reporting the least non-significant increase in rainfall over the last 100 years.

At the annual scale, SPI results indicated that the occurrence of wet and dry events coincided across all AERs for 27 of the 36-year study period (1983 – 2019). Differences were observed in 1987 when AER 2 experienced a slight positive value of 0.02 on the SPI scale whereas AERs 1 and 3 received below normal rainfall. Further, in 1989, AER 2 experienced a dry year while AER 1 and 3 received above average rainfall. The most recent differences were in 2018 when AER 1 and 2 experienced a generally dry year while AER 3 was characterized by above normal rainfall.

Therefore, the results of this study suggest that impacts of climate change, including prolonged number of dry days can be generalized to have had adverse effects on agricultural turbulence that was recorded by Mulenga and Wineman (2017). The optimal shift of rains onset and cessation, the reduced number of wet days, and the shrinking of the growing season have all affected the farming calendar in the three AERs of Zambia. Previously, rain onset occurred in early November, while cessation was in April but the findings of this research contradict these reports. This decline has been incremented by several factors, but mostly being excessive droughts and floods (Hertel, Burke, and Lobell 2010).

In addition, future changes in tropical circulation patterns may alter the seasonality, and lead to increasing uncertainty in the timing of rainy seasons (Feng et al., 2013). A delay in the wet season over the three AERs was identified, and associated with increasing strength of the Saharan Heat Low in late boreal summer, and a northward shift in the position of the tropical rain belt over August-December.

Over the three AERs of Zambia average rainfall per rainy day is projected to increase, while the number of rainy days in the wet season declines in regions of stable or declining rainfall, where rainfall is projected to increase. Adaptation strategies should account for shorter wet seasons, increasing intensity and decreasing rainfall frequency, which will have implications for crop yields and surface water supplies.

6.3. Implications on the length of crop growing season

These results of this paper compare well with previous findings of Hachigonta et al. (2008) who reported the seasonal declining between 1979 and 2002 in Zambia. It is evident from the current analysis that the season is indeed getting shorter and this has great consequences for food security as problems can arise due to these agro-climatic shifts (Harrison et al. 2011). Farmers must adjust their cropping calendars and possibly change their cultivars to suit the shorter crop growing period as well as the adoption of conservation agricultural practices that help in moisture retention, improving soil fertility and reducing the period of preparing land for crops (Umar, 2011, GRZ, 2007).

Furthermore, swift changes are needed to the local farmer practices to deal with this shortening crop growing season in Zambia. One of the most widespread strategies for dealing with the increasing trend of the onset of rains is to change planting dates and staggered planting. These can take care of the false starts which occur at the start of the rainy season. This would also lessen the exposure of the young plants to early dry spells which occur during the early part of the growing season.

The revelations of this research are partially in agreement with the study of Mubanga and Umar (2014) who found that over time, Zambia has experienced epic variations involving both increasing and decreasing trends in the rainfall quantities as well as differing periods of onset and offset of rainfall. Further, this study has also revealed that the country has experienced delays in start of rainfall, number of rain days and cessation of rainfall, length of growing season (Mulenga and Wineman, 2014; Chabala et al., 2013).

The findings of this study confirm the set hypothesis that due to the observed differences in rainy season onset and cessation dates, AER 3 experiences the longest rainy season which agrees with GRZ (2007). Overall, since it was found that the mean rainy season length over AER 3 is 121 days, while over AER 2 and 1, its 117 and 115, respectively. These findings did not coincide with what was pinned in GRZ (2007) where crop growing period was given to be 140 days for AER 3 for instance. The source of this discrepancy might be a result of different approaches or criterion used in identifying the onset of the growing season and the data sets. In this research CHIRPS data was utilized which is spatial and pixel wise while GRZ (2007) used observed rainfall data from the Zambia Meteorological Department stations. With spatial data, there might be some over estimation in the values. Nevertheless, the researcher advocated continuous monitoring of the seasons to detect any shifts if they would arise in future.

CHAPTER SEVEN
CONCLUSION AND RECOMMENDATIONS

7.0. Introduction

This chapter gives the conclusions and recommendations drawn from the study. This chapter is divided into two sections. The first section presents the conclusion of the study and the last section presents the recommendations.

7.1. Conclusion

The mean annual precipitation was found to exhibit an increasing trend; rainy season length showed a decreasing trend. This suggests that higher amounts of rainfall are falling within short periods of time thus, higher intensity. The observed increase in high rainfall intensity is consistent with earlier studies across the whole country. Studies have shown that high rainfall intensities are generally characterised by high kinetic energy raindrops which boost runoff and cause a decrease in infiltration (Huang et al., 2013). Rainfall with high intensity is also known to damage topsoil structure and reduce soil permeability which can translate into poor agricultural yields for the rural majority who depend on rainfed agriculture for their livelihoods.

Characterization of rainfall behaviour in Zambia using 36-years SPI At the annual scale, SPI results indicated that the occurrence of wet and dry events coincided across all agro-ecological regions for 27 of the 37-year study period (1983 – 2019). Differences were observed in 1987 when AER 2 experienced a slight positive value of 0.02 on the SPI scale whereas AERs 1 and 3 received below normal rainfall. Further, in 1989, AER 2 experienced a dry year while AER 1 and 3 received above average rainfall. The most recent differences were in 2018 when AER 1 and 2 experienced a generally dry year while AER 3 was characterized by above normal rainfall.

It was found that AER 3 experienced the highest number of wet events (21 years), followed by AER 1 with 20 and AER 2 with 19. This observed high number of wet compared to dry events across all agro-ecological regions, while rainy seasons are getting shorter implies that rainfall intensity was increasing across all the AERs. An increase in mean annual precipitation with reduced rainy season length translates into more intense precipitation events.

Trends in rainy season length were found to be declining across all agro-ecological regions with the steepest slope on the Sen's estimator (-0.11) being observed over agro-ecological region 2, followed by region 1 (-0.08) and region 3 (-0.06) respectively. However, these results were found not to be statistically significant at $\alpha = 0.95$, they could be expressing trends of what could be expected. Taken together, these findings suggest that the rainy seasons are becoming shorter across all agro-ecological regions with the magnitude being largest across agro-ecological region 2. However, this should be taken to indicate a possible trend whose magnitude could become significant with time.

7.2. Recommendations

In line with the findings of this research discussed above the following recommendations are made:

1. In agro-ecological region 3 which experiences a long growing season, farmers can potentially have multiple harvests in any given season or could easily diversify. However, in the case of the Agro ecological Regions 1 and 2, early maturity crops and establishment of irrigation systems seems like viable solutions to the observed decrease in rainy season length.
2. Climate data analysts and agro-meteorologists should advice rainfall dependent farmers on best varieties for planting in each agro ecological region.
3. Zambia Agriculture Research Institute (ZARI) should bring out new knowledge on climate matters and methods of monitoring climate variables such as rainfall. The findings from research will help farmers to adapt to the rainfall trends in each agro ecological region of Zambia.

4. Regarding the observed decrease in rainy season length, this ordinarily translates into shorter growing seasons. Therefore, this needs to be taken as one of the strongest recommendation in the choice of crops to be grown in each of the 3 Agro ecological Regions by small scale farmers who depend largely on rainfall.

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APPENDIX 1
Approval of Study

THE UNIVERSITY OF ZAMBIA
DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road Campus | P.O. Box 32379 | Lusaka10101 | Tel: +260-211-290 258/291 777
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APPROVAL OF STUDY

14th February, 2022

REF NO. NASREC-2021-DEC-005

Kapila Biggie Liteta
The University of Zambia
School of Natural Sciences
Department of Geography and Environmental Studies
P.O. Box 32379
LUSAKA

Dear Mr. Kapila,

RE: "TEMPORAL CHARACTERIZATION OF DAILY RAINFALL TRENDS IN ZAMBIA FROM 1983-2020: A CROP GROWING SEASON PERSPECTIVE."

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

Review Type	Ordinary Review	Approval No. NASREC-2021-DEC-005
Approval and Expiry Date	Approval Date: 14th February, 2022	Expiry Date: 13th February, 2023
Protocol Version and Date	Version - Nil.	13th February, 2023
Information Sheet, Consent Forms and Dates	• English.	To be provided
Consent form ID and Date	Version - Nil	To be provided
Recruitment Materials	Nil	Nil
Other Study Documents	Questionnaire.	

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,

Dr. E. M. Mwanaumo

CHAIRPERSON