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Impact of Rainfall Variability on Crop Yields and Its Relationship With Sea Surface temperature of Eastern Pacific ocean in Different Agro-Ecology Zone of South Wollo Amhara Ethiopia

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BAHIR DAR UNIVERSITY

INSTITUTE OF DISASTER RISK MANAGEMENT AND FOOD SECURITY
STUDIES MSC, IN CLIMATE CHANGE AND DEVELOPMENT

IMPACT OF RAINFALL VARIABILITY ON CROP YIELDS AND ITS
RELATIONSHIP WITH SEA SURFACE TEMPERATURE OF EASTERN
PACIFIC OCEAN IN DIFFERENT AGRO-ECOLOGY ZONE OF SOUTH
WOLLO AMHARA ETHIOPIA

BY

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April 2024

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN
CLIMATE CHANGE AND DEVELOPMENT

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CO-ADVISORS' DR. DESSALEGN CHANINE

April 2024
BAHIR DAR, ETHIOPIA

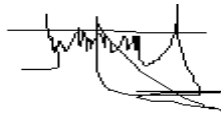
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Declaration

This is to certify that the thesis entitled “Impact of Rainfall Variability on Crop Yield And its Relationship With Sea Surface Temperature of Eastern pacific ocean in Different Agro-Ecology Zone of South Wollo Amhara Ethiopia” submitted in partial fulfillment of the requirements for the degree of Master of science in Climate Change and Development to the Graduate Program of Institute of Disaster Risk Management and Food Security Studies Post Graduate Program, Bahir Dar University, by Sisaynew Getahun is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificate. The assistance and help I received during the course of this investigation have been duly acknowledged.

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LIST OF ACRONYMS/ ABBREVIATIONS

CV	Coefficient of Variation
EAMSC	Eastern Amhara meteorological service center
EMI	Ethiopian Meteorology Institute
ENSO	El Niño Southern Oscillation
GDP	Gross Domestic Product
IPCC	International Panel on Climate Change
IQR	Inter-Quartile Range
MK	Mannkadel Trade Test
NMA	National Meteorology Agency
NMSA	National Meteorology Service Agency
NOAA	National Oceanic and Atmospheric Administration
PCI	Precipitation Index
Q1	Quartile one
Q3	Quartile three
SPSS	Statistical Package for Social Science
SRA	Standardize Rainfall Anomaly
SSA	Sub Saharan Africa
SST	Sea Surface Temperature
UNFCCC	United Nation Framework Convention on Climate change

ABSTRACT

Title: Impact of Rainfall Variability on Crop Yield and its Relationship with Sea Surface

Temperature of Pacific Ocean in Different Agro-Ecology Zone of South Wollo Amhara Ethiopia

By Sisaynew Getahun, supervised by Dr Dejena sahlun and Dr Dessalegn chania

Agriculture in Ethiopia is the backbone of the economy, because more than 85% of the population is depend on rain-fed agriculture. However, most parts of the country, especially south Wollo is vulnerable to recurrent drought and crop failure due to rainfall variability. This study examines the impacts of rainfall variability on crop yield and its relation to Nino 3.4 SST in different agro-ecology zones of south Wollo, Ethiopia. Rainfall data obtained from the Ethiopian meteorological institute, Nino 3.4 regions of the Pacific Ocean SST were downloaded from NOAA and major crop yield data were obtained from the South Wollo Central Statistical Agency. Mean, Coefficient of variation, precipitation concentration index, and standardized anomaly were employed to describe Crop yield and rainfall variability. INSTAT software used to determine onset and cessation dates of Kiremet season. R-Studio and Mann-Kendall trend test, used trend significance test. Correlation analysis to examine the relationship between rainfall characteristics with SST and crop yields, regression analysis to explain the impact of rainfall variability on crop yield. The analysis revealed that seasonal rainfall is moderate to highly variable in all Agro-Ecology Zones. Correlation between Kiremet rainfalls with SST lag 0, 2 shows negative significance in all Agro-Ecology Zones, and Belg rainfall with SST lag 0, shows positive significance in the Midland area. Rainfall characteristics correlated less to high with selected crop yields (Maize, Sorghum, Teff, Wheat, and Barley) in the study area. The result of Regression revealed that variability of Sorghum crop yield in the lowland area is explained by 88% of Rainfall characteristics. Maize, Sorghum, and Teff crop yield in the Midland area is explained by 69%, 69%, and 53% Rainfall characteristics respectively, Barley and Wheat crop yield in the Highland area is explained by 91% and 75% Rainfall characteristics respectively. Variability of Barley crop yield in the Upper Highland area is explained by 36% Rainfall characteristics. This shows that crop yields are highly variable due to Variability of Rainfall characteristics, so important adaptation strategies will be implemented for the study area to cope with the risks, sustain farming, and improve crop variety. So it is better further study investigated future projection of climate variability in the study area.

Key words; MK-Trend test, Correlation, Regression, Agriculture

CHAPTER ONE INTRODUCTION

1.1, Background of the study

The fact that Impact of Climate change and variability is already having a serious problem on the agriculture sector which is a fundamental challenge activity in developing countries (tsegaye *et al.*, 2020); because this sector depends on rainfall and household food security is particularly vulnerable to climate variability (Kyei-Mensah *et al.*, 2019; Ochieng *et al.*, 2021). Africa especially sub-Saharan Africa (SSA) is the most vulnerable region in the world to climate variability and climate change (Rettie *et al.*, 2022). The study revealed that the Impact of Climate change and variability poses huge challenges to the global economy and to social development (Mishra, Pandey, & Birara, 2018. Its Impact significantly affected sub-Saharan African countries such as Ethiopia because their economies are highly dependent on climate-sensitive activities such as rain-fed agriculture (Direse, 2020). Ethiopia is extremely vulnerable to drought and other natural disasters such as floods, heavy rains, frost, and heat waves, these events are caused by climate change and rainfall variability (Abegaz, 2020; A. Belay *et al.*, 2021).

So among different climate variables' rainfall variability is the most curial that influenced agriculture (Rettie *et al.*, 2022). In Ethiopia, the production of agriculture contributes more than 47% of the country's Gross Domestic Product (GDP) and also more than 70 million people (85% of the Ethiopian population) depend on agriculture directly or indirectly for their livelihoods (Alemayehu & Bewket, 2016; A. Asfaw *et al.*, 2021; W. Bahiru & Zewdu, 2021a). However, this sector is vulnerable to climatic variability in case of low adaptive capacity, low level of socioeconomic development, higher population growth, insufficient infrastructure, lack of institutional capacity, and high dependence on climate-sensitive natural resource-based activities. It has been also noted that rainfall is highly variable in amount and distribution, this variability of rainfall is influenced by the interaction of the oceanic and atmospheric systems, especially Nino3.4 Sea surface temperature is the main cause of rainfall variability and it becomes difficult to predictable across regions and seasons (Ayalew, 2020) . This variability of rainfall and recurrent droughts in Ethiopia affected the lives of millions of people as livelihood depends on agricultural production (Chemura *et al.*, 2021). So any impact on agriculture significantly affected the Ethiopian economy(Bayable *et al.*, 2021).

And also the impact on Ethiopia's GDP is likely to be significant because national income relies heavily on the export of agricultural products (Destaw & Fenta, 2021). The previous study shows crop yield rainfall has highly correlated. So the nature of agriculture and farming practices in any particular location is strongly influenced by rainfall variability (Direse, 2020). Especially the onset of the rain during plowing time, the amount of rainfall in the length growing period, and the cessation at the flowering stage of the crop determine the number of crop yields (Ayalew, 2020). However, nowadays rainfall variability becoming high and unseasonal rainfall is often observed in most parts of Ethiopia. Similarly Bahiru *et al.* (2020) stated that rainfall variability has been a major cause of food insecurity in Ethiopia. The Intergovernmental Panel on Climate Change (IPCC) concluded that increased frequency of heat stress, Droughts, rainfall variability, and floods negatively affected crop yields and livestock beyond the impact of mean climate change (Ochieng *et al.*, 2021). The previous researcher Getachew (2017) explains that impact of rainfall variability on the Ethiopian economy, who found that rainfall variability in the country leads to reducing production by 20% and increasing the poverty rate by 25%. Recent study shows that Ethiopia is currently experiencing its worst drought in last 50 years (Muluneh & Tesfaye, 2015). The worst affected areas include South wollo zone (Wolde-Georgis, 1997; Mishra *et al.*, 2018; A. Belay *et al.*, 2021; Wolde-Georgis *et al.*, 2021). Years like 1952, 1959, 1965, 1972, 1973, 1978, 1984, 1991, 1994, 1999, 2002 and 2015 were dry while 1958, 1961, 1964, 1967, 1968, 1977, 1993, 1996, 1998, and 2006 were wet (Korecha & Barnston, 2007). Rainfall variability and its impact on different sectors becomes a national problem that needs the attention of national leaders or scientists due to the frequent occurrences of damage particularly in agricultural sectors (Mihiretu *et al.*, 2021). In spite of these experiences as a country, their economy is heavily dependent on rainfall and its pattern, characterizing regional/local climate information is often cited as one of the most important factors in explaining various socioeconomic problem solutions.

Generally, rainfall becomes an important variable that can have a direct and indirect impact on farming activities. Among the more powerful determinants of crop yield were rainfalls at the onset and at the cessation date of the growing season (Amekudzi *et al.*, 2015). Getachew and Manjunatha (2021), revealed that climate variability and change in Ethiopia mainly manifested through the variability and decreasing trend in rainfall, and also that rainfall patterns show large regional differences. Thus, proper agro-climatic zoning is important for characterizing seasonal amounts and distribution of rainfall, which is a crucial system for minimizing the climatic risks

of rainfall variability and distribution on crop production. Hence, in Ethiopia, particularly the Amhara region, the risk of the variability of rainfall patterns that smallholders face is believed to be due to the lack of regional and local climatic information. So the main purpose of this study is to assess the impact of rainfall variability on major crop yields like Sorghum, Maize, Teff, Barley, and Wheat and its relation with the Nino 3.4 Sea surface temperature in the different agro-ecology zones of the south wollo Amhara region Ethiopia. For the purpose of this study, Rainfall and SST data obtained from 1987–2022, and crop yield data 2011–2022, were used. And a multiple regression model statistical approach to examine overall trends and the impact of rainfall variability on major crop yields within this study. The studies provide Climate information to the local community and impute for different stakeholders, about problems of rainfall variability and improve crop productivity in the study area.

1.2. Statement of the problem

Rainfall variability poses huge challenges to the global economy and social development today (Gezie & Tejada Moral, 2019; Gemedu *et al.*, 2021; Getachew & Manjunatha, 2021). Its impact was widely felt in sub-Saharan African countries like Ethiopia, whose economies are highly dependent on climate-sensitive activities such as rain-fed agriculture (Mishra *et al.*, 2018). This rainfall-dependent crop production is the basis of all subsistence farming in most parts of Ethiopia and accounts for more than 95% of the land area cultivated annually (Ayalew, 2020). The significant impact of rainfall variability on crop yields like (maize, sorghum, Teff, wheat, and barley) has been demonstrated by different authors with in some extent (*Bekele, 2015; Diress, 2020; W. Bahiru & Zewdu, 2021b*). Impact of rainfall variability has been historically a major cause of food insecurity and famine in Ethiopia. The previous study *Rettie et al. (2022)* stated that to minimize the risk of rainfall variability in agriculture and other sectors is important to conduct a detailed study at the local level and be able to manage the reduction of crop yield caused by rainfall variability. However, the studies conducted by different authors didn't consider important determinant factors on the existence of rainfall variability on crop yield in Ethiopia. Some Studies in Ethiopia revealed that the erratic nature of rainfall distribution; late onset and early offset, contributes to a decline in crop yields in almost all parts of the country. (Getachew, 2017; Legese et al., 2018). Some scholars like *Bewket (2009)* studied the impact of rainfall variability on crop production in the Amhara region, however, this author was not considering important determinant factors like onset, cession, length of the growing period, rainy

and dry days, and also that only two stations are represented in the south Wollo zone, and his study was conducted many years ago. Another researcher (Muluneh & Tesfaye, 2015); Mohammed *et al.* (2019) are studied rainfall variability in the south Wollo zone, however, those authors didn't regress with the determinants of crop production and used a limited number of meteorological stations. The research recommended by Tesfamariam *et al.* (2019) stated that considering Agro-ecologic zoning is important to get more accurate climate information. But the above listed scholars didn't considering the agro-ecologic zone of their study. In general, the impact of rainfall variability on crop yields and its relation with SST at sub-regional and zonal levels have not been studied yet. Therefore, this study fills the above listed gaps, including more important determinant variables, using more number of meteorological stations, considering agro-ecologic zone of the study area, provide up dated climatic information and studying the specific area in detail.

1.3. Objective of the study

1.3.1 General objective of the study

The main objective of this study is to investigate the impact of rainfall variability on Crop yields and its relationship with sea surface temperature in different agro-ecology zones of the South Wollo Zone, Amhara Region, Ethiopia

1.3.2 Specific objective of the study

- To asses rainfall characteristics in the study area
- To analyze the trend of rainfall in the study area
- To examine the nexuses between sea surface temperature and seasonal rainfall in the study area
- To estimate the magnitude of the relationship between rainfall characteristics and crop yield in the study area.

1.4 Research question

To achieve the above-stated objectives, the researcher raised the following key research questions:

- 1 What are the characteristics of rainfall the study area?
- 2 What is the trend of rainfall in the study area?
- 3 What are the nexuses between sea surface temperature and rainfall in the study area?

4 What is the relationship between crop yield and rainfall over the study area?

1.5 Significance of the study

Research is a way of acquiring knowledge; pointing out problems and informing decision-makers. So, this study is important to know and document local rainfall characteristics, variability and trends. The findings of this study will be used as inputs for community stakeholders to enable them to select suitable crops or varieties. It is important for policymakers to become aware and prepared for negative impacts on crop production at the micro level, and they will also be used as a reference or baseline for further studies. Generally, this study was used as input for the concerned stakeholders in the local community.

1.6 Scope of the study

The study aimed to assess the impact of rainfall variability on major crop yields and its relationship with the Nino 3.4 region SST in different agro-ecology zones of the south Wollo zone in the Amhara region of Ethiopia. The area has been chosen because for the past decades, it has been seriously affected by continuous drought hazards, due to the high rate of rainfall value. This study considers only Meher season crop yields (maize, sorghum, Teff, wheat, and barley), Belg season crop yields not include in this study because the contribution of Belg season is much less compared to Meher season, some part of south wollo zone are not Belg benefiting area and also not accessible for continuous crop yield data for Belg. This study includes thirty-six years of meteorological rainfall data from twelve stations, Nino 3.4 SST data from Nino region 5° N to 5° S latitude and from 120° W to 170° W longitude in the Pacific Ocean was downloaded and 12 years of five major crop yields data were collected from south wollo CSA and agricultural office. Methodologically, the mean ratio method is used to fill the missing data, the inter-quartile method is used for outlier detection using the mean monthly rainfall data; and a single mass cumulative curve is used for the homogeneity of climate data. The coefficient of variation, precipitation concentration index, and standardized anomaly were analyzed to describe crop yield and rainfall variability. The R-studio Mann-Kendall trend test and Sen's slope estimator were used for the trend significance and magnitude of the change in rainfall, respectively. *INSTAT software version 3.37* is used to summarize the daily data into annual, monthly, and seasonal totals to determine the onset, cessation, the length of the growing period (LGP), the number of rainy days and dry days, of the rainy (Kiremet) season. Finally, SPSS software was

used to analyze Correlation and regression to examine the relationship of rainfall with SST and crop yield in the study area and to explain the impact of rainfall variability and change on crop yields, respectively.

1.7 Limitation of the study

Due to a lack of meteorological station climate data other than rainfall, this study is restricted to only the impact of rainfall variability on crop yields and the other challenge of this study was Lack of the bench mark of Agro-ecology zone of the crop harvesting system, so the main challenge was to categorize crop yields in the different Agro-ecology zones in the study area. Hence, to overcome the challenges, categorizing woreda based on Agro-ecology zone and selecting major crop yields cultivated in that woreda.

1.8 Conceptual frame work of the study

This study was designed to analyze the impact of rainfall variability on major crop yields in the different agro-ecology zones of the south Wollo zone in the Amhara region of Ethiopia. Crop yield is the dependent variable of this study, and rainfall characteristics that influenced crop yield production are independent (exploring) variables of the study (figure 1.1).

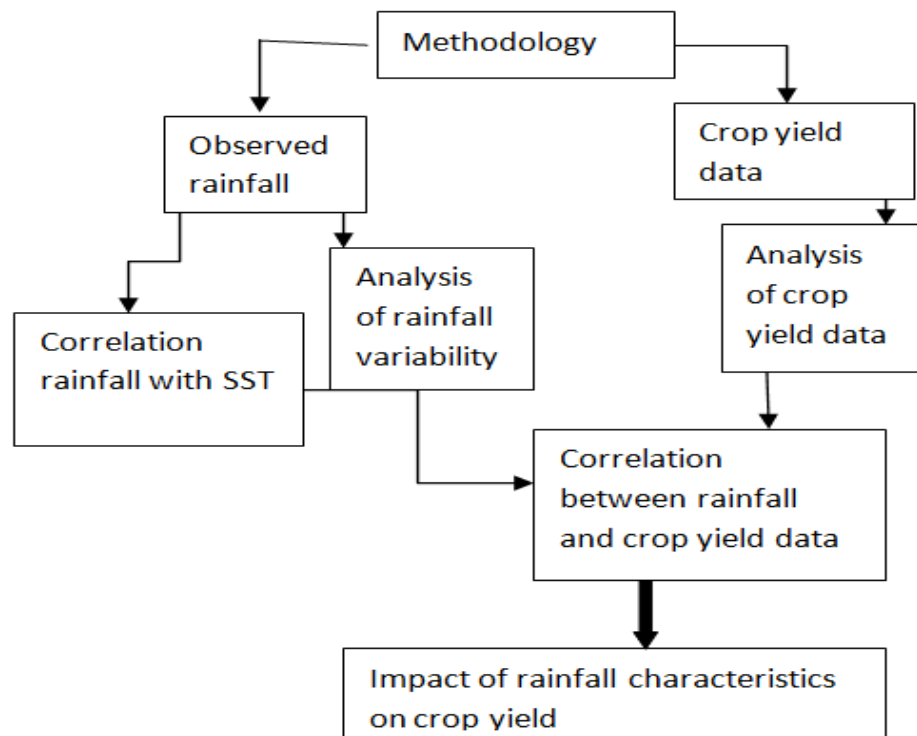


Figure1.1 Conceptual frame work

CHAPTER TWO LITERATURE REVIEW

2.1 Agro-ecology zone of Ethiopia

According to Gorfu and Ahmed (2012), There are different ways of classifying the climatic system of Ethiopia, including the traditional, kop pen's, Throthwaite's, rainfall regimes, and the Agro-climatic zone classification system. The most commonly used classification systems are the traditional and Agro-ecological zones (Gorfu & Ahmed, 2012; Ayalew, 2020). According to the traditional classification system, elevation is strongly influenced by rainfall and temperature M. Ayalew (2020). Based On traditional Agro-climatic classification, Ethiopia has five major Agro-ecological zones. Wurch (upper highland) has an altitude of 3200m and above; Dega (highland) is at 2300–3200 m; Woinadega (midland) is at 1500–2300 m; Kola (lowland) is at 500–1500 m; and Bertha (desert) is at less than 500m. The study area of the south Wollo zone lies in four Agro-ecological zones. Figure 2.1 and Table 2.1 below

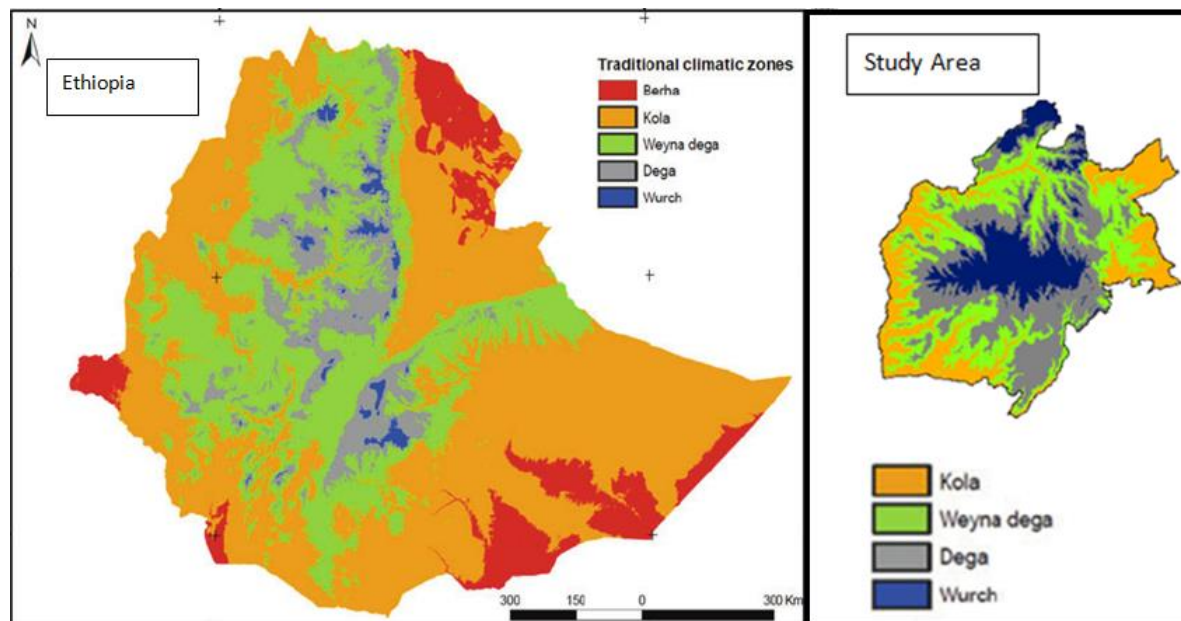


Figure 2.1 Traditional Agro-ecology classification of Ethiopia

Source Gorfu and Ahmed (2012)

Table 2.1 Traditional Agro-ecology zone and their physical characteristics

Zone	Altitude (meter)	Rainfall (mm/year)	Length of growing period (days)	Average annual temperature ($^{\circ}$ c)
Wurch (upper Highland)	> 3200	900-2200	211-365	<11.5
Dega (Highland)	2300-3200	900-1200	121-210	17.5-11.5
Weyina Dega (Midland)	1500-2300	800-1200	91-120	20-17.5
Kola (Lowland)	500-1500	200-800	46-90	27.5-20
Berha (Desert)	< 500	Under 200	0-45	>27.5

source M. Ayalew (2020).

2.2 Ethiopian Seasonal rainfall classification

The annual rainfall characteristics of Ethiopia are classified into three seasons documented by different authors (Bahiru *et al.*, 2020; W. Bahiru & Zewdu, 2021b; Gemedo *et al.*, 2021). These three different seasons are dry (October–January), small rainy (February–May), and main rain (June–September). And also, these seasons are locally known as Bega, Belg, and Kiremet, respectively. So the study area of the south Wollo zone is expressed as having the same seasonal rainfall classification as the country (W. Bahiru & Zewdu, 2021b). The study area received 350–500 mm Belg, 520–700 mm Kiremet, 70–150 mm bega, and 750–2000 mm annual rainfall.

2.3 Rainfall variability and trends in Ethiopia

The rainfall is highly variable both in amount and distribution across regions and seasons; the main climatic features that help explain Ethiopia’s climatic resources are the spatial and temporal distribution of rainfall (Alemu & Bawoke, 2020). The pattern of annual and seasonal rainfall distribution in Ethiopia is mainly influenced by different factors (Bekele, 2015), some of which are the oscillation of the inter-convergence zone (ITCZ), the micro-scale pressure system, monsoon flows related to the pressure system, sea surface temperature, and two moist wind systems, one blowing from the Atlantic Ocean and the other from the Indian Ocean (Abate, 2016). the previous study conducted by Mohammed *et al.* (2019) in south wollo zone a moderate inter-annual variability of the Belg season but lower variability in the Kiremet season. The rainfall trend in Ethiopia is not uniform in different parts of the country (M. Ayalew, 2020; Gemedo *et al.*, 2021). Some studies reported a declining trend in seasonal and annual rainfall amounts (Hill & Porter, 2017; Amogne Asfaw *et al.*, 2018). Conversely, other researchers

reported an increasing trend in annual rainfall (Tesfamariam *et al.*, 2019). Other scholars (Ayalew *et al.*, 2012; Gebre *et al.*, 2013; Abegaz & Abera, 2020; Bahiru *et al.*, 2020); Gebrechorkos *et al.* (2020); (W. Bahiru & Zewdu, 2021b) found that both an increasing and decreasing rainfall trend in different parts of the country. a Non-significant decline trend of the Belg season, a significantly increasing and decreasing trend of dry and wet days, respectively, and a significant increasing trend of Kiremet rainfall. Another researcher Muluneh and Tesfaye (2015) found that rainfall amount and coefficient of variation increased in the Belg season, while annual and remote rainfall showed less variability, decreasing rainy days and length of growing period, and increasing dry days for both Belg and Kiremet seasons.

2.4 Agriculture in Ethiopia

Ethiopian agriculture is predominantly characterized by traditional methods of farming, with very little change in farming practice over the past few centuries (Habtemariam *et al.*, 2016). The continuous use of such farming practices over a long period of time with little or no soil conservation measures has significantly eroded soil fertility and agricultural outputs (Gezie & Tejada Moral, 2019). The major factors behind the poor performance of Ethiopian agriculture are diminishing farm size and subsistence farming, soil erosion, inadequate and variable rainfall, climate-related disasters, tenure insecurity, a weak agriculture research base and extension system, a lack of a financial system, imperfect agriculture markets, and poor infrastructure (Alemayehu & Bewket, 2016). Crops are the major source of productivity and food in the country since most of the population depends on agriculture. At different times, famines that occurred in Ethiopia were attributed to crop failure due to climate variability (Abrham & Mekuyie, 2022). The major problem with crop productivity reduction in Ethiopia is low productivity due to a lack of integrated disease and insect pest control, heavy dependence on rain-fed agriculture, rainfall variability, and a shortage of techniques for proper conservation and utilization of water for full and supplemental irrigation at a critical stage of crops (F. Belay *et al.*, 2016; Habtemariam *et al.*, 2016).

2.5 Impacts of late onset and early cessation on crop yield

Different studies show that the number of rainy days serves as a marker that can be used to verify the distribution of rainfall (B. Megersa *et al.*, 2014; Bekele, 2015; G. Megersa *et al.*, 2019; W. Bahiru & Zewdu, 2021b). During the length of the growing season, farmers expected a balance between the distribution of rain days and the moderation of rainfall amounts per rainy day

throughout the season (Bekele, 2015; Muluneh & Tesfaye, 2015). The number of rainy days is associated with an increase in rainfall per day, indicating an increasing intensity of rainfall (Muluneh & Tesfaye, 2015). The increasing rainfall intensity may result in potential serious risks from an increasing flood frequency and severity of other related hazards. High daily rainfall may be responsible for highly destructive agriculture that is sensitive to areas that are prone to flooding (Bekele, 2015). The situation could be described as a problem of flooding, which led to unprecedented food price increases. Increasing the number of rainy days does not indicate a high amount of rainfall (Bekele, 2015). The onset of rain, which is defined as the first occasion after a selected date when the rain accumulated over three consecutive rainy days is at least 20mm and there are no dry spells lasting more than 9 days in the next 30 days, is used as a successful plantation date. The onset of the rainy season is a very important event for farmers in sub-Saharan Africa. The onset of rain marks the beginning of the main agricultural activities to take place: planting, weeding, and harvesting (Bahiru *et al.*, 2020). This enables us to determine the socioeconomic status and survival of the farming household. The importance of farming in the lives of these households also affected other activities; planting, which depends on and is influenced directly by the onset of the rainy season. Based on significant shifts in the onset of rain, which will affect both agriculture and many other non-agricultural activities of small-scale farmers (M. Ayalew, 2020). Several researchers have reported how the variability of the onset and cessation of the rainy season in tropical regions poses a serious challenge in the process of determining when the rainy season or planting season begins (W. Bahiru & Zewdu, 2021b). The cessation of the rainy season, which is defined as the decadal rainfall amount, is less than half of the corresponding reference Evapo-transpiration at the end of the rainy season. And the length of a growing period is the difference between the cessation and onset of rainfall. Studies in Ethiopia revealed that rainfall variability, unreliable occurrence of sufficient rainfall amount, prolonged dry spells, failure of Belg rainfall, delay in onset, and early cessation cause significant reductions in crop yields with reasonable amounts in almost all parts of the country (Bekele, 2015; Muluneh & Tesfaye, 2015; Getachew, 2017; G. Megersa *et al.*, 2019; Abegaz & Abera, 2020; M. Ayalew, 2020; Bahiru *et al.*, 2020).

2.6 The nexuses between Ethiopian Rainfall and Sea surface temperature

Ethiopian rainfall is influenced by the general atmospheric and oceanic factors that affect the weather conditions (Degefu *et al.*, 2016). The main rainy season contributes 74% of the country's

income; therefore, the failure of this rainy season would be disastrous for the country's economy, especially food production (Eshetie, 2021). The national meteorology agency of Ethiopia revealed that ENSO is strongly related to rainfall distribution in the country (Degefu *et al.*, 2016). El Nino originates in the eastern Pacific, but its warming effect is rapidly spread by the winds that blow across the ocean, altering the weather pattern is more than 60% of the continent (Degefu *et al.*, 2016). Some researchers and policymakers in Ethiopia stated that sea surface temperature (SST) in the Eastern tropical Pacific Ocean affects Ethiopian rainfall (Degefu *et al.*, 2016; Bayable *et al.*, 2021; Eshetie, 2021). Variability between high and low flood levels of the Nile River, whose major water source is the highlands of Ethiopia, is strongly related to ENSO. The previous researchers (Degefu *et al.*, 2016); Bayable *et al.* (2021); (Eshetie, 2021) revealed that El Nino/Southern Oscillation (ENSO) has more influence on rainfall variability in Ethiopia. During El Nino (La Nina), precipitation in equatorial East Africa might be positively or negatively affected by easterly or westerly wind anomalies. ENSO is cause of the inter-annual fluctuation of the atmosphere-ocean systems in the equatorial Pacific, and it has three phases: warm (El Nino), cold (La Nina), and Neutral. Neutral conditions occur when neither El Nino nor La Nina are present. Some study explained that the El Nino or warming of pacific ocean SST causes decreasing in Kiremet and increasing in Belg seasonal rainfall in Ethiopian (Bayable *et al.*, 2021). El Nino is a recurrent global atmospheric oceanic phenomenon associated with an increase in SST in the central tropical Pacific Ocean (Eshetie, 2021). It boosts the risk of heavy rainfall and flooding in some parts of the country and the risk of drought in other parts. The SST of the tropical Pacific shows a discrepancy both spatially and temporarily, and a high correlation exists between precipitation and SST. In Ethiopia, El Nino has been the cause of crop failure, livestock deaths, and food insecurity for many years, and the main cause of drought in the north eastern Ethiopia during Kiremet season. Examine El Nino/La Nina Southern Oscillation episodes are important to many sectors.

2.7 Relation between rainfall characteristics and crop yield

The impacts of rainfall on crop production in Ethiopia are closely related to its variability and the occurrence of dry and wet spells during the crop growing periods (Fitsum Bekele *et al.*, 2017; Wagaye *et al.*, 2020). The impacts of rainfall variability on crops vary with the types and varieties of crops cultivated (Ochieng *et al.*, 2021). A study by Bewket (2009) showed that among cereals grown in Amhara regional state, sorghum exhibited the largest year-to-year

variability in terms of total production and yields during the 1994–2003 time period, and this was markedly associated with the high inter-annual variability of rainfall. Moreover, during agro-meteorologically drier years, areas under cultivation and yield per unit of cultivated land become lower than in average years (Bekele, 2015). In dry areas, the productivity of crops is less than 31% of the average national grain yield of Ethiopia (Fitsum Bekele *et al.*, 2017). The previous Studies revealed that Bewket (2009) observed strong correlations between cereal yields like Teff, barley, and wheat with Kiremet rainfall. And another scholar, Getachew (2017) found that rainfall and Teff yield a statically significantly positive correlation; however, the correlation between maize, sorghum, and wheat with rainfall shows a less positive correlation; on the other hand, barely with rainfall shows a very weak positive correlation, almost zero. This implies that the increment or decrement of rainfall does not influence the yield. Another researcher, Wagaye *et al.* (2020) studied the north Wollo zone from 2010–2018 and found that the Onset and number of dry days had a negative correlation with Teff yield, and the number of rainy days, amount of rainfall, cessation date, and length of the growing period had a positive correlation with Teff yield. Another scholar (Bekele, 2015) found that Meher rainfall ($r = -0.161$ and $r = 0.479$) had low negative and moderate positive correlations with wheat yield in Harar and Gonder provinces in Ethiopia, respectively. On the other hand, Meher rainfall ($r = 0.009$ and $r = -0.255$) had a low positive and negative correlation at both locations in the country. In the study revealed by Abdi (2018) the regression analysis shows that rainfall amount had an impact on the wheat, sorghum, maize, and Teff yields, as well as the same result found by (Wagaye *et al.*, 2020) on the impact of rainfall characteristics on Teff yield in northern Ethiopia.

CHAPTER THREE MATERIALS AND METHODS

3.1 Description of the study area

Location

This study was conducted in the South Wollo zone and the area located in the northeast part of Ethiopia. Its geographical location lies within 10°12'N and 11°40'N latitudes and 38°30'E and 40°05'E longitudes (Mohammed *et al.*, 2019) (fig. 3.1).. It covers a total area of 17,053.45 km² and is divided into eighteen rural and two urban woreda, i.e., Dessie and Kombolcha. The South Wollo Zone is bordered on the south by North Shewa, on the west by East Gojjam, on the North by North Wollo, on the northeast by Afar Region, and on the East by the special Oromia Zone.

Topography

The highest point of the study area is Mount Ambaferit (4,247 meters). It is characterized by diverse topographic features in which high mountainous and deeply incised canyons and gorges, valleys, and plateaus with steep slopes dominate most parts. Total population size of the study area was 2,980,912 (Male 1,475,525 & Female 1,505,387) for 2014 (CSA, 2015).

Climate of the study area

Based on the traditional local system agro-climatic classification of Ethiopia, south wollo zone has 4 agro-climatic zones: Kola (low land) 36.8%; Woinadega (midland) 46.3%; Dega (high land) 16.3%; and Wurch (upper high land) 0.64% (Muluneh & Tesfaye, 2015). The general climate conditions of the study area are 14.0, 12.4, 11.3, and 4.2°C mean minimum annual temperatures and 29.7, 26.9, 22.4, and 15.2°C mean maximum annual temperatures in the lowland, midland, highland, and upper highland areas, respectively, and mean annual rainfall in the lowland, midland, highland, and upper highland areas are 853.2, 1119.2, 934.2, and 1072.3 mm, respectively, obtained from climatologically representative meteorological stations

Agriculture and Farming System

South wollo is one of the drought-prone and food aid-dependent areas in the Amhara region (Muluneh & Tesfaye, 2015). The main source of livelihood and economy in Ethiopia is agriculture. Like other parts of the country, South Wollo is mixed cereal livestock (Mohammed *et al.*, 2019). It is one of the drought-prone and food aid-dependent areas in the Amhara region (Muluneh & Tesfaye, 2015).

The farming system is diversified and characterized by the different Agro-ecological zones. Cereals like Teff, barley, sorghum, maize, and wheat are the dominant crops, accounting for 74.04% of the grain crop area and 76.29% of the production (G. Megersa *et al.*, 2019). Followed by pulses at 24% and the remaining 3% is oilseed. The most dominant crops in the south wollo zone are sorghum (Melkam, Teshale, Abshir and Gobye varieties) in the lowland area, sorghum (Gedo, Girana, Miskr varieties), maize, and Teff in the midland, Barley (HB.1307 and Traveler varieties and wheat in the highland, Barley (Holker, Ibone 173, and Agegnehu varieties in the upper highland (Gorfu & Ahmed, 2012).

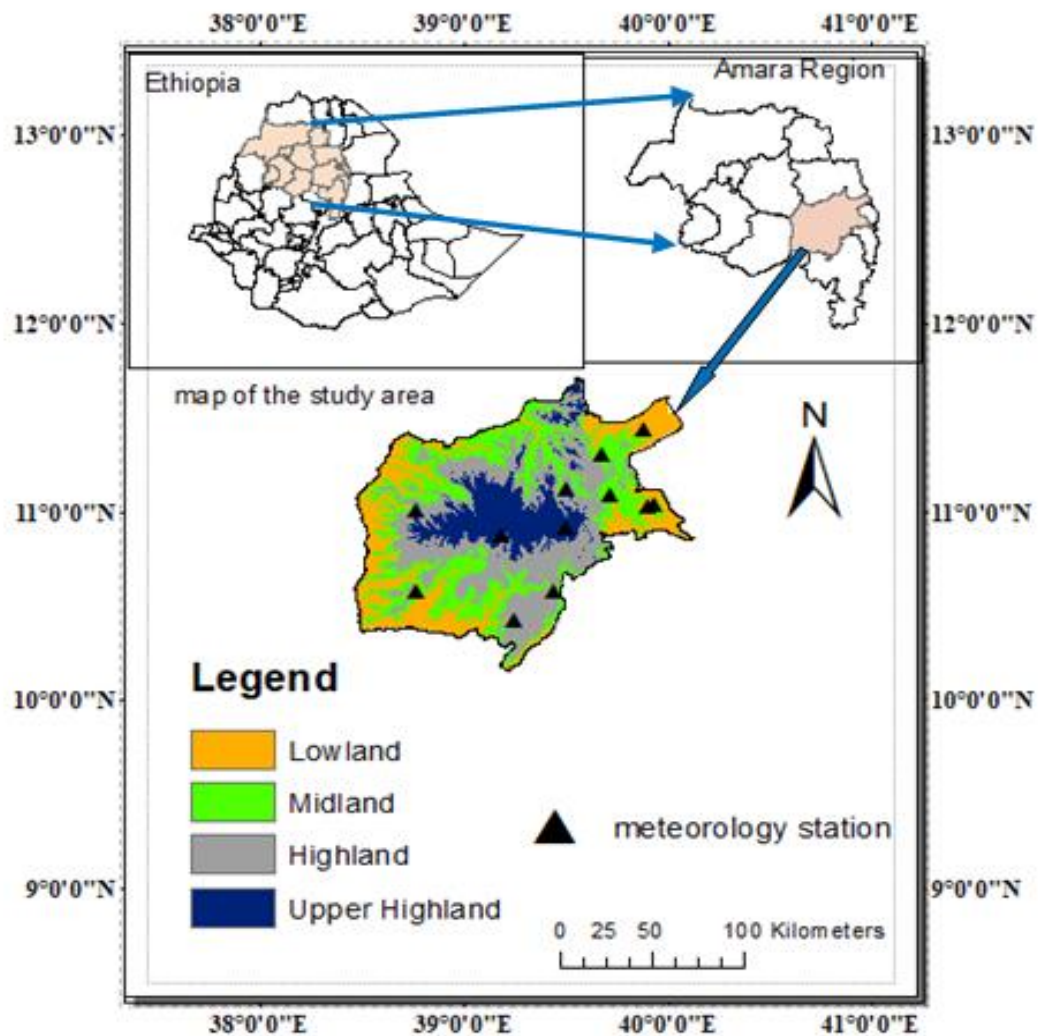


Figure3.3 Location of the Study Area

Source: Own Extraction from the Digital Elevation Model of the Amhara Region

3.2 Sampling techniques

South wollo zone is highly frequent drought affected area and vulnerable to climate variability and change. In this study the researcher was employed purposive sampling technique for drought prone area of south wollo zone as well as twelve representative meteorological stations are selected from different Agro-ecological zones based on availability of time serious data, three stations from lowland (Degan, Gerba and Bokeksa), two station from Midland (Kombolcha and Haik), five station from Highland area (Gerado, Jamma-degollo, Mekaneselam, Wereilu and Saint adjibar) and two stations from Upper Highland (Akesta and Guguftu) are selected.

3.3 Data source

Daily historical meteorological rainfall data were collected from 12 representative stations of the Ethiopian Meteorology Institute (EMI) shown table 3.1, Nino 3.4 region Sea Surface Temperature Data Download from the National Oceanic and Atmospheric Administration (NOAA) for the period 1987–2022.

Website:origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/detrend.nino34.ascii.txt

The Nino 3.4 index mean SST was calculated by taking the spatial average SST within the Nino 3.4 which extends from 5° N to 5°S latitude and from 120° W to 170° W longitude in the pacific ocean. Major crop yield data were obtained from the central statistical agency and agricultural office of the South Wollo Zone for the period 2011–2022.

Table3.1 Selected meteorological stations and their geographic locations					
Agro-ecology Zone	Station name	Latitude	Longitude	Elevation	Study time period
Lowland	Degan	11.03	39.90	1581m	1987-2020
	Gerba	11.03	39.93	1605m	1987-2020
	Bokoksa	11.44	39.88	1711m	1987-2020
Midland	Kombolcha	11.08	39.72	1857m	1987-2020
	Haik	11.31	39.68	1985m	1987-2020
Highland	Gerado	11.12	39.51	2303m	1987-2020
	Jama-Degolo	10.42	39.25	2601m	1987-2020
	Mekaneselam	10.58	38.76	2605m	1987-2020
	Werielu	10.58	39.44	2708m	1987-2020
	Saint Adjibar	11.01	38.77	2844m	1987-2020
Upper Highland	Akesta	10.87	39.18	3086m	1987-2020
	Guguftu	10.91	39.50	3431m	1987-2020

3.4 Method of Data analysis

The analysis of the data was conducted in line with the objectives of the study, so various methods of data analysis were employed in this study. The first mean ratio method was used to fill in the missing data and maintain the Quality of the data. The inter-quartile method is used for outlier detection using the mean monthly rainfall data, and the single mass cumulative curve method is used to check the homogeneity of climate data. After checking the quality of the data, areal rainfall was calculated in each agro-ecology zone. IN Stat software version 3.37 was used to summarize the daily data into annual, monthly, and seasonal totals to determine the onset, cessation of the growing season, the length of the growing period (LGP), the number of rainy days and dry days. The coefficient of variation, precipitation concentration index, and standardized anomaly were analyzed to describe rainfall and crop yield variability. The R-Studio Mann-Kendall trend test and Sen's slope estimator were used for the trend significance and magnitude of the change in rainfall, respectively. Finally, SPSS software was used to analyze Correlation and regression to examine the relationship between rainfall with Nino 3.4 SST, and crop yield data in the study area and to explain the impact of rainfall variability or change on crop yield respectively.

3.4. 1 Estimation of Missing data

Many methods are available for the estimation of missing data such as arithmetic mean methods, correlation methods, Isohyetal linear interpolation, and the mean ratio method (Hamisi, 2013). In the present study, missing rainfall records were encountered in the observed rainfall data from twelve stations, i.e., Degan, Gerba, Bokeksa, Kombolcha, Haik, Gerado, Jama-degollo, Mekaneselam, Wereilu, Saint Adjibar, Akesta, and Guguftu. The percentage of missing records was found to be 3%, given that the study required continuous data; therefore, the mean ratio method was used for the estimation of missing records, this method was mostly recommended by WMO. However, before the estimation of missing data, pairs of nearby stations were selected and their correlation coefficients computed in order to find the strength of the association between the rainfall data of the stations. The station that depicted the highest correlation with the one that has missing data is selected in the determination of missing data. Therefore, the estimation of missing gaps using mean ratio methods was between the stations that have the highest correlation value. Given that annual precipitation values P_1 , P_2 , P_3 , and P_m at neighboring M stations of station X 1, 2, 3, and m , respectively. The normal average

precipitation given by N1, N2, N3, Nm, Ni, etc. includes 12 stations. To find the missing precipitation P_x at station X, the following formula was used to calculate the missing gaps: The station that depicted the highest correlation with the one that has missing data is selected in the determination of missing data. Therefore, the estimation of missing gaps using mean ratio methods was between the stations that have the highest correlation value. Given that annual precipitation values P_1, P_2, P_3 , and P_m at neighboring M stations of station X 1, 2, 3, and m, respectively. The normal average precipitation given by N1, N2, N3, Nm, Ni, etc. includes 12 stations. To find the missing precipitation p_x at station X, the following formula was used to calculate the missing gaps:

$$P_X = \left[\frac{P_1}{N} + \frac{P_2}{N} \dots + \frac{P_m}{N_m} \right] \quad (1)$$

3.4. 2 Data quality control

3.4.2.1 Inter quartile range (IQR)

The quality of the data was understated for the historical time period prior to undertaking the analysis. Under this study, errors due to data organization and data reporting internal consistency, i.e., rainfall values less than 0 mm, were evaluated and managed. On the other hand, outliers in the time series data were detected correctly to check whether the value was really an outlier or a naturally extreme value. The inter-quartile range method is known as a technique that is resistant to outliers but still keeps the data free of extremes (W. Bahiru & Zewdu, 2021a). The detected outlier value was removed and substituted by the outlier threshold. The standard outlier threshold, which is defined using the inter-quartile range (IQR), was used to manage the outliers. The threshold values were estimated using the formula below, i.e.

$$THRESHOLD = Q1 - 3IQR, Q3 + 3IQR \quad (2)$$

Where $Q1$ is first quartile, $Q3$ is third quartile and also IQR is inter-quartile range (i.e. the difference between $Q3$ and $Q1$).

3.4.2.2 Homogeneity test

The homogeneity test is the most important aspect of data quality control. The single mass curve method is widely used in climate data quality checking (Hamisi, 2013). So In this study,

the single mass curve method was employed to test homogeneity. It involves plotting the cumulative rainfall total against time (Hamisi, 2013).

3.5 Average areal rainfall of the study area

The monthly rainfall series of all the stations was used to calculate an area's average rainfall for the region as follows: (W. Bahiru & Zewdu, 2021a).

$$R_j = I_j^{-1} \sum X_{ij} \quad (3)$$

Where R_j is a real integrated rainfall for year j ; X_{ij} is rainfall at station i for year j and I_j is the number of stations available for year j . Variability and trend in the area rainfall were also examined using the same methods.

3.6 Variability analysis using statistical test

3.6.1 The coefficient of variation

The coefficient of variation (CV) was used to analyze the seasonal and annual variations in the rainfall and crop yield data. Different scholars used the same method to analyze variability (Zerga & Gebeyehu, 2016; Legese *et al.*, 2018; Mohammed *et al.*, 2019; Bayable *et al.*, 2021; A. Belay *et al.*, 2021).

$$CV = \frac{SD}{\bar{X}} \quad (4)$$

The CV values are classified as follows: if $CV < 20$ it is low variability, if $20 \leq CV < 30$, it is moderately variability, if $CV \geq 30$, it is strong variability.

Where CV is coefficient of variation, SD is standard deviation while $\bar{x}$ is the long-term mean.

3.6.2 The Precipitation Concentration Index (PCI)

The precipitation concentration index was used as a statistical descriptor of rainfall variability Mondol *et al.* (2017); (Mohammed *et al.*, 2019; Abegaz, 2020; W. Bahiru & Zewdu, 2021a; A. Belay *et al.*, 2021); The PCI values were calculated as given by

$$PCI_{annual} = 100 * \frac{\sum_{i=1}^{12} (P_i)^2}{(\sum_{i=1}^{12} p_i)^2} \quad (5)$$

Where P_i is the rainfall amount of the I^{th} month; and Σ = summation over the 12 months, (Abegaz, 2020); W. Bahiru and Zewdu (2021a).

Classified the PCI values as low precipitation concentration or uniform $PCI \leq 10$, moderate precipitation distribution $11 \leq PCI \leq 15$, irregular precipitation distribution $16 \leq PCI \leq 20$, and strongly concentrated or strongly irregular distribution ($PCI > 20$).

3.7 Onset of rainy season

The onset of rain, which is defined as the first occasion after a selected date when the rain accumulated over three consecutive rainy days is at least 20mm and there are no dry spells lasting more than 9 days in the next 30 days, is used as a successful plantation date. Different authors used different thresholds value to determine the onset of the rain. The criteria use in this study, onset of the rainy season was determined as; the date when 20 mm or more of rainfall accumulated Over three consecutive rainy days after a starting date (1st of June for the Kiremet season with no dry spell length greater than 7 days in the next 30 days as used. INSTAT 3.37 Software is used to compute the start date of the growing season for each studied station; the previous researcher (Legese *et al.*, 2018); Wagaye *et al.* (2020) used the same method.

3.8 Cession or end of Growing Period

The end of the growing season was mainly dictated by the stored soil water and its availability to the crop after the rain stops. In this study, the end of the rainy season was defined as any day after the 1st of September for Kiremet season when the soil water balance reaches zero. Since the dominant soil for all studied locations was Vertisols with high clay content (>50%), 100 mm/meter of the plant's available soil water, and site-specific daily reference Evapo-transpiration (ETO) values were considered. The same method was conducted by several

authors to determine the end date of the growing season in different parts of Ethiopia (Legese *et al.*, 2018; Wagaye *et al.*, 2020).

3.9 Length of Growing Period

Length of growing period is the number of days in the year during rainfall and moisture stored in the soil exceed have of potential evapo-transpiration. The length of growing period (LGP) of Kiremet seasons was determined as the difference between the Cession and start of rainy seasons, different scholars used the same method to determine the LGP of the Kiremet seasons (Amekudzi *et al.*, 2015; Caroline M. Dunning¹, 2016; Ojo & Ilunga, 2018).

3.10 Number of rainy and dry days

The smallest recorded amount of rainfall is 0.1 mm; a threshold value of 1mm was used to define days as wet or dry because 0.1mm of rainfall almost has no impact on crop growth. Thus, in the current study, the number of rainy and dry days was determined by counting all days with rainfall of 1.0 mm as rainy and those days with less than 1.0 mm as dry days, respectively. Different researchers used the same definition. (Bekele, 2015; Legese *et al.*, 2018; Abegaz & Abera, 2020; Bahiru *et al.*, 2020; Wagaye *et al.*, 2020; W. Bahiru & Zewdu, 2021b).

3.11 Mann-Kendall Trend and significance test

Precipitation data show a long-term change in data or some pattern changes in the given temporal scale series. Hence, to describe a trend in a time series, the Mann-Kendall trend test was used to see whether there was a trend or not. Mann-Kendall statistics (S) is one of the non-parametric statistical tests used for detecting trends in climatic variables and this test is strongly recommended by the World Meteorological Organization (WMO) to detect climate variables (Ojo & Ilunga, 2018). It is the most widely used method since it is less sensitive to outliers (extraordinarily high values in time series data) because it considers the rank of the observation rather than actual data, is less affected by missing values and uneven data distribution, and is the most robust as well as suitable for detecting trends in precipitation (Kusiak *et al.*, 2017; Abegaz, 2020; Bayable *et al.*, 2021; A. Belay *et al.*, 2021; Getachew & Manjunatha, 2021).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(X_j - X_i) \quad (6)$$

Where X_j and X_i are the annual values in years j and i , $j > i$, respectively, and

Different software, such as SPSS and Excel, can be used for trend analysis and significant tests. However, SPSS and Excel software are very sensitive to outliers (extraordinarily high values). Hence, the Mann-Kendall trend test was used to detect the trend and a normalized Z-score for significant tests. A score of +1 is awarded if the value in a time series is larger, or a score of -1 is awarded if it is smaller. The total score for the time-series data is the Mann-Kendall statistic, which is then compared to a critical value to test whether the trend in rainfall is increasing, decreasing, or if no trend in rainfall can be determined.

$$sgn = (X_j - X_i) \begin{cases} 1 \text{ if } X_j - X_i > 0 \\ 0 \text{ if } X_j - X_i = 0 \\ -1 \text{ if } X_j - X_i < 0 \end{cases} \quad (7)$$

A positive value of S indicates an "upward trend or increasing trends" while a negative value of S designates a "downward trend or decreasing trends". It is necessary to compute the probability associated with S and the sample size, n , to statistically quantify the significance of the trend. The variance associated with S is calculated (Getachew & Manjunatha, 2021).

$$var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^m t_k(t_k-2t_k+5)}{18} \quad (8)$$

Where m is the number of tied groups and t_k is the number of data points in group k . In cases where the sample size $n > 10$, the test statistic $Z(S)$ is calculated from (Getachew & Manjunatha, 2021).

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{var(S)}} & \text{if } S < 0 \end{cases} \quad (9)$$

If Z is negative and the absolute value is more than the level of significance, the trend is said to be decreasing, while if Z is positive and the absolute value is greater than the level of significance, the trend is said to be increasing. There is no trend if the absolute value of Z is smaller than the level of significance. In this investigation, the desired value of α (0.05) is used.

Sen.'s method Sen.'s non-parametric method developed by Sen (1968) was adopted to quantify the change and the magnitude of a trend, and calculated as follows:

$$f_{(t)} = Q_t + B \quad (10)$$

Where $f(t)$, the estimated data at t year, Q is slope of trend line and, B is constant. Then the slope Q is estimated as Eq. (11).

$$Q_i = \frac{X_j - X_k}{j - k} \quad (11) \quad \text{Where } j > k$$

Where Q_i is Sen's slope estimator, X_j and X_k are the data values at times j and k ($j > k$), respectively. The median of these N values Q_i is represented as Sen's slope estimator and calculated as Eq. (12).

$$Se' estimator = \left\{ \begin{array}{ll} \frac{Q(R+1)i}{2} & \text{if } R \text{ is odd} \\ 0.5 * \left(\frac{QR}{2} + \frac{Q(R+2)}{2} \right) & \text{if } R \text{ IS even} \end{array} \right\} \quad (12)$$

A negative and positive value of Sen.'s estimator indicates a downward and an upward trend in the time series analysis, respectively (Getachew & Manjunatha, 2021).

3.12 Correlation and regression analysis

3.12.1 Correlation analysis

Pearson correlation and regression coefficient (r) analyses was used to measure the relation between two variables, according to In this study Pearson correlation evaluates correlation between Nino 3.4 SST and seasonal rainfall in the study area, And also the correlation between major crop yields (sorghum, Barley, maize, Teff, and Wheat) stable grown in the study area with different rainfall variables, i.e., seasonal rainfall, onset, cessation date, Number of rain days, length of the growing period, and number of dry days, to identify the most predictor variable. The Correlation coefficient value of r was close to +1 were interpreted as indicators of a strong positive correlation, and a correlation coefficient r close to -1 were interpreted as indicators of a strong negative correlation, while a correlation coefficient of r is 0 interpreted as indicators of no correlation or association. The following correlation coefficient formula is used to obtain the correlation coefficient:

$$r_{xy} = \frac{\frac{1}{n} \sum_{i=1}^n [(X - \bar{X}) * (Y - \bar{Y})]}{\left[\frac{1}{n} \sum_{i=1}^n (X - \bar{X})^2 * \frac{1}{n} \sum_{i=1}^n (Y - \bar{Y})^2 \right]^{\frac{1}{2}}} \quad (13)$$

Where, X is crop yield, Y is climatic variables value, $\bar{X}$ is the mean values of yield, $\bar{Y}$ is the mean values of climatic variables data value and n is the number of observation. r_{xy} , Pearson correlation coefficient.

3.12.2 Regression analysis

Regression analysis is a form of predictive modeling technique that investigates the relationship between a dependent variable (the target) and an independent variable (the predictor). Multiple regression analysis was used to determine the contribution of rainfall characteristics to crop yield. The analysis described the effects of the independent variables on the dependant variable or the yields of the crops. The regression model for the study was also computed as

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 \dots b_nx_n + e \quad (14)$$

Where; Y = the value of the dependent variable (sorghum, Wheat, barley and Teff yield Quintal/ha);

a = Y intercept, $b_1, b_2, b_3, b_4, \dots b_n$ = regression coefficients (each b represents the amount of change in Y (crop yield) for one unit of change in the corresponding x -value when the other x values are held constant; $x_1, x_2, x_3, x_4, \dots x_n$ = the independent variables (i.e. rainfall onset, cessation, LGP, Kiremet total rainfall and number of rain and dry days respectively); and e = the error of estimate or residuals of the regression.

4, CHAPTER FOUR RESULT AND DISCUSSION

4.1 Rainfall data quality control

Table4.1 Data quality checking

Station name	Missing data in %	Filling method	Outlier detection by IQR	Replaced by threshold value
Degan	-		June-1989, pick value 500	115
Gerba	-			
Bokoksa	-			
Kombolcha	-			
Haik	-			
Gerado	0.5%	Mean ratio	July-2015, pick value 797	395
Jama-Degolo	-			
Mekaneselam	1%	Mean ratio	July-2017, pick value 690	387
Weriellu	-			
Saint Adjibar				
Akesta	1.5%	Mean ratio		
Guguftu	-		August-2015, pick value 854	347

4.2 Homogeneity test

A single mass curve is a plot of annual cumulative rainfall against time. Twelve stations were almost straight lines, indicating that the data is homogenous. Figures 4.1–4.4 indicates that the homogeneity of a data each stations that lie in the same agro-ecological zones. The figure shows a straight line, indicating that the data have good quality.

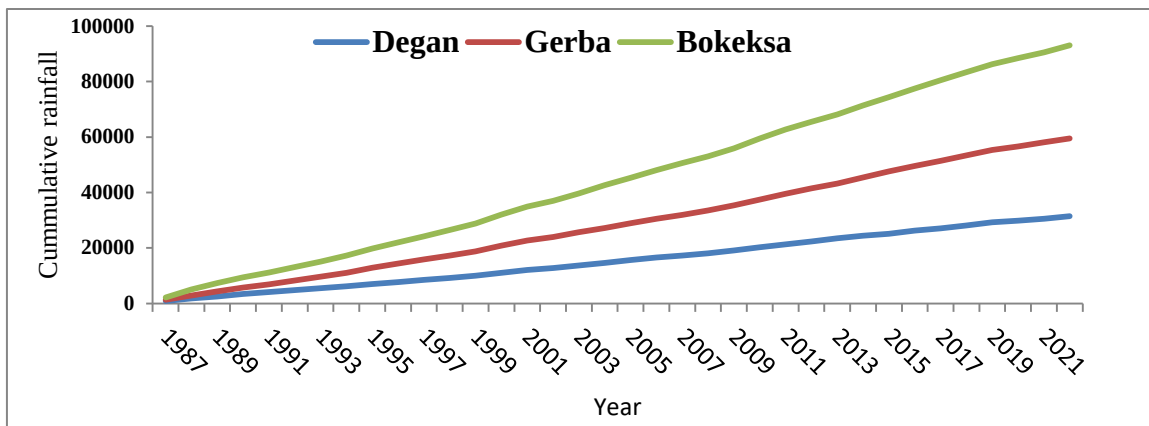


Figure4.4 Single mass curve of cumulative rainfall in lowland area

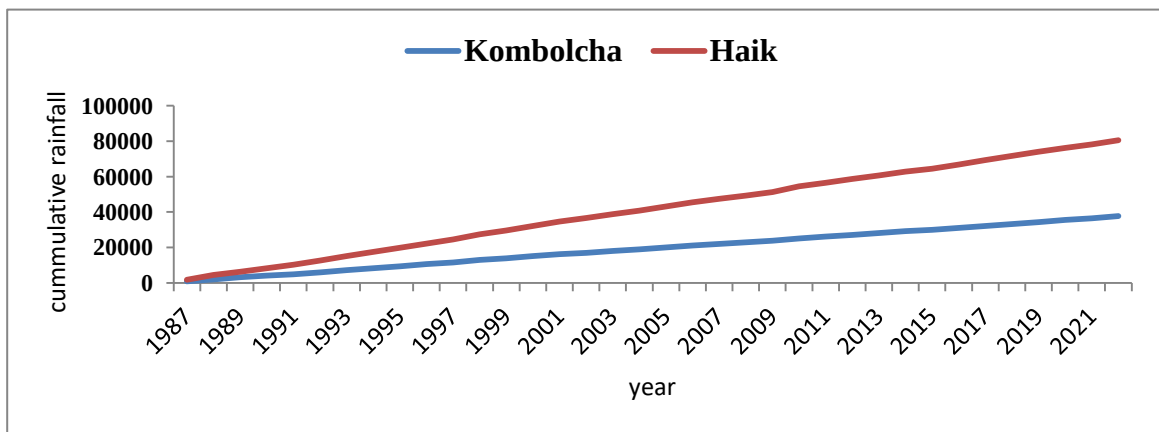


Figure4.5 Single mass curve cumulative rainfall in the midland area

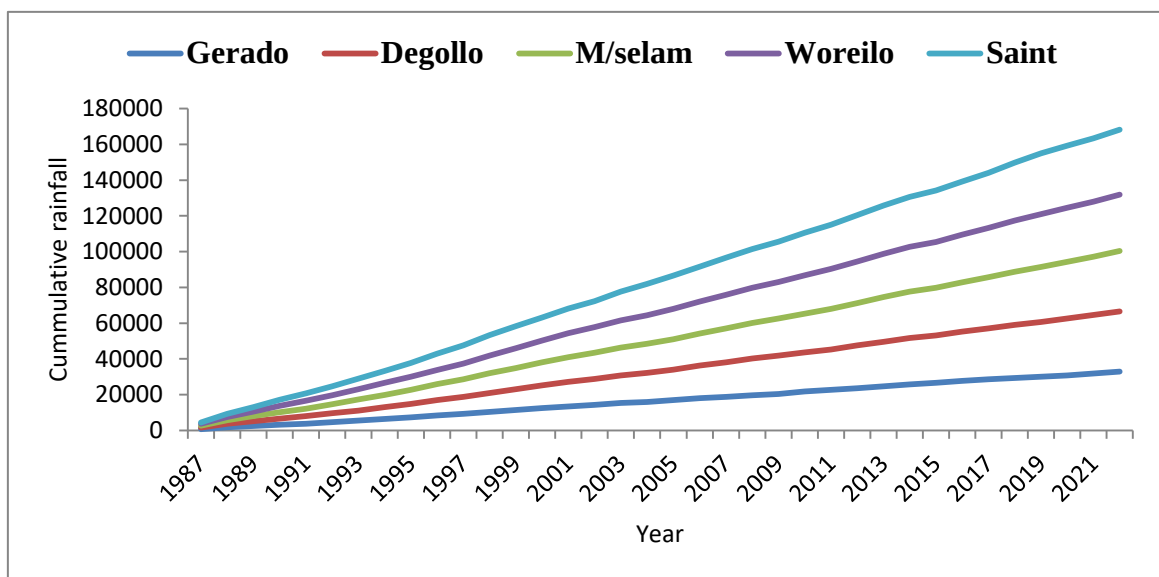


Figure4.6 Single mass curve of cumulative rainfall in the highland area

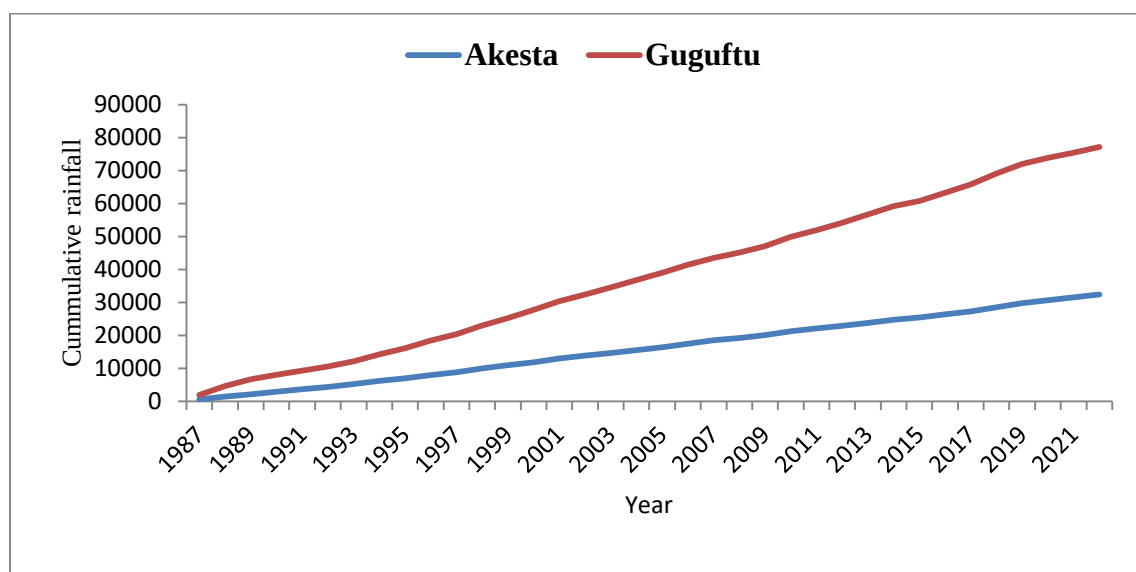


Figure4.7 Single mass curve of cumulative rainfall in the upper highland area

4.2 Climatologically rainfall distribution of the study area

In climatologically rainfall analysis, the time period from 1987 to 2022 In terms of rainfall distribution, the study area receives rainfall twice a year, as shown in the figure below. This rainfall time period lies June to September (Kiremet) and from February to May (Belg). Kiremet is the main rainy season in which most agricultural activities are conducted. Whereas the Belg season is a short rainy season, land preparation practices for the main growing season and long maturing sorghum and maize planting begin. The mean rainfall during the Kiremet season (June to September) and the short rainy season (February to May) and also bega seasons (October to January) are 700.3, 217.6 and 52.0 mm, respectively. June to September, or Kiremet season, is the major contributor (65 to 80% of the annual total rainfall), followed by the Belg (February to May) season, which contributes 37 to 68% of the annual total rainfall and bega season contribute small amount of the annual total rainfall from 5 to 10%. This finding is in line with the previous studies by Mohammed *et al.* (2019) studied the South Wollo zone. The better amount of rainfall received during the monthly, seasonal, and annual time periods in the midland area, and the low amount of rainfall received in the lowland area compared to the highland and upper highland areas See Figs. 4.5–4.9 below.

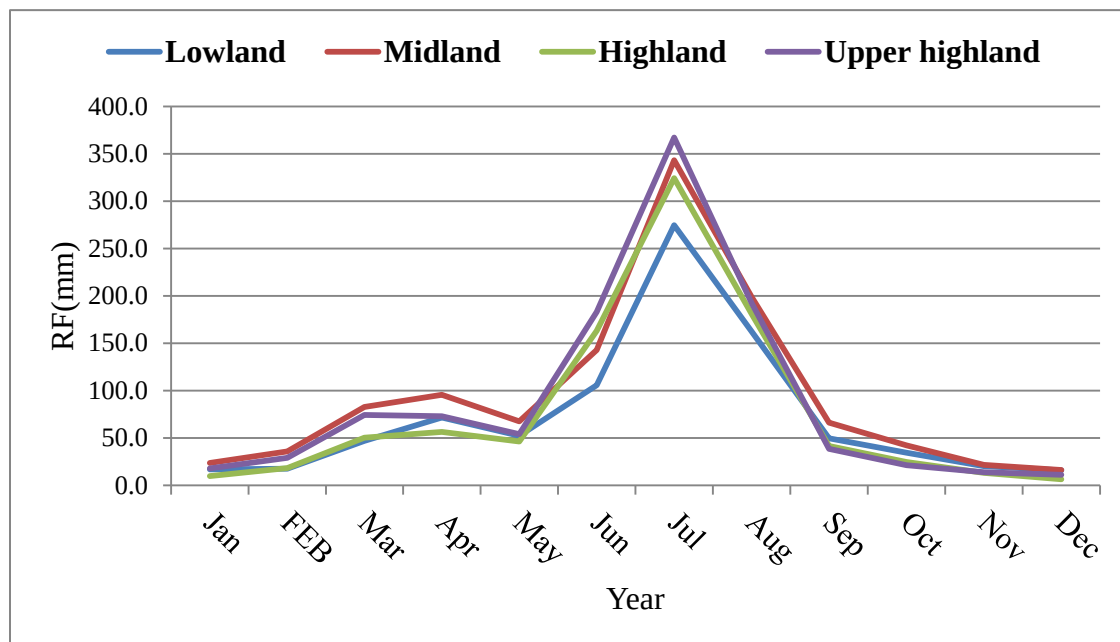


Figure4.8 Mean monthly rainfall distribution in the study Area (1987-2022)

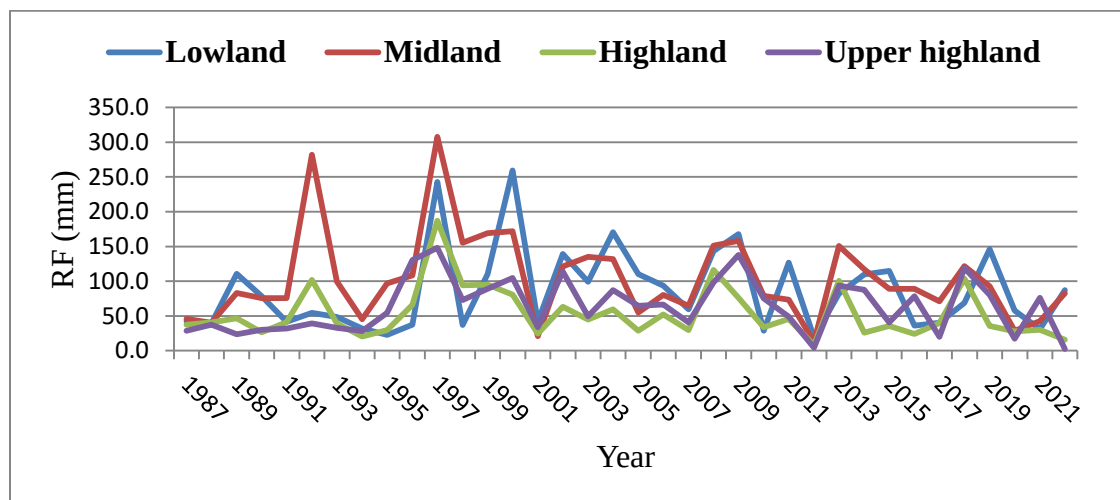


Figure4. 9 Mean Bega seasonal rainfall distribution in the study Area (1987-2022)

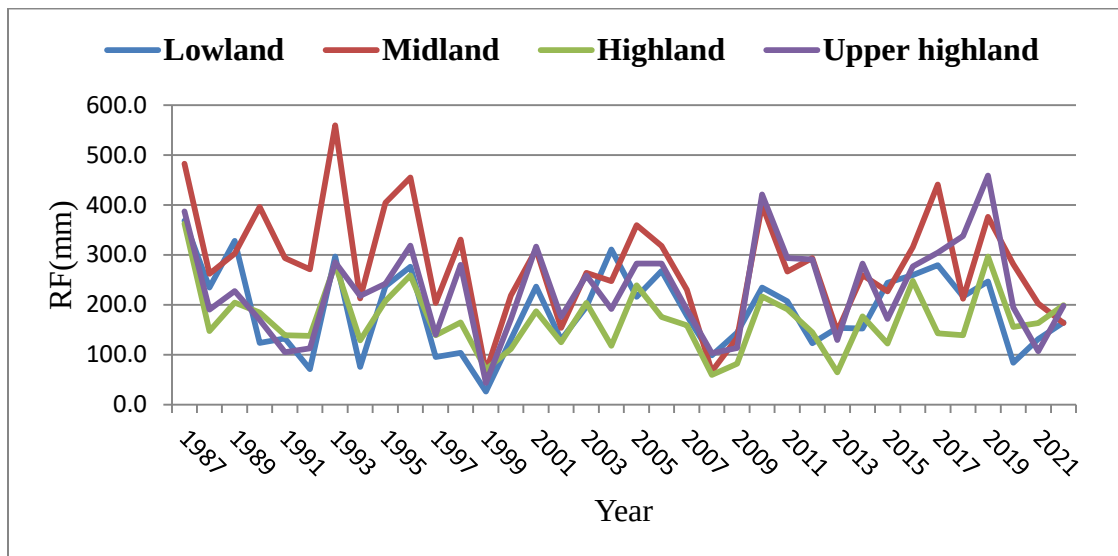


Figure4. 10, Mean Belg seasonal rainfall distribution in the study Area (1987-2022)

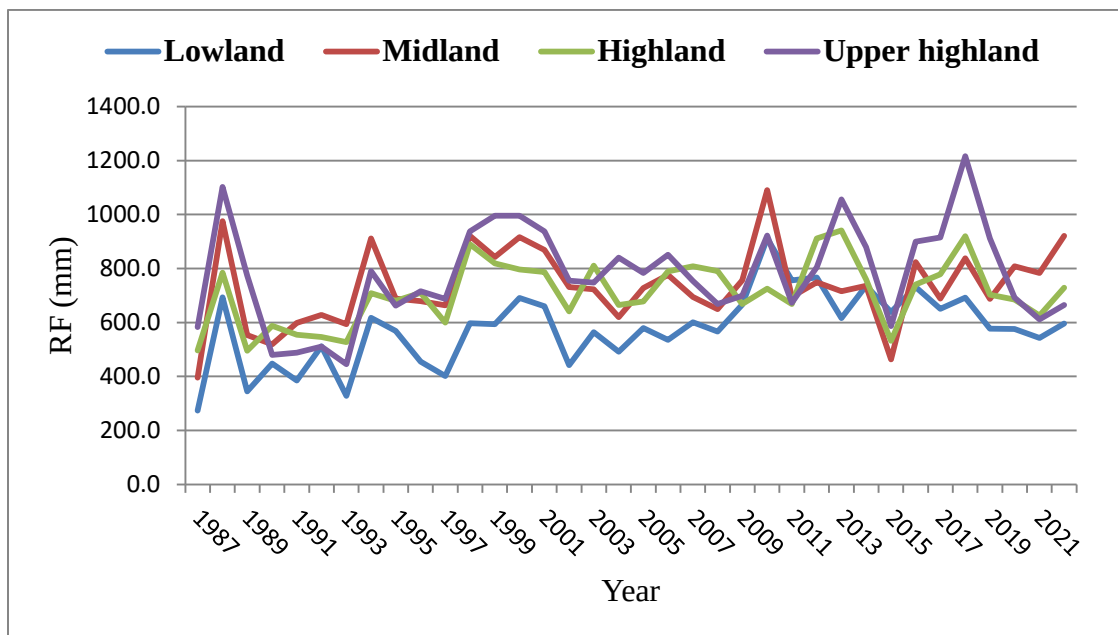


Figure4. 11, Mean Kiremet seasonal rainfall distribution in the study Area (1987-2022)

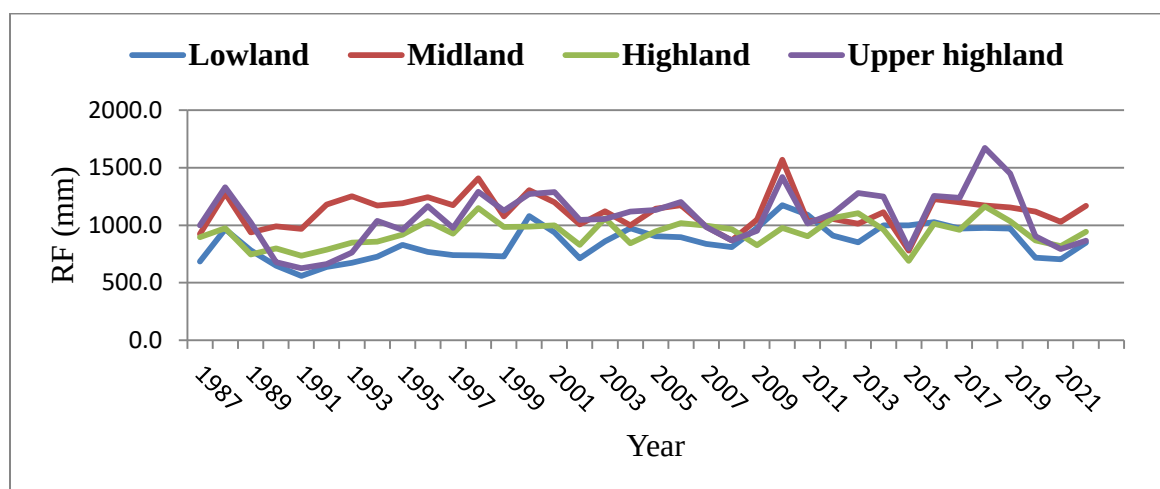


Figure 12.9 Annual rainfall distributions in the study Area (1987-2022)

4.2 Variability of seasonal and annual rainfall in the study area

Understanding the variation and trend of annual and seasonal rainfall is crucial for strategic planning of farming activities like what and when to plow the farm (Tesfamariam *et al.*, 2019; Wagaye *et al.*, 2020; Rettie *et al.*, 2022).

The analysis result of historical rainfall time series data indicates the magnitude of rainfall variability in the study area in different agro-ecological zone and seasons, See Table 4.1. The coefficient of variation statistics indicated that the annual rainfall variability of the study area ranges from 19.0 to 25.7% in the lowland, 15.5 to 16.3% in the midland, 17.1 to 27.1% in the highland, and 18.3 to 30.8% in the upper highland. Whereas rainfall variability during the Kiremet season varies from 27.2 to 30.4% in the lowland, 19.5 to 22.8 in the midland, 21.7 to 28.6% in the highland, and 22.5 to 30.8 in the upper highland area. The coefficient of variation of the Belg season: 49.0 to 59.9% in the lowland, 42.3 to 42.5% in the midland, 37.0 to 68.8% in the highland, and 45.4 to 47.6% in the upper highland area. And also the coefficient of variation of the Bega season: 82.5 to 89.9% in the lowland, 60.0 to 67.0% in the midland, 74.0 to 96.7% in the highland, and 66.8 to 70.1% in the upper highland area.

The result indicates that during the Belg season, the amount of rainfall variability is highly unstable compared to the main growing season (Kiremet), this is due to erratic nature of Belg rainfall. The seasonal rainfall variability was higher than the annual variability in all agro-ecological zones in the study area. This result agrees with the findings of previous studies conducted by Wagaye *et al.* (2020) who studied northern Ethiopia, and other scholars Legese *et al.* (2018) who studied the Bale highland area of southeastern Ethiopia.

Higher coefficients of variation of annual and seasonal rainfalls in the study area shown the table 4.2 below indicates higher year-to-year and season-to-season variation of rainfall. This implies that higher intra-seasonal and inter-annual variability of rainfall could be negatively affect agricultural practice (Bekele, 2015).

Table 2.2 Mean annual and seasonal rainfall (mm), coefficient of variation (CV %), contribution of Seasonal rainfall to the annual rainfall (CT %) and Precipitation concentration index (PCI) in different agro-ecological zones

		Bega RF			Belg RF			Kiremet RF			Annual RF		
		Mean	CV (%)	CT (%)	Mean	CV (%)	CT (%)	Mean	CV (%)	CT (%)	Mean	CV (%)	PCI %
Low land	Degan	82.4	82.2	9.6	203	49.0	23.6	575	27.2	66.9	860	19.0	17
	Gerba	63.8	88.9	8.3	146	51.7	19.0	556	33.5	72.7	766	25.2	19
	Bokeksa	114	87.2	12.3	216	59.9	23.2	601	30.4	64.5	932	25.7	16
	Areal	87.0	68.0	10.2	188	43.8	22.1	578	23.4	67.7	853	17.2	17
Mid land	Kombolc												
	ha	99.3	65.0	9.5	246	42.5	23.5	702	19.5	67.0	1047	14.5	16
	Haik	107	67.1	9.0	316	42.3	26.6	766	22.8	64.4	1190	16.3	16
	Areal	103	61.3	9.2	281	39.6	25.1	734	19.7	65.6	1119	13.5	16
Highland	Gerado	55.9	87.6	6.1	166	51.1	18.2	689	22.7	75.7	911	18.4	20
	Degollo	39.2	87.4	4.2	151	42.0	16.2	743	26.0	79.6	934	19.8	23
	M/selam	73.3	74.4	7.8	213	37.0	22.7	654	21.7	69.5	941	17.1	16
	Woreilu	32.3	74.3	3.7	143	68.8	16.4	701	27.3	79.9	877	20.4	23
	Saint	67.0	96.7	6.7	179	67.6	17.8	760	28.6	75.5	1007	27.1	20
	Areal	53.5	68.2	5.7	170	38.5	18.3	709	16.8	76.0	934	12.2	20
Upper highland	Akesta	57.2	70.1	6.3	236	45.4	26.2	608	22.5	67.5	902	18.0	18
	Guguftu	69.9	66.8	5.6	223	47.6	18.0	949	30.8	76.4	1242	30.0	21
	Areal	63.5	60.2	5.9	229	41.5	21.4	779	23.2	72.6	1072	21.9	19

4.4 Onset, Cessation date, length of growing period and number of rainy days

Agricultural productivity mainly depends on rainfall characteristics. An analysis of seasonal rainfall characteristics (onset, cessation, length of growing period (LGP), and number of rainy days) was investigated for the main growing season (June to September) using historical rainfall data. Detail studies of seasonal characteristics on the local scale like onset, cessation, length of growing season, and number of rainy days are important to manage the climate resource, early warning, and preparedness (Tilahun, 2006; Méndez-Lázaro *et al.*, 2014; Legese *et al.*, 2018; Tesfamariam *et al.*, 2019; Wagaye *et al.*, 2020; Ochieng *et al.*, 2021). So this study is important to manage agricultural activities in the study area. Table 4.3 and Figure 4.10 show statistics of estimated mean onset, cessation, LGP, rainy days, and coefficient of variation were summarized.

The result shows that the average Early onset of the season was 14-jun Mekaneselem stations (in the Midland Area) and late onset of the season was 10-Jul Gerba station (in the Lowland Area). The early average cessation date of the season was 17-sep atAkesta station (in the Upper High land Area) and late cessation of the season was 13-Oct at kombolcha station (Midland Area).

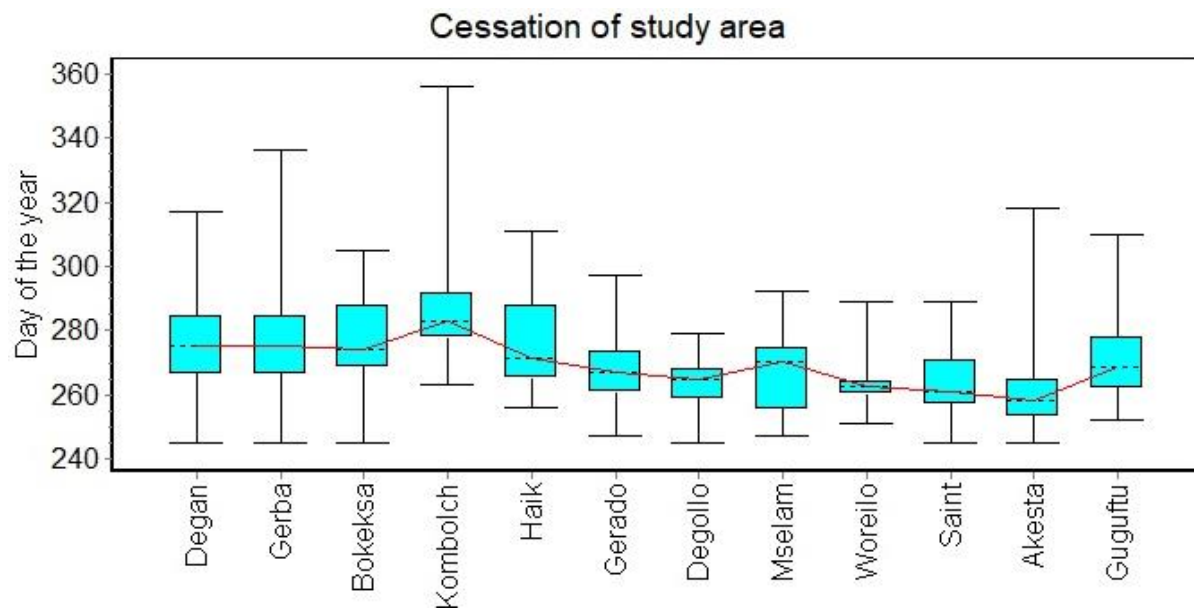
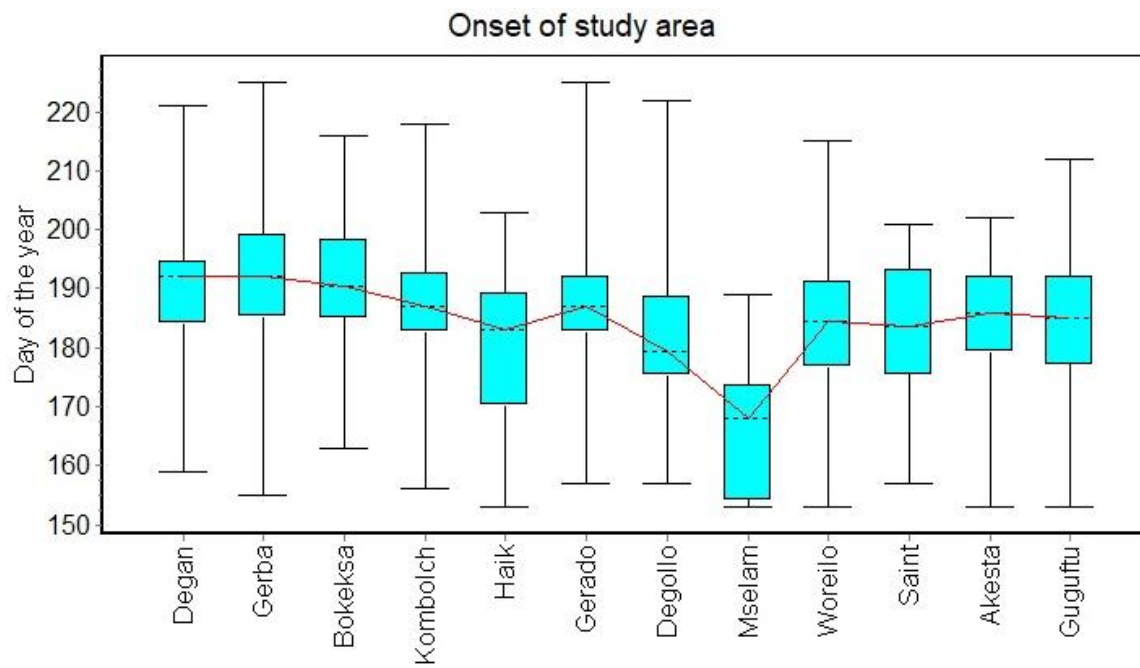
The result revealed that onset and cessation dates varied across Agro-ecological zones in the study area. Generally, the onset of rain was found to be predominantly in the months of June and July, and the cessation date of the season was September or October in all Agro-ecological zones. The length of the growing period and the number of rainy days also vary from 78 at Akesta station in the upper highland area to 102 at Kombolcha station in the midland area and 48 days Bokeksa station in the lowland area to 87 days at Mekaneselem station in the Highland area, respectively. Detail information's are presented the table4.3 below.

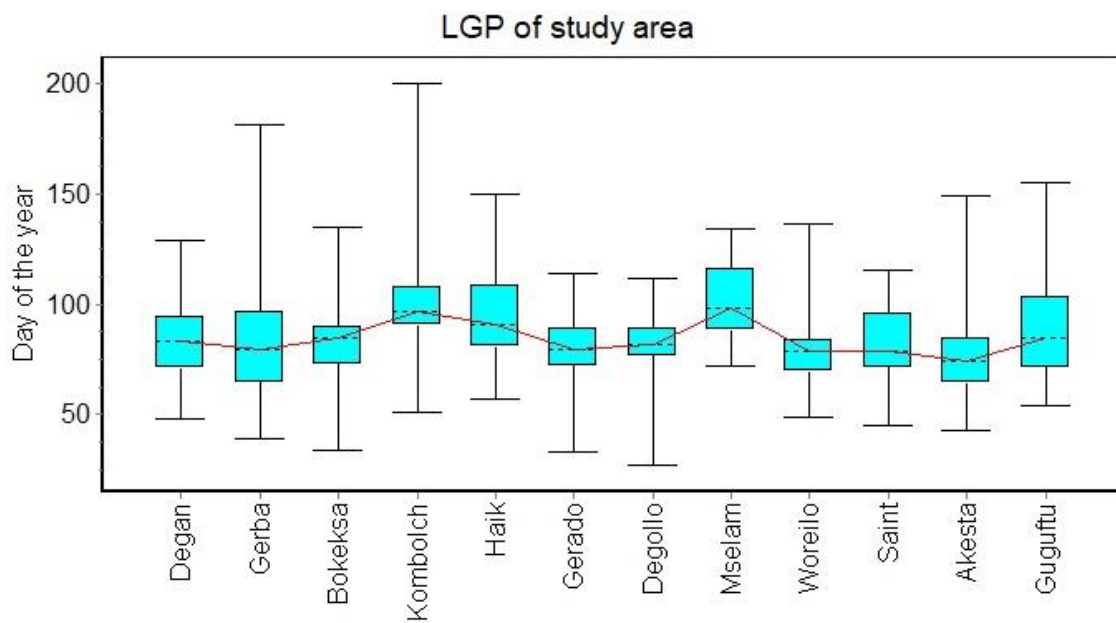
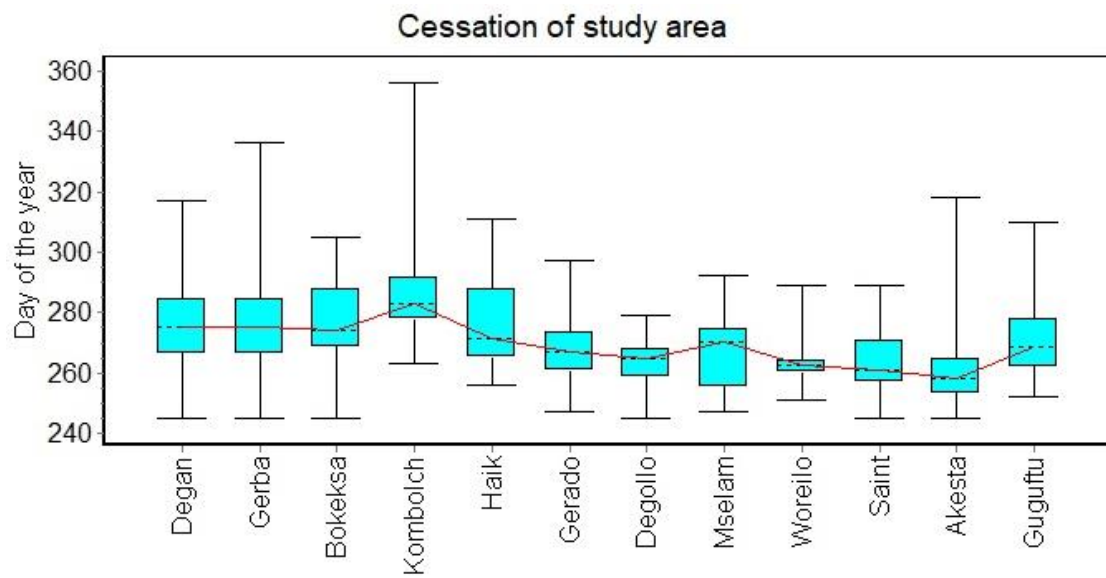
The Coefficient of Variation statistical results indicated that all Agro-ecological zones of the study area had less intra-seasonal onset and cessation date variation from 1987 to 2022 in the study period. Therefore, this lower variability implies that the patterns could be better understood the onset and cessation dates of the season, this is important to more reliable and predictable. On the other hand, moderate to higher variability in the length of the growing period and NRD of the seasonal rainfall were observed in all Agro-ecological zones of the study area. This implies that increasing the risks of water stress during vegetative and flowering stages, the period in which the water demand of plants is increasing, causes quality and quantity losses in production. This result agrees with the previous study by Wagaye *et al.* (2020) in the northeastern part of Ethiopia.

Table3.3 Summary statistics for onset, cessation, LGP, rainy days and coefficient of variation (1987 to 2022)

		Degan	Gerba	Bokeksa	Kombolcha	Haik	Gerado	Degollo	M/selam	Woreilo	Saint	Akesta	Gugufu
Onset	Minimum	7-Jun	3-Jun	11-Jun	4-Jun	1-Jun	5-Jun	5-Jun	1-Jun	1-Jun	5-Jun	1-Jun	1-Jun
	Maximum	8-Aug	12-Aug	3-Aug	5-Aug	21-Jul	12-Aug	9-Aug	7-Jul	2-Aug	19-Jul	20-Jul	30-Jul
	Mean	9-Jul	10-Jul	9-Jul	3-Jul	27-Jun	5-Jul	29-Jun	14-Jun	2-Jul	1-Jul	1-Jul	1-Jul
	CV	6	8	6	8	8	7	7	7	7	6	6	7
Cessation	Minimum	1-Sep	1-Sep	1-Sep	19-Sep	12-Sep	3-Sep	1-Sep	3-Sep	7-Sep	1-Sep	1-Sep	8-Sep
	Maximum	12-Nov	1-Dec	31-Oct	21-Dec	6-Nov	23-Oct	5-Oct	18-Oct	15-Oct	15-Oct	13-Nov	5-Nov
	Mean	1-Oct	3-Oct	1-Oct	13-Oct	2-Oct	23-Sep	19-Sep	23-Sep	18-Sep	20-Sep	17-Sep	27-Sep
	CV	6	8	6	6	6	4	3	4	3	4	6	5
LGP	Minimum	48	39	34	51	57	33	27	72	49	45	43	54
	Maximum	129	181	135	200	150	114	112	134	136	115	149	155
	Mean	84	84	84	102	97	80	82	101	78	81	78	88
	CV	24	34	26	26	25	22	19	16	20	23	28	24
NRD	Minimum	18	31	21	52	39	29	27	29	25	19	15	47
	Maximum	70	77	73	83	84	80	82	122	94	104	79	92
	Mean	49	55	48	69	66	60	65	87	62	63	56	69
	CV	24	20	31	11	16	18	23	23	25	32	28	16

NB: LGP is length of growing period, NRD is number of rainy day and CV is coefficient of variation.





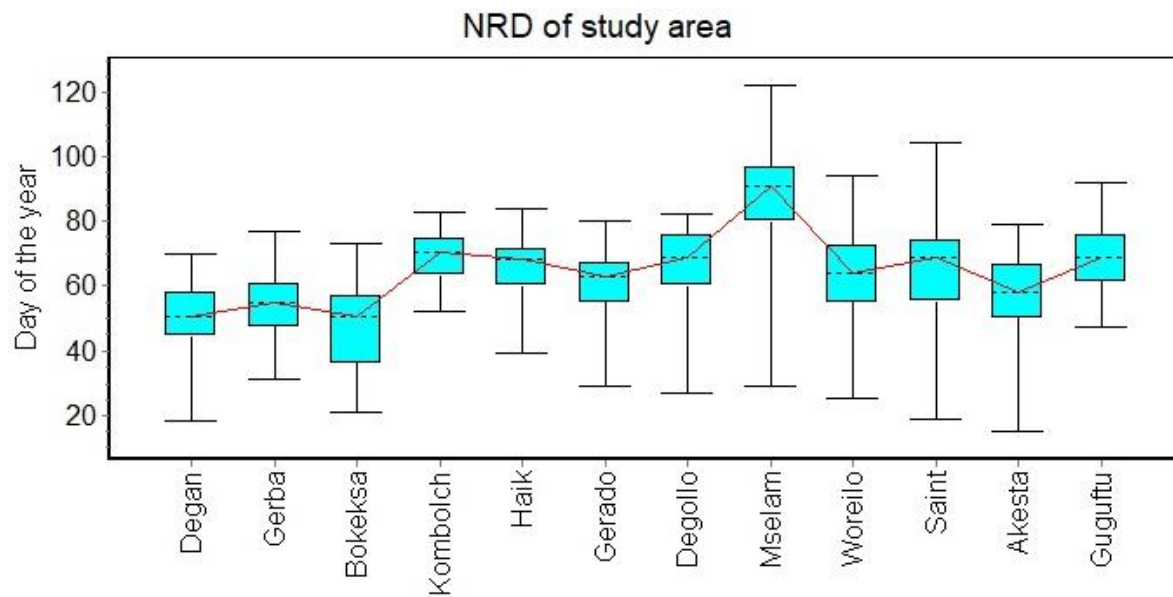


Figure 4.13 Onset, cessation, length of growing period (LGP) and number of rainy days (NRD) of the Study area

4.5 Trend of onset, Cessation and Length of growing period of Kiremet season

The trend and magnitude of onset, cessation, and length of the growing season of the main rainy season (June to September), which are detected using the Mann-Kendall trend test and Sen's slope estimator approach, were detected over a time span from 1987 to 2022. The result is indicated in Table 4. 4 shows, lowland, and midland areas show a non-significant increasing trend of onset, this is in line with (W. Bahiru & Zewdu, 2021b) report that a non-significant increasing trend was observed in the northeastern part of Ethiopia. Highland and upper highland areas observed a non-significant decreasing trend with the onset of the rainy season; this is also in line with Muluneh and Tesfaye (2015) who reported a non-significant decreasing trend in the northeastern part of Ethiopia.

Lowland, highland, and upper highland areas showed an increasing trend of cessation dates, but only the lowland area was statistically significant. This result is in line with W. Bahiru and Zewdu (2021b) who reported a significantly increasing trend of cessation of the main rainy season in northern Ethiopia Gebre *et al.* (2013). And also, a statistically significant decreasing trend of cessation in the midland area was observed. Generally the statistical analysis implies that early cessation of the rainy season shows a decreasing trend and the late cessation of the rainy season shows an increasing trend.

The length of the growing period was an increasing trend in the lowland, Highland, and Upper Highland areas; however, in the lowland area, the result is statistically significant, which agrees

with (W. Bahiru & Zewdu, 2021b) Studied in the northern part of Ethiopia, and the length of the growing period in the Midland area were significantly decreasing. This is due to the late onset and early cessation dates of the season in the Midland area; See Table 4.4 below.

Table4.4 Trend, Onset, Cessation and Length of growing season of the main rain season

		Onset			Cessation			LGP		
	Station	ZMK	Q	p-value	ZMK	Q)	p-value	ZMK	Q	p-value
Low land	Degan	0.67	0.08	0.50	1.27	0.50	0.21	0.40	0.16	0.69
	Gerba	-0.14	0.00	0.89	2.92	0.78	0.04**	2.15	0.83	0.01**
	Bokeksa	0.67	0.16	0.50	0.26	0.04	0.89	0.37	0.23	0.71
	Areal	0.78	0.11	0.44	2.06	0.40	0.04**	1.32	0.37	0.19
Mid land	Kombolcha	-1.64	-0.25	0.10	-0.87	-0.20	0.38	0.03	0.00	0.98
	Haik	2.14	0.44	0.03**	-3.60	-1.04	0.00**	-3.68	-1.38	0.00**
	Areal	0.48	0.09	0.63	-2.67	-0.57	0.00**	-2.00	-0.67	0.045**
High Land	Gerado	-1.24	-0.21	0.22	1.20	0.29	0.23	1.23	0.34	0.23
	Degollo	-1.07	-0.16	0.29	0.70	0.09	0.49	1.50	0.27	0.13
	M/selam	-0.16	0.00	0.88	0.35	0.05	0.72	0.14	0.04	0.89
	Woreilu	-2.47	-0.41	0.01**	1.55	0.12	0.12	2.52	0.54	0.01**
	Saint	-1.75	-0.33	0.08	1.96	0.39	0.06	2.34	0.65	0.02**
	Areal	-1.15	-0.15	0.25	1.70	0.24	0.09	2.02	0.33	0.04**
Upper highland	Akesta	-2.03	-0.33	0.04**	1.11	0.23	0.27	2.51	0.66	0.01**
	Guguftu	-0.52	-0.11	0.60	0.91	0.21	0.36	0.76	0.35	0.45
	Areal	-1.64	-0.23	0.10	1.43	0.22	0.15	1.59	0.51	0.11

ZMK is Mann-kendall trend test, Q is Sen.'s slope (change per year or decade), ** statistically significant trend when p-value < at 5% or 0.05 probability level.

4.6 Trend analysis of seasonal and annual rainfall in the study area

Mean annual and seasonal (Kiremet and Belg) time series rainfall data from 1987 to 2022 were organized to detect the trend and magnitude of rainfall over the study area. As presented Table 4.5 below, temporal rainfall variation was exhibited in the south wollo zone considering different Agro-ecological zones. Based on the results of the statistical analysis, Areal rainfall of the Belg season is non-significant decreasing trend in all agro ecological zones. This result was in line

with (W. Bahiru & Zewdu, 2021b) who studied in the north wollo zone Gubalafto district, and (Ayalew *et al.*, 2012) who studied north eastern Ethiopia. Kiremet and annual rainfall in the lowland area are significant increasing trend by 75.0mm/decade and 83.6mm/decade respectively. Annual rainfall in the highland area, Kiremet and annual rainfall in the midland and upper highland area shows non-significant increasing trend. And also Kiremet rainfall shows a significant increasing trend in highland areas by 46.7mm/decade. This result was in line with Wagaye *et al.* (2020) (Gebremichael *et al.*, 2014; Wagaye *et al.*, 2020; W. Bahiru & Zewdu, 2021b) studied in the northern part of Ethiopia. Generally significant increasing trend implies the cause of floods, soil erosion, and landslides, and a decreasing trend implies the cause of drought, crop faller, and a shortage of water (Ndamani & Watanabe, 2014). And also, a non-significant trend may show high variability in seasonal and annual rainfall.

Table5.5 Mann –Kendal trends test result of annual and seasonal (Kiremet and Belg) rainfall time period of 1987-2022.

	Station	Belg RF			Kiremet RF			Annual RF		
		ZMK	Q	P-value	ZMK	Q	P-value	ZMK	Q	P-value
Low land	Degan	0.74	1.47	0.46	1.72	4.81	0.09	1.83	5.87	0.07
	Gerba	-1.63	-2.02	0.11	4.32	10.94	0.00**	2.57	7.39	0.01**
	Bokeksa	0.01	0.01	0.10	2.36	6.12	0.02**	2.67	9.00	0.01**
	Areal	-0.01	-0.02	0.99	3.04	7.50	0.00**	2.96	8.36	0.00**
Mid land	Kombolcha	-1.08	-1.57	0.28	1.61	4.11	0.11	0.15	0.56	0.88
	Haik	-1.84	-4.07	0.07	1.48	4.19	0.14	-0.91	-3.10	0.36
	Areal	-1.59	-2.91	0.11	1.95	4.87	0.51	0.31	0.51	0.75
	Gerado	0.2	0.3	0.9	1.13	2.83	0.26	0.87	3.08	0.38
High land	Degollo	-1.5	-1.2	0.1	2.10	5.72	0.04**	1.55	4.40	0.12
	M/selam	-0.3	-0.3	0.8	2.33	4.15	0.01**	1.95	3.61	0.05
	Woreilu	-1.2	-1.3	0.2	1.08	3.05	0.28	-0.26	-0.76	0.81
	Saint	-1.1	-1.3	0.3	1.54	4.92	0.12	0.64	2.85	0.52
Upper highland	Areal	-0.5	-0.5	0.6	2.03	4.67	0.04**	1.70	3.67	0.09
	Akesta	0.1	0.1	0.96	2.64	6.31	0.01**	1.72	4.69	0.09
	Guguftu	1.2	2.3	0.2	0.61	4.09	0.54	1.10	8.69	0.27
	Areal	-1.0	-1.3	0.3	1.29	4.81	0.28	1.27	6.90	0.21

ZMK is Mann-kendall trend test, Q is Sen.'s slope (change per year or decade), ** statistically significant trend when p-value < at 5% or 0.05 probability level.

4.7 Relation between Nino 3.4 SST and rainfall

This work investigates the concurrent and lagged correlation between Nino 3.4 SST and seasonal rainfall in a different agro-ecology zone of the south Wollo zone, calculating the value considering a seasonal division of 0–2 season lags. Two seasons were considered: one main rainy season/Kiremet (June to September), and a small rainy season/Belg (February to May). Tables 4.6 and 4.7 show the correlation between SST and seasonal rainfall in the different Agro-ecology zones of the Kiremet and Belg seasons, with their respective seasonal lags, therefore the ENSO region in the equatorial Pacific ocean for lag 0 for the Kiremet season correlates with lag 0-2, i.e., lag 0 Kiremet (June–September), lag 1 Belg (February–May), and lag 2 Bega (October–December and January). And also, Belg seasons correlate from lag 0-2, i.e., lag 0 Belg (February-May), lag 1 Bega (October-December, and January). Lag 2 Kiremet (June–September)

Table 4.6 depicts that the correlation between Kiremet rainfall and Nino 3.4 SST lag 0 shows strong statistically significant negative correlation in the Midland area, and lag 0 and 2 shows moderate significant negative correlation in all agro- ecological zones except Midland area lag 0. And also, the correlation between Kiremet rainfall and Nino 3.4 SST lag 1 show a weak negative correlation in all Agro-ecology zones, but not statistically significant. This implies that SST decreases the amount of Kiremet rainfall increase; at lags 0 and 2, Kiremet rainfall is more influenced by SST in the study area, but at lag 1, it is less influential on Kiremet rainfall in the study area. On the other hand, Table 4.7 depicts that the correlation between Belg rainfall and Nino 3.4 SST lag 0 shows positive statistical significance, with strong correlation in the Midland area and moderate correlation in the Highland and Upper Highland area. This implies that SST lags 0 increases, the amount of Belg rainfall increase in the Midland, Highland and Upper Highland areas. However, Nino 3.4 SST lags 1 and 2 in a weak positive correlation with Belg rainfall in the study area. The current study agrees with the previous study conducted by Eshetie (2021) in the upper awash basin, who reported that the correlation between SST and rainfall was negative and positive in the Kiremet and Belg seasons, respectively. And the Eastern Pacific SST shows a negative correlation with rainfall in various parts of Ethiopia during the Kiremet season. This implies that the increasing/warming phase of SST causes decreasing rainfall in the Kiremet season and enhanced rainfall in the Belg season. This finding agrees with the previous study (Degefu *et al.*, 2016; Bayable *et al.*, 2021; Eshetie, 2021)

Table6.6 Correlation between Kiremet rainfall and Nino 3.4 Sea Surface Temperature

	Kiremet RF(6-9)			
	Lowland	Midland	Highland	Upper Highland
SST (6-9),Lag0	-0.43**	-0.63**	-0.45**	-0.39**
SST (2-5),Lag1	-0.11	-0.16	-0.30	-0.21
SST (10-12 and1),Lag2	-0.35**	-0.45**	-0.40**	-0.30

** Significance at ($\delta=0.05$)

Table7.7 Correlation between Belg rainfall and Nino 3.4 Sea Surface Temperature

	Belg RF(2-5)			
	Lowland	Midland	Highland	Upper Highland
SST (2-5),Lag0	0.17	0.51**	0.42**	0.31
SST (10-12) and 1,Lag1	0.11	0.05	0.08	0.04
SST (6-9),Lag2	0.11	0.05	0.04	0.02

** Significance at ($\delta=0.05$)

4.8 Correlation between crop yield (Q/H) and rainfall characteristics (rainfall amount, onset, cession, LGP, NRD and NDD)

The result of the correlation analysis between seasonal rainfall characteristics and cereal production is given in Table 4.8 below. In the lowland area, the length of the growing period, cession, and a number of rainy days had a weak to moderately positive correlation with sorghum crop yield. Rainfall amount, onset of the season, and number of dry days were weak to moderate negative correlation with sorghum crop yield, but Kiremet rainfall was statistically significant; this implies that variability of rainfall amount more influenced crop yields (Ndamani & Watanabe, 2014). In the Midland area, Kiremet rainfall, cession, length of the growing period, and the number of rainy days had a positive correlation with maize, sorghum, and Teff crop yields, with a weak to moderate correlation. In Table 4.8, the onset of the season and the number of dry days has a weak negative correlation with maize, sorghum, and Teff crop yields. Belg seasonal rainfall has a weak negative correlation with maize and sorghum crops and a weak positive correlation with Teff crop yields. But when compared comparatively between the lowland and the Midland areas, sorghum crop yield is significantly negatively correlated with rainfall amount in the lowland area and significantly positively correlated in the Midland area.

In the highland area of Kiremet, rainfall, number of rainy days, and length of growing period have a moderate positive correlation with barley and wheat crop yields and a weak correlation

with Belg rainfall. Whereas the onset of the season and the number of dry days had a moderately negative correlation with barley and wheat crop yields and a weak correlation with the cessation date. In the upper highland area, barley had a weak to moderate positive correlation with seasonal rainfall, cession, length of growing period, and number of rainy days, whereas onset and the number of dry days had a moderate negative correlation with barley yield. Generally, Kiremet rainfall is the most determinate factor among all crops in the study area. This implies that crop yields were the most sensitive to the variability of Kiremet rainfall. Barley and wheat yields that were cultivated in the highlands and upper highlands were more sensitive to the variability of the number of rainy and dry days, the length of the growing period, and the onset of the season. The onset of the season had a negative correlation with all crop yields. This indicates that the negative correlation or early cession of the season was increasing crop yields (Bahiru *et al.*, 2020; W. Bahiru & Zewdu, 2021b).

Table8.8 Correlation between crop yield (Q/H) and Seasonal rainfall characteristics (rainfall amount, onset, and cession, LGP, NRD and NDD)

AEZ	Lowland	Midland	Highland		Upper Highland		
Crop type	Sorghum	Maize	sorghum	Teff	Barley	Wheat	Barley
Kiremet rainfall	-0.74**	0.49	0.64**	0.27	0.78**	0.77**	0.55
Belg rainfall	-0.12	-0.16	-0.15	0.26	0.05	0.08	0.23
Onset	-0.25	-0.18	-0.16	-0.29	-0.91**	-0.65*	-0.51
Cession	0.02	0.22	0.05	0.38	-0.04	-0.02	0.18
LGP	0.21	0.18	0.13	0.39	0.77**	0.55	0.39
NRD	0.42	0.10	0.29	0.26	0.73**	0.74**	0.56
NDD	-0.41	-0.10	-0.10	-0.28	-0.71*	-0.73**	-0.56

*Significant at the 0.1 level; **significant at the 0.05 level; ***significant at the 0.01level

4.9 Cereal production in different Agro-ecology condition

The major cereal crops like Sorghum (Melkam, Teshale, Abshir and Gobyie crop varieties in Lowland and Sorghum (Gedo, Girana, Miskr varieties), Maize, and Teff in Midland area, wheat and Barley (HB.1307, Traveler varieties are the most stable crops cultivated in the Highland area, Barley (Holker, Ibone 173, and Agegnehu varieties in the upper highland. In terms of yield, Maize has more cultivated crops in the Midland area. Sorghum exhibits high year-to-year variability in the lowland and barley in the upper highland area, compared to the other cereals (Table 4.9). The production of cereals is showing an increasing trend in the study area; however, there is a high fluctuation of cereals in the study period. This crop yield variability is insight the Figure 4.11 (A, B, C, and D) below a better understood.

Table9.9 Summery statistics of cereal yields (q/h) from (2011-2022)

AEZ	Crop type	Minimum	Maximum	Mean	CV%
Lowland	Sorghum	10.0	28.9	19.5	30.2
Midland	Maize	12.0	32.0	20.6	26.1
	Sorghum	10.0	31.1	18.9	27.4
	Teff	7.0	16.0	12.0	24.6
Highland	Barley	8.0	25.8	19.8	22.7
	Wheat	11.0	27.5	18.9	27.4
Upper Highland	Barley	8.0	27.9	16.0	31.3

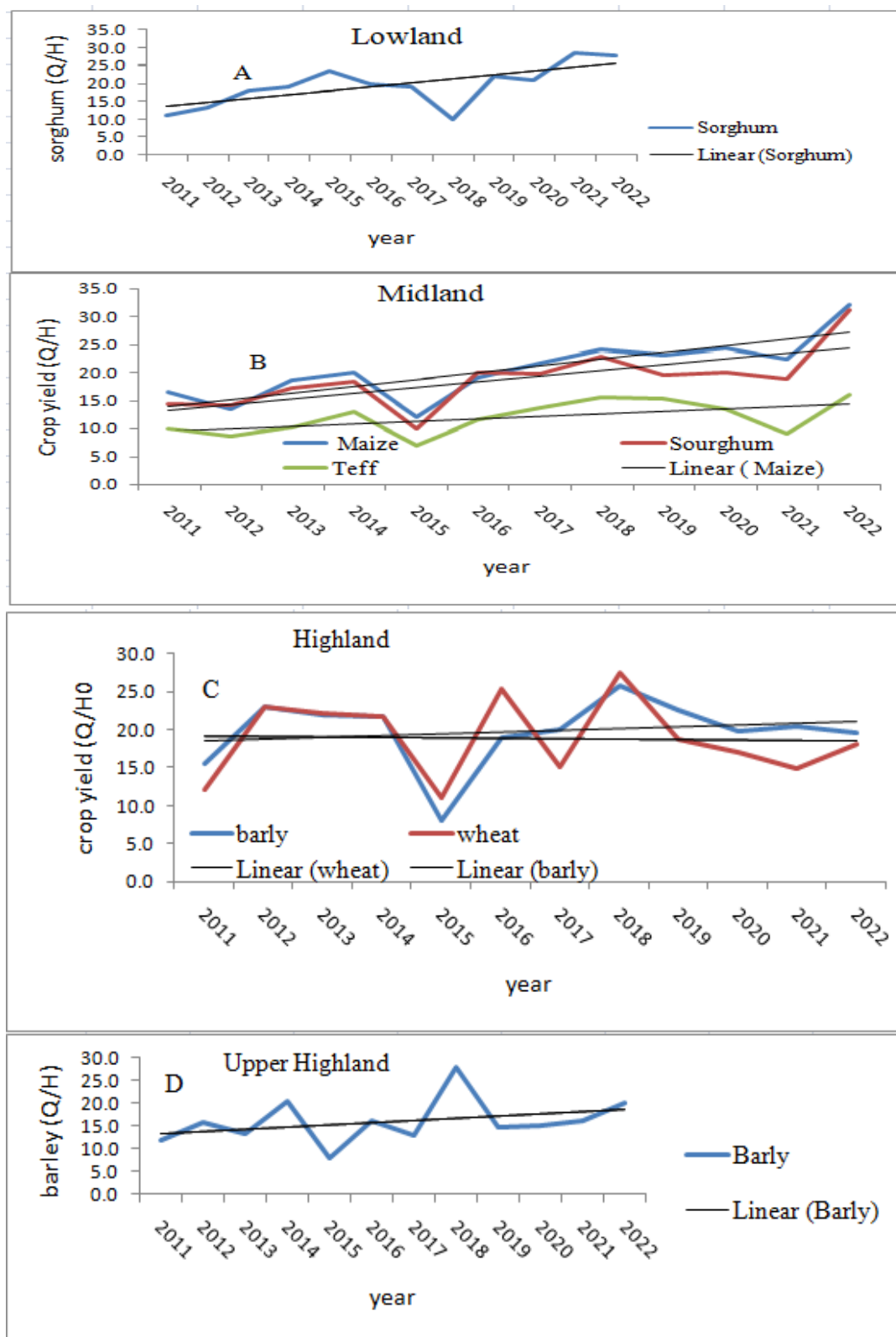


Figure4.14 Trend of Sorghum, Maize, Wheat, Teff and Barley crop yields (Q/H) in different Agro-ecology

Figure 4.11 (A, B, C, and D) indicates that the trend of sorghum crop yield is recorded 28.9 Q/H in 2021 maximum amount and 10.0 Q/H in 2018 the minimum amount in the lowland area. Maize, sorghum, and Teff crop yields recorded 32.0, 31.1, and 16.0 Q/H maximum amounts in the year 2022 and 12.0, 10.0, and 7.0 Q/H minimum amounts in the year 2015, respectively, in the midland area. The maximum amount of crop yields obtained in the year 2022 was due to the higher rainfall amount received during the Kiremet season in this year, and the minimum amount of crop yields recorded was due to the low amount of rainfall recorded in 2015 during the Kiremet season. Barley and wheat crop yields recorded 25.8, 27.5 Q/H maximum amounts in 2018, and 8.0, 11.0 Q/H minimum amounts in 2015, respectively, in highland areas. This barley and wheat crop yield recorded a maximum amount in 2018 due to better rainfall in the year 2018 and obtained low crop yields in 2015 due to severe drought in the highland area. Barely yields recorded 27.9 Q/H in the 2018 maximum amount and 8.0 Q/H in the 2015 minimum amount. The result shows the annual variability of crop yields due to various climatic parameters in the study area.

4.10 Regression analysis between crop yield and rainfall characteristics

Table 4.10 presents the result, which indicates that the coefficient of determination R^2 of sorghum in the lowland area was 0.88. This R^2 is used to determine the percentage variability of sorghum crop production due to rainfall characteristics. This implies that 88% of the sorghum crop was influenced by the variability of rainfall characteristics, and the other 12% of sorghum crop production was influenced by another factor other than rainfall characteristics; it may be due to land management and agricultural inputs like fertilizer and insecticides.

In the Midland area, the coefficient of determination R^2 of maize, sorghum, and Teff crop yield are 69, 69, and 53, respectively, with the probability of (0.25, 0.25, and 0.54) R getting zero. This R^2 is used to determine the percentage variability of maize, sorghum, and Teff crop production due to rainfall characteristics. This results in 69%, 69%, and 53% Indicating that maize, sorghum, and Teff crop yields were influenced due to rainfall characteristics, respectively, and the other 31%, 31%, and 47% of maize, sorghum, and Teff crops were influenced due to another factor rather than rainfall characteristics.

Table 10.10 Regression analyses between crop production (Q/H) and Kiremet rainfall characteristics in the lowland and Midland area

AEZ	Crop	R	R ²	P-Value
Lowland	Sorghum	0.94	0.88	0.035
	Maize	0.83	0.69	0.25
	Sorghum	0.83	0.69	0.25
Midland	Teff	0.73	0.53	0.54

Table 4.11 presents the highland area coefficient of determination R² for barley and wheat at 0.91 and 0.75, respectively, with the probability of (0.02 and 0.16) R getting zero. This 91% and 75% of R² were used to determine the percentage variability of barley and wheat crop productions Due to rainfall characteristics. And the other 9% and 25% of barley and wheat crops were influenced by another factor rather than rainfall characteristics due to either land management or agricultural inputs like fertilizer and insecticides.

In the upper highland area, the coefficient of determination of barley R² is 0.36, with the probability of (0.66) R getting zeros. This 36% of R² was used to determine the percentage variability of barley crop yields due to rainfall characteristics. The other 64% of barley crop production was due to another factor that was not included in this study.

Table 11.11 Regression analyses between crop production (Q/H) and Kiremet rainfall characteristics in the Highland and Upper highland area

AEZ	Crop	R	R ²	P-Value
Highland	Barley	0.95	0.91	0.02
	Wheat	0.87	0.75	0.16
Upper Highland	Barley	0.60	0.36	0.66

CHAPTER FIVE, CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Ethiopia's agriculture is highly depending on rain, so rainfall variability comprises an important source of uncertainty in agricultural production decisions. Information on seasonal Kiremet and seasonal Belg rainfall amount is crucial in the rainfed agriculture of Ethiopia since more than 85% of the population is dependent on agriculture particularly on rain fed farming practices. However climate variations influence agricultural production and hence it affects crop productivity and land use pattern. This study investigated the impact of rainfall variability on crop yields and its relationship with sea surface temperature of the Pacific Ocean in different Agro-ecology zones of south wollo Amhara Ethiopia. The analysis on long term rainfall data for the study area showed large inter-annual and seasonal variation in the amount and distribution of rainfall. This variability of rainfall is significantly linked with the eastern Pacific Ocean in all Agro-ecological zones of the study area. The rainfall trends showed decreasing in Belg while increasing in both annual and Kiremet in all Agro-ecological zones. However, the detected trends are non-significant in the time series of Belg season and significant trend of Kiremet and annual rainfall in the lowland area. Over the last period trends of rainfall events such as onset date, cessation date and length of the growing period were changed significantly in the study area. The variability of seasonal rainfall causes fluctuations in production of major crops. Due to high correlations between crop production and seasonal rainfall characteristics, small changes in amount and distribution of seasonal rainfall cause significant negative impacts on crop production that varies from reduced yield to the total loss of the crop. As a result major crop yields exhibit the largest year to year variations in the study area. The result of regression analysis indicates that rainfall characteristics in the lowland area contributed 88% in explaining the variations in the yield of sorghum crop. In the Midland area, contributed 69%, 69%, and 53% explaining the variations in the yield of maize, sorghum, and Teff crop yields respectively. In the highland area contributed 91% and 75% explaining the variations in the yield of barley and wheat crop yields respectively. In the upper highland area, contributed 36% explaining the variations in the yield of barley crop was influenced due to rainfall characteristics. This high inter-annual variability of crops is caused by rainfall variability where in the rainfall components

of amount of rain, number of rainy day, onset and cessation date and length of growing period often play the biggest role.

5.2 Recommendation

Farmers to practices include water harvesting, supplementary irrigation, run-off management, conservation tillage and integration of more leguminous species into rotation systems. Improved soil surface management practices, small water harvesting systems and small irrigation systems have been shown to offer great potential for making maximum use of rainwater. In addition, such practices allow farmers to intensify their production activities and encourage increased diversity in production of high value crops. It is also advised to further study including other climatic variable like temperature in the future and investigated future projection of climate variability in the study area.

Reference

- Abate, L. (2016). *Assessment of climate change effects on rain fed crop production and coping mechanisms: the case of smallholder farmers of west Shoa zone, Oromia, Ethiopia*. Retrieved from <http://etd.aau.edu.et/bitstream/handle/123456789/6277/Leta%20Abate.pdf?sequence=1&isAllowed=y>
- Abdi, Y. (2018). *EFFECT OF RAINFALL AND TEMPERATURE VARIABILITY ON CROP YIELDS OVER WEST GOJJAM ZONE*.
- Abegaz, W. B. (2020). Rainfall Variability and Trends over Central Ethiopia. *International Journal of Environmental Sciences & Natural Resources*, 24(4). doi:10.19080/ijesnr.2020.24.556144
- Abegaz, W. B., & Abera, E. A. (2020). Temperature and rainfall trends in north eastern Ethiopia. *J Climatol Weather Forecast*, 8, 262.
- Abraham, T., & Mekuyie, M. (2022). Effects of climate change on pastoral households in the Harshin District of the Somali Region, Ethiopia. *Jamba*, 14(1), 1202. doi:10.4102/jamba.v14i1.1202
- Alemayehu, A., & Bewket, W. (2016). Local climate variability and crop production in the central highlands of Ethiopia. *Environmental Development*, 19, 36-48. doi:10.1016/j.envdev.2016.06.002
- Alemu, M. M., & Bawoke, G. T. (2020). Analysis of spatial variability and temporal trends of rainfall in Amhara region, Ethiopia. *Journal of Water and Climate Change*, 11(4), 1505-1520. doi:10.2166/wcc.2019.084
- Amekudzi, L., Yamba, E., Preko, K., Asare, E., Aryee, J., Baidu, M., & Codjoe, S. (2015). Variabilities in Rainfall Onset, Cessation and Length of Rainy Season for the Various Agro-Ecological Zones of Ghana. *Climate*, 3(2), 416-434. doi:10.3390/cli3020416
- Asfaw, A., Bantider, A., Simane, B., & Hassen, A. (2021). Smallholder farmers' livelihood vulnerability to climate change-induced hazards: agroecology-based comparative analysis in Northcentral Ethiopia (Woleka Sub-basin). *Heliyon*, 7(4), e06761. doi:10.1016/j.heliyon.2021.e06761
- Asfaw, A., Simane, B., Hassen, A., & Bantider, A. (2018). Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. *Weather and climate extremes*, 19, 29-41.
- Ayalew. (2020). The Role of Rainfall Amount and Distribution on Agriculture Systems and Crop Cropping Systems of Different Agro-Ecological Regions of Ethiopia: A Review. *International Journal of Research in Agriculture and Forestry*, 7(5), 26-40.
- Ayalew, D., Tesfaye, K., Mamo, G., Yitafaru, B., & Bayu, W. (2012). Variability of rainfall and its current trend in Amhara region, Ethiopia. *African Journal of Agricultural Research*, 7(10), 1475-1486.
- Ayalew, M. (2020). The Role of Rainfall Amount and Distribution on Agriculture Systems and Crop Cropping Systems of Different Agro-Ecological Regions of Ethiopia: A Review. *International Journal of Research in Agriculture and Forestry*, 7(5), 26-40.
- Bahiru, Wende, E., Mohammed, L., Mohammed, Y., Adem, H., & Demmisie, Y. (2020). Assessing the impacts of rainfall variability on Teff production and farmers perception at Gubalafto district, North Easter, Ethiopia. *Int J Earth Sci Geophys*, 6, 2-19.

- Bahiru, W., & Zewdu, E. (2021a). Analysis of Spatial and Temporal Climate Characteristics in North Eastern Ethiopia: Case Study of North Wollo Zone. *International Journal of Energy and Environmental Science*, 6(3), 57. doi:10.11648/j.ijees.20210603.12
- Bahiru, W., & Zewdu, E. (2021b). Analysis of spatial and temporal climate characteristics in North Eastern Ethiopia: case study of North Wollo Zone. *Int J Energy Environ Sci*, 6(3), 57.
- Bayable, G., Amare, G., Alemu, G., & Gashaw, T. (2021). Spatiotemporal variability and trends of rainfall and its association with Pacific Ocean Sea surface temperature in West Harerge Zone, Eastern Ethiopia. *Environmental Systems Research*, 10(1). doi:10.1186/s40068-020-00216-y
- Bekele, F. (2015). Characterizing current and future rainfall variability and its effect on wheat and barley production in Sinana District, South Eastern Ethiopia. *Unpublished MSc Thesis. Haramaya University.*
- Belay, A., Demissie, T., Recha, J. W., Oludhe, C., Osano, P. M., Olaka, L. A., . . . Berhane, Z. (2021). Analysis of Climate Variability and Trends in Southern Ethiopia. *Climate*, 9(6), 96. doi:10.3390/cli9060096
- Belay, F., Gasses, G. G. H., Household, H., Index, S. S. V., & Index, L. L. V. (2016). Households' Vulnerability to Climate Change and Adaptation Strategies: The Case of Choke Mountain Watershed, Eastern Gojjam Zone, Ethiopia. *change*, 6(3).
- Bewket, W. (2009). *Rainfall variability and crop production in Ethiopia: Case study in the Amhara region*. Paper presented at the Proceedings of the 16th international conference of Ethiopian studies.
- Caroline M. Dunning¹, E. C. L. B., ², and Richard P. Allan^{1,2,3}. (2016). <JGR Atmospheres - 2016 - Dunning - The onset and cessation of seasonal rainfall over Africa.pdf>. doi:10.1002/2016JD025428
- Chemura, A., Mudereri, B. T., Yalew, A. W., & Gornott, C. (2021). Climate change and specialty coffee potential in Ethiopia. *Sci Rep*, 11(1), 8097. doi:10.1038/s41598-021-87647-4
- Degefu, M. A., Rowell, D. P., & Bewket, W. (2016). Teleconnections between Ethiopian rainfall variability and global SSTs: observations and methods for model evaluation. *Meteorology and Atmospheric Physics*, 129(2), 173-186. doi:10.1007/s00703-016-0466-9
- Destaw, F., & Fenta, M. M. (2021). Climate change adaptation strategies and their predictors amongst rural farmers in Ambassel district, Northern Ethiopia. *Jamba*, 13(1), 974. doi:10.4102/jamba.v13i1.974
- Diress, G. (2020). *EFFECTS OF CLIMATE CHANGE ON DROUGHT AND ITS IMPLICATIONS ON AGRICULTURE IN EASTERN AMHARA REGION, ETHIOPIA.*
- Eshetie, G. G. (2021). Impact of rainfall variability on crop yields and its relationship with sea surface temperature in northern Ethiopian Highlands. *Arabian Journal of Geosciences*, 14(22). doi:10.1007/s12517-021-08316-4
- Fitsum Bekele, Diriba Korecha, & Negatu, L. (2017). Demonstrating Effect of Rainfall Characteristics on Wheat Yield: Case of Sinana District, South Eastern Ethiopia.
- Gebre, H., Kindie, T., Girma, M., & Belay, K. (2013). Trend and variability of rainfall in Tigray, northern Ethiopia: analysis of meteorological data and farmers' perception. *Academia Journal of Agricultural Research*, 1(6), 088-100.
- Gebrechorkos, S. H., Bernhofer, C., & Hulsmann, S. (2020). Climate change impact assessment on the hydrology of a large river basin in Ethiopia using a local-scale climate modelling approach. *Sci Total Environ*, 742, 140504. doi:10.1016/j.scitotenv.2020.140504

- Gebremichael, A., Quraishi, S., & Mamo, G. (2014). Analysis of seasonal rainfall variability for agricultural water resource management in southern region, Ethiopia. *J. Nat. Sci. Res*, 4(11), 56-79.
- Gemeda, D. O., Korecha, D., & Garedew, W. (2021). Evidences of climate change presences in the wettest parts of southwest Ethiopia. *Heliyon*, 7(9), e08009.
- Getachew, B. (2017). Impacts of climate change on crop yields in South Gonder Zone, Ethiopia. *World Journal of Agricultural Research*, 5(2), 102-110.
- Getachew, B., & Manjunatha, B. R. (2021). Climate change projections and trends simulated from the CMIP5 models for the Lake Tana sub-basin, the Upper Blue Nile (Abay) River Basin, Ethiopia. *Environmental Challenges*, 5, 100385. doi:10.1016/j.envc.2021.100385
- Gezie, M., & Tejada Moral, M. (2019). Farmer's response to climate change and variability in Ethiopia: A review. *Cogent Food & Agriculture*, 5(1), 1613770. doi:10.1080/23311932.2019.1613770
- Gorfu, D., & Ahmed, E. (2012). Crops and agro-ecological zones of Ethiopia. *Ethiopian Institute of Agricultural Research*.
- Habtemariam, L. T., Gandorfer, M., Kassa, G. A., & Heissenhuber, A. (2016). Factors Influencing Smallholder Farmers' Climate Change Perceptions: A Study from Farmers in Ethiopia. *Environ Manage*, 58(2), 343-358. doi:10.1007/s00267-016-0708-0
- Hamisi, J. (2013). *Study of rainfall trends and variability over Tanzania*.
- Hill, R. V., & Porter, C. (2017). Vulnerability to drought and food price shocks: evidence from Ethiopia. *World Development*, 96, 65-77.
- Korecha, D., & Barnston, A. G. (2007). Predictability of June–September Rainfall in Ethiopia. *Monthly Weather Review*, 135(2), 628-650. doi:10.1175/mwr3304.1
- Kusiak, A., Rezazadeh-Joudi, A., & Sattari, M.-T. (2017). Assessment of different methods for estimation of missing data in precipitation studies. *Hydrology Research*, 48(4), 1032-1044. doi:10.2166/nh.2016.364
- Kyei-Mensah, C., Kyerematen, R., & Adu-Acheampong, S. (2019). Impact of Rainfall Variability on Crop Production within the Worobong Ecological Area of Fanteakwa District, Ghana. *Advances in Agriculture*, 2019, 1-7. doi:10.1155/2019/7930127
- Legese, W., Koricha, D., & Ture, K. (2018). Characteristics of Seasonal Rainfall and its Distribution Over Bale Highland, Southeastern Ethiopia. *Journal of Earth Science & Climatic Change*, 09(02). doi:10.4172/2157-7617.1000443
- Megersa, B., Markemann, A., Angassa, A., Ogutu, J. O., Piepho, H.-P., & Zaráte, A. V. (2014). Impacts of climate change and variability on cattle production in southern Ethiopia: Perceptions and empirical evidence. *Agricultural systems*, 130, 23-34.
- Megersa, G., Tesfaye, K., Getnet, M., & Tana, T. (2019). Rainfall Variability and its implications for wheat and barley production in Central Ethiopia. *Ethiop. J. Crop Sci*, 7(2), 89-111.
- Méndez-Lázaro, P. A., Nieves-Santiago, A., & Miranda-Bermúdez, J. (2014). Trends in total rainfall, heavy rain events, and number of dry days in San Juan, Puerto Rico, 1955-2009. *Ecology and Society*, 19(2). doi:10.5751/es-06464-190250
- Mihiretu, A., Okoyo, E. N., & Lemma, T. (2021). Causes, indicators and impacts of climate change: understanding the public discourse in Goat based agro-pastoral livelihood zone, Ethiopia. *Heliyon*, 7(3), e06529. doi:10.1016/j.heliyon.2021.e06529
- Mishra, S. K., Pandey, R. P., & Birara, H. (2018). Trend and variability analysis of rainfall and temperature in the Tana basin region, Ethiopia. *Journal of Water and Climate Change*, 9(3), 555-569. doi:10.2166/wcc.2018.080

- Mohammed, Y., Yimer, F., Tadesse, M., & Tesfaye, K. (2019). Variability and trends of rainfall extreme events in north east highlands of Ethiopia. *International Journal of Hydrology*, 2(5). doi:10.15406/ijh.2018.02.00131
- Mondol, M. A. H., Ara, I., & Das, S. C. (2017). Meteorological Drought Index Mapping in Bangladesh Using Standardized Precipitation Index during 1981–2010. *Advances in Meteorology*, 2017, 1-17. doi:10.1155/2017/4642060
- Muluneh, G. T., & Tesfaye, K. (2015). *Analysis of Past and Future Intra-Seasonal Rainfall Variability and its Implications for Crop Production in the North Eastern Amhara Region, Ethiopia*. Haramaya University.
- Ndamani, F., & Watanabe, T. (2014). Rainfall variability and crop production in Northern Ghana: The case of Lawra District.
- Ochieng, J., Kirimi, L., & Mathenge, M. (2021). Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya. *NJAS: Wageningen Journal of Life Sciences*, 77(1), 71-78. doi:10.1016/j.njas.2016.03.005
- Ojo, O. I., & Ilunga, M. F. (2018). Application of Nonparametric Trend Technique for Estimation of Onset and Cessation of Rainfall. *Air, Soil and Water Research*, 11, 117862211879026. doi:10.1177/1178622118790264
- Rettie, F. M., Gayler, S., T, K. D. W., Tesfaye, K., & Streck, T. (2022). Climate change impact on wheat and maize growth in Ethiopia: A multi-model uncertainty analysis. *PLoS One*, 17(1), e0262951. doi:10.1371/journal.pone.0262951
- Tesfamariam, B. G., Gessesse, B., & Melgani, F. (2019). Characterizing the spatiotemporal distribution of meteorological drought as a response to climate variability: The case of rift valley lakes basin of Ethiopia. *Weather and climate extremes*, 26, 100237.
- Tilahun, K. (2006). The characterisation of rainfall in the arid and semi-arid regions of Ethiopia. *Water SA*, 32(3), 429-436.
- tsegaye, k. a., t.Aderajew,a., fetene, t., yimer, a., sisaynew, g., tanaw, k., & Ebabu, K. (2020). *Training Manual for the Farming Community on the Use of Weather, Climate and Agrometeorological Information in Ethiopia*. Retrieved from Training Manual for the Farming Community on the Use of Weather, Climate and Agro-meteorological strict Climate Information in Ethiopia.
- Wagaye, B., Endalamaw, W., Lubaba, M., Yimer, M., Hassen, A., & Yilma, D. (2020). Assessing the Impact of Rainfall Variability on Teff Production and Farmers Perception at Gubalafto District, North Eastern, Ethiopia. *International Journal of Earth Science and Geophysics*, 6(2). doi:10.35840/2631-5033/1842
- Wolde-Georgis, T. (1997). El Nino and drought early warning in Ethiopia. *Internet Journal of African Studies*(2).
- Wolde-Georgis, T., Gebru, A. A., Kinfu, Y. W., & Bahiru, K. M. (2021). Ethiopia: The Case of the 2015–16 El Niño. *El Niño Ready Nations and Disaster Risk Reduction: 19 Countries in Perspective*, 211.
- Zerga, B., & Gebeyehu, G. (2016). Climate change in Ethiopia variability, impact, mitigation, and adaptation. *Journal of Social Science and Humanities Research*, 2(4), 66-84.

Appendix

Appendix 1 Mean monthly rainfall of the study area

	Degan	Gerba	Bokeksa	Kombolch	Haik	Gerado	Degollo	M/selam	Woreilu	Saint	Akesta	Gugufu	Grade mean
Jan	12.2	7.4	30.5	22.5	24.8	6.1	13.3	11.3	12.5	5.3	18.6	16.9	15.1
Feb	21.7	13.8	17.4	27.1	44.5	15.0	16.6	19.8	25.5	13.2	30.8	27.0	22.7
Mar	52.1	34.9	53.8	64.5	100.9	38.5	52.5	56.5	45.5	58.4	82.9	65.6	58.8
Apr	72.6	50.5	91.2	95.5	95.6	63.5	48.0	70.4	40.2	59.2	73.3	72.2	69.3
May	56.5	46.5	53.9	59.1	75.6	49.0	34.3	66.7	32.5	48.8	49.1	58.7	52.6
Jun	109.3	93.9	113.4	137.7	147.8	127.7	169.6	161.8	167.5	189.2	163.8	202.6	148.7
Jul	284.3	257.0	282.5	320.2	366.2	319.5	343.4	265.0	338.9	354.5	288.6	446.4	322.2
Aug	148.2	173.7	165.3	192.9	205.1	201.1	203.0	156.1	173.9	172.0	140.3	244.7	181.4
Sep	47.1	44.6	56.8	69.1	63.2	57.5	22.6	62.5	18.0	46.7	18.2	58.5	47.1
Oct	34.1	30.1	39.3	44.0	40.2	32.9	15.5	36.0	7.3	30.7	13.0	29.0	29.3
Nov	21.6	13.9	24.9	17.5	25.7	11.5	6.1	18.3	7.1	21.9	13.0	14.4	16.3
Dec	14.6	12.3	20.0	15.4	16.8	5.4	4.3	7.8	5.4	9.1	12.6	9.6	11.1

Appendix 2 Mean Annual and seasonal rainfall in the lowland, midland, highland and upper highland area

	Lowland			Midland			Highland			Upper highland		
Year	Belg	Kiremet	Annual	Belg	Kiremet	Annual	Belg	Kiremet	Annual	Belg	Kiremet	Annual
1987	368.5	273.5	684.8	482.9	395.3	923.7	362.9	496.8	896.9	387.0	583.5	999.0
1988	234.3	693.2	966.9	262.1	975.5	1277.7	147.5	784.5	972.8	190.0	1102.0	1329.5
1989	328.0	344.3	782.9	302.7	553.0	938.7	204.7	495.0	746.3	227.5	773.5	1024.5
1990	123.3	447.7	649.5	396.4	519.4	991.4	184.4	587.8	798.8	170.0	479.5	679.5
1991	132.7	385.0	559.3	293.5	598.4	967.5	138.8	554.6	734.4	105.0	488.0	625.0
1992	71.3	511.7	637.7	271.1	627.9	1181.1	138.0	546.5	786.5	113.0	510.5	663.0
1993	297.0	327.7	673.0	559.7	593.3	1252.6	281.4	527.6	848.4	285.4	445.3	763.6
1994	75.3	617.7	725.0	213.1	912.0	1170.3	128.6	708.9	857.7	218.2	790.9	1037.2
1995	237.0	569.3	829.0	404.8	688.6	1190.0	207.6	680.1	917.4	242.0	662.8	959.5
1996	276.3	455.7	769.3	455.2	679.6	1243.0	258.9	709.6	1034.4	318.4	716.3	1164.9
1997	95.7	402.0	740.3	203.7	664.3	1175.6	138.8	600.0	925.8	140.5	687.8	976.3
1998	104.0	597.0	738.0	331.0	921.1	1407.3	164.9	890.4	1149.2	280.0	937.9	1290.8
1999	26.3	593.3	729.7	65.0	843.3	1077.5	70.2	818.7	983.9	43.2	995.9	1128.0
2000	130.9	690.7	1080.8	218.3	916.0	1306.0	111.7	796.5	988.7	171.4	996.1	1271.9
2001	236.7	659.8	938.1	311.2	868.5	1200.6	187.2	787.5	999.2	316.4	938.0	1288.0
2002	130.1	441.9	711.3	153.5	731.7	1006.3	124.9	640.7	828.8	175.6	755.7	1045.0
2003	195.9	563.7	858.8	263.8	722.6	1121.4	203.9	811.3	1060.1	258.7	747.6	1055.8
2004	310.6	492.4	973.5	247.2	620.3	999.4	117.6	665.5	842.7	191.5	840.5	1119.0
2005	216.1	579.4	905.8	359.7	728.0	1142.6	238.8	677.9	945.2	282.9	784.2	1131.7
2006	268.0	535.5	896.9	318.3	776.8	1175.1	175.6	789.3	1017.2	282.9	851.3	1200.7
2007	178.1	600.6	838.4	230.4	694.3	989.3	159.1	808.7	997.5	190.1	754.2	985.1
2008	98.6	566.7	808.7	66.5	649.8	867.5	59.7	790.3	966.0	103.1	668.2	869.4
2009	144.4	665.9	977.8	133.8	756.8	1048.9	82.2	668.3	826.5	113.3	699.5	950.6
2010	234.7	911.7	1175.0	400.2	1090.6	1569.5	216.3	726.0	976.2	421.2	922.0	1418.6

2011	206.8	756.1	1089.5	266.7	695.5	1035.5	190.9	668.8	905.5	293.9	673.4	1016.2
2012	123.3	767.4	909.7	293.7	749.2	1055.3	144.5	911.2	1063.8	291.3	805.3	1100.8
2013	153.6	615.8	851.7	146.5	716.1	1013.3	64.6	940.9	1106.1	129.6	1056.2	1279.2
2014	152.7	736.6	999.1	259.3	736.2	1112.6	176.6	760.4	963.0	282.9	880.2	1250.5
2015	244.4	638.7	997.9	226.7	463.5	778.9	122.5	532.6	690.6	171.7	586.8	799.0
2016	259.9	731.1	1026.9	315.4	823.5	1228.0	248.0	740.6	1012.6	276.8	899.3	1254.6
2017	279.4	651.3	971.2	441.1	688.5	1200.4	143.1	778.4	961.1	304.5	914.8	1239.4
2018	216.4	692.8	977.7	212.3	838.6	1172.5	139.0	919.5	1162.3	337.5	1216.3	1672.7
2019	246.9	577.6	970.6	376.1	687.4	1156.2	297.1	702.5	1035.0	459.3	911.3	1450.6
2020	83.9	576.1	717.9	281.5	808.5	1118.5	156.0	685.4	869.3	194.5	692.5	904.0
2021	131.3	542.7	705.0	202.6	783.7	1028.6	163.6	625.5	819.4	107.0	611.5	794.5
2022	164.6	595.7	847.6	163.6	921.7	1167.8	199.6	729.1	944.6	198.0	665.0	865.5

Appendix 3 Onset, cessation, LGP, NRD and NDD the lowland and midland area

Lowland						Midland				
Year	Onset	Cessation	LGP	NRD	NDD	Onset	Cessation	LGP	NRD	NDD
1987	185	254	69	24	98	193	282	90	46	70
1988	185	278	93	37	85	172	301	129	67	50
1989	202	256	55	31	91	174	281	108	56	48
1990	191	268	77	55	67	193	297	104	58	60
1991	186	246	60	37	85	176	299	123	54	65
1992	193	293	99	57	65	194	307	113	59	57
1993	194	245	51	39	83	188	312	124	60	53
1994	192	278	86	59	63	178	288	110	72	46
1995	179	275	96	58	64	166	299	133	77	44
1996	190	268	78	52	70	171	293	122	69	54
1997	186	247	61	54	68	157	319	162	78	45
1998	190	279	89	65	57	184	309	125	74	46
1999	184	301	117	62	60	171	314	143	69	48
2000	190	284	93	54	68	187	294	107	74	43
2001	195	284	90	51	71	186	284	99	76	46
2002	192	270	78	47	74	192	284	92	62	61
2003	181	290	109	60	62	178	291	114	75	48
2004	199	269	70	52	70	177	280	103	67	58
2005	188	279	90	53	68	194	273	79	69	45
2006	179	279	100	52	70	188	280	93	69	46
2007	186	269	83	57	65	183	277	94	67	50

2008	187	302	115	55	64	189	283	94	70	53
2009	177	293	116	62	58	177	274	98	74	48
2010	188	273	85	55	67	193	274	81	66	53
2011	200	273	74	46	76	198	277	79	59	62
2012	192	269	78	49	73	173	267	94	73	49
2013	189	272	83	48	74	191	289	99	71	52
2014	198	292	93	47	74	177	296	119	71	50
2015	203	287	84	48	74	207	278	71	56	62
2016	180	279	99	60	62	175	283	108	80	41
2017	188	289	101	47	75	187	283	97	67	58
2018	204	285	82	47	75	163	283	121	84	38
2019	177	281	105	47	75	183	293	110	66	58
2020	198	275	77	50	72	163	303	140	68	49
2021	194	274	80	50	72	184	279	95	68	58
2022	193	275	82	56	66	195	273	78	66	46

Appendix 4 Onset, cessation, LGP, NRD and NDD, the highland and upper highland area

Highland						Upper Highland				
Year	Onset	Cessation	LGP	NRD	NDD	Onset	Cessation	LGP	NRD	NDD
1987	187	265	78	46	93	195	256	61	35	87
1988	188	283	95	75	58	189	283	94	58	64
1989	187	274	87	57	74	192	272	80	46	77
1990	153	270	117	31	68	197	264	67	38	85
1991	194	270	76	32	87	187	268	81	44	79
1992	195	281	86	56	66	198	272	75	41	81
1993	194	276	81	53	74	188	272	85	57	65
1994	185	272	87	69	56	180	277	97	72	49
1995	188	272	84	66	65	187	271	84	62	60
1996	185	267	82	71	63	174	275	101	67	55
1997	173	262	89	77	59	168	276	108	71	51
1998	182	289	107	78	59	188	276	88	71	52
1999	183	281	98	71	51	183	287	104	73	50
2000	179	284	105	76	53	186	284	98	76	47
2001	180	269	89	73	55	177	309	133	70	51
2002	192	269	77	63	77	192	273	81	58	64
2003	183	287	104	84	55	189	278	89	70	52
2004	178	274	96	68	68	186	277	92	65	57
2005	182	272	91	67	59	177	270	93	61	61
2006	183	275	92	72	58	189	276	88	69	53
2007	177	280	103	81	59	173	269	96	67	55
2008	184	276	92	73	50	189	272	84	57	66

2009	184	269	84	67	51	176	268	92	61	61
2010	184	267	83	64	61	195	268	74	56	66
2011	191	276	85	65	73	190	269	79	50	72
2012	171	275	103	85	42	176	263	88	66	57
2013	178	292	113	79	60	173	282	110	78	44
2014	186	282	96	67	57	187	308	121	68	54
2015	191	283	92	59	71	203	279	76	61	62
2016	174	278	104	72	50	163	294	131	80	42
2017	188	279	91	70	63	187	282	96	70	53
2018	164	273	109	84	49	161	274	113	86	37
2019	183	293	111	80	63	168	299	131	66	56
2020	186	281	95	77	54	184	268	85	59	64
2021	190	274	85	60	53	198	279	82	60	62
2022	182	275	93	69	62	189	275	87	65	58

Appendix 5 Summary statistics for onset, cessation, LGP, rainy days and coefficient of variation (1987 to 2022)

		Onset		Cessation		LGP		NRD	
	Station	Mean	CV(%)	Mean	CV(%)	Mean	CV(%)	Mean	CV (%)
Low land	Degan	9-Jul	6.0	1-Oct	5.8	84	22.4	49	24.3
	Gerba	10-Jul	7.8	3-Oct	7.5	85	34.0	55	20.1
	Bokeksa	3-Jul	8.2	1-Oct	5.8	90	26.4	48	30.7
	Areal	7-Jul	3.8	1-Oct	5.1	86	18.9	51	17.2
Mid land	Kombolcha	1-Jul	7.3	13-Oct	6.4	104	26.1	69	10.7
	Haik	27-Jun	7.9	15-Oct	5.9	110	23.7	66	15.6
	Areal	29-Jun	6.1	14-Oct	4.5	107	18.9	67	11.9
High land	Gerado	7-Jul	6.7	7-Oct	4.3	92	18.0	60	17.6
	Degollo	1-Jul	5.2	29-Sep	3.2	89	11.7	65	23.3
	M/selam	19-Jun	18.5	6-Oct	4.3	110	28.4	87	23.0
	Woreilu	4-Jul	6.7	27-Sep	2.7	85	19.9	62	24.6
	Saint	1-Jul	5.7	30-Sep	4.9	91	21.8	63	31.8
	Areal	30-Jun	4.6	2-Oct	2.7	93	11.4	68	18.5
Upper highland	Akesta	1-Jul	6.6	26-Sep	6.0	87	26.9	56	27.8
	Guguftu	2-Jul	6.7	8-Oct	4.5	98	20.0	69	15.6
	Areal	1-Jul	5.5	2-Oct	4.1	93	18.6	62	18.6

Appendix 6 Major crop yield in the lowland, midland, highland and upper highland area

	lowland	Highland			Highland		Upper Highland
Year	sorghum	Maize	sorghum	Teff	Barely	Wheat	Barley
2011	11.0	16.4	14.5	10.1	15.5	12.2	12.0
2012	13.4	13.3	14.1	8.7	23.0	23.0	15.7
2013	18.2	18.6	17.2	10.3	22.0	22.1	13.2
2014	19.2	20.0	18.4	12.9	21.8	21.8	20.3
2015	23.4	12.0	10.0	7.0	8.0	11.0	8.0
2016	19.9	19.0	20.2	11.6	19.0	25.4	16.3
2017	19.1	21.7	19.8	13.7	20.0	15.1	13.0
2018	10.0	24.1	22.9	15.5	25.8	27.5	27.9
2019	22.2	23.1	19.7	15.2	22.5	18.7	14.7
2020	20.9	24.2	20.1	13.5	19.7	17.0	15.0
2021	28.7	22.2	18.8	9.1	20.5	14.9	16.2
2022	27.8	32.0	31.1	16.0	19.5	18.2	20.2