# SEASONAL CLIMATE VARIABILITY ANALYSIS AND CHARACTERIZATION FOR MAJOR CROPS AND VEGETABLES PRODUCTION IN SIRARO-KOFELE POTATO-VEGETABLE LIVELIHOOD ZONE OF ETHIOPIA

**MSc THESIS**

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**OCTOBER 2016**

**HARAMAYA UNIVERSITY, HARAMAYA**

# Seasonal Climate Variability Analyses and Characterization of Major Crops and Vegetables Production in Siraro-Kofele Potato-Vegetable Livelihood Zone of Ethiopia

**A Thesis Submitted to the School of Natural Resource Management and Environmental Sciences**
**Postgraduate Programs Directorate**
**HARAMAYA UNIVERSITY**

**In Partial Fulfillment of the Requirement for the Degree of**
**MASTER OF SCIENCE IN AGRO-METEOROLOGY AND NATURAL RISK MANAGEMENT**

**Chaka Natai Abdo**

**October 2016**

**Haramaya University**

## APPROVAL SHEET
## HARAMAYA UNIVERSITY
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We hereby certify that we have read and evaluated this Thesis titled: ***Seasonal Climate Variability Analyses and Characterization for Major Crops and Vegetables Production in Siraro-Kofele Potato-Vegetable Livelihood Zone of Ethiopia*** prepared under our guidance by Chaka Natai. We recommended that it be submitted as fulfilling the thesis requirement.

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As members of the Board of Examiners of the MSc Thesis Open Defense Examination, we certify that we have read and evaluated the Thesis prepared by Chaka Natai and examined the candidate. We recommended that the Thesis be accepted as fulfilling the Thesis requirement for the degree of Master of Science in Agro-Meteorology and Natural Risk Management.

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## DEDICATION

Dedicated to my beloved God and family.

## STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this Thesis. Any scholarly matter that is included in the thesis has been given recognition through citation.

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# BIOGRAPHICAL SKETCH

The author, Chaka Natai Abdo, was born in Becho Woreda, Southwest Shoa Zone of Oromiya Regional State, and Ethiopia in July 26, 1968. He began his education at Tullubolo Fitawurari Habtegorigis Aba Mechal Elementary and Junior Secondary School and completed his high school at Medianealem Secondary School in Addis Ababa on September 16, 1982. He joined Jimma University's Continuing Education program on September 18, 1996 and graduated with Bachelor of Science degree in Horticultural Sciences on April 17, 2007.

Then, he was employed by National Meteorological Agency of Ethiopia since1989 and served as meteorological observer until he joined the Postgraduate Program at Haramaya University to pursue his MSc study in Agro meteorology and Natural Risk Management in October 2014.

# AKNOWLEDGEMENT

I take the advantage of this special occasion to express my sincere gratitude and appreciation to my major and co-advisors, Dr. Diriba Koricha and Kibebew Kibret, respectively, for their boundless, insightful and professional constructive advice that they provided me from the day I was about to write a proposal, to the very last moments I barely remember. Had it not been for their commitment, careful through and conscience reading of the manuscript, unlimited guidance and follow up as well as provision of comments and suggestions, this piece of work would not have been achieved.

I would like to express my appreciation to the National Meteorological Agency of Ethiopia (NMA) for giving me the chance to pursue my study and providing long-term climatic data free of charge and RUFORUM through Haramaya University for granting me the research fund. Also, I thank Central Statistics Agency for providing me crop yield data. I do not know how I would return the favor that my friends Tilahun Dendesa and Abdisa Alemu rendered me in software training. I also would like to thank Zerihun Walilign and Yosef Mokenin, for their assistance in data collection. My genuine gratitude also goes to Jemal Gebeyehu and Asamenew Teshome, for their support in arranging hybrid meteorological data. I am extremely grateful to my brothers; Girma Natai and Bulto Natai for their support and for all people who gave me constructive ideas for better of my work.

Last but not least, my great appreciation goes to my beloved wife Abeba Haile for her wonderful caring of my family in my absence. I honor the lord, for giving me such a caring, lovely and beloved family with whom I am always peaceful and healthy and my soul praises God for all his wills upon me.

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CDF | Cumulative Density Function |
| CDFs | Cumulative Density Functions |
| CEEPA | Centre for Environmental Economics and Policy In Africa |
| CRV | Central Rift Valley |
| CSA | Central Statistic Agency |
| CV | Coefficient of Variation |
| DD | Degree Day |
| DOY | Days of the Years |
| ECPA | European Crop Protection Association |
| ENSO | Elino Southern Oscillation |
| EOS | End of Season |
| FAO | Food and Agricultural Organization |
| FEWS NET | Food Security Early Warning Systems Network |
| FSD | First Stochastic Dominance |
| GDs | Growing Degrees |
| GDD | Growing Degree Day |
| GDDs | Growing Degree Days |
| GDP | Growth Domestic Product |
| IOD | Indian Ocean Dipole |
| IPCC | Intergovernmental Panel For Climate Change |

| | |
|---|---|
| ITCZ | Inter Tropical Convergence Zone |
| ILRI | International Livestock Research Institute |
| JJAS | June, July, August and September |
| LEAP | Livelihoods, Early Assessment and Protection |
| LGP | Length of Growing Period |
| LLJ | Low Level Jet |
| LR | Long Rain |
| LRS | Long Rainy Season |
| MAM | March, April and May |
| NMA | National Meteorological Agency |
| NMHSS | National Meteorological And Hydrological Services |
| NMSA | National Meteorological Service Agency |
| NOAA | National Oceanic and Atmospheric Administration |
| NRD | Number of Rainy Days |
| PCI | Precipitation Concentration Index |
| PET | Potential Evapotranspiration |
| RA | Normalized Rainfall Anomaly |
| RAI | Rainfall Anomaly Index |
| RSCZ | Red Sea Convergence Zone |

| | |
|---|---|
| SD | Standard Deviation |
| SD | Stochastic Dominance |
| SSD | Second Stochastic Dominance |
| SKV | Siraro- Kofele Potato Vegetables Livelihood Zone |
| SOI | Southern Oscillation Index |
| SOS | Start of Growing Season |
| SPI | Standardized Precipitation Index |
| SRA | Standardized Rainfall Anomaly |
| SRS | Short Rainy Season |
| SSA | Sub Saharan Africa |
| SST | Sea Surface Temperature |
| SSTAS | Sea Surface Temperature Anomalies |
| STJ | Sub Tropical Jet |
| TEJ | Tropical Easterly Jet |
| UB | University of Babylon |
| WMO | World Meteorological Organization |

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## ABSTRACT

*The failure or the success of seasonal and annual rainfall amount and distribution is extremely critical for rain fed agriculture. The objective of this study was to analyze, examine, and characterize the seasonal and inter-annual temporal variability of rainfall variables, and understand and identify degree of vulnerability of crop production to rainfall variability in Siraro-kofele potato-vegetable livelihood zone. Instat software version +v.3.37, R-statistical package and Excel 2010 were used for analysis. Annual and seasonal rain fall amount was more variable at Aje where rainfall amount is less. In all climatic parameters; coefficient of variation was showed high variability in Belg than Kirmet. Variability of season onset, cessation, length of growing period, dry spell of different length and changes in number of rainy days indicated high year to year or season to season variability and were the most determinant climatic factors of crop production of the livelihood zone. Length of the growing period of Belg was more explained by onset while of main rainy season more influenced by cessation of the season. Most of drought prevailed during the study period were mild drought followed by moderate and manageable. Contrary to this wet condition is also frequently exhibited during study period. Rainfall variability and crops yield was showed direct relationship. Observed Teleconnection between rainfall regimes and large scale climate patterns sea surface temperature and southern oscillation index revealed positive results towards better understanding of the causes of climate extreme events. Kiremt rain was positively and negatively correlated to the Southern oscillation index and Sea surface temperature anomalies respectively. The more variable Belg rain describes the opposite. Temperature variability and calculated Growing Degree-Days also showed positive and negative relation with crops yield. However, for improving precision and reliability of the application of the findings for practical use, increasing the number of study stations and further intensifying climate related research are critically important.*

# 1. INTRODUCTION

## 1.1 Background

Climate variability and change are affecting the whole world (IPCC, 2007). Some researchers have documented that climate related impact is stronger in Africa, where agriculture is important for the daily subsistence, and where adaptive capacity is low (Cooper *et al.*, 2006; Nuhu *et al.*, 2007). Africa in general and Sub Saharan Africa (SSA) in particular is the most vulnerable region in the world to climate variability and climate change (Michael, 2006).Climate information issued by National Meteorological and Hydrological Services (NMHSs) is not informative due to low level of understanding of the users (local authorities, extension workers, and farmers) to the terminology used and also their ability to use climate (forecast) information for supporting farming activities. In many cases, the end users always seek information and use it when it is beneficiary.

Previous studies in many parts of Ethiopia emphasized on analysis of trends in annual and seasonal rainfall totals (Mekasha *et al.*, 2014) disregarding intra-seasonal rainfall variability such as timing of season start date and season end date, number of rainy and dry days, dry spells at different lengths and other vital aspects of rainfall variability for agricultural planning. Drier parts of central rift valley of Ethiopia continue to experience high unpredictable rainfall patterns, persistent dry-spells or droughts coupled with high evapotranspiration. Generally, the total amount of rainwater is enough; however, it has been reported to be poorly distributed over time with 25% of the annual rain often falling within a couple of rainstorms; as a result crops suffer from water stress, often leading to complete crop failure. Recha *et al.* (2011) noted that most studies do not provide information on the much-needed character of within-season variability despite its critical influence on soil-water distribution and productivity. The rainfall is highly variable both in amount and distribution across regions and seasons (Mersha, 1999; Tilahun, 1999; Tesfaye, 2003).Rainfall performance limits potential crop yields in these areas (Graef and Haigis, 2001). Very few studies have tried to quantify the spatial and temporal variability of rainfall in the semi-arid tropics of sub- Saharan Africa (Graef and Haigis, 2001; Odenkunle *et al.*, 2007). The high degree of rainfall variability, when combined with relatively low asset base of most rural households, restricts household crop management strategies and overall crop water productivity. Ethiopia, for instance agricultural sector directly supports about 85% of the total

population in terms of employment and livelihood, contributes about 50% of the country's gross domestic product (GDP), generates about 88% of the export earnings, and supplies around 73% of the raw material requirement of agro –based domestic industries Centre for Environmental Economics and Policy in Africa(CEEPA, 2006). More than 50 per cent of variation of crops yield is determined by climate and this needs accurate measurement of rainfall and close study of rainfall variation (Seifu, 2004).Recent research hold promise to reduce some adverse effects by formulating suitable adaptation strategies that combines indigenous knowledge, weather information, and modern risk management methods, approaches, practices and location specific seasonal climate outlooks. Studies in this area mostly focus on how rainfall in a particular year affects production.

To optimize agricultural productivity in livelihood zone, there is a need to quantify rainfall variability at a local and seasonal level as a first step of combating extreme effects of persistent dry-spells or droughts and crop failure.

The critical question in agriculture however is often a place receives too little, enough or too much rain for a particular form of crop production to be carried out this study attempts to show patterns of rainfall that would provide insight into the preparation of an early warning system for crop planning in this area successfully. Most studies derive a value for a minimum annual rainfall required to support a particular crop. This study attempts to show patterns of rainfall that would provide insight into the preparation of an early warning system for crop planning in this area. Using station level rainfall data from 1983-2015 and agricultural production data of major cereal crops and vegetables of 1995-2015 for four districts of livelihood zone. The use of such information for an early warning system is currently widely publicized in most developed countries. Benefits of climate information for agricultural production and mitigation of loses are very crucial in reducing risk.

## 1.2. Statement of the Problem

One important limitation of the study springs from the broken data for both monthly and daily time steps. Station histories are not known but, it's highly likely that the rainfall records have been subjected to changes in location and instrumentation. The daily data for the relatively longer rainfall records suffer from similar interruption.

The availability of short series of rainfall records for much of Ethiopia is a setback for similar Climate studies. Yet, significant progress has so far been made in recent years towards better understanding.

However, despite a handful of empirical studies, in-depth analysis and well-established scientific evidences on the nature and extent of climate variability, magnitude of impact on agricultural crops in the area is virtually lacking. Information on the seasonal climate variability provides the best opportunity for farmers to adjust time of sowing date, cultivar selection, rate of seeding, input utilization, farm management practices and other response farming activities.

## 1.3. Significance of the Study

In recent time, increasing climate variability such as rising temperature and erratic rainfall is critical problem of crop production. The main hazard in this livelihood is the shortage of water, which arises from inadequate rainfall, dry spells and early cessation of rains during critical crop growth and seed setting periods have negative impact on harvest and the resultant water shortage has led to the substantial decline in agricultural productivity. This study is designed to avail climate variability impact on crop yield and to provide valuable information and scientific knowledge. Moreover, findings of this research can play significant role to enhance and facilitate exchange of climate knowledge and information among local communities, field experts, policy makers and researchers.

## 1.4. Objective of the Study

### 1.4.1. General objective

The overall objectives of this study was to characterize spatial and temporal time climate variability and examine vulnerability of crop production to rainfall and temperature variability and assess relationship with crop production to seek solution to weather or climate related risks of crop production in the Siraro-Kofele Potato -Vegetables (SKV) livelihood zone.

### 1.4.2. Specific objectives

- To examine local scale rainfall and temperature variability to characterize climate variability;
- To assess impact of rainfall and temperature variability on selected major six crops production;
- To prepare agro meteorological advisory plan that will be used for cropping according to predicted El Nino, La Nino and neutral or normal conditions that are expected to prevail.

### 1.4.3. Research questions

1. How was temporal variation of rainfall and temperature in the study area?

2. What was the marginal effect of climate variability on agricultural crops in the study area?

3. To what extent is localized rainfall of the study livelihood zone influenced by large scale atmospheric patterns?

### 1.4.4. Scope and limitation of the study

The scope of this study was mainly focused on two themes: the first was analysis of climate variability from two climatic parameters (rainfall and temperature) and the second was analyzing the marginal effect of climate variability on the productivity and production level of major agricultural food crops in the study area. Given the complexity of the study, various efforts were exerted to make the research more scientific, reliable and applicable. One of the limitations of this study was that it considered the total all annual agricultural crops into one category although climate variability affects different crop differently. A related challenge was lack of time-series data on crop production of at root level. Lastly, this study did not take into account impact of water supply and availability as well as technological changes on climate.

### 1.4.5. Working definition of livelihood

A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stress and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base. (Chambers and Conway, 1991)

# 2. LITERATURE REVIEW

## 2.1. Characteristics of Ethiopian Climate

Agricultural production in Ethiopia is predominantly rain fed, variation of rainfall in space and time affects the agricultural production system in the country. Seasonal climate variability is a major source of crop production risks (Harwood *et al.*, 1999). The drier parts of central Rift Valley continue to experience unpredictable rainfall patterns, persistent dry-spells or droughts coupled with high evapotranspiration (Belay, 1990). The seasonal and annual rainfall variations usually resulted from the fluctuation of macro-scale pressure systems and monsoon flows which are related to the changes in the pressure systems (Beltrando and Camberlin, 1993; NMSA, 1996).The most important weather systems that cause rain over Ethiopia include Sub-Tropical Jet (STJ), Inter Tropical Convergence Zone (ITCZ), Read Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and low level Somalia Jet (LLJ) (NMSA, 1996). The spatial variation of the rainfall is, thus, influenced by the changes in the intensity, position, and direction of movement of these rain-producing systems over the country (Taddesse, 2000).Moreover, the spatial distribution of rainfall in Ethiopia is significantly influenced by topography (NMSA, 1996; Camberlin, 1997; Taddesse, 2000), which also has many abrupt changes in the Rift Valley.

### 2.1.1. Ethiopian seasonal climatic characteristics

Though in the tropics there are only wet and dry seasons, in Ethiopia the types of the season are categorically divide in to four distinct parts based on rainfall pattern. According to NMSA (1996) seasonal classification varies with spatial location, i.e. central, north eastern and eastern Ethiopia have three seasons: namely, main rainy season summer (*Kiremt*) from June to September, dry season winter (*Bega*) from October to January and small rainy season spring (*Belg*) from February to May. Extreme minimum night and early morning temperatures occur during the October to December season mainly over north eastern, central, eastern and southern high lands, so that the lowest minimum temperature recorded during this period favours occurrence frost which may damage some sensitive crops.

Particularly, over SKV livelihood zone, the first rains of *Belg* and *Kiremt* seasons occur in early March and June respectively. The weakening and strengthening of the *Kiremt* rains are associated with shifting in the location of ITCZ, strengthening of cross equatorial flows and monsoon troughs, which usually induce wide spread rains that usually accompanied by heavy falls, cover much of SKV livelihood zone, particularly when cross equatorial flows are strong enough to pump abundant moisture into the high grounds of the central and north eastern Ethiopia and hence lifts up ITCZ to the northern highlands (Korecha, 2002).

### 2.1.2. Seasonal climate variability

Climate is typically defined and aggregated average of 30 years consecutive time series data (WMO, n.d),whereas climate variability can be defined as variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events (Fussel and Klein, 2006). Similarly, seasonal climate variability describes variability of climatic elements from season to season. Season has different meanings, but meteorologically, defined as a period when an air mass characterized by homogeneous weather elements such as temperature, relative humidity, wind and rainfall etc., influences or dominate a region or part of a country (NMSA, 1996).

The two most important climatic parameters that dominantly determine crop production are moisture and temperature. According to Braun (1991), 10% decrease in seasonal rainfall generally converts into a 4.4% decrease in the country's food. The impact of rainfall on crop production can be related to its total seasonal amount or its intra-seasonal distribution (Woldeamlak, 2006). Intra-annual rainfall variability refers to the distribution of rainfall within a year (Obasi, 2003).Time of seasonal onset can be considered as predictor of seasonal rainfall behavior that is to say early onset believed to be more rainfall and late onset less seasonal rainfall which is not always true. Initial decisions are kept open to facilitate revision of earlier decisions based on relationships between rainfall received early in the season and eventual total seasonal rainfall.

### 2.1.3. Weather producing systems during different seasons

*Bega* (winter) is generally dry season that covers the period from October to January. During this season, most part of the country predominantly falls under the influence of warm and cool north-easterly winds; these dry air masses originate either from the Saharan anticyclone and /or from the ridge of high pressure extending into Arabian, from the large high surface pressure over central Asia, Siberia (NMSA, 1996; Gonfa, 1996). However, there is occasionally unseasonal rain-particularly over parts of Ethiopia where *Kiremt* is the major rainy season.

*Belg* (spring) refers to small rainy season that covers the period from mid-February to mid-May. However, the rainfall is highly characterized by inter annual and inter seasonal variation. Major systems during *Belg* season are:-development of thermal low over South Sudan, generation and propagation of disturbances over the Mediterranean Sea, sometimes coupled with easterly waves, development of high pressure over the Arabian Sea, some of the interaction between mid-latitude depressions and tropical systems accompanied by troughs and the subtropical jet and occasional development of the Red Sea Convergence Zone (NMSA, 1996; Gonfa, 1996).

*Kiremt* (summer) season refers to long and main rainy season, which normally occurs from June to September. Major rain producing systems during *Kiremt* season are the following; Northward migration of ITCZ, development and persistence of the Arabian and south Sudan thermal low along $20^{o}$N latitude, development of quasi-permanent high pressure systems over south Atlantic and south Indian oceans, development of TEJ and the generation of LLJ that enhance low level south westerly flow (Tadesse, 1994; NMSA, 1996; Segale and Lamb, 2005). During this season, ITCZ and the moist south westerly monsoon flow from the southern hemisphere are the main rain producing structure. The onset and spatial distribution of rainfall are also found to follow the oscillation of the ITCZ and the intensity of the southern hemispheric anticyclones (Tadesse, 1994; Segele and Lamb, 2005).

### 2.1.4. Global phenomena causing climate variability over Ethiopia

2.1.4.1. ENSO-events

More than 100 years ago, the name El Nino was originally coined by Peruvian fishermen to describe the unusually warm waters that would occasionally form along the coast of Peru and Ecuador (eastern Pacific region) peaking near Christmas (Trenberth,1991).El Nino in Spanish means *the child*, with specific reference to the Christ child. La Nino, Baby girl in Spanish it is opposite weather condition to El Nino (Child Christ).

El Nino and La Nina are two phases of the ENSO that involves changes in water temperature in the central and east- central equatorial Pacific, both in surface and sub-surface. El Nino is warm phase oceanic behavior of ENSO. La Nina is cold phase of ENSO. Essential components of the ocean-atmosphere interactions and therefore assume a particularly important position in seasonal rainfall prediction. A characteristic period of occurrence varies from 3 to 7 years and tendency to alternate El Nino or La Nino events. Understanding of the influence on climate variability and computation of the associated risks in crop production at a particular location and season is a developing aspect of the existing climate forecasting techniques.

When the sea surface temperature is lower than normal and persists for five consecutive months of the seasons, the phenomenon is referred to as La Nina. During La Nina events, the equatorial trade winds strengthen, resulting in colder water being brought up from the ocean's floor, when SST warmer than the normal condition is referred to as El Nino phase and Neutral is the term for when neither El Nino nor La Nina are present in the Pacific (Trenberth, 1997). Under neutral conditions, trade winds blow from east to west near the Equator in the Pacific Ocean. El Niño is the overall dominant influence in regional seasonal climate variability worldwide, though other modes of sea-surface temperature variability can be more important in some regions (Folland *et al.*, 1991).The most important feature of sea surface temperature variability that can cause large scale weather disruptions is El Nino and its counterpart La Nina, a near basin-wide warming and cooling of the equatorial Pacific Ocean, known as ENSO (Goddard *et al*., 2001).

Many authors have documented how ENSO events have strongly linked with various atmospheric system and rainfall distribution over Ethiopia (Korecha and Barnston, 2007). For instance, the principal cause of drought in Ethiopia is asserted to be the fluctuation of the global atmospheric circulation, which is triggered by sea surface temperature (SST) anomalies, occurred according to ENSO events. The phenomena have significant impact on displacement and weakening of the rain producing mechanisms of the seasons. ENSO episodes and other regional systems have impact on seasonal rainfall performance and rainfall variability over Ethiopia is due to remote teleconnections system (NMSA, 1996; Gissila, 2001; Korecha, 2002; Korecha and Barnston, 2007). There are two types of El Nino groups which formed due anomaly increasing in SST. In the first group, the anomaly increases considerably in the period from January to June, while in the second during July to December. Though, group two types of El Nino events may have had relatively less negative effect on *Kiremt* rains; Group One type of El Nino is always associated with severe and widespread drought during *Kiremt* (Bekele 1993).

The time between successive El Nino and La Nina events is irregular, but they typically tend to recur every 3 to 7 years, lasting for 12-18 months once developed.

2.1.4.2. Southern oscillation index (SOI)

SOI is a normalized difference between Tahiti, French Polynesia minus Darwin, Australia surface air pressure, after typical seasonal variations have been subtracted out. Periods of SOI greater in magnitude than 0.5 are shaded to emphasize the relationship with El Nino and La Nino episodes. Low SOI is associated with warm sea temperatures (El Nino), and high SOI with cold sea temperatures La Nina (Seifu, 2004).

## 2.2. Temporal and Spatial Climate Variability

### 2.2.1. Annual, seasonal and monthly rainfall amount variability

Rainfall variability is a prominent and an unavoidable aspect of rain fed farming all over the world (Hansen, 2002). Rainfall in Ethiopia is characterized by seasonal and inter-annual variability (Camberlin 1997; Shanko and Camberlin 1998; Conway 2000; Seleshi and Zanke

2004).In Ethiopia extreme climate events; particularly drought has been recurring phenomena. Climate variability over the last three decades of the 20th century resulted in droughts and famine in several African countries (Conway and Schipper, 2011; Dixit *et al.*, 2011). Climate variability, particularly rainfall variability and associated droughts, have been major causes of food insecurity and famine in Ethiopia (Conway, 2000; Hulme *et al.*, 2001; Seleshi and Zanke, 2004; Thornton *et al.*, 2006; NMA 2007; Conway and Schipper, 2011; Demeke *et al.*, 2011; Perrin *et al.*, 2011; Rosell, 2011).

### 2.2.2. Intra-seasonal and inter-seasonal climate variability

Intra-Seasonal variability refers to variation within a given specific season while inter-seasonal to seasonal variability is to mean variability within season and among seasons (Felix and Romuald, 2014). The intra-seasonal and inter-annual variability of rainfall over tropical and extra tropical area are teleconnected with the global atmospheric and oceanic parameters. Seasonal rainfall amount, intra-seasonal rainfall distribution and dates of onset or cessation of the rains influence crop yields and determine the agricultural calendar (Traore, 2014). Inter-annual rainfall variations cause great stress to the farming activities, crop production and crop yield.

Intra-seasonal climate variability; seasonal rainfall variability shows significant differences, with relatively highly variation across the lowlands and Rift Valley regions. Intra-annual rainfall variability determines seasonal agricultural performance. Annual rainfall across the country has fluctuated significantly since the 1980s (NMA, 2012) and Livelihoods, Early Assessment and Protection (LEAP, 2013).

Inter-seasonal to seasonal climate variability; inter- and intra-seasonal rainfall variability over total annual rainfall is important in determining livelihood and food security outcomes (FEWS NET, 2003). Ethiopia is characterized by seasonal and inter-annual variability (Camberlin 1997; Shanko and Camberlin 1998; Conway 2000; Seleshi and Zanke 2004). Despite the absence of significant trends in rainfall patterns, the high inter-annual variability and season to season variation implies a challenge to rain fed agriculture (Kassie *et al.*, 2013). Past and future trends in inter-annual and inter seasonal rainfall variability; declining rainfall amount, variability in the length of the growing seasons and in season dry spells together with increasing temperature generally indicate an increasing risk for rain fed crop production in the CRV(Kassie *et al.,* 2013). Crop yield varies from season to season owing to variation in climate during the growing seasons (Bewket, 2009; Ayalew *et al.*, 2012; Hadgu *et al.*, 2013).

When seasonal variations are present within a set of data, it often helps to express the data in terms of standardized anomalies. Standardized anomalies also referred to as normalized anomalies. They generally provide more information about the magnitude of the anomalies because influences of dispersion have been removed. It is not necessary that a dataset have a particular distribution to express it in terms of standardized anomalies. It measure of distance, in standard units, between a data value and its mean and removes influences of location and spread from data. It make easier to discern normal vs. unusual values. Drought begins when the standardized rainfall anomaly first falls below zero and ends with the first positive value (McKee *et al.*, 1993).

The coefficient of variation and a normalized measure of relative dispersion were used to assess overall rainfall variability. Inter annual departures, expressed as Rainfall Anomaly Indices (RAI) or (SRA = standardized rainfall anomaly). Anomalies, or the deviation from the mean, are created by subtracting climatologically values from each observation, then dividing by the standard deviation. The drought severity classes are extreme drought severe moderate drought and no drought .The standardized rainfall anomalies were calculated and graphically presented to evaluate inter-annual fluctuations of rainfall in the study area of SKV livelihood zone over the period of observation (1983-2015).

### 2.2.3. Onset, cessation date and length of growing seasons variability

#### 2.2.3.1. Onset of rainy season variability

Different threshold values can be used to determine onset of the rainy season. One of the commonly used onset of the season can be defined as the moment when cumulative rainfall for three consecutive days is larger than 20 mm and there is no dry period longer than 10 days with no rainfall within the following first 30 days after onset (Barron *et al.*, 2003; Stern and Cooper, 2011).Onset marks beginning of a season though different researchers have put it differently. Tesfaye and Walker (2004) defined onset as the date in which 20mm or more rainfall accumulated over three consecutive rainy days after a specified date with no dry spell greater than 7 days in the next 30 days. For *Kiremt* season onset rain was Defined by (Segele and Lamb,2005) rainfall total of 20 mm or more in consecutive 3 days or more with no dry spell length of 10 days or more in the next 30 days should occur with an earliest starting day first of June . For *Belg* season onset rain was defined by Mesay (2006), rainfall total of 10 mm or more in consecutive 3 days or more with no dry spell length of 9 days or more in the next 30 days should occur with an earliest starting day first of February .The onset and spatial distribution of rainfall are found to follow the oscillation of the ITCZ and the intensity of the southern hemispheric anticyclones (Tadesse, 1994; Segele and Lamb, 2005). World Bank (2006) reported that the late start of the *Kiremt* in 1997 caused a reduction in average yield of cereals by 10% across Ethiopia. Recently Befekadu and Berhanu (2000) indicated that lack of adequate rainfall combined with variability on the onset and duration of rains remain a threat to agricultural production in Ethiopia. A good understanding of seasonal variability patterns is of critical importance because of the highly unstable onset of the rainy season and the high frequency of dry spells (Traore, 2013).According to the study of past and future intra seasonal rainfall variability in terms of onset, cessation date and length of rainy season, number of rainy days, length of dry spell within the growing period and its trend is important for agricultural purposes in the dry land area than annual and seasonal totals (Hadgu *et al.*, (2013).

2.2.3.2. Cessation of rainy season variability

Cessation of rainy season marks withdrawal of rainy season. Like onset, cessation of rainy season is also defined differently by different authors. For instance, Mesay (2006) used to determine cessation of *Belg* rain with an earliest possible day of May 1, the capacities of soils to persist precipitation with a water balance equal to zero. Whereas Tesfaye and Walker (2004) defined cessation of rainy season (for *Kiremt)* as the date when the available soil water content drops to 10 mm/month of the available water after September 11. In another study, Mamo (2005), Mesay (2006) and Taye *et al.* (2013), defined as any date when water balance reaches zero after the first date of September (for *Kiremt*). On the last day of rain that is greater than 0.5 potential evapotransparation (PET), provided that the date is not proceeded by a dry spell (< 1mm average daily rainfall) or more than five days (Mubvuma, 2013). In this study cessation rainy season is defined as the first dry day of the last month of the season first day when water balance of the soil become zero, with assumption that initially soil is to be at field capacity (100 mm) and daily evapotranspiration is to be 3mm for Kofele and 3.5mm for both Shashamene and Aje.

2.2.3.3. Length of growing seasons variability

Length of growing period (LGP) is the time from sowing to harvest or the time from planting to harvest. It can also be defined the difference between start of the SOS and EOS. Many definitions of cessation of growing season use a simple water balance equation. The date, in each year, that the water balances first falls to zero; this is a possible definition of the cessation of the growing season. Camberlin and Okoola (2003) observed a reduction of 25–30% in maize yield in Kenya due to a 20-day delay of the main rainfall season.

### 2.2.4. Dry spells, number of rainy and dry days variability of growing seasons

2.2.4.1. Dry spells variability of the seasons

In analysis of number of rainy days there are several threshold values depending on the required discipline. Being a season-based analysis, the cumulative impact of rainfall amount is strengthened. Even though the smallest recorded rainfall amount is 0.1 mm, a threshold value of 0.2mm/day was used to determine wet and dry days (NMSA, 2001). Therefore, a rainy day is considered to be any day that received more than 0.2 mm of rainfall as identified by the WMO, while the reverse of this definition can be used to define dry day. The rainfall of 0.1mm has almost no effect on growth of crops (Robel *et al.*, 2013).

In Mvomero district, Tanzania in 1996 and 2002 the total amount of rainfall was high while the number of wet spells was low and at the same time crop production was poor. Crop production was poor because of fewer numbers of wet spells. On the contrary, in 2004 the amount of rainfall was low but the number of wet spells was high and crop production was better (Mukonda, *et al.*, 2014).Thus, fair distribution of wet spells is very important as it ensure the sustainability of wet on the ground.

On the other hand, heavy rainfall with few wet spells in the growing season might have no favor to crop production because it occurs with fewer wet spells while crop production is favored by numerous and fairly distributed wet spells. A decrease in the number of rainy days with an increase in the mean rainfall per rainy day has been observed over the past few decades, signifying an increase in the intensity of rainfall, particularly for the *Kiremt* (Kassie *et al.*, 2013).

2.2.4.2. Number of rainy and dry days variability of the season

According to NMSA (2001), a day is said to be dry if it accumulate rainfall<1 mm and dry spell length is the maximum number of consecutive dry days with rainfall less than 1 mm per day exceeding 5, 7, 10, and 15 ( Tesfaye and Walker, 2004). Mesay (2006) found mean dry spell length of up to 28 days in the north western, northern and eastern parts of Ethiopia during *Belg* season. Araya and Stroosnijder (2011) also indicate that dry spells of 10 days are among the major causes of crop failure in rain fed farming systems of Ethiopia.Araya and Stroosnijder(2011) indicated that 20% of crop failure in drought-prone parts of Ethiopia is due to dry spells during the growing season. Frequent dry spell with high evapotranspiration demand in CRV may lead to a decrease in yield of up to 40% because of insufficient water supply during grain filling stage (Barron *et al.*, 2003). Although total rainfall may be adequate for crops growth the distribution is usually uneven over the cropping season leaving dry spells during which the crop is exposed to sever moisture stress that is substantially affecting its growth and yield (Segele and Lamb 2005).

Dry and wet spells: The following definitions were used to describe dry and wet days according to Stern *et al.* (2003). Dry day is any day with rainfall less than 0.85 mm received within a period of 24 hours. In rain-fed farming, the recurrent dry spell becomes critical, particularly for the seedling establishment during the first 30 days or so after planting. Because of the changing nature of planting dates with the variable characteristics of rainfall distribution of each season, calculations of dry spells on a calendar day basis have limited importance for specific application in crop production (Siva Kumar, 1991; Tesfaye and Walker, 2004). Therefore, to provide a viable decision aid to various practitioners, different dry spell lengths had examined as documented by (Mamo,2005).Therefore, it is necessary to compute the probabilities of dry spells occurrence after the start dates (successful planting dates) were determined.

### 2.2.5. Spatial rainfall variability

Meze- Hausken (2004) reported that rainfall variability is highest for short rains as compared to the long rain for the northern Ethiopia. In contrast, Rosell (2011) found higher rainfall variability during the long rain season in the central highlands of Ethiopia for the period 1978–2007. The difference in the findings indicates the existence of large spatial variations in climate across the country. Not all crop growing regions showed statistically significant influence of year-to-year variations in climate on crop yield variability (Ray *et al.*, 2015).However, the vast majority of crop harvesting regions did experience the influence of climate variability on crop yields, the percentage of global total average production harvested over these regions and thus influenced by climate variability. In specific locations, within the top global crop production regions, climate variability accounted for greater than 60% of the variability in a crop's yield, though there were also political units where climate impacts have been statistically insignificant (Ray *et al.*, 2015).Where and how much of a crop's yield varied on account of climate has been highly, location- and crop–specific. Averaged globally over areas with significant relationships, we find that 32–39% of the maize, rice; wheat and soybean year-to-year yield variability was explained by climate variability (Ray *et al.*, 2015). This translates into climate explained annual production fluctuations of ~22 million tons, ~3 million tons, ~9 million tons and ~2 million tons for maize, rice, wheat and soybean, respectively (Ray *et al.*, 2015). In Ethiopia, particularly in CRV, seasonal patterns of crop production depend on the rainfall regimes and can be classified into three categories: Those; planted and harvested in *Belg (*spring), planted in *Belg* and harvested in *Meher* and planted in *Kiremt* (summer) and harvested in *Meher (*winter).

Spatially detailed assessment of the relationship between climate variability and yield variability shows distinct spatial patterns in the relative effects of temperature, precipitation and their interaction within and across regions. Due to the high population density, there are regions in the Rift valley and the central Ethiopian highlands that must be considered extremely water-limited, despite annual precipitation of more than 1000 mm (Funk *et al.*, 2005).

The temporal variability and occurrence of various rainfall and temperature indices were evaluated at selected weather stations based on the analysis of a set of indicators defining variation and extreme conditions, following Trnka *et al.* (2011) and Vergni and Todisco (2011).

### 2.2.6. Maximum, minimum and mean temperature variability

In the CRV where evapotransipiration is very high and exceed rainfall amount even during the rainy season (Belay, 1990). During December to February, there were warm anomalies in the extreme ends of maximum temperature exceeding 90th percentiles over most of the country except over south– central Ethiopia, which were normal in 2014 with respect to the 1981-2010 The June-August season 90th percentile maximum temperatures were also above average over most parts of Ethiopia in 2014 (Mengistu Tsidu *et al*., 2015). Observations during September, October and November were similar to June-August specifically over northern Ethiopia (Mengistu Tsidu *et al*., 2015).

### 2.2.7. Seasonal climate variability characterization

Studies on rainfall patterns in the region have been based principally on annual averages. Understanding seasonal rainfall patterns by evaluating its variables including; rainfall amount, rainy days, lengths of growing seasons, and dry-spell frequencies. However, understanding the average amount of rain per rainy day and the mean duration between successive rain events aids to understand long-term variability and patterns. The temporal variability and occurrence of various rainfall and temperature indices evaluated at weather stations based on the analysis of a set of indicators defining variation and extreme conditions, following; (Trnka *et al.*,2011) and Vergni and Todisco (2011).The rainfall indices include values of accumulated rainfall (monthly, annual and seasonal), number of rainy days, mean daily rainfall intensity, precipitation concentration index (PCI), normalized rainfall anomaly (RA), start of the growing season (SOS), cessation the growing season (EOS), length of growing period (LGP) and dry spells crop.

2.2.7.1. Characterization of rainfall amount

The temporal variability and occurrence of various rainfall and temperature indices evaluated at selected weather stations based on the analysis of a set of indicators defining variation and extreme conditions, following Trnka *et al* .(2011) and Vergni and Todisco (2011) characterization was done. The rainfall indices include values of accumulated rainfall (monthly, annual and seasonal), number of rainy days, mean daily rainfall intensity, precipitation concentration index (PCI), normalized rainfall anomaly, start of the growing season, cessation the growing season, length of growing season, and dry spells are useful characterization parameters. Finally, evaluation of variability done based on coefficient of variation (CV) in rainfall amount and number of rainy days was characterized for stations considered in study area according to variable rainfall.

2.2.7.2. Characterization of onset, cessation and length of growing season

Growing seasons can be defined as the period of time when temperature and moisture conditions are suitable for crop growth. Length of rainy season is the duration in days between onset date and cessation date ( Odekunle, 2004; Segele and Lamb 2005; Hadgu *et al.*, 2013; Hadgu *et al.*, 2014; Kassie *et al.*, 2014). According to Borrell *et al.* (2003), length of growing season analysis is very important to advice farmers in selecting suitable crop variety that can be produced in specific area. Knowing when suitable time of crop growth have been occurred help researchers, policymakers, and farmers to better manage their land and water resources and to better understand how variability in climate affects the ability of farmers to plant, grow, and harvest specific crops. The concept of growing seasons takes into account the seasonality and length of potential growing periods during the year. The growing periods can also be determined based on the start of the rainy season (rainfall amount divided by evapotranspiration is equal to 0.5 mm) and temperature. Indeed, statistical associations between rainfall and crop production at sub-regional scales have not been studied in any detail (Woldeamlak, 2009). In the recent years, the debate on climatic variability has led to a renewed interest in the effects of climatic variability on agriculture

Thornton *et al.* (2006) reported that in many of the regions across Africa including Ethiopia, there will be little to moderate reduction in the length of the growing period (<20%). Steeg *et* *al*. (2009), for instance, indicate that the growing season in some parts of Ethiopia could be 20% shorter by 2050 relative to the current baseline period (1960–90), which would have negative repercussions on food production. The World Bank (2006) has linked changes in economic productivity to rainfall variability such that years with higher economic growth are associated with years with higher rainfall. Several investigations have been done on the relation between the Ethiopian rainfall and the state of the ENSO. Most of these and other previous related studies found good correlation between ENSO and Ethiopian rainfall (Gissila, *et al.*, 2004; Korecha and Barnston, 2007. June to September (JJAS) is normally the major rainy season over most of Ethiopia. JJAS is a seasonal rainfall for almost whole Ethiopia, except the south and southeast other portions of the nation benefited, particularly for the southwest, west, north, central and east regions of Ethiopia. However, the onset, cessation and the spatial and temporal distribution of *Kiremt* rainfall varies from place to place (Segele and Lamb, 2005).

The intra seasonal rainfall variability also shows significant differences, with relatively highly variation across the lowlands and Rift Valley regions. ENSO have an impact on a seasonal shifting of the normal rainy seasons in some regions, as a result a shortening or lengthening of the rainy seasons, particularly over tropical regions (Mason and Goddard, 2001). In line with this, there could be a significant teleconnection linkage between ENSO and the Ethiopian JJAS rainy season (Gissila *et al.*, 2004; Segele and Lamb, 2005).

Various studies indicate that future climate change will lead to an increase in climate variability and in the frequency and intensity of extreme events (Boko *et al.* 2007).There is also an emerging consensus that Eastern Africa, and particularly Ethiopia, is one of the most vulnerable regions regarding the impacts of climate variability and change (Slingo *et al.*, 2005; Boko *et al.*, 2007; Challinor *et al.*, 2007; Thornton *et al.*2011). In general, the changing rainfall pattern could make rain fed agriculture more risky and aggravate food insecurity in Ethiopia.

2.2.7.3. Characterization number of rainy and dry days

Frequent rain delay, erratic precipitation, drought, seasonal variation, heavy fall, unseasonal rainfalls, and occurrence of unusual long rainy and dry season are indicators of climate change and variability (Mikias, 2014). Although total rainfall may be adequate for crops growth the distribution is usually uneven over the cropping season leaving dry spells during which the crop is exposed to sever moisture stress that is substantially affecting its growth and yield (Segele and Lamb 2005).

2.2.7.4. Droughts and dry-spell characterization

To optimize agricultural productivity in the region, there is a need to quantify rainfall variability at a local and seasonal level as a first step of combating extreme effects of persistent dry-spells/droughts and crop failure. The probability of occurrence of dry-spells of various durations varied from month to month of the growing season. The probability of having a dry-spell increased with shorter periods (for instance, more chance of having a 3-day than a 10- or 20-day dry-spell).Probability of a dry-spell of length days, for, 5,7, 15, and 20, in each seasonal-cropping month was analyzed based on rainfall data of meteorological stations. Knowing spell lengths and defining a dry day is a preliminary task, when looking at dry spells. The obvious definition is any day with zero rainfall. We usually use a value of just under 1mm and define a day to be dry if its value is less than this threshold. But, according to WMO; a dry day is taken as a day that received either less than 0.2 mm or no rainfall at all is preferred.

The SPI (Standardized Precipitation Indices), as described by McKee *et al.* (1993), was used to define drought periods. Requiring only precipitation as input, the SPI covers a variety of time scales and allows comparison of drought severity both between periods in time and between different locations. In regions like Ethiopia, where the access to data is limited, there are good reasons for choosing a precipitation-based drought measure. Drought is an extreme weather event, which results when rainfall is far below average (failure of rainfall). Correspondingly McKee *et al. (*1993) used standardized rainfall anomalies to classify degree of drought. Drought event may be defined as a period during which the SPI is continuously negative and reaches a value of −1 or less at one or more time steps. Drought begins when the SPI first falls below zero and ends with the first positive value (McKee *et al.*, 1993).The SPI may be calculated at any time scale, depending on which effect of drought one wishes to detect. The SPI of a specific observation of precipitation is the standard deviation of the normal curve at the same cumulative. Ntale and Gan (2003) compared different drought indices for East Africa, concluding that a modified SPI is the best indicator for monitoring East African droughts.

2.2.7.5. Characterization of temperature variability

The temperature indices are the annual minimum and maximum temperature, mean annual temperature, minima and maxima of daily minimum and maximum temperature. Occurrences of abnormal hot and cold temperature are severe concerns for all the communities and some of the indicators of climate change and variability in the study area (Mikias, 2014).

## 2.3. Impact of Climate Variability on Major Selected Six Crops

### 2.3.1. Climatic requirement of selected six major crops

2.3.1.1. Climatic requirement *of tef (Eragrotis tef)*

*Tef* is one of major crops and vegetables grown in (SKV) livelihood zone.*Tef* is a small-grained cereal grass species that has been grown as a food crop in east Africa for thousands of years. The temperature range of 10 to 27°C is most suitable to avoid frost (Ketema, 1997), Being a C4 plant, the crop responds well to warm temperatures and can be grown in areas experiencing moisture stress as well as in waterlogged areas (Balsamo *et al.,* 2005) as it has the ability to withstand anaerobic conditions better than many other cereals (Ketema, 1997).It is reported that Ethiopia, believed to be the center of origin of *tef*, maximum production occurs at altitudes between 1800 and 2100 m with growing season rainfall of 450-550 mm and a temperature range of 10 to 27 °C (Stallknecht *et al.*, 1993). The plant performs better at altitudes of 1700 to 2400m and in areas where the rainfall reaches an annual average of 1000mm during the growing period (Stallknecht *et al.,* 1993).

2.3.1.2. Climatic requirement *of durum wheat (Triticum durum)*

Wheat is an important crop in the highland of Ethiopia. Ethiopia wheat is a cool-weather grain crop that is commonly grown at elevations ranging from 1,500 to 3,200 meters above sea level. Overall, the highest wheat producing districts are principally located in three Oromia zones (West Arsi, Arsi, and Bale). This area, the "wheat belt" of Arsi-Bale zones, has nine of the top ten producing *districts* as well as 16 of the top 25. The crop is grown mostly during the main (*Kiremt*) rainy season from June to September and harvested from October through January. It is very sensitive to drought and it is recommended to avoid growing in dry areas. The most suitable areas for wheat production are those with an average annual rainfall of1200mm with 600mm well distributed during the growth period. For high yield water requirements are 450 to 650 mm depending on climate and length of growing period. The plant gives the best results in areas where an annual average rainfall of 1000 to 2000mm with 650 to 700mm well distributed during the main growth per period (Lomas *et al.,* 2000).

2.3.1.3. Climatic requirement of *maize (Zea mays)*

Maize is a member of the grass family (gramineace). It is an introduced crop to Ethiopia and it has been expanding widely in the recent years because of the very favorable conditions found in large areas of the country. Successfully, it can be grown in a wide range of altitude ranging from lowland areas below 1000m up to 1800m above sea level. And it can be grown preferably in areas where the annual rainfall reaches an average of 800mm equally distributed over the whole growing period (Funk *et al.,* 2012). A major conclusion of research findings in Ethiopia is that yield is generally influenced more by the date of sowing than any other factor. Sowing should take place the first two weeks of May or as early as possible at the onset of the main rainy season. In addition, the growth period is 4 to 5 months even if it depends on the variety planted and temperature. For maximum production a medium maturity grain crop requires between 500 and 800 mm of water (Funk *et al.,* 2012). Maize production has many climate and weather constraints. The crop is very sensitive to moisture stress at emergence, flowering and grain feeling stages. Hence to avoid coincidences of moisture stress at these critical stages need thoroughly analysis of most important climatic parameters such as onset, cessation, total amount and distribution of rainfall, probability of prevalence of prolonged dry spell and total length of growing period are among many very crucial climatic elements that influence production and should be considered to reduce risk.

2.3.1.4. Climatic requirement of haricot bean *(Phaseolus vulgaris)*

Haricot bean or the common bean is a highly variable species that has a long history of cultivation. The common bean is (also known as the string bean, field bean, flageolet bean, French bean, garden bean, green bean, haricot bean, pop bean, or snap bean).It is widely cultivated throughout different parts of Ethiopia. It is produced in four major agro ecological zones, including the central, eastern, southern and western zones (Mesfin *et al.*, 2014). In general, beans are grown in every continent except Antarctica (Kassie *et al.*, 2013).Haricot bean best grown under worm weather condition as it is worm season tropical crop. It is also tolerant to moisture stress to certain extent.

2.3.1.5. Climatic requirement of potato (*Solanum tuberosum* L.)

Despite potato is regarded as a high potential food security crop; its production in Ethiopia is much less than the average world potato production. Potato is sensitive to high temperature and moisture deficits. Temperature requirement for optimal tuber growth and potato yield ranges between 16 and 22°C.Higher temperatures favor foliar development and retard tuberization. Potato crop faced challenges from changing seasonal rainfall patterns. Potato is suited for areas having an altitude of 1600-2800m above mean sea level with rainfall 750-1000 mm.

2.3.1.6. Climatic requirement of onion (*Allium cepa*)

Though shallots are the traditional crop in Ethiopia, onions are becoming more widely grown in recent years. The best growing altitude for onions under Ethiopian condition is between 700 and 1800 m above mean sea level (Aklilu, 1997). Research for the past 20 years has been on variety development, cultural management, cost of production studies and different seed production techniques.

The crop can be grown under wide range of climate from temperate to tropical. They flourished in mild climate without extremes in temperature and excessive rainfall. For initial growth period, cool weather and adequate water is advantageous for proper establishment, whereas during ripening, warm dry weather is beneficial for high yield of good quality (Aklilu, 1997). The optimum mean daily temperature varies between 15 and 20°C.The length of the growing varies with climate but in general 130 to 175 days are required from sowing to harvest.

### 2.3.2. Impact of rainfall variability on six major crops yield

This study analyzed rainfall to determine the frequency of cycle and overall patterns as well as the responses of crops to such changing rainfall patterns. Most studies report a strong correlation between the El Nino phenomenon and rainfall patterns in Africa (Tsegay, 1998). El Nino, drought and famine occurrences show the incidence of drought as it correlates with the changing overall weather conditions that follow El Nino episodes in Ethiopia.

### 2.3.3. Impact of temperature variability on six major crops yield

Temperature affects the plant growth directly and indirectly almost all physiological processes of plant such as germinations photosynthesis, respiration, absorption, osmosis, etc. are influenced by air and soil temperature. For completing each development process in plant there is a certain level or limit of temperature in which the process of development continues. Plant growth occurs within the limit of maximum and minimum temperatures. Not all plants grow best in the same temperature range. Each plant community has its own minimum, optimum and maximum temperature known as their cardinal temperature. Like growth process development processes also have cardinal temperature, they are: Base or threshold temperature: at this temperature developmental process begins. Optimum temperature: development rate is highest at this temperature. Ceiling temperature: at this temperature development rate is minimum and beyond this temperature the process of development is ceased.

A maximum temperature is a temperature above which the plant growth stops. Since temperature is directly dependent on altitude, it is very important to take this factor into consideration, particularly during determining the length of the growing cycle of crops. High temperatures cause increased respiration sometimes above the rate of photosynthesis. This means that the products of photosynthesis are being used more rapidly than they are being produced. For growth to occur photosynthesis must be greater than respiration.

An optimum temperature is the one at which the maximum plant growth occurs. The threshold value or point at which appreciable growth can be detected is called base temperature. For cool season crops it ranges between 25 and 31$^{o}$C, while for warm season crops it ranges between 31 and 37$^{o}$C.

Temperature affects the productivity and growth of a plant depending upon whether the plant variety is a warm-season or cool-season crop.C4 cereals such as sorghum respond better to increased temperature than C3 plants. A remarkable aspect of vegetable production is that plants function within quite narrow temperature limits. The extreme temperature range is between the killing frost temperature of 0°C and death by heat and desiccation at 40°C. One of primary factors influence the phenology of the environmental year is growing degree-days (GDD). Growing degree day is total number of days with temperature optimum for growth of specific crop of a given thresholds of that crop. In other words it is total amount of heat required for entire cycle of growth of crops. Degree days are a measure of how many degrees above or below a mean the temperature has been over a period of time. In general, both precipitation and temperature determines length of crops cycle or crop calendar.

Overall, the sensitivity of crops to a temperature increase varies among cultivars because plants have adapted to a relative wide range of thermal environments.

In recent decades, the raising temperature is associated with increased spatial and temporal variability in amount and distribution of rainfall that exceeded the long term spatial and seasonal variability (Ayalew *et al.,* 2012; Taye *et al.*, 2013). The warming of a few degrees, decrease in rainfall and increase in frequency of extreme weathers, drought, will have an immediate and direct effect on the agricultural sector (Tagel and Van der Veen, 2013).A recent meta-analysis of fully fertilized maize experiments in southern and eastern Africa showed that an increase in the temperature during the growing season can lead to a significant decrease of 3% in maize grain production (Lobell *et al.,* 2011).

Growing degree day is total number of days with temperature optimum for growth of specific crop of a given thresholds of that crop. In other words, it is the total amount of heat required for entire cycle of growth of crops. Crop growth is influenced by temperature as every plant has its specific degree-days requirement. A degree-day or heat unit is the departure from the mean daily temperature above the minimum threshold temperature. The minimum threshold is the temperature below which no growth takes place. The threshold varies with different species of plants and for majority ranges from $4.5^0$C to $12.5^0$C.

The growing season of a given area can be affected by its relative distance from the equator, as well as elevation. Plants require a certain amount of warmth to begin growth. Unless stressed by other environmental factors like moisture, the development rate from emergence to maturity for many plants depends upon the daily air temperature. Since weather can be highly variable from season to season, calendar dates are often not good predictors of when a particular plant will leaf out, bloom or set fruit. The daily totals are accumulated for each month and the monthly totals are accumulated for the "heating year" from July through June help to develop monthly and annual average GDD's for many long term climate stations. Growing degrees (GDs) can also be defined as the number of temperature degrees above a certain threshold base temperature, which varies among crop species and stages of development of crops. The base temperature is that temperature below which plant growth is zero. Base temperature, also known as neither balance temperature, is that point at which neither heating nor cooling is required. The temperature of 10 °C is the most common base for GDD calculations; however, the optimal base is often determined experimentally based on the lifecycle of the plant in question. In most of Ethiopia rain fed agriculture concerning moisture; growing period in general extends from March to October to incorporate both seasons. Long-term average GDD's can be utilized for variety selection when used in conjunction with other climatic indices such as frost dates. The summation of daily GDD units can be used for a variety of things: comparing one region to another, comparing one season to another, and predicting important stages in development (bloom, veriason, and maturity, to present GDD information on a probability basis for all geographic regions. Cumulative GDD is a running total of GDD from start of season through cessation season. By developing rule of thumb measures and it is anticipated that knowledge of the mean GDD's above 5.5 $^{0}$C and 10$^{0}$C can be used to assess information at different probability levels and for different base temperatures. These will provide the minimal necessary information that will lead the user to a wealth of risk management Shoko (2006).

#### 2.3.4. Crop yield risk under different ENSO phases

A stochastic dominance criterion is a decision rule that provides a partial ordering of risky alternatives for decision makers, whose preferences conform to specified conditions about their utility functions (preferences for consequences). According to Anderson and Dillon (1992) Cumulative Density Functions (CDF) is likely to be the first and most understandable graph of the distribution, in which it is possible to compare the dynamic values of random variables for risk assessment. FSD analysis requires the pair wise comparison of all the pairs of distributions with the provision that once an alternative has been found to be dominated by another, then the dominated one can be dismissed from all further considerations (Hardaker *et al.,* 1998; Mamo, 2005).

### 2.4. Agro meteorological Advisory to Mitigate Climate Variability Impact on crops yield

Climate information is likely to have greatest value if communicated through advisors who farmer already know and trust. Any initiative must either work through existing institutions and advisory networks, or invest considerable time and effort to establish trust and credibility. Studies and observation shows that if agro meteorological advisory information wisely and properly used, the yield can increased by almost 10-25% in most of the crops with maximum increase in the fruit crops (Lomas *et al.,* 2000).Moreover, it help to use in put economically according to seasonal rainfall variability for instance the optimum application of nitrogen fertilizer on wheat for seasonal rainfall of 200mm is 100kg/ha at the sowing and rise to160kg/ha when seasonal rainfall is 500mm (Lomas *et al.,*2000).In general, application of knowledge of meteorology to agriculture is essential, since every aspect of agricultural activity depends on the weather. A farmer without the knowledge of the basic concepts of agro meteorology can never get the profitable yield neither can exploit optimum capacity of land in terms of production.

Unlike other studies, this paper singles out how susceptible the cropping pattern is to the amount of rainfall in the study area and also tries to see district differences in terms of patterns of rainfall and impacts of rainfall on yield. Ethiopia’s agriculture is highly rainfall dependant; given the pattern of rainfall and crop-specific need for the amount of rainfall, it is possible to minimize rainfall risk by changing the cropping pattern in the way pattern of rainfall dictates. It is true that the current cropping pattern is the result of weather condition that prevails in a particular region, but as the weather condition changes, the patterns of rainfall change, farmers may have difficulty in changing the cropping pattern dictated by earlier rainfall systems. Given the management skills, experience and investments of farmers on a given cropping pattern, there is resistance by the farmers to changes in cropping pattern. The existing system is based on farmers’ informal techniques, and when crop failures occur consecutively, farmers respond by abandoning that particular crop. Kates (2000) indicates that with a high level of adaptation to severe weather conditions, cereal production increases in some climate scenarios in developed countries. He further notes that despite the high level of adaptation in developed countries, losses were reduced but not eliminated.

# 3. MATERIALS AND METHODS

## 3.1. Description of the Study Area

### 3.1.1. Location

The study was conducted in the Siraro-Kofele Potato and Vegetable (SKV) livelihood zone, which consists of 4 administrative districts (Shashamene*Zuria*, Siraro, Shalla and Kofele). The study area, located at about 240 km south of Addis Ababa, is found in West Arsi zone of Oromia National Regional State of Ethiopia (Figure 1). Part of the MirabArsi Zone located in the Great Rift Valley, Shashamene*Zuria*, district partly found in Central Rift valley (CRV) of Ethiopia. Kofele is a high land completely found out of CRV to the south. The administrative center of Siraro district is Rope. Shalla was separated from Seraro district recently. The administrative centre of this district is Aje. Both Siraro and Shalla are totally found in CRV.

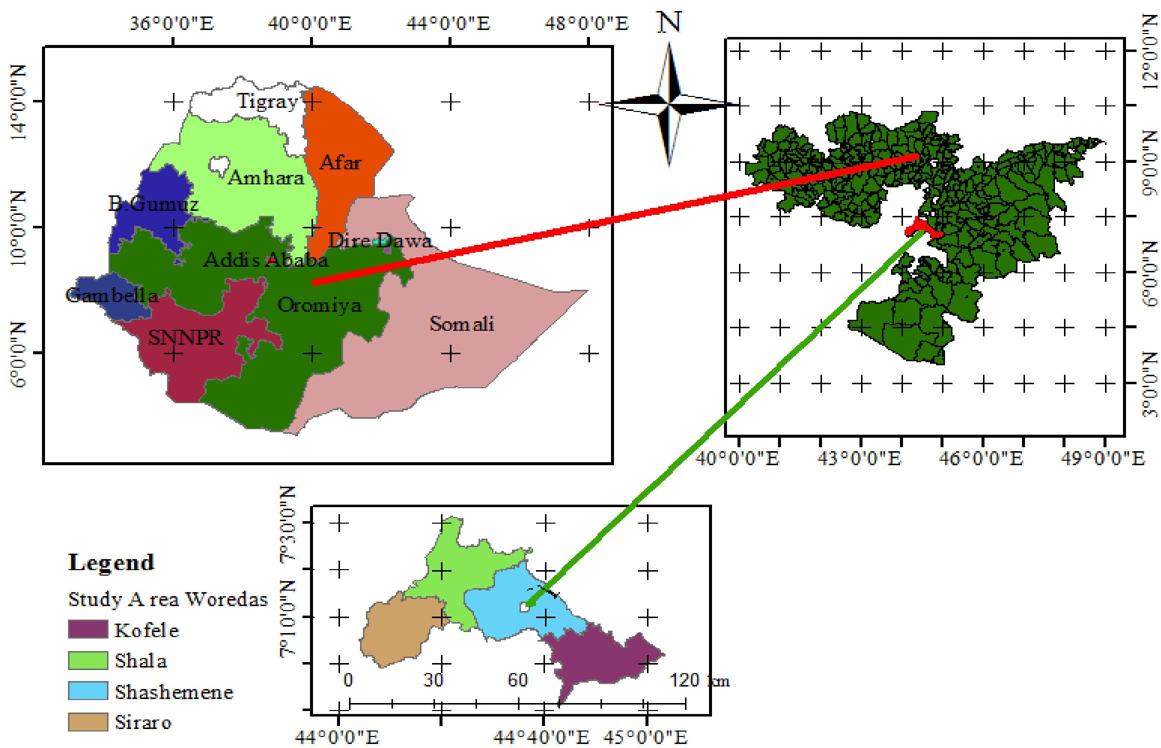


Figure 1. Map of Siraro - Kofele Potato - Vegetables production livelihood zone

Source: Haramaya University GIS Lab.

### 3.1.2. Climate and soil types

The topography is mostly plains but is undulating in some parts with altitude that ranges from 1500 to 3050 meters above mean sea level. Based on temperature, rainfall, altitude and vegetation, the study area covers three agro-ecological zones; low, mid and high land. The mean total annual precipitation varies from less than 600 mm to around 1400 mm. Total rainfall is broadly related to altitude and the mountains and escarpments exhibit strong orographic (landform) effects, with the highest rainfalls occurring on the high lands, and the lowest occurring in the trough containing Lake Shala. Rainfall is comparatively low and varies more in districts found in CRV than out of it.

The temperatures is moderate to hot and ranging from 12 to 25 $^{0}$C. The mean annual temperature of the zone is between 20 to 25°C in the lowlands and 10 to 15°C in the central highlands. However, there is a slight variation of temperature by months. February to May is the hottest months while October to January is the coldest months. The coldest month is October, while the hottest is May. The soil of the study area is lightweight, friable loam and clay loam. The loamy soil is highly fertile. Sandy soil is more common in the Shashemene and Siraro as reported by International Livestock Research Institute (ILRI, 2007).This type is with high sand content, low water holding capacity, and low inherent fertility. The three main, traditional Ethiopian ecological/altitude divisions: the relatively hot and dry agricultural lowlands below some 1500 meters above sea level (m.a.s.).; the temperate middle highlands and dry agricultural lowlands below some 1500 (m.a.s.).; the temperate middle highlands between about 1500 and 2300 m.a.s., often subdivided into 'dry', up to about 1900 m.a.s., and 'wet' from 1900 to 2300 m.a.s.; and then upwards of 2300 the highlands which tend also to have the highest precipitation in addition to cool temperatures. According to this classification, Siraro and Shala are dry land, Shashamene is middle high land and Kofele is high lands.

### 3.1.3. Agriculture and vegetation cover

The major economic activity is vegetable and crop production. Agricultural production is entirely rain fed. Its fertility and sufficient amounts of rain are factors contributing to the surplus production in the area. Thorn scrub, olive, and acacia are some of the common vegetation covering the zone. Some forests; including Arsi State forest, are found in

Shashemene and Kofele districts. The monthly distribution of rainfall is bimodal with the main *Kiremt* rains falling from June to September. Maize, potatoes, wheat, *tef,* millet and haricot bean and onion are among major crops grown both for consumption and sale. In Siraro and Shala maize, haricot bean and *tef* were dominantly grown. Potato is also grown in these districts. Kofele is dominantly grown wheat and potato but maize and *tef* also grown in significant amount. Shashamene district can be said home of all six crops. Onion is dominantly grown in this district.

Maize is the long cycle crop planted from February to May. The harvesting period for maize is in July and October. Green maize is consumed in May and August. Potato and haricot bean are harvested two times a year. Potatoes are harvested in May and November whereas haricot bean are harvested in July and October. Stalk borer is a crop pest affecting maize and haricot bean while rust affects potato and wheat production. The agricultural activities that require more labor are land preparation, weeding, and harvesting.

## 3.2. Data Source

### 3.2.1. Observed daily rainfall data

A long-term observed daily rainfall data were collected from meteorological stations located in districts of the study livelihood zone from archives of the National Meteorological Agency at Addis Ababa. Based on data availability, quality and relative length of time, three stations were selected for this study with a reasonably good geographic distribution in the study area. As the stations found in the study area are few and have missed data, two additional stations, Awassa and Arsi Negele data, were used for data gap filling for better quality of data. The rainfall data used in this study consist of daily, monthly and annual rainfall for the period 1983 to 2015. Station histories are unknown and it’s likely that they have endured changes due to station relocation and changes in instrumentation. As a result, all records were examined for discontinuities, outliers and compared with records from nearby stations.

Table 1. Geographical information of Aje, Shashamene and Kofele meteorological stations

| Meteorologcal stations | Longitude(E) | Latitude(N) | Altitude(m) | Years of observation | No. of years with missed data |
|---|---|---|---|---|---|
| Aje | 7.29066 | 38.352 | 1846 | 1983-20015 | 3.5 |
| Kofele | 7.07 | 38.80 | 2620 | 1988-20015 | 3 |
| Shashemene | 7.2002 | 38.6 | 1927 | 1983-20015 | 2 |

Prior to analysis, daily rain gauge data, and air temperature in data base starting from 1983 to 2015 were carefully inspected for their quality and completeness. Missed data were filled by normal ratio method. In region where the annual average rainfall differs considerable between locations the normal –ratio method is preferred in missed rainfall data gap filling (University of Babylon, 2011). Before filling missed data, the data of each station was correlated with each other and data of nearby stations was found to be correlated by-more than 90%.The selection of rainfall stations considered representative to agro ecological zones, and the percentage of missing data where-less than 10% for a given year is required literarily be filled-by WMO standard.

**3.2.2. Crop yield, weather or climate indices and soil data**

Data were gathered from Central Statistical Agency (CSA), national and regional agricultural offices. Southern Oscillation Index (SOI) and Sea Surface Temperature (SST) were downloaded from National Oceanic and Atmospheric Administration (NOAA) website. Selected crops' yield was regressed to total annual and seasonal rainfall to see the extent of impact of rainfall on crop production.

## 3.3. Methods of Data Analysis

Analysis of rainfall data involved characterizing long-term mean values and variability at different temporal scales. The coefficient of variation (CV) and the precipitation concentration index (PCI) were used as statistical descriptors of rainfall variability. In order to study monthly seasonal and annual variability of rainfall in the study area, CV was calculated as the ratio of standard deviation to the mean (NMSA, 1996).

INSTAT software version +3.37, R-statistical package and Excel 2010 were used in data analysis. During data analysis mainly descriptive statistics including minimum, maximum, percentage, mean, standard deviation, coefficient of variation and frequency were used in the process of identifying and describing the analysis of the following parameters: rainfall and temperature variability at different time scale; monthly, seasonal and annual variations in rainfall amounts, start and cessation of the growing season, number of rainy days, dry spell, growing season analysis and characteristics of droughts and heat requirement as well as maximum, minimum temperature and extremes variability in the study area. In general , growing degree days (GDD) for cycle of growth of major crops and vegetables were carried out. Finally, correlation and regression of temperature and rainfall variability with crop yield were done to see strength of relationship. At last, characterization and agro-meteorological advisory were organized.

## 3.4. Analysis of Climatic Parameters

### 3.4.1. Analysis of temporal rainfall amount

In analysis of rainfall amount, Excel 2010 was used to calculate rainfall amount on monthly, seasonal and annual bases.

### 3.4.2. Inter-seasonal rainfall variability analysis

Inter-annual variability was evaluated using standardized anomalies for rainfall with respect to the long term normal conditions for a specific time scale. Inter-annual variability was evaluated using standardized anomalies for rainfall with respect to the long term normal conditions for a specific time scale. The standard deviation weighs the extreme events more strongly than the average deviation Agnew and Chappel (1999). The coefficient of variation of seasonal rainfall variability was analyzed by Eq.1:

$$CV=\left(\frac{SD}{\overline{X}}\right)*100 \qquad (1)$$

Where SD is standard deviation and $\overline{X}$ is long year mean and N is total number of years of observation and SD is standard deviation. When *CV* < 20% it is less variable, *CV* from 20% to 30% is moderately variable, and *CV* > 30% is highly variable. Areas with *CV* > 30% are said to be vulnerable to drought. The coefficient of variation and the PCI were used as statistical descriptors of rainfall variability. The PCI values (Eq.2) were calculated as given by the method described by Oliver (1980):

$$PCI = 100*[\Sigma Pi^2/(\Sigma Pi)^2] \qquad (2)$$

Where *Pi* is the rainfall amount of the $i^{th}$ month; and $\Sigma$ = summation over the 12 months.

Wide-range of statistical analysis was made in order to discuss about precipitation concentration indices and classification, it needs to know about it clearly. Uniformity of precipitation is indicated by a low index while increasingly seasonal distributions show higher value (Oliver, 1980).According to Oliver's classification: PCI < 10 indicates uniform precipitation distribution (low precipitation concentration), PCI >11 and <15 indicates moderate precipitation concentration, PCI >16 and < 20 indicates irregular distribution, PCI > 20 indicates a strong irregularity (i.e., high precipitation concentration).

Standardized anomalies (Eq.3) of rainfall were calculated and used to assess frequency and severity of droughts as in Agnew and Chappel (1999):

$$S=\frac{[P_t-P_m]}{\sigma} \qquad (3)$$

Where, S = standardized rainfall anomaly.

$P_t$= annual rainfall in year t.

$P_m$= long-term mean annual rainfall, over a given period of observation.

$\sigma$ = standard deviation of rainfall over the period of observation.

The monthly rainfall series (Eq.4) of all the stations were used to calculate an area average rainfall for livelihood zone as follows:

$$Rj = Ij^{-1} \Sigma Xij \quad (4)$$

Where *Rj* is areally integrated rainfall for year *j*; *Xij* is rainfall at station *i* for year *j* and *Ij* is the number of stations available for year *j*. Variability and trend in the area rainfall was also examined using the same methods.

It is important to note here that consideration of production of cereals will be more appropriate than yield in investigating the influence of rainfall variability, because the latter can miss out impacts of extreme climatic conditions involving severe droughts that might lead to abandonment of planted areas prior to harvest. In other words, total production aggregates impacts of climate on both production and yields and harvested areas and thus has greater economic relevance than yield. Further, amount and temporal distribution of rainfall also has influence on area cultivated in a given year. Although production is more preferable than yield to correlate with rainfall, for the reason of high expansions of area of production and fluctuation from year to year for reason other than rainfall, yield per hectare was correlated with rainfall in this study. Thus, correlation and regression were used to examine relationships between main seasonal rainfall and six main crops yield. The patterns of inter-annual rainfall variability and fluctuations in cereal yield were presented graphically to gain a better insight into rainfall-crop production relationships in the livelihood zone.

### 3.4.3. Determining mean onset, cessation of rainy season and length of growing season

There are several methods of computing onset, cessation and duration of the rain. In this study, the onset of season was defined as any day after March first in which the rainfall amount for three consecutive days is larger than 20 mm and there is no dry spell greater than 10 days within the following first 30 days after onset. The threshold value used for defining rainy day is 1mm. This is because of high evapotranspiration in the study area where rainfall less than this threshold is believed to be not satisfying crop water requirement. This definition was also used in INSTAT software version +3.37 for data analyses. Initial soil water content assumed at field capacity (100 mm). The cessation can also be defined as the first date on which soil water is depleted or become zero. Thesis definition was used for determining cessation. Length of growing period (LGP) can be defined the difference between start of the SOS and EOS calculated using INSTAT software version +3.37. For *Kiremt* season onset rain was Defined by (Segele and Lamb,2005) rainfall total of 20 mm or more in consecutive 3 days or more with no dry spell length of 10 days or more in the next 30 days should occur with an earliest starting day first of June.

### 3.4.4. Analysis of seasonal number of rainy and dry days

This implies that contribution of very small amount of rainfall to effective rainfall or to agriculture is insignificant. For these reasons; threshold value of 1mm was deliberately selected to determine number of rainy days in this study.

### 3.4.5. Drought and dry spell analysis

In this study as suggested by Edwards and McKee (1997) using 3-month and 4-month and 12-month accumulated precipitation for *Belg*, *Kiremt* and annual used in analysis of the SPI drought index respectively. For this study, due to the high value of evapotrnspiration in the livelihood zone which reduces effectiveness of rainfall, a value of 1mm of rainfall was used to determine dry spells. The probability of dry spells longer than 5, 7, 10, 15, and 20 days were analyzed thoroughly using the Markova's-chain formula in INSTAT version +3.37 software package.

SPI (Eq.5) values were classified into seven categories (Hayes *et al.*, 2000):

$$SPI = \frac{X_i - \overline{X}}{SD} \qquad (5)$$

$$Z = \frac{X_i - \overline{X}}{S}$$

Where, Xi is the observed precipitation value, and X and S are the mean and standard deviation, respectively, over a defined period. Z is the number of standard deviations that the observation is from the normal, assuming that the observations are normally distributed. This is to indicate some important SPI.

# 3.5. Spatial Rainfall Variability Analysis

The spatial variability of monthly rainfall is expressed with the CV using total monthly rainfall data. Also, total annual rainfall amounts for each locality are recorded and the average annual rainfall was calculated and determined. How each location's annual rainfall varies from each other was determined by using the CV.

## 3.6. Temporal and Spatial Temperature Variability Analyses

Seasonal, annual and monthly maximum, minimum and mean temperatures were computed from daily data. Finally, patterns temperature determined by means of graphs.

First of all average daily temperature was calculated from daily maximum and minimum temperature. The annual temperature for each locality was used to calculate average temperature. Then monthly mean temperature and finally annual mean temperature were analyzed. To determine how each rainfall location's annual temperature varies from each other, CV was used. The spatial variability of monthly temperature was expressed with the CV using total monthly temperature data. A large CV value indicates that the total annual temperature across the location is highly variable.

## 3.7. Characterization of Climate Variability

### 3.7.1. Characterization of rainfall variability

First, to characterize the spatial patterns of the length of growing period parameters, for seasonal start of growing season, and cessation of growing season and length of growing season .Then, examine temporal variations in the length of growing season parameters over the SKV livelihood zone. To assess changes in the timing of the observed length of growing period parameters, anomalies in the start, cessation, and length of the growing season of was carried out. Then, anomalies were classified the growing season onset, end, and length into two categories: years with advances and/or increases in the growing seasons and years with delays and/or decreases in the growing seasons.

### 3.7.2. Characterization of onset, cessation and length of growing season

Anomalies were used to characterize onset, cessation and length of growing season.

### 3.7.3. Characterization of number of rainy days variability of the season

Anomalies were used to characterize number of rainy days variability of the season.

### 3.7.4. Droughts and dry-spell characterization

The SPI is a statistical measure indicating how unusual an event is, making it possible to determine how often droughts of certain strength are likely to occur. SPIs may also be compared directly between different locations. However, the practical implication of an SPI-defined drought, the deviation from the normal amount of precipitation, was varying from one place to another. The percentage of the normal amount of precipitation also calculated for periods of SPI-defined drought. All drought measures were calculated based on accumulated precipitation at *Belg, Kiremt* and annual levels. In this study drought at time scales of 3-month, 4-month and 12 month were considered. Indices for May and September were used to describe the *Belg* and summer *Kiremt* seasons, respectively.

### 3.7.5. Characterization of temperature variability

The temperature indices were used for characterization of the annual minimum and maximum temperature mean annual temperature, minima and maxima of daily minimum and maximum temperature, and number of days with daily maximum temperature exceeding 35°C (summer day).In a flexible system of farming, a key decision making affecting crop water utilization and crop yield are need to modify each season in response to pre-season and early season predictions of season rainfall parameters. Finally, Agro meteorological advisory was developed for crops studied. Characterization of annual minimum and maximum temperature, mean annual minima and maxima based on analysis of daily minimum and maximum temperature and determine number of days with daily maximum temperature exceeding $35C^0$ (summer days if any) during study period.

## 3.8. Impact of Climate Variability on Six Major Crops Yield

### 3.8.1. Impact of rainfall variability on six major crops yield

3.8.1.1. Analysis of six major crops yield under and different ENSO phases

In this study, zonal crops data available for (1995 to 2014) was used for data analysis. Crop yield was measured for each crop in quintal per hectare (Qt/ha) and was converted into *Z*-scores-a normal distribution to help compare different scores from different distributions. Positive score shows data is above the mean, while negative score shows data is below the mean. In general, Z-score help to identify the extent of impact of climate variable on crop yield. CV to further analyses the variations of crops yield in response to the climate variables was also considered. CV is a ratio of SD to the mean of the crop yield time series. The yield was established as the ratio of total production to the harvested area. The classic regression approach was used to establish the relationship between the crop yield and one or more independent parameters related to climate/weather parameters. Regression equations of the form $Y = a + bX + e$, where $Y$ = the dependent variable; $a$ = intercept on y-axis; $b$ = partial regression coefficient of the independent variables; X = the independent variable; $e$ = the random error term representing the proportion of unexplained variation were used.

3.8.1.2. Crop yield risk analysis under variable climate and different ENSO phases

The first degree stochastic dominance (FSD) and second degree stochastic dominance (SSD) is a method used to analyze CDFs. Crops yield and associated rainfall values for zonal level were incorporated into a simple tool. This tool contains applications that allow a user to examine the rainfall forecast for individual Zone based on the ENSO phase and to evaluate crops yield risk analysis. This study considered SD analysis of six major crops; *tef*, wheat, maize, haricot bean, vegetables such as onion and potato with different ENSO Phases; El Nino, La Nino and normal phenomena was analyzed for risk management and to answer which phase has better yield performance for which crop type. Stochastic dominance rules assume that farmers must decide whether to invest crop production in La Nino ,f, or an alternative El Nino events ,g, and normal condition ,h, with cumulative density functions given by F(x),G(x) and H(x) respectively. For instance La Nino year crop yield dominates the El Nino year crop yield alternatively by first-order stochastic dominance (Mc Carl, 1996).

(FSD) if and only if $G(x) - F(x) \geq 0 \ \forall x \ \varepsilon \ R$ (6)

And the cumulative density function can be calculated

$$F(X), G(X), H(X) = \int_0^X F(X, \mu, \delta) dx, F(X, \mu, \delta) = \frac{1}{\sqrt{2\pi\delta^2}} \exp \frac{(x-\mu)2}{2\delta^2} \quad (7)$$

Where F(x), G(x) and H(x) are crop yield cumulative density functions or zonal seasonal rainfall given during La Nina, El Nino events and Normal phase respectively. Given 'X' represent crop yield in quintal per hector during crop yield risk analysis and *Kiremt* Seasonal zonal rainfall in mm while analyzing zonal rainfall risk.

### 3.8.2. Impact of temperature variability on six major crops yield and heat requirement

3.8.2.1. Analysis impact of temperature variability on major six crops yield

Analysis of impact of annual mean maximum, annual mean minimum and annual mean temperature

3.8.2.2. Analysis of impact of temperature variability on crops heat requirement

Seasonal and monthly variability of temperature and inter annual variability of the onset and cessation of the seasons have negative impact on the proper sowing and phenology of crops. This condition in turn affects LGP of crops which may lead to moisture stress at end of season. Temperature also determines length of growing period under unlimited moisture status.

$$T_{mean} = \frac{T_{max} + T_{min}}{2} \quad (8)$$

Heat unit (degree days) was estimated using the following equation (Source of the equation):

$$DD = \sum_{i=1}^{d} T_{mean} - T_{base} \quad (9)$$

# 4. RESULTS AND DISCUSSION

First, the variability in terms of seasonal rainfall amount, on monthly, seasonal and annual, bases, anomalies on annual and seasonal time scale, onset, cessation, length of growing period of crops, number of rainy days were discussed thoroughly. Second, characterization above parameters, drought and dry spell and temperature were made. Then, impact of rainfall and temperature on crops yield were discussed. Finally, agro meteorological advisory were prepared at according to given seasonal forecast.

## 4.1. Observed Rainfall Amount Variability at Different time Scales

In response to determine rainfall variability, the analysis was made for annual, *Belg* and *Kiremt* rainfall. Variability of seasonal rainfall in Aje, Shashemene and Kofele stations in terms of annual, seasonal, monthly amount, onset, cessation, length of growing period of crops, number of rainy days, drought, dry spell of different length and anomalies, variability in maximum and minimum temperature, were analyzed thoroughly. Seasonal and annual variations of rainfall have been discussed and characterized for the three rain gauge stations located in Siraro-Kofele Potato- Vegetables livelihood zone.

### 4.1.1. Observed annual rainfall amount variability

This study indicated that the calculated annual PCI values varied from 6, to 16% in Kofele and Aje, which shows uniform and irregular distribution, respectively. The PCI value of 14% of Shashemene exhibited moderate distribution of rain. Precipitation concentration index (PCI) exhibits less to high monthly concentration. Higher values are observed in the low lands Aje (Siraro and Shalla), while lower values are evident further over the high lands (Kofele).

The rainfall also shows less to very high inter annual variability as shown by the coefficients of variations (Table 2). Similar to results of this study, Engida (1999), after analyzing rainfall data obtained from 419 stations in the country, also indicated that *Belg* and *Bega* rainfalls are more variable than *Kiremt* rainfall. Engida (1999) also reported that rainfall variability is higher in areas of low annual rainfall. The extreme concentration of rainfall can also be seen from the contribution of the single largest monthly total to annual total rainfall at each of the

Table 2. Descriptive statistics of observed annual rainfall totals at Aje, Shashamene and Kofele (1983-2015)

| Station | Statistics | | | | | |
|---|---|---|---|---|---|---|
| | Max (mm) | Min (mm) | Mean (mm) | SD (mm) | CV (%) | Range (mm) |
| Aje | 1165.4 | 115.2 | 636.7 | 199.9 | 31.4 | 1050.2 |
| Kofele | 1807.9 | 844.7 | 1223.8 | 226.3 | 18.5 | 963.2 |
| Shashamene | 1197.7 | 292.8 | 746.8 | 252.9 | 33.9 | 904.9 |

Previous studies confirmed the idea that the precipitation CI values are noticeably larger in places where both annual total precipitation and number of rainy days are lower (Oliver, 1980). In general, the calculated PCI showed that rainfall in the SKV livelihood zone is generally characterized by less to high monthly concentration. The rainfall also shows less to very high inter annual variability as shown by the coefficients of variations (Table 3). Generally, the *Belg* (small rainy season, March-May) and the *Bega* (dry season, October-February) rainfalls were much more variable than the *Kiremt* (main rainy season, June-September). Similar to results of this study, Engida (1999), after analyzing rainfall data obtained from 419 stations in the country, also that *Belg* and *Bega* rainfalls are more variable than *Kiremt* rainfall. In related study by Tesfaye (2003) also mentioned that, on an average the south-western part of the country gets the highest mean annual rainfall (1581.7 mm) with CV of 7.8% while the northern part receives the minimum mean annual rainfall (562.9 mm) with very high CV of up to 63%.

Table 3. Annual and seasonal mean rainfall (mm), coefficient of variation and PCI of Aje, Shashamene and Kofele (1983-2015)

| Station | Annual | | *Kiremt* | | *Belg* | | *Bega* | | PCI |
|---|---|---|---|---|---|---|---|---|---|
| | Mean (mm) | CV (%) | Mean (mm) | CV (%) | Mean (mm) | CV (%) | Mean (mm) | CV (%) | |
| Aje | 636.7 | 31.4 | 317.0 | 36.9 | 282.6 | 46.7 | 82.9 | 72.9 | 16.0 |
| Kofele | 1223.8 | 18.5 | 559.6 | 18.3 | 414.1 | 23.7 | 244.9 | 53.7 | 6.0 |
| Shashemene | 746.6 | 33.9 | 346.4 | 34.2 | 262.2 | 47.7 | 138.0 | 64.7 | 14.0 |

This study identified that rainfall in livelihood zone is bimodal in pattern and the relative contribution of main season (*Kiremt)* and *short* rainy season (*Belg)* to annual total rainfall were; varied from 46% to 49% and 34% to 38 % respectively (Table 4). This implies that contribution for annual total crop production of the two seasons is proportional. Therefore, any sort of change in the more variable short rainy season (SRS) pattern frequently affects the livelihood of the farming community nearly equally in magnitude as changes in main season. According to this study SRS is only three months (MAM) Therefore; long dry season(*Bega)* according to this study can be defined *as* October to February but normally according NMA (October to January). This classification was made because of *Belg* rain rarely occurred recent time. However, this new categorization of *Bega* made considerable contribution ranging from13%to 20% to the annual total in SKV livelihood zone. A comparable study result of main (*Kiremt*) rain season contribution to the annual rainfall totals was reported by Ayalew *et al.* (2012). Gashaw (2009) also reported that *Kiremt* season contributes 60% to total annual rainfall at Ziway, having maximum of 146.2mm (July). Monthly distribution shows that driest and wettest months at Aje November and July, while the corresponding months for Kofele and Shashemen December and August, and January and September, respectively (Table4).

Table 4. Average monthly and the highest monthly rainfall contribution to the annual total (in percent) and PCI at Aje, Shashamene and Kofele (1983- 2015)

| Station | *Kiremt* | *Belg* | *Bega* | Highest monthly rainfall | PCI (%) |
|---|---|---|---|---|---|
| Aje | 49 | 38 | 13 | 14 | 16 |
| Kofele | 46 | 34 | 20 | 13 | 6 |
| Shashemene | 46 | 35 | 19 | 14 | 14 |

Table5.Average monthly rainfall in mm at Aje, Shashamene and Kofele (1983- 2015)

| | Monthly mean rainfall in (mm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
| Aje | 16.9 | 30.1 | 74.4 | 82.0 | 81.2 | 57.2 | 89.7 | 86.7 | 75.3 | 24.3 | 2.8 | 9.8 |
| Kofele | 38.7 | 45.1 | 126.3 | 147.6 | 140.1 | 116.1 | 127.3 | 160.3 | 155.9 | 92.1 | 39.5 | 34.8 |
| Shashemene | 15.0 | 26.1 | 59.4 | 101.9 | 100.9 | 64.3 | 92.7 | 85.4 | 104.1 | 63.7 | 17.8 | 15.4 |

Table 6.Monthly rainfall contribution in (%) to total annual rainfall at Aje, Shashamene and Kofele (1983-2015)

| Station | Monthly contribution (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
| Aje | 2.5 | 4.8 | 11.6 | 13.1 | 13.1 | 9.4 | 14.7 | 14.2 | 12.3 | 4.0 | 0.4 | 1.5 |
| Kofele | 3.2 | 3.7 | 10.3 | 12.1 | 11.5 | 9.5 | 10.4 | 13.1 | 12.7 | 7.5 | 3.2 | 2.8 |
| Shashemene | 2.0 | 3.5 | 8.0 | 13.6 | 13.5 | 8.6 | 12.4 | 11.4 | 13.9 | 8.5 | 2.4 | 2.1 |

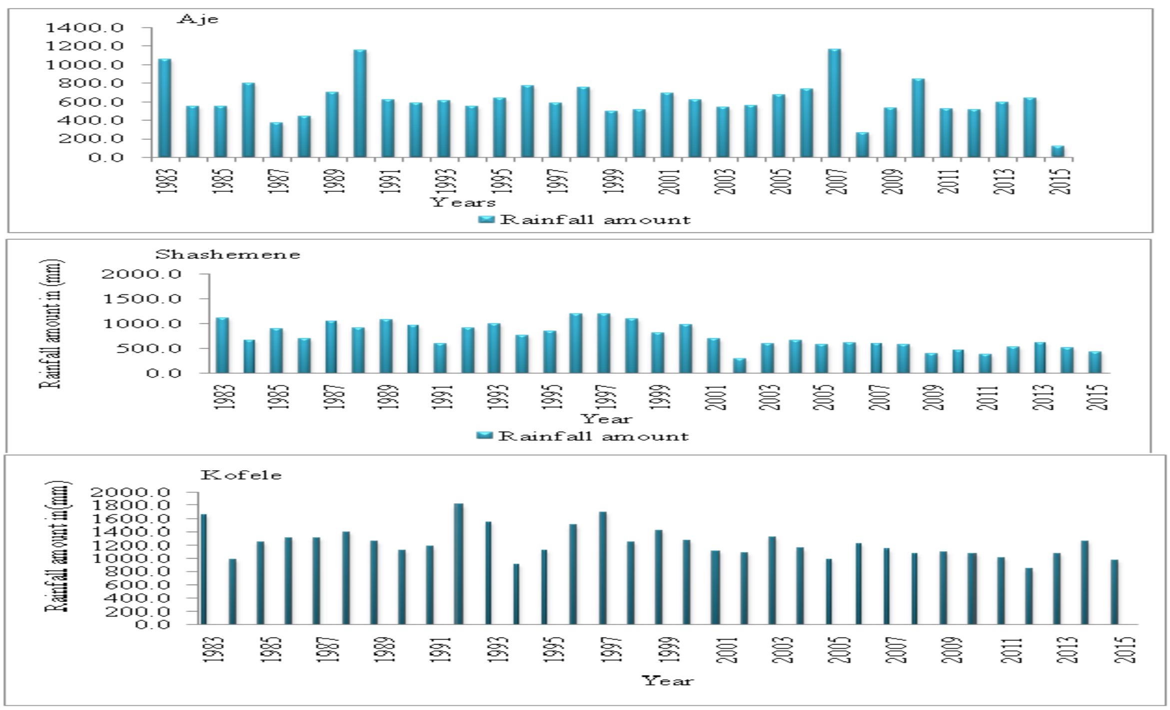


Figure 2.Annual rainfall total of Aje, Shashemene and Kofele (1983-2015)

### 4.1.2. Observed Seasonal and monthly rainfall amount variability

Minimum monthly mean rainfall was recorded at month of starting of rainy season. The contribution of monthly rainfall to the respective *Belg* total rainfall varied from 23 to 39% for all the three stations (Table7). This mean value indicated evenly distribution of monthly rainfall compared with actual value of rainfall each year. The actual value of rainfall highly varies from year to year. In all the three stations monthly distribution was uniform except Shashemene at the start of the season during March received nearly half of April and May month each. On the average the wettest months were April and May for Aje and Shashemene and April for Kofele respectively.

Table7. Monthly rainfall and contribution in % to total *Belg* rainfall in mm at Aje, Shashamene and Kofele (1983-2015)

| Station | Monthly rainfall (mm) | | | Monthly contribution (%) to total *Kiremt* rain from the month of | | |
|---|---|---|---|---|---|---|
| | March | April | May | March | April | May |
| Aje | 72.5 | 82.0 | 82.1 | 30.6 | 34.7 | 34.7 |
| Kofele | 126.3 | 147.6 | 140.1 | 30.5 | 35.6 | 33.8 |
| Shashemene | 59.4 | 101.9 | 100.9 | 22.6 | 38.9 | 38.5 |

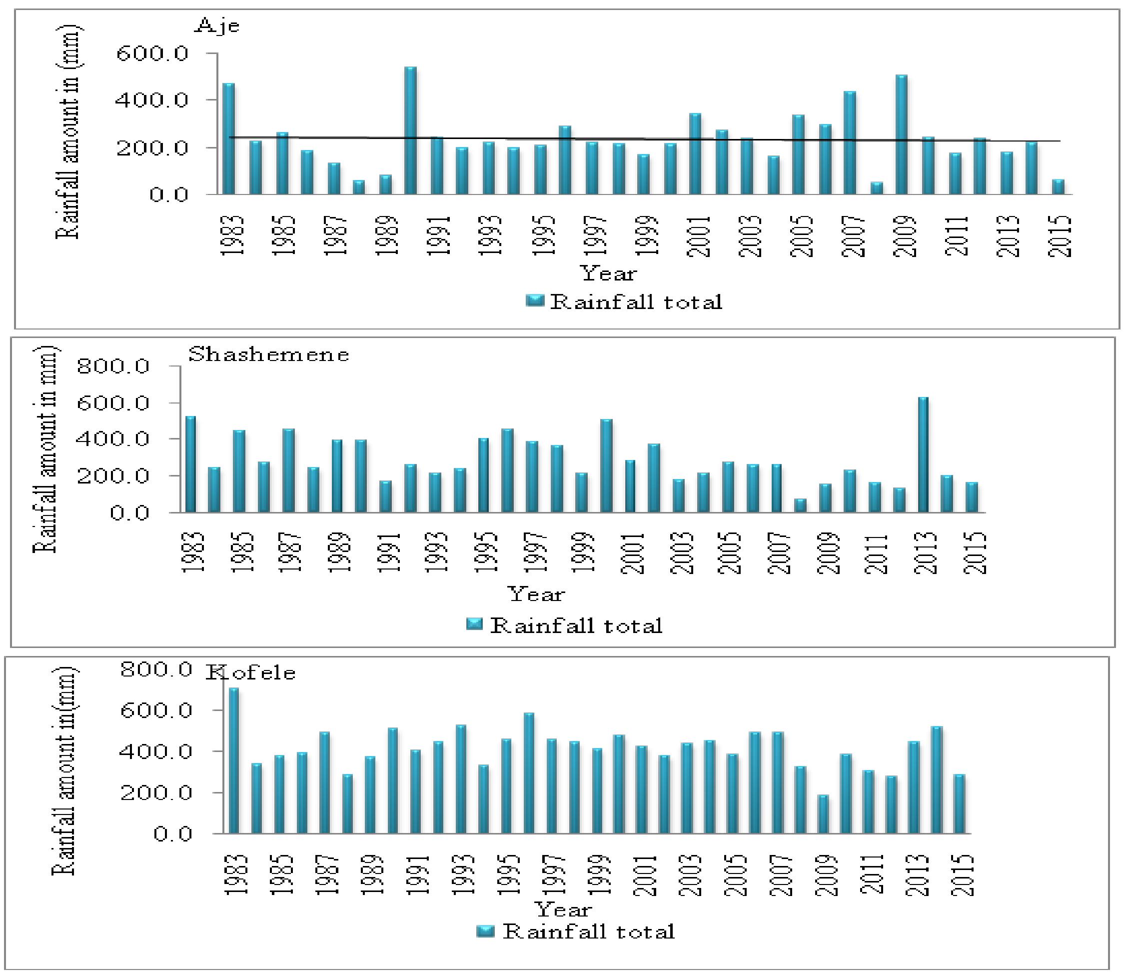


Figure 3 *Belg* rainfall total in mm at Aje, Shashemene and Kofele (1983-2015)

Table 8.Monthly means rainfall and contribution (%) to total *Kiremt* season rainfall in mm

| Station | Monthly rainfall (mm) | | | | Monthly contribution (%) to total *Kiremt* rain from the month of | | | |
|---|---|---|---|---|---|---|---|---|
| | June | July | August | September | June | July | August | September |
| Aje | 57.2 | 89.7 | 86.7 | 75.3 | 19.1 | 29.9 | 28.9 | 24.9 |
| Kofele | 116.1 | 127.3 | 160.3 | 155.9 | 20.7 | 22.7 | 28.6 | 27.9 |
| Shashemene | 64.3 | 92.7 | 85.4 | 104.1 | 18.6 | 26.8 | 24.7 | 30.0 |

Knowledge of monthly distribution of rainfall is important because it tells how much water is available for the biomass in rain-fed agriculture. The wettest months at Aje, Kofele and Shashemene are July, August and September respectively. The monthly distribution of rainfall for main (*Kiremt*) was from June to September. The three stations received monthly mean minimum during June. The percent monthly distribution was uniform for all months except that slightly lower during June. But this is not true when we consider each season during the last 3 decade.

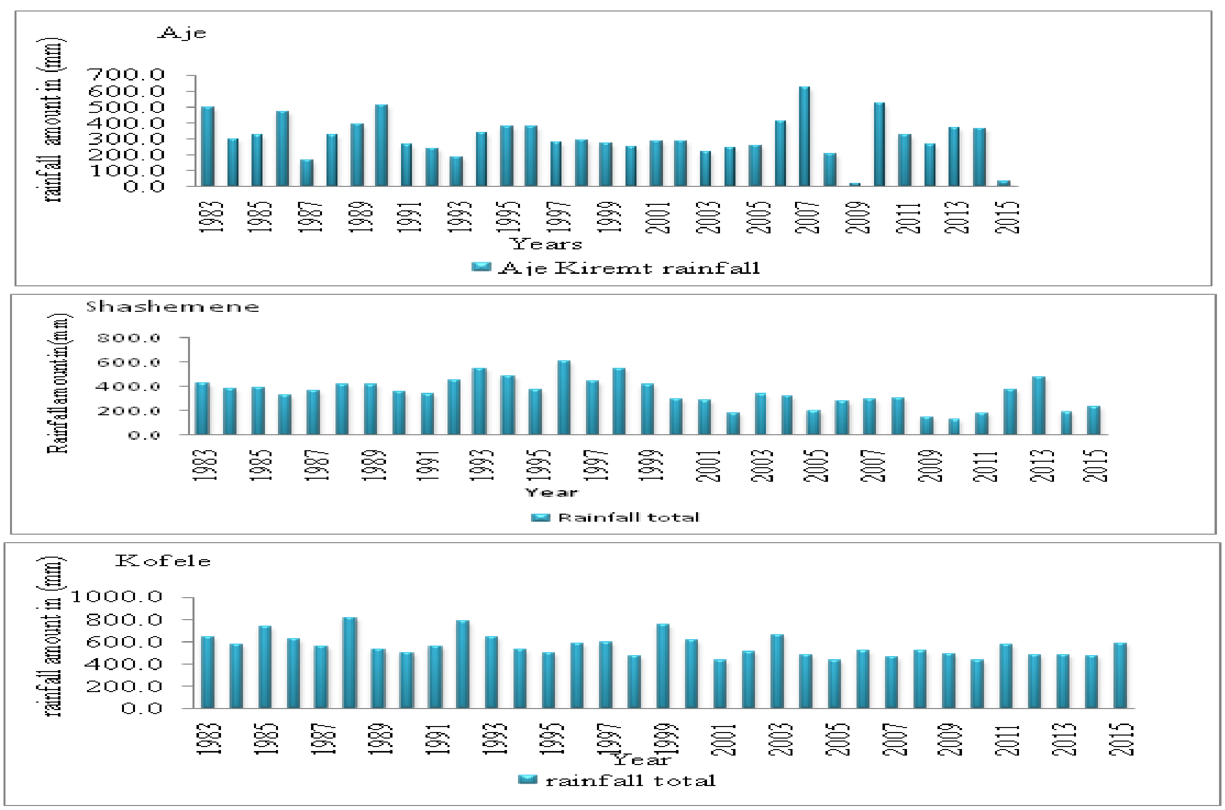


Figure 4.*Kiremt* total rainfall in mm at Aje, Shashamene and Kofele (1983-2015)

## 4.2. Inter-Season Rainfall Variability and Correlation SOI and SST

### 4.2.1. Annual rainfall anomaly

The annual rainfall anomaly showed negative and positive anomalies ranging from 52 % to 61% and 39% to 48% respectively during the last 33 observation years. This indicates that they were experiencing an amount lower and greater than the long term mean at all the three stations respectively. This value indicated that probability of dry and wet years were nearly half to almost once every two years. Drought analysis, showed that at Aje station years 1987, 2008 and 2015 were moderately, severely and extremely dry while years; 1983, 1990, 2007and 2010 were moderately to extremely wet respectively. At Shashemene station years 2002, 2009, 2010, 2011 and 2015 were moderately to very dry. On the other hand years,1983, 1987, 1989, 1993, 1996, 1997 and 1998 were moderately to extremely wet. At Kofele years 1984,1994,2005,2011, 2012, 2014 and 2015 were moderately to severely dry. Contrary to this, years 1983, 1992, 1993, 1996 and 1997 were moderately to extremely wet years. In all the three stations year 2015 was the driest in the last 33 years. Thus, in the studied livelihood zone years; 1984, 1987, 1991, 1992, 1993, 1997, 2005, 2008, 2009, 2012, 2015 at Aje, years, 1984, 1986, 1991, 2001, 2015 at Shashemene and years 1984, 1990, 1991, 1994, 1995 and 2001-2015 except 2003 at Kofele were characterized by annual rainfall below the mean of the study period (Figure.5) and could be classified as moderate to severe drought years. Although the three stations are not very far from each other, the drought severity highly varies from year to year over the three stations.

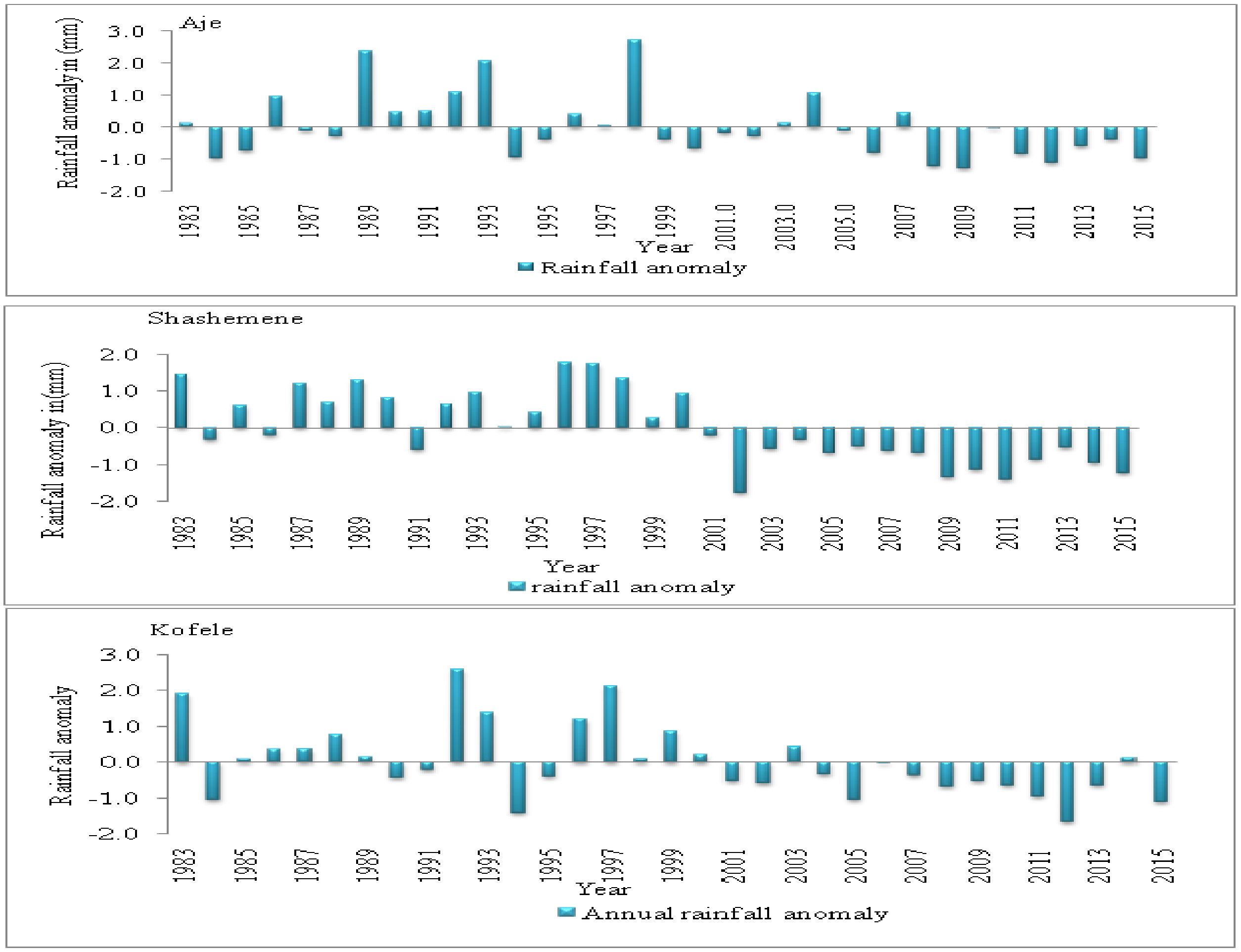


Figure5.Annual rainfall anomalies in mm at Aje, Kofele and Shashemene (1983-2015)

### 4.2.2. Seasonal rainfall anomaly

In this study both *Belg and Kiremt* rainfall anomaly showed that (46 % to 64%) of the observation years were experiencing an amount lower than the long term mean. The studied three stations showed that years, 1984,1987,1991-1993,1997-2005,2008,2009,2012 ,2015 at Aje, years,1986,1991,2000-2014 except 2011 at Shashemeneand at Kofele years 1987,1989-1991,1994,1995,1998 and 2001-2014 except 2003 and 2011 was characterized by *Belg* rainfall below the mean of the study period (Figure. 6) and could be classified as moderate to extreme drought years. Accordingly, the years 1983, 1986, 1988 and 1996 were observed to have a *Belg* rainfall total above the long term mean across all the studied stations.


Figure 6. *Belg* rainfall anomalies in mm at Aje, Kofele and Shashemene (1983-2015)

The present study implies that the *Kiremt* rainfall in the SKV livelihood zone was characterized by dry and wet conditions more or less in alternating manner (Figure 7). In addition to this, *Kiremt* rain at the three stations during the last three decade was below long term mean anomalies for 15 years (1984, 1985, 1986, 1987, 1988, 1989, 1992, 1995, 1997, 2000, 2004, 2008, 2011 and 2013, 2015) at Aje. For 12 year (1984, 1986, 1988, 1989, 1991, 1994, 2002, 2005, 2008, 2011, 2012 and 2015) at Kofele and Shashemene 1984, 1988, 1991, 1993, 1994, 1998, 1999, 2002, 2003, 2004, 2006-2015 respectively. Moreover, the study revealed that during the MAM of the last 33 years were received (46% to 64 %and 36% to 55%) rainfall anomalies below and above long term mean respectively. One can clearly understand from this information that rain fed crop production in the study livelihood zone has been challenged by risk of dry years during the study period. On the other hand, over high land (kofele), 1983, 1984, 1994, 2007, 2011 and 2015 were moderately to severely drought years were observed during (1983-2015). Contrary to this, *Bega* 1992, 1997 and 2009 were exhibited very wet to extreme wet condition. At shashemene years1994, 2003,2007,2011,2012, 2013 and 2015 were moderate drought years. In agreement with the present study, Bewket (2009), Ayalew *et al.* (2012), Viste *et al. (2012*) noticed that the rain fed agriculture was highly at risk in the SKV livelihood zone.

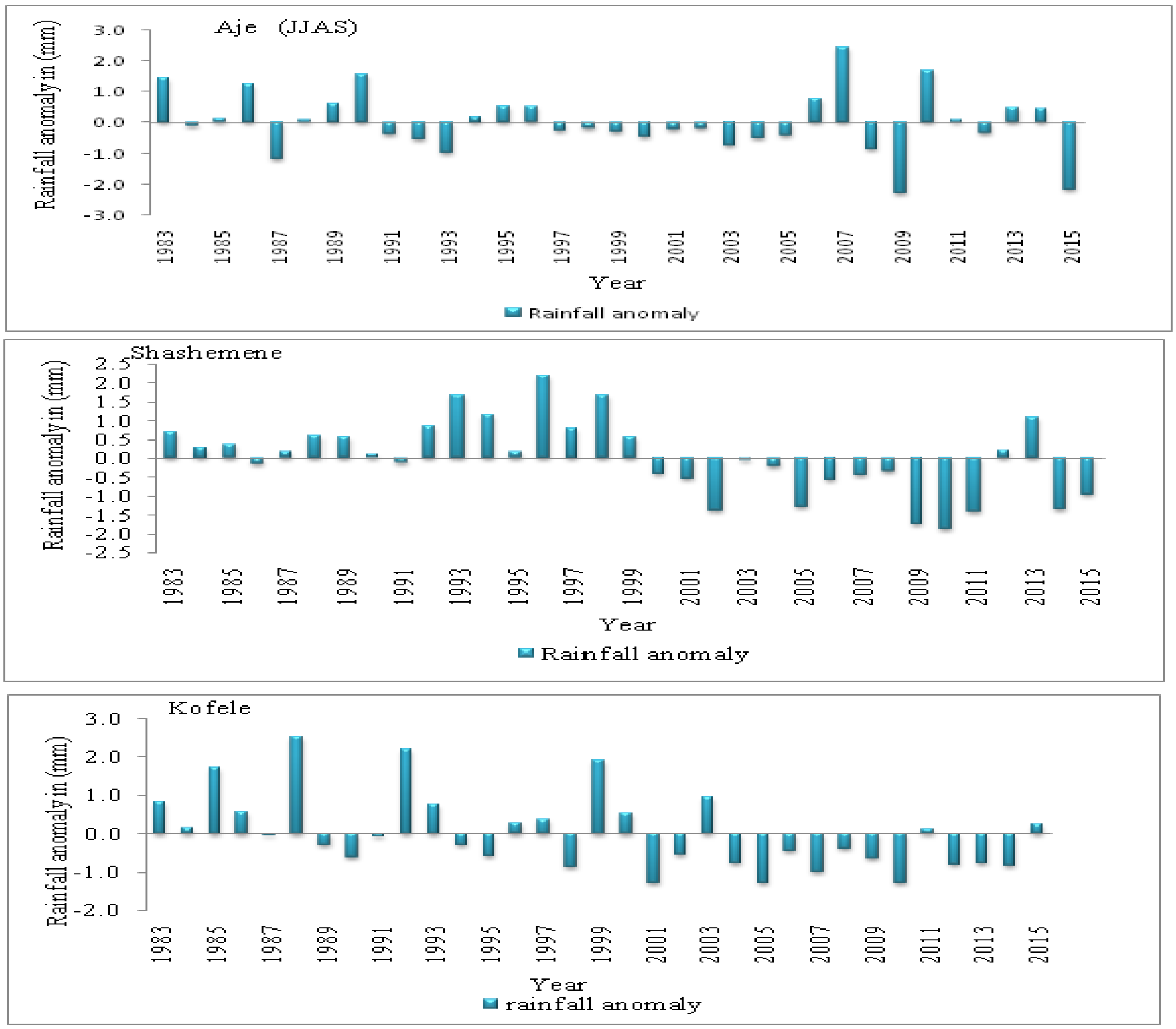


Figure 7. *Kiremt* rainfall anomalies in mm at Aje, Shashamene and Kofele (1983-2015)

### 4.2.3. Rainfall correlation with SOI

This study indicated relationship between seasonal rainfalls, SST over the tropical eastern Pacific Ocean and SOI have differently correlated the two seasons. *Kiremt* rain is positively and negatively correlated to the SOI and SSTAs respectively. The more variable *Belg* rains, on the other hand revealed the opposite. (Table.9). The SOI has direct relation with *Belg* rain and inverse relation with *Kiremt* rain. But as indicated in (Table.9) the relationship is not strong as all correlation values were low. This result showed that monthly correlations have discovered bonds between the onset and cessation of the *Belg* and *Kiremt* seasons respectively. This indicated that the relationship is more influenced onset and cessation or linked with them. Related previous study showed that the correlation between rainfall, the southern oscillation index and global atmospheric circulations varies spatially with a strong Teleconnection present only in some regions (Gissela *et al.* 2004). Large scale climate circulations significantly influence rainfall patterns in some parts of the country though distinguishably variable from region to region. More of previous works were strengthen these results and said that June-September rainfall over the Ethiopian highlands is positively correlated to the equatorial East Pacific sea level pressure and the SOI (Gissela *et al.* 2004). Contrary to this, some previous studies showed that coupling between the East African long rains and ENSO did not show any significant correlations (Hastenrath *et al.* 1993; Rowell *et al.* 1994). This study also identified that kiremt 1983 was wet year contrary to intense El Nino prevailed during this period. Some others previous studies confirmed that the 1982-83 El Nino, which was by far the most intense did not produce a very dry *Kiremt* (Ward and Yeshanew, 1990).These findings are at odds with several other studies that noted a relationship between Nino-3.4 SST and rainfall across the season (Nicholson 1996 and Nicholson and Kim 1997). Contradicting reports have so far been made while assessing rainfall trend in Ethiopia. The use of different time periods in the analyses of rainfall is the main reasons for the contrasting results (Bewket *et al.*, 2007). Many of the contradictions may also be explained by the arbitrary division of the study area as well as the quality of available data (Easterling *et al.*, 2000; Seleshi and Zanke, 2004).

Table 9. Monthly SOI correlation with monthly mean rainfall of SKV livelihood zone.

| Month | Jan | Feb | Mar | April | May | June | July | August | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aje | -0.35 | -0.25 | -0.12 | 0.02 | 0.02 | 0.26 | 0.32 | 0.16 | 0.15 | -0.01 | -0.26 | -0.08 |
| Kofele | 0.02 | 0.05 | 0.06 | 0.04 | 0.01 | 0.02 | 0.04 | -0.01 | 0.01 | 0.01 | 0.04 | 0.04 |
| Shashem | -0.52 | -0.48 | -0.02 | -0.05 | 0.02 | -0.02 | 0.05 | -0.02 | -0.06 | 0.25 | -0.11 | -0.07 |

### 4.2.4. Rainfall correlation with SST

This study indicated that changes in SST over central and eastern pacific parallel and the opposite of where the *Belg* and *Kiremt* were negatively and positively correlated respectively as showed in (Table 10 and Figure 8). Similarly, Bekele (1993) investigated 209 rainfall stations from each corners of the country and concluded that negative and Sea Surface Temperature Anomalies (SSTA) were strongly linked to inadequate *Belg* and higher *Kiremt* falls respectively, while the opposite is true for positive anomaly. Seleshi and Zanke, (2004) confirming again those ENSO episodes are associated with below average June-September rainfall over the Ethiopian Highlands. This indicated that La Nina and El N (cooling below and warming above normal SST). This indicated that La Nina and El N (cooling below and warming above normal SST) that means that cooling of SST below normal associated with deficit *Belg* rain and excess of *Kiremt* rain and the opposite is true for warming.

Table 10.Three month running mean of SST correlated with monthly mean rainfall during (1983-2015) at SKV livelihood zone.

| Month | Jan | Feb | Mar | April | May | June | July | August | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aje | 0.30 | 0.12 | 0.08 | 0.06 | 0.22 | -0.05 | - 0.41 | - 0.41 | -0.33 | 0.08 | -0.11 | 0.06 |
| Kofele | 0.42 | 0.43 | 0.17 | 0.25 | 0.08 | -0.34 | - 0.22 | 0.37 | -0.17 | 0.17 | 0.24 | 0.23 |
| Shasheme | 0.35 | 0.37 | 0.12 | 0.04 | - 0.03 | -0.17 | -0.15 | 0.14 | -0.23 | -0.13 | 0.20 | 0.03 |

Standardized *Belg* rainfall indicated wet or positive anomaly during El Nino years 1983, 1992-1995, 2002, 2004 2005, 2010 and 2015 of which1983, 1987 and 1992 were very wet as indicated in (Figure.8).Contrary to this during La Nina years dry or negative anomaly prevailed in years 1984-1990 except 1987, 1996-2001 except 1997, 2006-2009 and 2011-2014 of which 1985, 19989, 1999, 2000 and 2008 very dry. Standardized *Kiremt* rainfall anomaly indicated wet or positive anomaly during La Nina years 1985, 1986, 1995,1996, 2006, 2007, 2010, 2013and 2014 of which 1986, 2007and 2010 were very wet as indicated in (Figure.8). Contrary to this during El Nino years dry or negative anomaly prevailed in years 1987, 1988, 1991-1993 and 1997-2006, 2008, 2009 and 2012 of which 1987, 1993, 2008 and 2009 very dry. On the other hand, unlike the other El Nino years, *Kiremt* 1983 was very wet(Figure 8.).

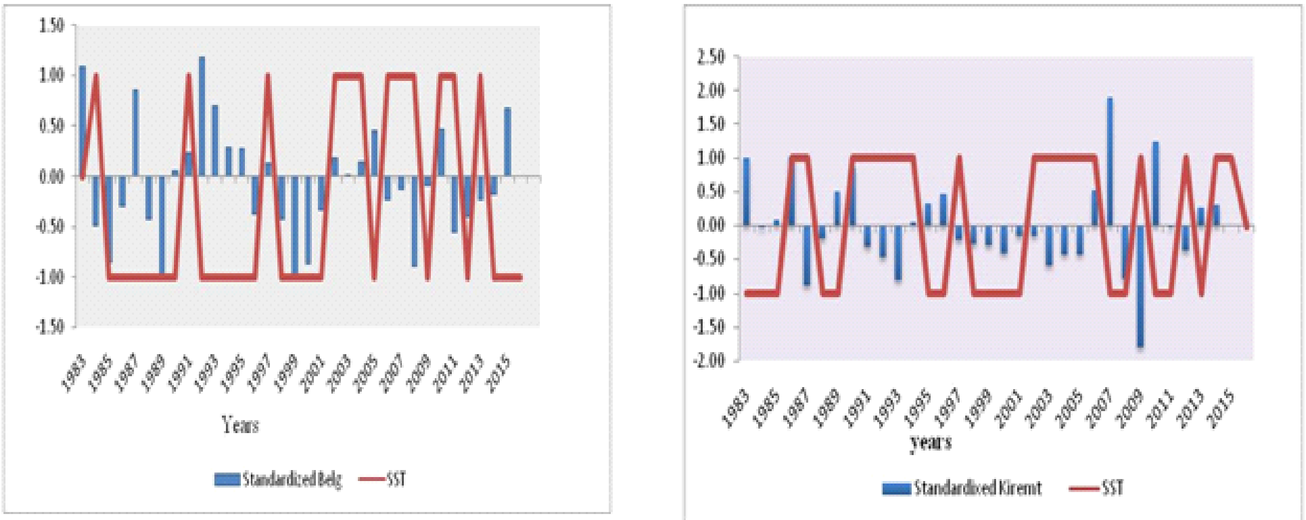


Figure 8. *Belg* mean and *Kiremt* mean rainfall at SKV livelihood zone (1983-2015)

Table 11.Seasonal correlation of SOI and SSTA with mean rainfall of SKV livelihood zone for the period of 1983-2015

| 1983- 2015 | SOI (Standardized) | SST(Standardized) |
|---|---|---|
| Mean *Kiremt* | 0.195 | - 0.37 |
| Mean *Belg* | -0.026 | 0.27 |

## 4.3. Onset, Cessation and Length of Growing Period Variability

### 4.3.1. Onset of growing seasons variability

The mean, median, maximum and minimum start date of season (SOS) of *Belg* at Aje were 90, 83, 145 and 61at Shashamene, 94, 89, 149, 61 and at Kofele 81, 79,138 and 61days of the year (DOY) respectively. The mean, median, maximum and minimum SOS of *Kiremt at* Aje were 174, 172, 252 and 0 at Shashamene, 181,173,222 and157 and at Kofele 171,163,228and 153 (DOY) respectively. On an average, Belg and main rainy season started on March 30, April 3, and March 20 and June 22, 29 and 19 at Aje, Shashemene and Kofele, respectively. In addition to these, upper quartile (Q3=75%) SOS of *Belg* season of the study years has value less than 110, 116, 91 at Aje, Shashamene and Kofele respectively, While the lower quartile (Q1=25%) SOS value of *Belg* season was lower than 68, 73 and 68 Aje, Shashamene and Kofele respectively. The SOS value of upper quartile and Lower Quartile of *Kiremt* season had value less than 188,200,177 and 162,165 and 157 at Aje, Shashamene and Kofele respectively.

Inter annual variability of CV and SD of SOS varies from season to season and from station to station. The SOS CV of *Belg* and *Kiremt* seasons was 29%, 27% and 20% and 23%, 11% and 12% for Aje Shashamene and Kofele respectively. This result clearly showed that three parameters mentioned above seriously challenging crop production of SKV livelihood particularly the low land parts. Related study reported by (EPCC,2015) the risk of onset date of rainfall for MAM season in Gato (high land ) station is lower than the two stations (Hosaina and Welkite) although its variation in end date and LGP is higher than the two indicating instability.

This paper identified that there was no onset for year 2008 of MAM at for Aje and 2008 and 2009 at Shashemene. This implies that rainfall exhibited during these years was very erratic and did not fulfill criteria used for defining the onset.

### 4.3.2 Cessation of growing seasons variability

The mean, median, maximum and minimum cessation date of *Belg* season (EOS) of Aje was 134,130,147,128 of Shashamene, 134,131,151,129 and of Kofele 134,132,143 and 129 (DOY) respectively. The mean, median, maximum and minimum EOS of *Kiremt* season of Aje were 257, 254 , 313, 0 of Shashamene, 295, 297, 353, 245and of Kofele 334, 332,366, 307 and 129 (DOY) respectively. On the average, *Belg* and *Kiremt* ceased on May 18 for all the three station and September 17, October 20 and November 29 respectively. Similarly Ethiopian panel on Climate Change (EPCC, 2015) reported that central and southern Ethiopia has cessation in October. The highest variability of the mean cessation occurs over southern, south-eastern Ethiopia which has standard deviation of 26 to 32 days, while the lowest variability is over north-eastern and north-western regions, where the standard deviation ranges from 10 to 18 days (EPCC, 2015). Moreover, the time gap between cessation of short rain season (MAM) and onset of main rainy season is very short and in some years merge with main season and challenging harvesting of *Belg* crops.

Upper quartile (Q3=75%) EOS of *Belg* season the study years have less than 138,139and141 for Aje, Shashamene and Kofele respectively, While the Lower Quartile (Q1=25%) EOS value of *Belg* season lower than 128, 129 and 130 Aje, Shashamene and Kofele respectively. In similar manner upper quartile (Q3=75%) EOS of *Kiremt* season the study years have less than

279,331and 344 for Aje, Shashamene and Kofele respectively, While the lower quartile (Q1=25%) EOS value of *Kiremt* season lower than 245, 278 and 321 Aje, Shashamene and Kofele respectively. The EOS value of CV of *Belg* and *Kiremt* showed variability of 5%, 5%, 4% and 20%, 10% and 4% with SD of 7, 6, 16 and 51,31and 15 days for Aje, Shashamene and Kofele with SD respectively. The highest variability of the mean cessation occurred over Aje while the lowest variability is over Kofele. This result indicates that CV varies more during *Belg* than *Kiremt* and more over the low lands. The relative value for SD in the same order was 26, 26, 16 and 41, 19, 21 days. The CV and SD over low land and mid high land prevailed that EOS is very serious problem during the last 3 decades.

### 4.3.3. Length of growing seasons variability

The mean, median, maximum and minimum length of gorwing period (LGP) of *Belg* at Aje was 57, 62 ,83, 20 at Shashamene 46, 49, 72, 9 and at Kofele 49, 48, 81 and 22 respectively. The mean, median, maximum and minimum LGP of *Kiremt* at Aje was 83, 75,160 and 0, at Shashamene 115,118, 42and at Kofele163, 165, 206, and 102 respectively. Similarly LGP value of *Belg* season indicated that upper quartile and lower quartile of Aje, Sahashemene and Kofele were 69, 65, 66 and 47,31and 33 respectively.

Similarly LGP value of *Kiremt* season indicated that upper quartile and lower quartile of Aje, Sahashemene and Kofele were 106,144,180 and 60, 87, and 148 respectively. LGP indicated very high variability with CV for *Belg* and *Kiremt* 30%, 47%, 40% and 48%, 30% and 27% for Aje, Shashamene and Kofele with SD of 17, 21, 19 and 40, 34 and 17days respectively.

In similar study by Ethiopian panel on Climate Change (2015), the (LGP) for maize production in the main rainy season in Hosaina area ranges from 124 to 253 days with a mean of 193 ±12days, CV and SD of 8% and 35days respectively. (Abiy *et. al,* 2014) also indicates that the LGP of the growing season of MAM (Gato) was very variable from 6-121 days (CV=42%) which needs more attention for planning of agricultural water for crop production.

LGP is the difference between EOS and SOS and has positive and negative correlation with former and later respectively. LGP is the difference between EOS and SOS and has positive and negative correlation with former and later respectively. The LGPs of *Belg* at Aje was highly correlated with SOS of MAM, while of *Kiremt* was with EOS of JJAS. Thus, LGP of MAM showed SOS ($R^2$=0.92) and EOS ($R^2$=0.17), while that of JJAS SOS ($R^2$=0.12) and EOS ($R^2$=0.65). The LGPs of *Belg* and *Kiremt* at Shashamene were also highly correlated with SOS of MAM ($R^2$= 0.95) and EOS of JJAS ($R^2$= 0.13) whereas of JJAS SOS ($R^2$= 0.49) and EOS ($R^2$= 0.84) respectively. LGPs of *Belg* and *Kiremt* at Kofele were highly correlated with SOS value of MAM ($R^2$= 0.95) and EOS ($R^2$= 0.59) and SOS of JJAS ($R^2$= 0.42) and EOS ($R^2$= 0.93). This relationship showed that LGP of SRS more influenced by SOS than EOS, while inverse is true for JJAS. Moreover (Figure 9a and b) more illustrate about SOS, EOS and LGP of *Belg* and *Kiremt* season at 3 stations. In related previous study this variation is also highly correlated with end date ($R^2$=0.80) than onset ($R^2$=0.4) (Abiy *et. al*, 2014). Other related report by Ethiopian panel on Climate Change (2015), the mean length of the growing season has high special variability with values ranging from 40 to 260 days. Southern and south-western parts of Ethiopia have the longest mean growing season from 180 to 260 days, followed by central and north-western regions (121 to 180 days). The annual variability of the mean length of the growing season is shown in (Table 12).

Table 12. Descriptive statistics of *Belg* and *Kiremt* SOS, EOS and LGP at Aje,Shashamene and Kofele (1983-2015)

| | | Belg | | | Kiremt | | |
|---|---|---|---|---|---|---|---|
| Aje | | SOS | EOS | LGP | SOS | EOS | LGP |
| | Mean | 90.0 | 133.7 | 57.0 | 174.3 | 256.6 | 83.1 |
| | SD | 26.0 | 6.8 | 17.3 | 40.6 | 51.4 | 39.6 |
| | CV | 28.9 | 5.1 | 30.3 | 23.3 | 20 | 47.6 |
| | Median | 82.5 | 130.0 | 62.0 | 172.0 | 254 | 75.0 |
| | Max | 145.0 | 147.0 | 83.0 | 252.0 | 313 | 160.0 |
| | Min | 61.0 | 128.0 | 20.0 | 0.0 | 0 | 0.0 |
| Shashamene | Mean | 93.5 | 133.9 | 45.8 | 180 | 249 | 114.5 |
| | SD | 25.5 | 6.3 | 21.5 | 19.1 | 30.5 | 34.8 |
| | CV | 27.3 | 4.7 | 46.8 | 10,6 | 10.3 | 30.4 |
| | Median | 89.0 | 131 | 49 | 173 | 297 | 118 |
| | Max | 149 | 151 | 72 | 222 | 353 | 180 |
| | Min | 61 | 129 | 9 | 157 | 245 | 42 |
| Kofele | Mean | 77.9 | 134.1 | 54 | 171.4 | 333.8 | 162.5 |
| | SD | 16.4 | 5.7 | 16.8 | 21.2 | 14.8 | 26.8 |
| | CV | 20.1 | 4.2 | 31.2 | 12.4 | 4.4 | 16.5 |
| | Median | 73 | 132 | 56 | 163 | 332 | 165 |
| | Max | 138 | 143 | 81 | 228 | 366 | 206 |
| | Min | 61 | 129 | 30 | 153 | 307 | 102 |

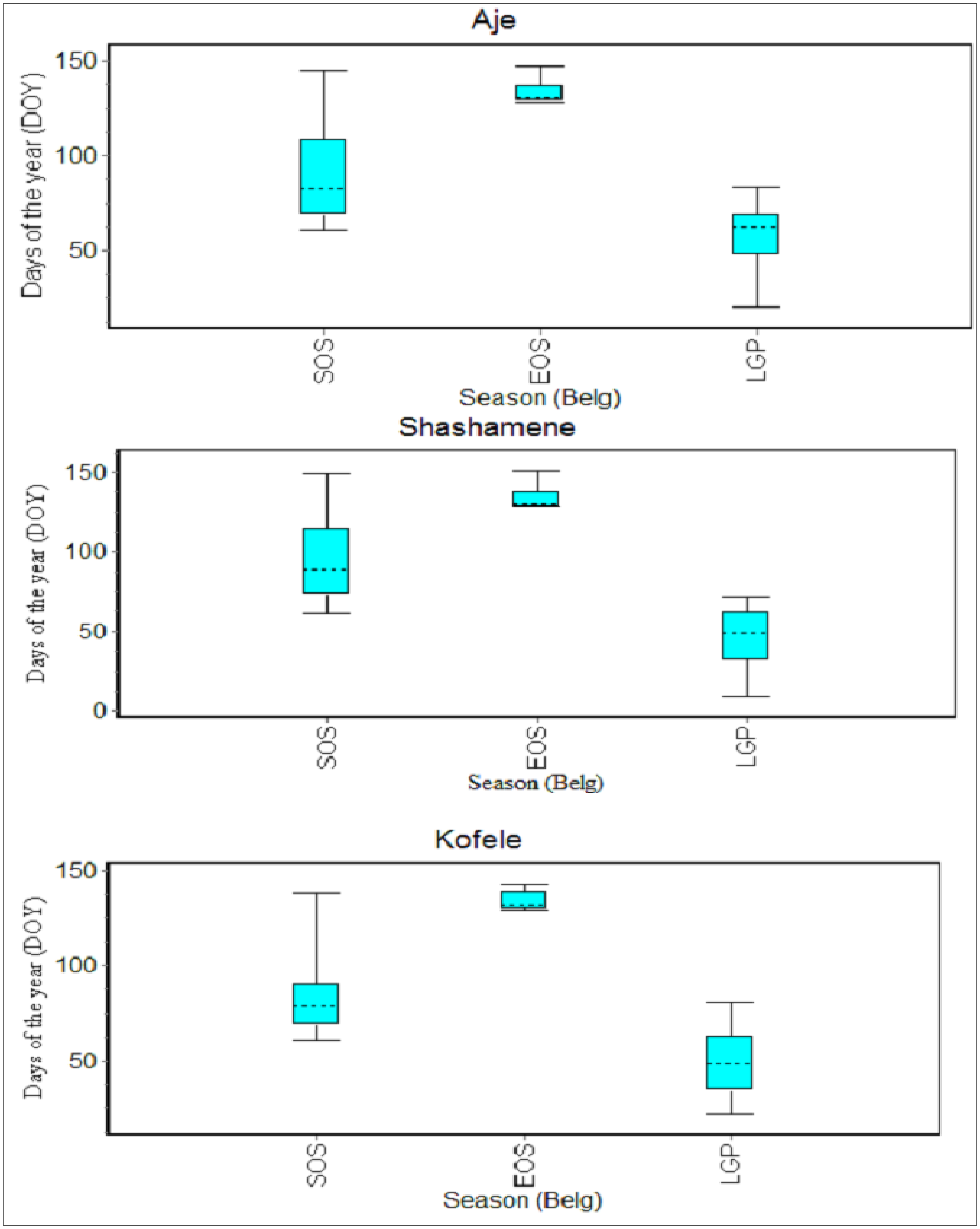


Figure 9a.*Belg* season onset, cessation and length of growing period at Aje,Shashamene and Kofele (1983-2015)

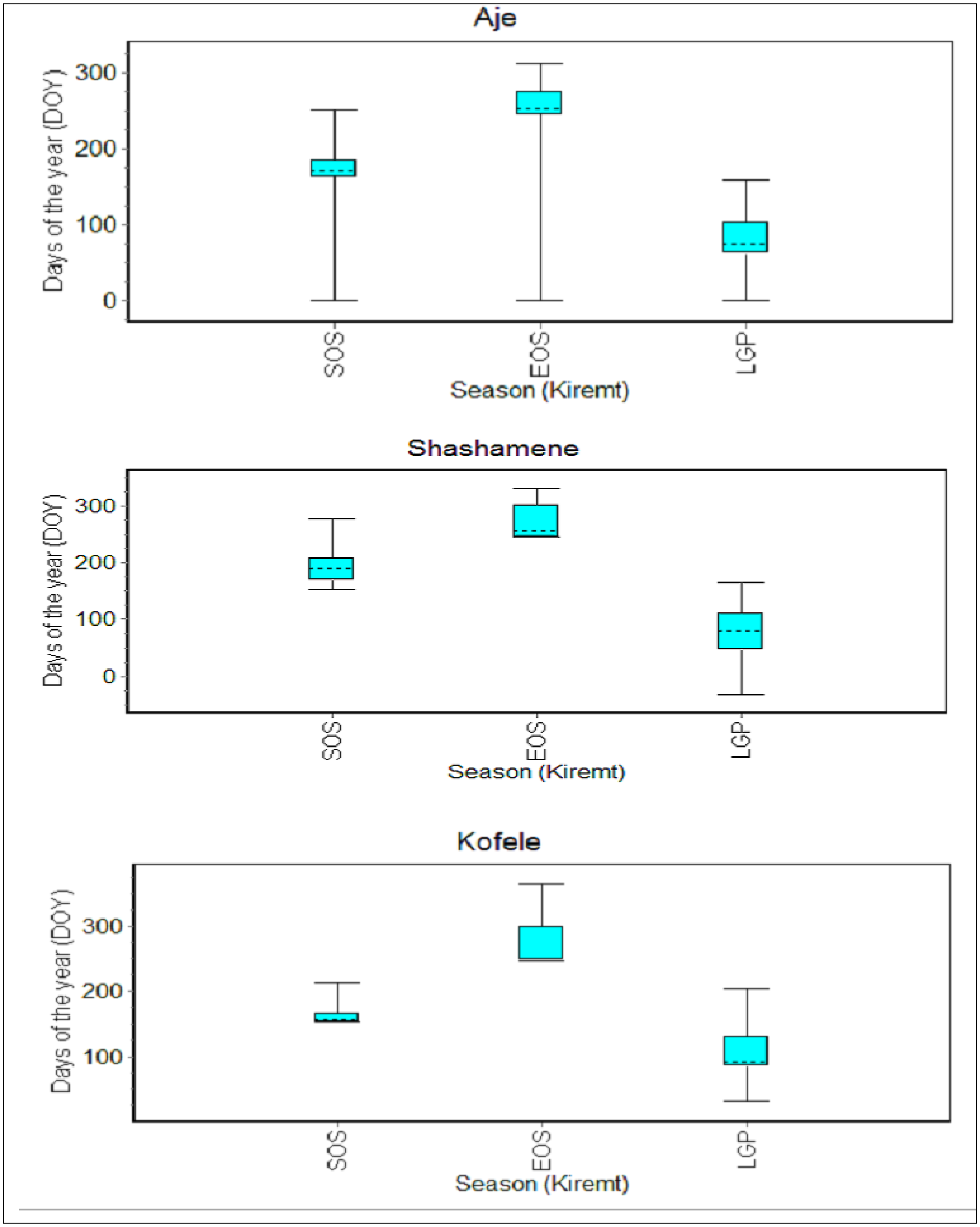


Figure 9b. *Kiremt* season onset, cessation and length of growing period at Aje,Shashamene and Kofele (1983-2015)

## 4.4. Number of Rainy, Dry Days and Length of Growing Season Variability

### 4.4.1. *Belg* season number of rainy and dry day's variability

The number of seasonal *Belg* rainy days (NRD) and dry days (NDD) during 1983-2015 at the three stations of SKV livelihood zone is depicted in (Table13).The result showed that during *Belg* season; the observed NRD varied from 11 days at Aje to 56 days at Kofele (Table13). There were, on average, more *Belg* season NRD (46 days) in a year at Kofele (highland) than the rest of the studied stations. The observed CV of *Belg* season NRD also showed that there was less variable to very high inter annual variability in the NRD at all the studied stations with the smallest values at Kofele (15 %) and the highest values at Aje (31%). This indicated that the NRD in the last three decade *Belg* season was less dependable particularly in the low land of the study area. On the other hand, the observed seasonal *Belg NDD* varied from 36 days at Kofele to 81 days at Aje. Moreover, the present study has shown that the number of rainy days were more variable during the *Belg season* than during *Kiremt* season except slightly less variable at Kofele. The standard deviations of NRD and NDD for each station and season were equal and indicating that the two parameters complementary to each other. During *Belg* of the last three decade, the standard deviation of the two stations was under ten and it was 18 at Aje. In addition to this, during *Belg* the recorded number of rainy days were slightly exceed one fourth of total days of the season (> 23 days or 25% of total NRD) in years; 19841986, 1988, 1991, 2000, 2004, 2008 and 2010 2015 at Aje, 1984, 1989, 1991, 1992, 1994, 1995, 1997, 1998, 2002-2005, 2008, 2009 and 2015 at Kofele and years; 1988, 1991, 1993, 2002, 2008, 2012 and 2015 at Shashemene. Although annual average rainfall of study site was 869mm, the bulk of the rains were received in a short duration which caused water logging in fields. Then rain was preceded by dry spells of 5 to 15 days particularly during the start and end of the season. This dry spell usually resulted in numerous crop failures especially with late planted crops (planted of long cycle crops in April and May or short cycle crops in August due late onset of main rainy season).Even though there were several declining trends in number of rainy days were in NRD prevailed statistically non significant. From agricultural point of view, high inter annual variability in the number of rainy days shows less dependability of the rains for planning activities which may lead to crop failures. Particularly, the high variability of rainy days for the *Belg* season could be a great problem for farmers who lack instruments to quantify rainfall amount but rather depend on number of rainy days to plan cropping calendar.

### 4.4.2. *Kiremt* Season number of rainy and dry day's variability

The observed *Kiremt* NRD (Table 13) varied from 0 days at Aje to 89 days at Kofele. The zero value indicating that the received rainfall did not exceed threshold (1mm). This situation indicated in year 2009 (Table.13). Observed CV of *Kiremt* NDD in the present study also indicated that there was relatively more inter annual variability of seasonal *Kiremt* NDD at Aje 18 days. The following years; 1983-1993, 1995, 2005 and 2008-2010 at Aje and 1991,1995, 2002, 2005 and 2009- 2012 at Shashemene received number of rain days less than 25% .Similarly Zanke and Seleshi (2004) reported comparable result in NDD for *Kiremt* seasons at rainfall station in eastern, southern and south western Ethiop for the study period of 1965-2002.

Table13. Descriptive statistics of seasonal number of rainy and dry days, at Aje,Shashamene and Kofele (1983to 2015)

| Season | Indices | | Station | | |
|---|---|---|---|---|---|
| | | | Aje | Kofele | Shashemene |
| Belg | NRD | Mean | 30.2 | 45.6 | 37.8 |
| | | SD | 9.5 | 7.0 | 8.5 |
| | | CV | 31.1 | 15.1 | 22.2 |
| | | Median | 31.0 | 46.0 | 37.0 |
| | | Max | 49.0 | 56.0 | 53.0 |
| | | Min | 11.0 | 33.0 | 24.0 |
| Kiremt | NRD | Mean | 43.5 | 75.8 | 56.2 |
| | | SD | 14.1 | 7.8 | 11.3 |
| | | CV | 26.2 | 10.1 | 19.8 |
| | | Median | 47.0 | 75.0 | 57.0 |
| | | Max | 61.0 | 89.0 | 79.0 |
| | | Min | 0.0 | 60.0 | 34.0 |
| Belg | NDD | Mean | 61.8 | 46.4 | 54.2 |
| | | SD | 9.5 | 7.0 | 8.5 |
| | | CV | 15.2 | 14.8 | 15.5 |
| | | Median | 61.0 | 46.0 | 55.0 |
| | | Max | 81.0 | 59.0 | 68.0 |
| | | Min | 43.0 | 36.0 | 39.0 |
| Kiremt | NDD | Mean | 78.5 | 46.2 | 65.8 |
| | | SD | 14.1 | 7.8 | 11.3 |
| | | CV | 18.0 | 16.6 | 16.9 |
| | | Median | 75.0 | 47.0 | 65.0 |
| | | Max | 122.0 | 62.0 | 88.0 |
| | | Min | 61.0 | 33.0 | 43.0 |

The probabilities of wet/ days during *Kiremt* of the last three decade were calculated by dividing the sum of number of wet days of 33 years by the total number of days in 33 seasons P(NRD)= 1437/4026 =0.357 for Aje, 1854/4026 = 0.461 for Shashemene and 2501/4026=0.621 for Kofele which indicated that high probability of rainfall occurrence over high land than low lands

Table14. Probability of NRD of *Belg* and *Kiremt* seasons atAje,Shashamene and Kofele (1983 - 2015)

| Seasons | *Belg* | | | *Kiremt* | | |
|---|---|---|---|---|---|---|
| Station | NRDin 33 years | No of days in33 seasons | Probability | NRDin33 years | Number of days In seasons of 33 | Probability |
| Aje | 995 | 3036 | 0.328 | 1437 | 4026 | 0.357 |
| Kofele | 1504 | 3036 | 0.495 | 2501 | 4026 | 0.621 |
| Shashemene | 1246 | 3036 | 0.410 | 1854 | 4026 | 0.461 |

The probability of NDD is obtain just by subtracting NRD from 1, P (NDD) = 1- NRD (Table15). Similarly Zanke and Seleshi (2004) reported comparable result in NDD.

Table 15. Numbers of rainy and dry days at Aje,Shashamene and Kofele (1983-2015)

| | Aje | | | | Kofele | | | | Shashemene | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Belg | | Kiremt | | Belg | | Kiremt | | Belg | | Kiremt | |
| Years | NRD | NDD | NRD | NDD | NRD | NDD | NRD | NDD | NRD | NDD | NRD | NDD |
| 1983 | 34 | 58 | 41 | 81 | 55 | 37 | 65 | 57 | 51 | 41 | 58 | 64 |
| 1984 | 16 | 76 | 25 | 97 | 33 | 59 | 62 | 60 | 32 | 60 | 57 | 65 |
| 1985 | 24 | 68 | 42 | 80 | 40 | 52 | 74 | 48 | 46 | 46 | 62 | 60 |
| 1986 | 18 | 74 | 36 | 86 | 42 | 50 | 73 | 49 | 32 | 60 | 60 | 62 |
| 1987 | 36 | 56 | 27 | 95 | 52 | 40 | 74 | 48 | 50 | 42 | 48 | 74 |
| 1988 | 16 | 76 | 32 | 90 | 39 | 53 | 89 | 33 | 29 | 63 | 70 | 52 |
| 1989 | 24 | 68 | 61 | 61 | 42 | 50 | 78 | 44 | 44 | 48 | 65 | 57 |
| 1990 | 29 | 63 | 35 | 87 | 52 | 40 | 78 | 44 | 35 | 57 | 54 | 68 |
| 1991 | 23 | 69 | 47 | 75 | 43 | 49 | 84 | 37 | 25 | 67 | 44 | 78 |
| 1992 | 34 | 58 | 47 | 75 | 48 | 44 | 84 | 38 | 40 | 52 | 50 | 72 |
| 1993 | 49 | 43 | 43 | 79 | 50 | 42 | 83 | 39 | 26 | 66 | 66 | 56 |
| 1994 | 34 | 58 | 57 | 65 | 41 | 51 | 84 | 38 | 36 | 56 | 52 | 70 |
| 1995 | 34 | 58 | 45 | 77 | 40 | 52 | 63 | 59 | 41 | 51 | 34 | 88 |
| 1996 | 46 | 46 | 50 | 72 | 56 | 36 | 74 | 48 | 37 | 55 | 64 | 58 |
| 1997 | 43 | 49 | 59 | 63 | 46 | 46 | 69 | 53 | 36 | 56 | 45 | 77 |
| 1998 | 31 | 61 | 49 | 73 | 33 | 59 | 77 | 45 | 33 | 59 | 75 | 47 |
| 1999 | 31 | 61 | 50 | 72 | 51 | 41 | 88 | 34 | 44 | 48 | 67 | 55 |
| 2000 | 28 | 64 | 52 | 70 | 48 | 44 | 86 | 36 | 39 | 53 | 55 | 67 |
| 2001 | 45 | 47 | 51 | 71 | 54 | 38 | 69 | 53 | 46 | 46 | 56 | 66 |
| 2002 | 35 | 57 | 49 | 73 | 44 | 48 | 78 | 44 | 27 | 65 | 42 | 80 |
| 2003 | 33 | 59 | 51 | 71 | 42 | 50 | 80 | 42 | 31 | 61 | 65 | 57 |
| 2004 | 27 | 65 | 50 | 72 | 39 | 53 | 74 | 48 | 35 | 57 | 61 | 61 |
| 2005 | 43 | 49 | 44 | 78 | 49 | 43 | 63 | 59 | 51 | 41 | 44 | 78 |
| 2006 | 42 | 50 | 57 | 65 | 56 | 36 | 86 | 36 | 44 | 48 | 57 | 65 |
| 2007 | 36 | 56 | 59 | 63 | 52 | 40 | 75 | 47 | 49 | 43 | 68 | 54 |
| 2008 | 15 | 77 | 24 | 98 | 38 | 54 | 83 | 39 | 28 | 64 | 72 | 50 |
| 2009 | 31 | 61 | 0 | 122 | 37 | 55 | 72 | 50 | 40 | 52 | 41 | 81 |
| 2010 | 29 | 63 | 45 | 77 | 55 | 37 | 60 | 62 | 45 | 47 | 39 | 83 |
| 2011 | 20 | 72 | 50 | 72 | 50 | 42 | 73 | 49 | 32 | 60 | 40 | 82 |
| 2012 | 28 | 64 | 53 | 69 | 37 | 55 | 74 | 48 | 24 | 68 | 47 | 75 |
| 2013 | 26 | 66 | 45 | 77 | 52 | 40 | 75 | 47 | 53 | 39 | 79 | 43 |
| 2014 | 24 | 68 | 55 | 67 | 51 | 41 | 81 | 41 | 40 | 52 | 57 | 65 |
| 2015 | 11 | 81 | 6 | 116 | 37 | 55 | 73 | 49 | 25 | 67 | 60 | 62 |
| Mean | 30.2 | 61.8 | 43.5 | 78.5 | 45.6 | 46.4 | 75.8 | 46.2 | 37.8 | 54.2 | 56.2 | 65.8 |
| SD | 9.5 | 9.5 | 14.1 | 14.1 | 7.0 | 7.0 | 7.8 | 7.8 | 8.5 | 8.5 | 11.3 | 11.3 |
| CV | 31.1 | 15.2 | 26.2 | 18.0 | 15.1 | 14.8 | 10.1 | 16.6 | 22.2 | 15.5 | 19.8 | 16.9 |
| Medi | 31 | 61 | 47 | 75 | 46 | 46 | 75 | 47 | 37 | 55 | 57 | 65 |
| Max | 49 | 81 | 61 | 122 | 56 | 59 | 89 | 62 | 53 | 68 | 79 | 88 |
| MIN | 11 | 43 | 0 | 61 | 33 | 36 | 60 | 33 | 24 | 39 | 34 | 43 |

## 4.5. Spatial Variability of rainfall; Drought Frequency, Intensity and Dry Spells

### 4.5.1. Drought (extreme precipitation events), intensity, frequency and variability

In this study recurrent annual drought years were identified as moderate to extreme drought in years 1987, 2008 and 2015 for *Kiremt* with years;1987, 1993, 2009 and 2015were moderate to severe drought years, *for Belg* moderate to severe drought years, were1988, 1989, 2008 and 2015 at Aje respectively. At Shashemene, annual moderate to severe drought was experienced in years 2002, 2009,2010,2011,2014 and2015. *Belg* exhibited moderate to severe drought in years 2002, 2008, 2012 and 2013. While moderate to severe drought were occurred during years; 2002, 2005, 2009,2010,2011,2014 and 2015 were found to have *Kiremt* rainfall experienced moderate to extreme dry condition in the study period. Accordingly at Kofele on basis of annual scale moderate to severe drought years were in the years; 1984, 1994, 2005, 2011, 2012 and 2015, and the *Kiremt* drought years were 2001, 2005, 2007 and 2010.While *Belg* moderate to extreme drought years were in years; 2008, 2009, 2011, 2012 and 2015. This study revealed 2015 and 1997 as indicated by Viste *et al.* (2012) were found as severe to extreme *Kiremt* drought years over the SKV livelihood zone during the study period. This study also showed that interval of drought frequency was on the process of diminishing .This process can be observed from positive and negative anomalies obtained from SPI in alternating manner among years during the last three decade. Previously was about ten years however; since 1993 drought frequency is approximately every 3 to 5 years. World Bank report (2003), confirms the same figure with significant occurs events every 3–5 years. In the Ethiopian context experience from the previous drought and the frequent rainfall anomalies suggest that the return period of drought is 3-5 years in the northern and 6-8 years over the whole country (Haile, 1998). Similar report also has been made by Hadgu*et al.* (2013).

### 4.5.2. Dry spells variability of growing season

Accordingly, given a condition that first week of March is a potential planting date, the probability of dry spells longer than 5, 7, 10, 15 and 20 days were analyzed.This study identified the probability of dry spells of 5,7,10, 15 and 20 days length at three stations in the SKV- livelihood zone. The probability of dry spells occurrence of *Belg* season highly varies among stations. The probability of dry spell of 5 days length occurrence at the three stations; was above 90% at Aje, 64% at Shashemene and 47% at Kofele. On the other hand, the observed probability of dry spell occurrence greater than 7days length was 60% at Aje, 40% at Shashemene and at, Kofele 20%. Whereas, the probability of dry spell occurrence 10 days length was observed being 6% at Kofele, 20%, Shasheme, 40% and Aje (Figure10.). The probability of dry spells occurrence longer than 15 days was less than 10% across the study stations except it was 16% at Aje. This showed that the probability of dry spells occurrence increases from the first week of April (DOY100) and descends down to 0 (its minimum position ) from the middle of June to cessation over all studied stations, and the period after this is the time when there is minimum risk to the emergence, establishment and subsequent growth of annual crops. This is also demonstrated how the probability of 5 and 7 days dry spell curves stays at their maximum value of 1.0 (100%) during the earlier and later months relative to the growing seasons(Figure10.). Thus, the reason behind including the dry spell length conditions into the later months of the growing season is to provide a complete picture of how the dry spell length of various magnitudes are distributed during the entire growing season as well as to examine the associated risk that might prevails at each location and specific time of growing season. All dry spell length probability curves converge to their minimum only during the peak rain period (April and May or DOY 90-120) at Aje, (80-120 DOY) at Shashemene and Kofele and turn upward again around Sept (230-240 DOY) signalling cessation of the growing season. This suggests that standing crops frequently exposed to moisture stress at critical stage of growth particularly at low lands of study livelihood zone. When look in to the probability of dry spell occurrence of 15 days length, it was at 0% at all the three stations of the study livelihood zone particularly at the main rainy season *(Kiremt*). The harvesting period after short rainy season was very short even it is not clearly seen particularly over the high land (Kofele) which usually harvesting very difficult as a result of frequent merging of the two seasons.

From the dry spell graphs, one can see that probability of occurrence of dry spell of 5 and 7 days during the main rainy season it was 80% and 40% at Aje and 40% and 20% at Shashemene, it was under 10% at Kofele. There was very low chance for the occurrence of dry spell greater than 10, 15 and 20 days lengths during the peak months of main rainy season. When looked in to the probability of dry spell occurrence of 15 days length, it was 0% at all the three stations of the study livelihood zone particularly at the main rainy season *(Kiremt*). The harvesting period after short rainy season was very short even it is not clearly seen particularly over the high land (Kofele) which usually harvesting very difficult as a result of frequent merging of the two seasons.

This implies that the predictability of dry spells occurrence greater than 10 days length were easy for decision makers contrary to dry spell of short period of time. This indicates that dry spell of short period has high probability of occurrence compared to long dry spells. As the length of dry spell threshold becomes short, the probability of dry spells occurrence increases and conversely, as the dry spells threshold becomes longer, the probability of dry spells occurrence decreases with-in the growing seasons.

From the SOS, EOS, LGP and dry spell analysis result in present study for growing seasons, it is necessary to choose a terminal drought tolerant variety and if one wants to select crop variety to plant a maturity length should not less than 75 and 90 days for Aje, 90 and 120 days for Shashemene and 130 and 180 days for Kofele during the short and long rainy seasons respectively, in order to fully utilize the regions' resources.

The dry spells and the associated probability information can serve different farming groups working under different practical settings for setting tactical decisions and take appropriate actions within their own real life, particularly to combat or avoid fate of drought that would have negative consequences on farming practices. In addition, knowing the dry spell lengths and probability of occurrence of rain enables meteorologist to give monthly and seasonal climate prediction. Likewise, information of dry spell lengths helps decision makers, local communities and NGOs to plan economic activities in advance while reducing the harmful effects of drought, manage water resources and agricultural activities (Figure10.) showed different dry spell length prevailed at Aje, Shashamene and Kofele meteorological stations.

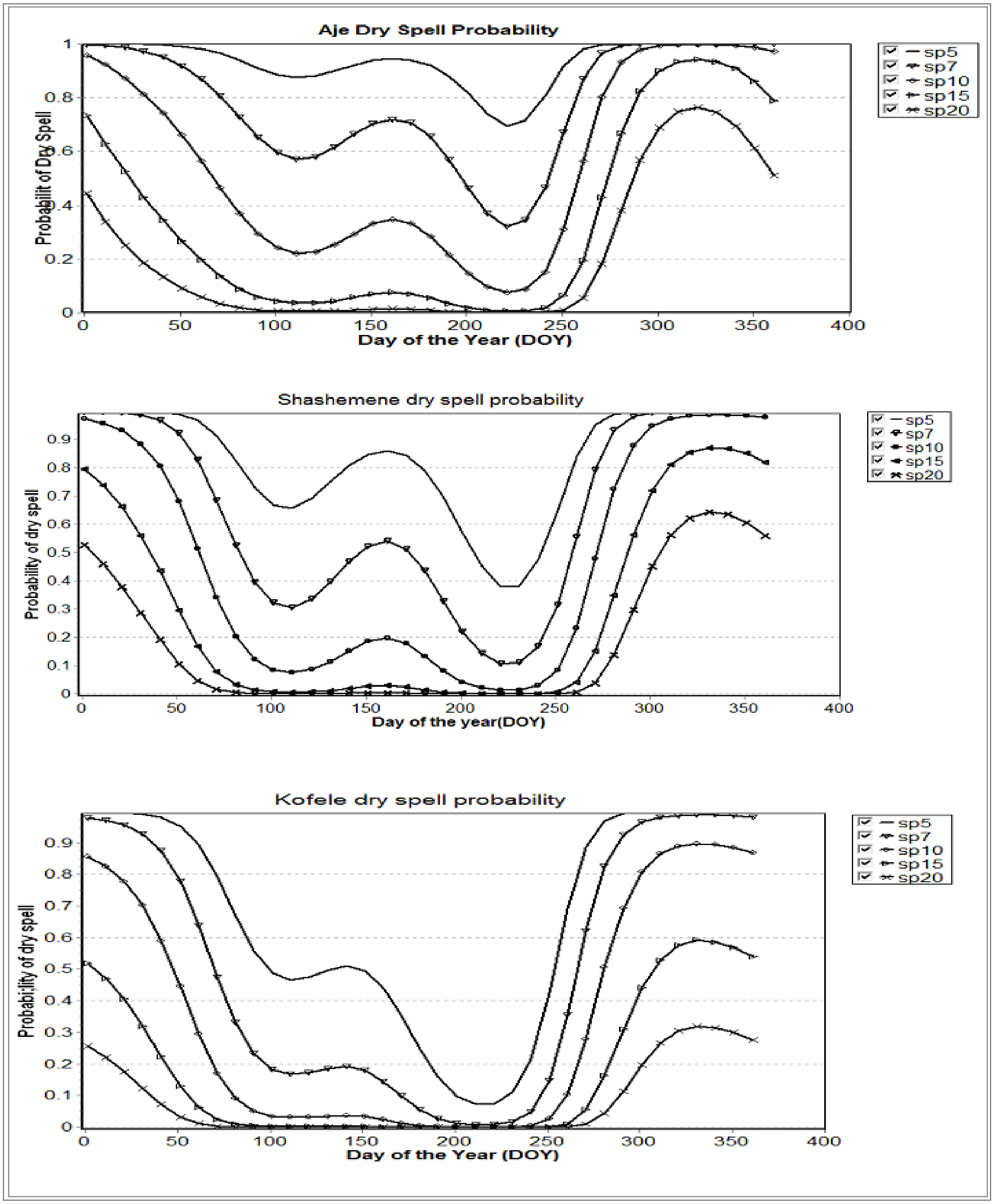


Figure 10 Probability of dry spells length of (5, 7, 10, 15 and 20 days) at Aje,Shashamene and Kofele (1983-2015)

### 4.5.3. Spatial rainfall variability

The spatial variability of monthly rainfall expressed with CV using total monthly rainfall revealed data large value CV indicate large spatial variability. Also total annual rainfall amounts for each locality were recorded and the average annual rainfall was calculated and determined how each rainfall location's annual rainfall varies from each other was determined by using the A large CV also indicated total annual rainfall across the rain gauge station is highly variable. The season's rain was variable across the rain gauge stations. The CV during annual, *Belg* and *Kiremt* seasons were 31.4%, 46.7%, 36.9% at Aje, 33.9%,47.7%, 34.2% at Shashemene and 18.5%, 23.7%, 18.3% at Kofele. The total maximum and minimum rainfall for 1983 to 2015, varied from 115.2 mm to 1165.4 mm at Aje, 292.8mm to variables1197.7mm at Shashemene and 844.7 mm to 1807.9mm at Kofele respectively.

The observed variation in total annual rainfall across the district was mainly due to location of areas in relation to the topography. Station located over the high land experienced higher rainfall compared to the station in the low lands. The minimum rainfall experienced over the high lands (866.7mm) was close to maximum rainfall exhibited over the low lands (1165.4mm). The number of rainy days was more over the high lands than the low lands. In general, CV of rainfall varied more over low lands than high lands. Thus, annual, *Kirem* and *Belg* seasons were varied by 31.4%, 36.9%, 46.7%, at Aje, 33.9%, 34.2%, 47.7%, at Shashemene and 18.5%, 18.3% and 23.7% at Kofele. In addition to these, *Bega* CV was extremely high at Aje 72.9%, at Shashemene 64.7% and Kofele 53.7% respectively. For more clarification monthly mean rainfall of three stations and average of each station indicated in (Figure 11.). The monthly mean of the three stations was below monthly mean of Kofele and above monthly mean of Shashemene and Aje each.

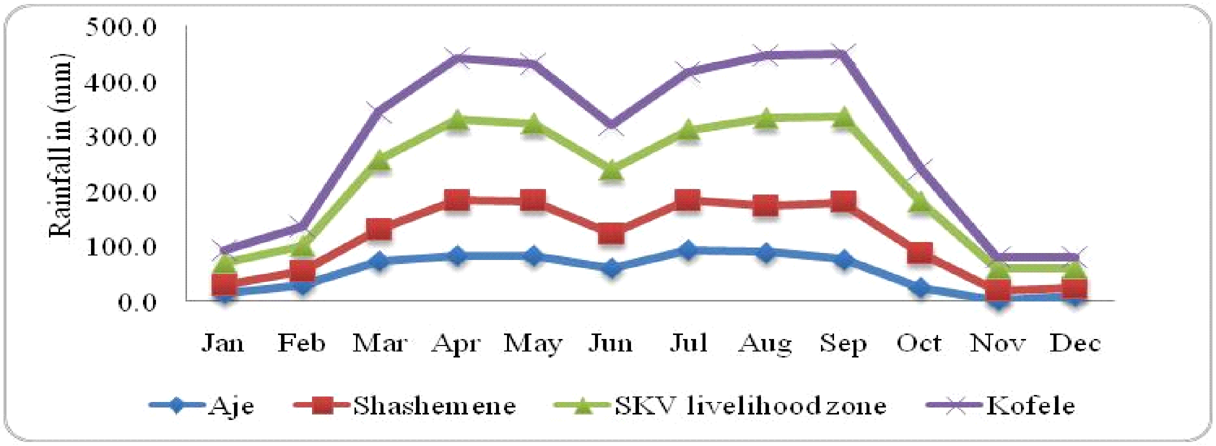


Figure 11 Monthly mean rainfall distribution at Aje Shashamene, Kofele and area mean of SKV livelihood zone (1983-2015)

## 4.6. Temporal and Spatial Temperature Variability

### 4.6.1. Maximum temperature variability

At Aje station the highest and the lowest annual mean maximum temperature observed were 28.8°C and 24.8°C in years 2009, 2015 and 1990 respectively. The highest and lowest mean annual maximum temperature of 21.0°C and 18.5°C were observed at Kofele in years 1984 and 1987 respectively as showed in temperature (Figure 13).

### 4.6.2. Minimum temperature variability

The highest and the lowest mean minimum recorded were 13.9°C and 9.8°C in years 1987 and 2006 at Aje. Wile, the highest and the lowest mean annual minimum temperature were 8.7°C and 1.7°C were observed at Kofele in years 1998 and 2012 respectively as showed in temperature (Figure 13).

### 4.6.3. Mean temperature variability

The highest and the lowest mean annual temperature of 20.7°C and 18.3°C were recorded at Aje in years 2009 and 2007 respectively. The highest and the lowest mean annual temperature were 14.7°C and 10.6°C recorded at Kofele in years 1998 and 2013 respectively as showed in temperature (Figure 13).

Table 16. Statistical description of maximum and minimum temperature at Aje and Kofele (1983 to2015).

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum and minimum temperature at Aje | | | | | | | | | | | | | |
| Mean | 27.1 | 27.8 | 28.2 | 27.7 | 27.4 | 26.4 | 24.8 | 24.2 | 25.4 | 26.6 | 27.2 | 28.9 | |
| SD | 0.98 | 1.13 | 1.38 | 1.35 | 1.02 | 1.52 | 1.68 | 2.40 | 1.06 | 1.22 | 1.02 | 3.08 | |
| CV | 3.60 | 4.07 | 4.89 | 4.87 | 3.72 | 5.76 | 6.78 | 9.90 | 4.18 | 4.60 | 3.75 | 10.63 | |
| Max | 30.2 | 29.1 | 30.5 | 31.2 | 29.5 | 30.3 | 29.5 | 28.4 | 28.4 | 29.9 | 29.8 | 35.3 | |
| Min | 24.6 | 24.5 | 24.0 | 25.3 | 25.4 | 23.9 | 22.3 | 12.6 | 23.5 | 24.1 | 24.8 | 23.8 | |
| Mean | 10.9 | 11.7 | 12.8 | 13.3 | 13.2 | 13.2 | 13.4 | 13.3 | 12.8 | 11.5 | 10.4 | 10.5 | |
| SD | 1.38 | 1.52 | 1.28 | 0.82 | 0.79 | 1.11 | 0.88 | 0.91 | 0.70 | 1.13 | 1.48 | 1.66 | |
| CV | 12.64 | 13.04 | 10.02 | 6.15 | 5.99 | 8.42 | 6.56 | 6.88 | 5.48 | 9.78 | 14.14 | 15.83 | |
| Max | 13.9 | 14.3 | 15.0 | 14.8 | 15.0 | 15.3 | 14.4 | 15.2 | 14.5 | 13.2 | 14.1 | 15.8 | |
| Min | 8.1 | 9.0 | 9.0 | 10.4 | 11.6 | 8.8 | 10.0 | 10.1 | 11.2 | 8.2 | 7.3 | 7.8 | |
| Maximum and minimum temperature at Kofele | | | | | | | | | | | | | |
| mean | 20.8 | 21.8 | 22.0 | 20.8 | 20.2 | 18.8 | 17.7 | 17.8 | 18.7 | 19.4 | 20.1 | 20.2 | |
| SD | 0.83 | 1.12 | 1.40 | 1.23 | 0.86 | 0.98 | 0.87 | 0.75 | 0.75 | 0.68 | 0.75 | 0.74 | |
| CV | 4.02 | 5.14 | 6.38 | 5.94 | 4.27 | 5.20 | 4.93 | 4.20 | 4.02 | 3.52 | 3.71 | 3.64 | |
| MAX | 22.3 | 25.0 | 26.3 | 24.3 | 22.3 | 20.6 | 19.3 | 19.3 | 21.1 | 21.1 | 21.9 | 22.1 | |
| MIN | 19.3 | 19.9 | 20.0 | 18.3 | 18.7 | 17.3 | 15.8 | 16.6 | 17.5 | 18.2 | 18.9 | 18.8 | |
| mean | 5.3 | 6.2 | 7.1 | 7.9 | 7.9 | 8.0 | 8.1 | 8.0 | 7.5 | 6.5 | 5.1 | 4.7 | 6.9 |
| SD | 2.08 | 2.33 | 2.01 | 1.84 | 1.93 | 1.83 | 1.93 | 1.84 | 1.83 | 2.21 | 1.88 | 2.07 | 1.81 |
| CV | 2.04 | 2.30 | 1.98 | 1.81 | 1.90 | 1.80 | 1.90 | 1.81 | 1.80 | 2.17 | 1.85 | 2.04 | 1.79 |
| MAX | 8.9 | 9.8 | 9.3 | 9.8 | 10.0 | 10.2 | 10.3 | 9.7 | 9.5 | 9.0 | 8.5 | 8.3 | 8.7 |
| MIN | -0.2 | 0.2 | 2.0 | 2.6 | 2.3 | 2.7 | 2.6 | 2.3 | 1.7 | 0.8 | 0.5 | -0.9 | 1.7 |

### 4.6.4. Spatial temperature variability

Temperature variability of Aje (Low lands) and Kofele (high lands) was indicated in (Table 16) and no need of repeating. Shashamen has temperature record less than 5 years and analysis is not done.

## 4.7. Characterization of Climate Variability

### 4.7.1. Characterization of rainfall amount variability

Annual rainfall amount varied from slightly over 100 to more than 1800 among station in the study SKV livelihood zone while, mean rainfall ranged from 636.7 to 1223.8mm with CV varied from 18.5% to 33.9% respectively. Similarly *Kiremt* seasonal mean rainfall ranged from 317 to 559.6mm with CV varied from 18.3% to 36.9% respectively. While the *Belg* seasonal mean rainfall varied from 262.2 to 414.1mm with value CV ranged from 23.7% to 47.7%. Average contribution of *Kiremt*, *Belg* , *Bega* and the highest monthly contribution to annual rainfall were 49%,39%,13% and 14% at Aje, 46%,34%,20% and 13% at kofele 46%,35%,19 %and 14% at Shashemene respectively.

Mean monthly contribution of highest and lowest months at Aje were 89.7mm in July and 2.8mm in November with 13%and 0.4% respectively, at Kofele 160.3mm in August and 34.8 mm in November with contribution of 14.7 %and 2.8 % respectively and at Shashemene 104.1mm in September and 15.0 mm in Jan with 13.9%and 2 % respectively. The mean annual rainfall during the last three decade at Aje was 39%, 55% and 6% above, below and equal to long year mean respectively. *Kirem* mean rainfall also account for 46% and 55% positive and negative anomalies respectively. Similarly, mean *Belg* rainfall was 36%, 58% and 6 above, below and equal to long year mean respectively. In the same way mean annual rainfall at Shashemene was 52%, 42% and 3% above, below and equal to long year mean respectively. *Kiremt* and *Belg* mean rainfall at Shashemene was 52% and 49% and 3%, 61% and 6% above, below and equal to mean respectively. In the same way, mean annual rainfall at Kofele was 42%, 55% and 3 %, above, below and equal to mean. While, *Kiremt* and *Belg* rainfall at Kofele were 46% and 55% and 49%, 46% and 6% above, below and equal to long year mean respectively. During the last 3 decade positive and negative anomalies were dominantly observed indicating that extreme cases particularly high negative anomalies were more frequent prevailed. Contrary to this, normal condition was extremely very low and maximum anomaly exhibited was not exceeding 6% during the last 33 years of study period. This situation revealed that how climate variability have been threaten current and future crop production.

### 4.7.2. Characterization of onset, cessation and length of growing season

Early and late onset of *Belg* season at Aje was; 30% and 70%, while that of *Kiremt* were 49% and 52% respectively. Although, there was no marked cessation of *Belg* fulfilled cessation criteria in most cases, there were 15%, 24% and 61% early on time and late respectively. Since there is no well developed cessation criteria and short dry period confusing with dry spell it is challenging task to analysis cessation particularly over the mid and high lands. Main rainy cessation showed 52% and 49% positive and negative anomalies respectively. *Belg* length of growing period (LGP) showed positive and negative anomalies (elongating and shorting) of growing season by 46% and 55% respectively. The LGP of *Kiremt* was exhibited 61% and 39% positive and negative anomalies.

At Shashemene *Belg* and *kiremt* seasons early and late onset were similarly revealed 42% and 58% While of *Belg* early, late and normal cessation were; (9 %, 58% and 33%) observation years respectively. *Belg* season LGP was 18% and 82 % longer and shorter than long term mean of length of growing period, while main rainy season LGP was (55% and 46%) longer, shorter than normal respectively.

*Belg* season onset at Kofele was early and late by 58% and 42 %, while of *kiremt* were account for (73% and 27%) respectively. *Belg* and *Kiremt* early, late and normal cessation were 9%, 73% and 18%respectiely. *Belg* season LGP was 24% and 33% and 42% longer, shorter than and equal to long term mean, while of main season was 61% and 33% and 6% longer, shorter than and equal to normal respectively. Occurrence of normal LGP has been experienced during study period of 1983 to 2015 was very low. In analysis of SOS, EOS and LGP when normal occurred only once it considered with positive anomalies.

Table 17a. Anomalies of *Belg* onset, cessation and length of growing period at Aje, Shashamene and Kofele (1983-2015)

| | *Belg* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Aje | | | Shashamene | | | Kofele | | |
| | SOS | EOS | LGP | SOS | EOS | LGP | SOS | EOS | LGP |
| 1983 | -1.9 | -1.4 | 1.0 | -3.7 | -20.6 | -2.1 | -0.4 | -23.7 | -0.1 |
| 1984 | -0.2 | 0.2 | 0.6 | 0.1 | -20.6 | -2.1 | 0.0 | -23.7 | 0.0 |
| 1985 | 0.2 | 0.1 | -0.1 | -0.6 | -20.6 | -2.1 | 0.4 | -23.7 | 0.0 |
| 1986 | -1.1 | -2.4 | 1.6 | -0.3 | -20.6 | -2.1 | 0.1 | -23.7 | 0.0 |
| 1987 | -0.1 | 0.0 | 0.2 | 1.1 | -0.7 | -1.7 | -0.9 | -23.7 | -0.1 |
| 1988 | 0.7 | 0.7 | 0.0 | -1.2 | -0.7 | 1.0 | 1.3 | -0.9 | 0.5 |
| 1989 | 0.0 | -3.1 | -1.3 | 0.3 | -0.4 | -0.7 | -0.6 | -0.4 | -3.9 |
| 1990 | 0.2 | 0.3 | 0.1 | -0.8 | -0.7 | 0.5 | -1.0 | -23.7 | 0.0 |
| 1991 | 0.4 | 0.1 | -0.4 | -1.2 | -0.1 | 1.2 | -0.8 | -23.7 | 0.0 |
| 1992 | 0.3 | 0.1 | -0.3 | -1.0 | 0.9 | 1.2 | -1.0 | -23.7 | -0.1 |
| 1993 | 1.1 | 0.1 | -1.5 | 0.9 | -20.6 | -2.1 | 1.2 | -23.7 | 0.0 |
| 1994 | 0.4 | 0.1 | -0.4 | 0.1 | -0.7 | -0.6 | -0.4 | -23.7 | 0.0 |
| 1995 | 0.5 | 0.7 | 0.3 | -0.8 | -0.5 | 0.5 | -0.3 | -0.9 | -0.7 |
| 1996 | 0.1 | 0.0 | -0.1 | -0.6 | -0.1 | 0.5 | -0.6 | -23.7 | -0.1 |
| 1997 | 1.0 | 0.1 | -1.3 | -1.0 | -20.6 | -2.1 | -0.6 | -0.7 | -2.3 |
| 1998 | 0.6 | 0.0 | -0.8 | -0.5 | -20.6 | -2.1 | 1.2 | -0.2 | 6.8 |
| 1999 | 0.3 | 0.0 | -0.4 | 0.7 | -20.6 | -2.1 | 0.9 | -23.7 | 0.0 |
| 2000 | 1.5 | 0.8 | -1.0 | 2.3 | -20.6 | -2.1 | 1.2 | -23.7 | 0.0 |
| 2001 | -0.2 | 0.3 | 0.7 | 0.5 | -20.6 | -2.1 | -0.5 | -23.7 | -0.1 |
| 2002 | -0.1 | 0.5 | 0.9 | -0.7 | -20.6 | -2.1 | -0.9 | -23.7 | 0.0 |
| 2003 | -1.7 | -1.4 | 0.7 | 1.2 | -20.6 | -2.1 | -1.0 | 1.4 | 0.2 |
| 2004 | 0.1 | 0.0 | -0.1 | 0.9 | -0.5 | -1.5 | -0.2 | 1.6 | -0.4 |
| 2005 | 0.7 | 0.0 | -0.9 | 0.2 | 0.6 | -0.3 | -0.7 | -23.7 | -0.1 |
| 2006 | 1.8 | 1.0 | -1.2 | 0.7 | 2.7 | -0.2 | -0.4 | -23.7 | 0.1 |
| 2007 | -0.2 | 1.3 | 2.0 | -0.7 | -20.6 | -2.1 | 0.1 | -23.7 | 0.1 |
| 2008 | 0.4 | 0.0 | -0.5 | -0.5 | -20.6 | -2.1 | 0.7 | -23.7 | 0.1 |
| 2009 | -1.7 | -2.1 | -0.1 | -3.7 | -20.6 | -2.1 | 0.7 | -0.7 | 3.8 |
| 2010 | 0.0 | 1.1 | 1.5 | -3.7 | -20.6 | -2.1 | -1.0 | -23.7 | 0.0 |
| 2011 | 0.0 | 0.5 | 0.8 | -1.2 | -20.6 | -2.1 | 3.7 | -23.7 | 0.2 |
| 2012 | 0.4 | 0.2 | -0.2 | 1.9 | -20.6 | -2.1 | 0.8 | 0.9 | -2.1 |
| 2013 | 0.1 | 0.6 | 0.7 | -3.7 | -20.6 | -2.1 | -0.2 | -23.7 | 0.0 |
| 2014 | 0.0 | 1.4 | 1.8 | -1.2 | -20.6 | -2.1 | -0.9 | -23.7 | 0.0 |
| 2015 | -3.3 | 0.0 | -2.2 | 1.4 | -20.6 | -2.1 | 0.2 | -23.7 | 0.0 |

Table17b. Anomalies of *Kiremt* onset, cessation and length of growing period at Aje,Shashamene and Kofele (1983-2015)

| | Kiremt | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Aje | | | Shashamen | | | Kofele | | |
| | SOS | EOS | LGP | SOS | EOS | LGP | SOS | EOS | LGP |
| 1983 | -1.2 | -0.6 | 0.0 | -1.1 | 0.5 | 1.0 | -0.5 | 0.5 | 0.7 |
| 1984 | 1.2 | -0.2 | -0.9 | -0.4 | -0.4 | -0.1 | 1.6 | -1.2 | -2.0 |
| 1985 | -1.0 | -3.6 | -3.0 | -0.7 | -0.4 | 0.0 | -0.7 | -0.9 | 0.1 |
| 1986 | -0.5 | -0.4 | -0.2 | -1.1 | 0.1 | 0.7 | -0.6 | 1.2 | 1.1 |
| 1987 | -1.8 | -0.4 | 0.6 | -1.2 | 0.9 | 1.5 | 2.0 | 0.5 | -1.3 |
| 1988 | 0.9 | 0.2 | -0.3 | -1.2 | 0.2 | 0.8 | -0.8 | -0.1 | 0.6 |
| 1989 | -0.7 | -0.5 | -0.1 | -0.8 | 0.5 | 0.8 | -0.4 | 2.2 | 1.5 |
| 1990 | -0.2 | 0.6 | 0.7 | 0.5 | -0.1 | -0.4 | -0.8 | -0.9 | 0.1 |
| 1991 | 0.3 | 0.1 | 0.0 | 0.3 | -1.3 | -1.3 | 0.7 | -1.8 | -1.6 |
| 1992 | 0.1 | 0.6 | 0.5 | -0.7 | 0.3 | 0.6 | -0.5 | 2.2 | 1.6 |
| 1993 | 2.0 | 0.6 | -0.4 | 1.1 | 1.1 | 0.4 | -0.9 | 0.9 | 1.2 |
| 1994 | 0.2 | -1.5 | -1.6 | 1.4 | 0.2 | -0.6 | -0.4 | -1.7 | -0.6 |
| 1995 | 0.5 | 0.2 | 0.0 | -0.4 | 0.1 | 0.3 | -0.2 | -1.1 | -0.5 |
| 1996 | -0.7 | 0.6 | 0.9 | -1.0 | 0.6 | 1.0 | -0.1 | -1.1 | -0.5 |
| 1997 | 0.2 | 1.0 | 0.9 | 0.1 | 1.3 | 1.1 | -0.8 | -0.5 | 0.4 |
| 1998 | 0.8 | 0.8 | 0.4 | 2.0 | 1.1 | -0.1 | -0.2 | 0.9 | 0.6 |
| 1999 | 0.2 | 0.8 | 0.7 | -0.1 | 0.0 | 0.1 | -0.9 | -0.2 | 0.6 |
| 2000 | 2.8 | 0.7 | -0.9 | 0.6 | 1.9 | 1.4 | -0.4 | 0.4 | 0.5 |
| 2001 | -1.2 | 0.4 | 1.0 | -0.9 | 1.6 | 1.9 | -0.3 | 0.4 | 0.5 |
| 2002 | -0.9 | -0.1 | 0.4 | 2.2 | -0.5 | -1.6 | -0.6 | -0.8 | 0.1 |
| 2003 | -0.8 | -0.3 | 0.1 | -1.2 | -1.6 | -0.7 | -0.2 | -0.1 | 0.1 |
| 2004 | 1.3 | 1.0 | 0.3 | -0.7 | -1.4 | -0.9 | -0.7 | 0.4 | 0.8 |
| 2005 | 1.1 | 0.2 | -0.4 | 1.0 | 1.6 | 0.8 | 2.6 | 1.6 | -1.2 |
| 2006 | 0.5 | 1.0 | 0.7 | 0.4 | -1.6 | -1.6 | -0.6 | 0.1 | 0.5 |
| 2007 | -1.2 | 0.9 | 1.6 | -0.4 | -1.6 | -1.2 | 1.5 | -0.9 | -1.7 |
| 2008 | 0.4 | 0.5 | 0.3 | -1.1 | -1.3 | -0.6 | -0.7 | 0.9 | 1.0 |
| 2009 | 0.5 | -2.6 | -2.9 | 1.2 | -1.6 | -2.1 | -0.2 | -0.3 | 0.0 |
| 2010 | -0.7 | 0.5 | 0.8 | 1.2 | -0.7 | -1.2 | -0.1 | -0.1 | 0.0 |
| 2011 | -0.6 | -0.6 | -0.2 | 1.0 | 0.5 | -0.1 | 0.5 | -0.3 | -0.5 |
| 2012 | 0.3 | -0.3 | -0.5 | 1.3 | -0.4 | -1.0 | 2.7 | -0.3 | -2.3 |
| 2013 | -0.5 | 0.3 | 0.6 | -0.6 | 0.3 | 0.6 | -0.9 | 0.0 | 0.7 |
| 2014 | -0.7 | 0.7 | 1.1 | -0.4 | 0.0 | 0.2 | 0.1 | 0.9 | 0.4 |
| 2015 | -0.6 | -0.5 | -0.2 | -0.4 | 0.0 | 0.2 | 0.5 | -1.0 | -1.0 |

### 4.7.3. Characterization of number of rainy days variability of the season

Fluctuation in number of rainy days from year to year is one of the challenges in recent. *Belg* and *Kiremt* mean NRD at Aje, Shashmene and Kofele were 30, 38, 46 and 44, 56 and 76 respectively. The NRD was fluctuating up and down around the long term mean. The positive anomalies of *Belg* NRD were 55% for Aje and 46% for Kofele and Shashemene. The number of positive anomalies of rainy days in *Kiremt* was 64%, 55% and 46% at Aje, Shashene and Kofele respectively. *Belg* and *Kiremt* negative anomalies were 48% and 30%, at Aje 52% and 42% at Shashemene and 48% and 54% at kofele respectively. *Belg* positive and negative NRD anomalies at Aje were 52% and 49% respectively. In Similarly *Kiremt* mean NRD was 64%, 30% and 6% above, below and equal to mean NRD s at this specific station. *Belg* and *Kiremt* of the last three decade at Shashemene showed anomalies of 49 % and 52% and 55%, 42 % and 3% equal to mean respectively.

*Belg* and *Kiremt* anomalies at Kofele were 52% and 49 % and 46%, 55% above and below long term mean respectively.

### 4.7.4. Droughts and dry-spells characterization

In this study the droughts of kiremt 1987 and 1993 at Aje were moderate while years 2009 and 2015 were extreme droughts. *Belg* drought of 1987 to 1989, 2008 and 2015 were moderate. Special characteristic of drought in year 2015 was, two consequent drought events; severe drought in *Belg* followed by extreme drought in *Kiremt* which made them the most devastating droughts caused major loss in crop production in the last 33 years. At Shashemene drought frequency and intensity was less particularly compared to Aje. As a result of this during the main rainy season severe drought occurred only in years2009 and 2010 and moderate drought in year 1994 and 2005.In *Belg* three severe droughts were occurred in years 2002, 2008 and 2013 and one moderate drought in year 2012.Drought condition at Kofele was less frequent and intense compared to both stations; only one extreme in year 2009 and four moderate drought in year 1988, 2011, 2012 and 2015.

In drought history of 1983 to 2015 four classes of droughts were occurred, which identified as mild, moderate, severe and extreme were droughts strongly associated with drought events. In these drought events history most of the prevailed drought were mild drought followed by moderate drought. Contrary to this, probability of occurrence of severe to extreme drought was very low. These droughts were categorized into annual, *Belg* and *kiremt* for which data analysis was done for 12, 3 and 4 months respectively. At Aje annual mild drought occurred in years ;1984, 1985,1988, 1992,1994, 1997, 1999, 2000, 2003 ,2004, 2009 and 2011-2013, moderate drought in year 1987, severe drought in years 2008 and extreme drought in years 2015.*Belg* mild drought in year 1989, moderate drought occurred in years 1984- 1987, 1992 -2000 except 1996, 2004, 2011, 2013 and 2014, severe drought occurred in years 1988,2008 and 2015,while *Kiremt* mild drought in years; 1984, 1991,1992,1997-2005, 2008 and 2012, moderate drought in years 1987and 1993,severe drought in year 1988, extreme drought in years 2009 and 2015.The annual mild drought occurred at Shashemene in years ;1984, 1986, 1991, 2001-2013 except 2002, 2009, 2010 and 2011, moderate drought in years; 2009-2015 except 2012 and 2013, severe drought 2002 and no extreme drought. There was mild drought during *Belg* in years; 1984, 1988, 1991, 1993, 1994, 1998, 1999, 2003, 2004, 2006, 2007, 2009, 2010, 2011, 2014 and 2015, moderate drought 1992, 2012 and 2013 severe drought 2002 and 2008 and no extreme drought case. *Kiremt* mild drought occurred in years; 1986, 1991, 2000-2008 except 2002 and 2005, moderate drought in years; 2002, 2003, 2011, 2014 and 2015, severe drought in years; 2009 and 2010 and no case of extreme drought. The annual mild drought occurred at Kofele in years; 1990, 1991, 1995, 2001-2013 except 2003, 2005, 2006 and 2011, moderate drought, in years; 1984, 1994, 2005, 2011, 2015, severe drought in year 2012 and no case of extreme drought. *Kiremt* mild drought during 1984-1986, 1989, 1991, 1994, 2002, 2005, 2008 and 2010, moderate drought during1988, 2011, 2012 and 2015, no case severe drought and extreme drought in 2009, *Kiremt* mild drought during 1987-1991 except 1988, moderate drought 2001, 2005, 2007, 2010, 2013 and 2014 and no cases of severe and extreme droughts.

At Aje *Belg* extreme precipitation events; (drought verses wet event) years were; 1986 and 1993 moderately wet, years 1983, 1990 and 2010 very wet and year 2007 was extremely wet. During the year 1983 very wet *Belg* was followed by extreme wet *Kiremt*, while the reveres occurred in year 2007. On the other hand, in year 1987 both seasons were moderately dry. Moreover, in year 2009 extreme wet *Belg* was followed by extreme dry main rainy season which resulted in no rainy days with rainfall exceeded 1mm was recorded within a day.

At Shashemene, *Belg* 1983 was extreme wet and years; 1985, 1987, 1996, 2000 were wet. On the other hand, *Belg*; 1989, 1990, 1995 and 1997 were moderately drought years. Moreover, the main rainy season of year 1996 was extreme wet, while, years; 1993, 1994 and 1998 were very wet at Shashemene. To sum up years; 1983, 1986, 1990, 2007and 2010 were moderately to extremely wet.

Over the high land (Kofele) frequency and intensity of wetness was more compared to the rest of stations. During the main rainy season year 1983extreme wet and years; 1985, 1996, 2000 were very wet years and 1989, 1990, 1995 and 1997 were moderately wet. On the other hand, years 1993, 1994, 1996, 1998 and 2013 were found to be moderately to extremely wet at Kofele during *Belg*, while moderately to extreme wet moisture status exhibited in 1985,1988,1992,1999 and 2003 during the same season.

Table18. Different drought types and frequency of occurrence in number and percent at Aje,Shashamene and Kofele (1983 to 2015)

| Station | Season | Milddrought | | Moderate drought | | Sever Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| | | % | Freq | % | Freq | % | Freq | % | Freq |
| Aje | Annual | 45.5 | 15 | 3 | 1 | 3 | 1 | 3 | 1 |
| | *Belg* | 48.5 | 16 | 3 | 1 | 9 | 2 | 0 | 0 |
| | *Kiremt* | 42.4 | 14 | 6 | 2 | 3 | 1 | 6 | 2 |
| Shashem | Annual | 36.4 | 12 | 15 | 5 | 3 | 1 | 0 | 0 |
| | *Belg* | 48.5 | 16 | 9 | 3 | 6 | 2 | 0 | 0 |
| | *Kiremt* | 27.3 | 9 | 15 | 5 | 6 | 2 | 0 | 0 |
| Kofele | Annual | 33.3 | 11 | 15 | 5 | 3 | 1 | 0 | 0 |
| | *Belg* | 30.3 | 10 | 12 | 4 | 0 | 0 | 3 | 1 |
| | *Kiremt* | 39.4 | 13 | 18 | 6 | 0 | 0 | 0 | 0 |

### 4.7.5. Characterization of temperature variability

This study revealed that mean monthly maximum temperature at Aje varied from 25 $^{0}$C and 30 $^{0}$C during the last 3 decade with SD and CV ranged from 0.98°C to 3.08°C and 3.6% to 10.6% in January and December respectively (Table16.). Mean monthly minimum temperature at Aje concentrated around 10°C moved up in and down during the study period. While mean temperature concentrated around 20°C slightly oscillate up and down. And retry December was the hottest months and maximum temperature varied more in December and less in January than the rest of the months. The SD and CV values range from 0.7°C to 1.7°C and 5.5% to 15.8% varied less in month of September and more in December respectively. This indicated that minimum temperature more variable compared to maximum temperature. December is the hottest month with monthly mean maximum temperature of 28.9°C.The coolest months was November with monthly mean minimum temperature of 10.4 °C. Kofele concentrated close to 15 and moves up and down. Mean monthly maximum temperature over the high land (Kofele) was concentrated around 20°C with SD and CV varied from 0.68°C to 1.4°C and 3.5% to 6.4% in October and March respectively. Mean monthly minimum varied from 5°C to 10°C. The SD and CV varied from 0.98°C to 1.2°C in April and July and 1.8% to 2.0%in December and January respectively. Mean monthly mean ranged from 10°C and 15°C.These results indicated that variability in temperature was less over high lands compared to the low lands.

## 4.8. Impact of Climate Variability on Selected Six Major Crops

### 4.8.1. Rainfall variability under different ENSO phases and impact on major six crops yield

The occurrence and frequency of different ENSO phases during 1995 to 2014 or the last 20 years El Nino years were 7 (1995, 1998, 2002, 2003, 2007 and 2010), La Nina 9 (1996, 1997, 1999, 2000, 2001, 2008, 2009, 2011 and 2012) and normal years were only 4 (2004, 2006, 2013 and 2014) When expressed as a percentage La Nina was 45%, El Nino 35% and normal was only 20%.These percentages indicate how climate variability becomes serious and normal dramatically diminishing at current time. In relation with these very high climate irregularities, six selected crops; *tef,* wheat, maize, haricot bean, onion and potato yield analyzed indicated fluctuated highly during this period. The coefficient of variation (CV %) of crop yield was ranged from 18.5% to 36.4%. CV for *tef,* wheat, maize, haricot bean, onion and potato were; 23%, 33%, 28.6%, 36.36, 21.1% and 18.5% respectively. Potato yield is less variable, *tef* and maize moderately and wheat and haricot bean were vulnerable to drought.

Table 19. Descriptive statistics of selected crops yield for year (1995- 2014) from (CSA).

| Crops | Mean | SD | CV | Max | Min |
|---|---|---|---|---|---|
| Tef | 11.06 | 2.06 | 23.61 | 15.47 | 7.35 |
| Wheat | 19.51 | 6.46 | 33.12 | 34.43 | 10.75 |
| Maize | 24.70 | 7.07 | 28.61 | 39.12 | 15.01 |
| Haricot bean | 10.46 | 3.8 | 36.36 | 19.68 | 4.37 |
| Onion | 89.28 | 18.87 | 21.14 | 134.8 | 57.49 |
| Potato | 82.89 | 15.30 | 18.46 | 131.25 | 71.01 |

### 4.8.2. Six major crops risk assessment during three SST phases

4.8.2.1. *Tef* crop yield risk analysis under three ENSO phases

Twenty years of crop data associated with seasonal ENSO phases of 7 El Nino years, 9 La Nia years, and 4 Neutral years result showed that, the dominating variable would be preferred by any decision maker who prefers "more" to "less", regardless of the attitude towards risk. La Nina phase is preferable, since cumulative density function (CDF) of plot of line of *tef* yield during La Nina phase is to the right of CDF plot during El Nino phase, as described in *tef* yield CDF production in (Figure 12) which illustrated that, those CDFs of *tef* yield during La Nina SST phase are dominant relative to crop yield CDF of during 'El Nino' SST phase in the first stochastic dominance (FSD) sense. This means that for every risk percentile point on the Y axis, a farmer gets at least x amount of more crop yield from CDF of Normal or La Nina SST phase as compared to the yield from CDF during El Nino SST phase. This analysis confirmed that *tef* practically need more moisture at sowing for better yield and La Nina phase fulfils this condition. The seasonal climate information may further support in the selection of crop variety or types, field allocation and other strategic management activities with respect to less crop risks.

The cross-over between CDF during La Nina phase and CDF during Normal phase implies in (Figure 12) that curves meet the requirements for second stochastic dominance (SSD) and the comparison should be handled using the higher order stochastic dominance techniques to be the first choice as described by (Mc Carl, 1996).

Comparing the total area under the CDF of (Figure 12), during Normal phase is bigger than CDF during 'La Nina' phase at upper percentile points. SSD requires that the area under the cumulative density function during normal SST phase at lower tail is smaller than the area under the cumulative density function during La Nina phase at upper tail as described in (Figure 12).Therefore, during ‘Normal’ phase standard algorithms for identifying stochastic dominance utilize pair-wise area comparisons of *tef* yield distributions CDF during La Nina and Normal phase for *tef* production yield has better performance. Every risk-averse, farmer therefore prefers Normal phase alternative that dominated by SSD. Therefore, Normal phase is found to have the best risk efficient set identified for *tef* production planning. *Tef* yield has good performance during Normal SST phase than El Nino and La Nina phase; users can make comparisons based on alternate ENSO forecasts for further insight for crop risk planning and management strategy.

4.8.2.2. Wheat yield risk analysis under three different ENSO phases

Wheat crop yield CDF during Normal phase lied to the left of CDF during La Nina at the lower level of the yield data series, meaning that the during La Nina phase alternative is better choice in this range of the yield data distribution, while CDF during La Nina lies to the left of CDF during Normal at the upper tail of the series, meaning that during Normal phase is a better and less risky choice in the upper range of the wheat yield (Figure 12).

Comparing the total area under the CDF (Figure 12), during Normal phase is bigger than the CDF during La Nina phase at the upper percentile points. SSD requires that the area under the cumulative density function during normal SST phase at lower tail is smaller than the area under the cumulative density function for the La Nina phase at the upper tail as described in (Figure.12).Therefore, during Normal phase standard algorithms for identifying stochastic dominance utilize pair-wise area comparisons of wheat yield distributions CDF during La Nina and Normal phase for wheat production yield has better performance. Every risk-averse, farmer therefore prefers Normal phase alternative that dominated by SSD. Therefore, Normal phase is found to have the best risk efficient set identified for zone crop production planning. Crop yield has good performance during Normal SST phase than during El Nino and La Nina phase; users can make comparisons based on alternate ENSO forecasts for further insight for crop risk planning and management strategy.

4.8.2.3. Maize yield risk analysis under three different ENSO phases

Maize crop yield CDF during Normal phase lied to the left of CDF during the La Nina phase at the lower level of yield data series, meaning that during La Nina phase the alternative is better choice, while CDF during El Nino lied to the left of CDF during the Normal at the upper tail of the series, meaning that during Normal phase it is better and less risky choice in the upper range of the maize yield (Figure 12).

In maize yield data series plot, El Nino CDF is found to the right of both La Nina and Normal CDFs at the lower level of the yield data series. This situation indicates that maize is more sensitive to time of planting and dry planting is less risk compared to delay planting. In related study Camberlin and Okoola (2003) observed a reduction of 25–30% in maize yield in Kenya due to a 20-day delay of the main rainfall season. Normal CDF was to right of El Nino CDF at upper or SSD in indicates that maize need sufficient moisture at flowering and grain feeling stage for better yields.

4.8.2.4. Haricot bean yield risk analysis under three different ENSO phases

El Nino CDF of haricot bean was at the right of La Nina CDF during FSD and the two lines were very close to each other indicating that both phases were risk and not suitable for haricot production. The haricot bean production decision making is less risk during El Nino years compared to La Nina during FSD. At upper side La Nina CDF shift to the right of El Nino CDF indicating haricot bean production decision was less risk compared to El Nino CDF during SSD. Unlike cereals growing haricot bean during La Nina more risky implied it need normal condition for better yield and minimum risk. This situation indicated that it is more risk to decide to grow this crop compared to the rest five crops under La Nina phase (Figure 12).

4.8.2.5. Onion yield risk analysis under three different ENSO phases

La Nina CDF line found to the right of both Normal and El Nino CDFs during FSD. This implied that decision making for growing onion was less risk and gives better yield compared to both CDFs. On the other hand, during SSD lines of CDFs of El Nino and La Nina were reversed indicating decision making for growing onion during El Nino was less risk and resulted in good yield compared to La Nina years. El Nino CDF showed that yield of onion even better yield than normal year CDF. This indicated that onion more sensitive to excess moisture than moisture stress at later of growing period (Figure 12).

As result onion indicated positive or good response to El Nino year more than the rest five crops. Justification this positive response can be due to main possible reasons of yield affecting factors; Irrigation and agricultural input utilization are relatively costly but more reliable technique for ameliorating the moisture constraint in areas with short growing periods. Another very important point is that when water supply (rainfall) doesn't meet crop water requirement, crops vary in their response to water deficient.

Moreover, according to survey interview made among farmers reporting an increase in crop yields, 64% attributed the increase to good rainfall, 23% to fertilizer use, and 5% to better seeds. Although rainfall is the main explanation for most crops, fertilizer is commonly given as a reason in the case of several cereals (particularly black/mixed *tef* and wheat), vegetables, onions, and potatoes (Nicholas M. and Bradley S., 2013).

According to (Alemayehu,2008) report; out of a total of more than 12.3 million hectares cultivated existing irrigation schemes cover less than 2 percent – with higher shares in fruits and vegetables cultivation. Almost 14% of the farms in the four main regions of Ethiopia have irrigation on at least one plot of land for at least one of the two planting seasons. The percentage of farms with irrigated land is highest in Oromiya (23%) and less than 10% in the other three regions. The survey data also allows us to calculate the percentage of agricultural land that is irrigated. Overall, about 3% of cropland is irrigated. Again, the percentage is highest in Oromiya (almost 6%) and less than 2% in the other three regions.

Within the 2006/10 Plan for Accelerated and Sustained Development shows a shift in strategy toward a more market-oriented agriculture. Increasing the production and export of higher value commodities such as horticultural products would be a feasible primary target for such an effort Alemayehu (2008). Main instruments to achieve these objectives are: improvement of specialized extension services; the promotion of specialized export crops (such fruits and vegetables); increase of irrigated area through multi-purpose dams; introduction of reforms to improve the availability of fertilizer and seeds FAO (2010). Through the Productive Safety Net program scheme; public works in soil and water conservation, water harvesting, small-scale irrigation, horticultural development and water supply schemes. Extension workers are expected to provide advice to identify investment opportunities to develop new farm income-generating activities FAO (2010). All these programs contributed a lot for improving intensive vegetable production particularly during El Nino phase, contrary to extensive cereal crops producing farming system FAO (2010).

In addition to these, in drought years agricultural activities were delayed by late on set of season and erratic rainfall which affect more extensive field crops grown on large area than intensive vegetables farm relatively grown on small area due to difference management practices. When *Belg* rain was well below normal level plantings were disrupted by the late *Belg* rain which led to the failure of many *Belg* crops caused poor yields of long-season maize normally planted in April and May or to their substitution by short-season crops such as *tef*, wheat and pulses that are normally planted with *Meher* rains in June and July FAO (2010).

Moreover, area expansion of field crops reduce yield per unit area especially more exacerbated during drought years due to moisture stress and shortage time to carry out agricultural activities on time. Cereal production shares the constraints and potentials associated with crop production more broadly. All aforementioned idea can be taken as supportive idea of onion yield positive response El Nino phase. The Central rift valley region which is supposed to start large scale irrigation since 1970s is expected to use wisely these potential particularly in times when the rain stops (Gashaw, 2009). Commercially valuable crops were commonly grown and this is good opportunities for farmers previously practicing rain fed farming. Further elaborating these supportive ideas; since 1998, the subsidy on fertilizer has been withdrawn while the price of fertilizer has risen. This high price forced farmers to hesitate to use fertilizer particularly during drought years on field crops and shift to use on vegetables. In 2002, many farmers were heavily in debt and withdrew from the fertilizer schemes. The expanding horticultural production is making increasing use of chemical inputs, often with little or no understanding of how to use them correctly Alemayehu *(2008)*.

The limited use of modern inputs is a major characteristic of cereal production in Ethiopia that explains its current low productiveness. Consider fertilizer application, only about 40 percent of cereal hectare benefit from chemical fertilizers Alemayehu *(2008)*. Farmers fear risk to apply fertilizer as normal year and applied amount itself do not properly used by crops due to moisture stress and cause yield reduction. Ethiopia totally depends on imports to meet its annual fertilizer demand. The fertilizer application rates for *tef*, wheat, maize, and barley are generally in the range of 50 to 100 kg/ha. The fertilizer application rate for vegetables is also high, which is not surprising given that they are high-value crops that respond well to fertilizer FAO (2010), although it is important to recognize that vegetables are typically grown on very small plots. Potatoes, onions, and other vegetables have fertilizer application rates of more than 45 kg/ha. The fertilizer application rates of vegetables are low compared with cereals FAO (2010). This indicates that vegetables are high value crops and need less fertilizer per unit area but give more yields per unit area and planted on small area compared to cereals. This condition made farmers not hesitate to use fertilizer even during drought year which inverse is true for cereals.

In extending the discussion, two types of *tef*, wheat, and other cereals are often fertilized (more than 50% of the plots) but less commonly receive manure (less than 15% of the plots). In contrast, maize commonly fertilized (less than 50% of the plots), but receive manure more often (more than 15% of the plots). Percentage of crops received *tef* white 9.8, Black/mixed *tef* 6.8, wheat 13.1, maize grain 37.3, haricot bean 7.5, onion 36.4 and potato 53.1 respectively FAO (2010). This application of organic fertilizer gives advantages for onion during drought years.

4.8.2.6. Potato yield risk analysis under three different ENSO phases

La Nina CDF line found to the right of both normal and El Nino CDFs during FSD which implied that decision making for potato production during La Nina years was less risk and resulted in better yield compared to El Nino and normal CDFs. During SSD this situation reversed; normal and El Nino CDFs were presented to right position of La Nina CDF. This condition implying that decision making for growing potato during La Nino years was more risk and fewer yields at SSD. This indicates potato more sensitive to excess moisture during late growing period and to moisture deficit at early stage (Figure 12).

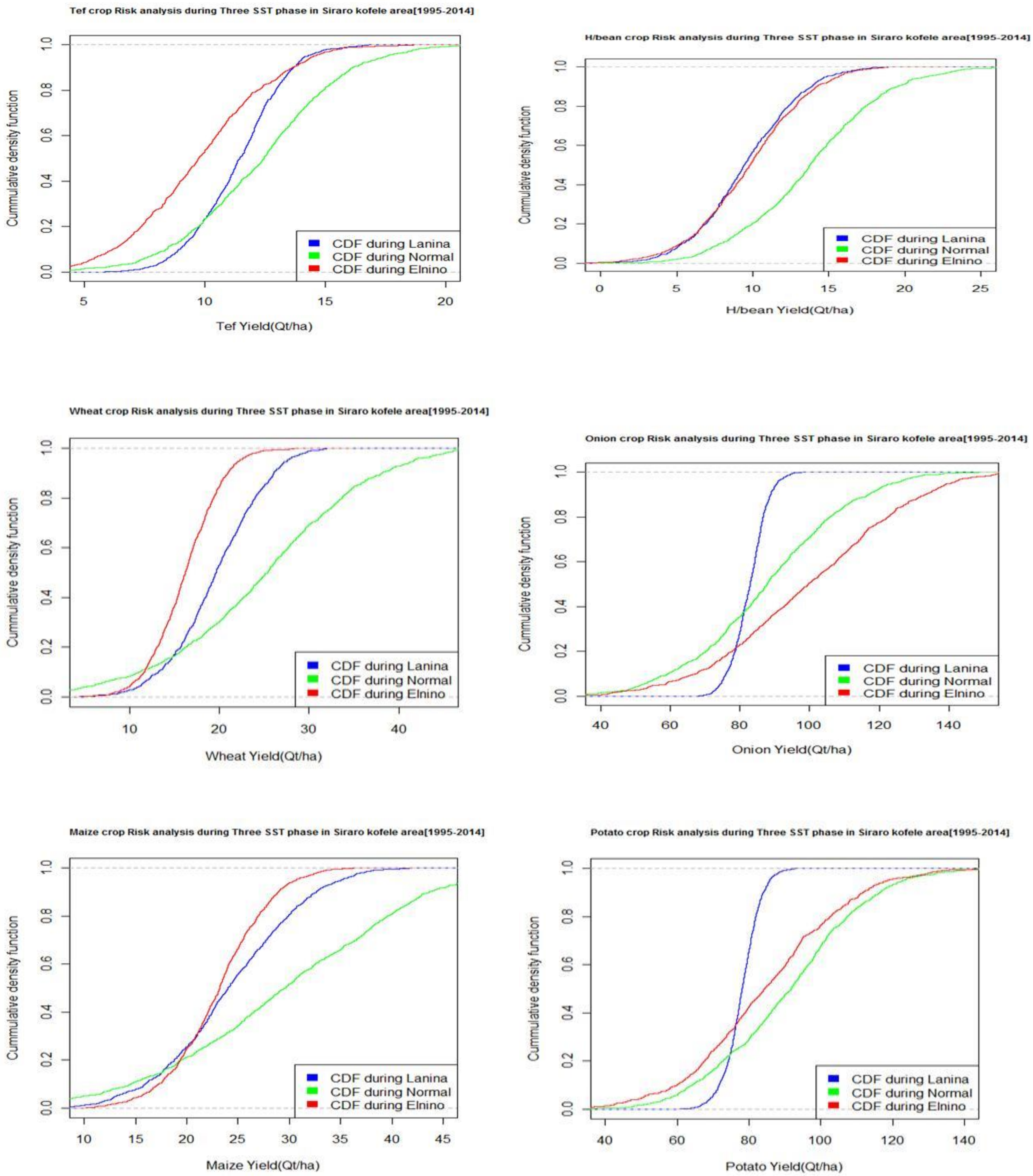


Figure 12. *Kiremt* tef, wheat and maize yield risk analysis under different ENSO phases at west Arsi zone (1995-2014).

### 4.8.3. Impact of temperature variability on major six crops yield

Impact of mean annual maximum, mean annual and mean annual minimum temperature of Aje and Kofele showed in (Figure 13). Since recorded temperature at Shashamene was less than 5 years analysis d was not done. At Aje mean annual maximum temperature negative anomaly was experienced in years; 1986, 1990, 1996, 1998, 2008 while positive anomaly was received in 1984, 1987, 1997 and 2009- 2012. Similarly, at Kofele lower mean annual minimum temperature lower than long term mean recorded in years; 1983-1990 and 2010-2013 and warmer minimum (positive anomaly) or mean annual temperature exhibited in years; 1988, 2002-2006.In year's annual mean temperature was above and below long term mean temperature , crops suffer excess and deficit heat required. This situation explained more in crops heat requirement analysis in growing degree day indicated (Figure 13).


Figure 13 Mean annual maximum, minimum and mean temperature in (C°) at Aje and Kofele (1983-2015)

### 4.8.4. Impact of temperature variability on crops heat requirement

Seasonal and monthly variability of temperature has negative impact on the proper sowing and phenology of crops. This study identified relationship between mean temperature and crops growing degree day (GDD) in (Figure 16).This figure was prepared by dividing annual mean

GDD by ten to bring the number closer to mean annual temperature for smoothing the figure. During cold years mean temperature of the study period, GDD and crops yield were indicated negative anomalies (below the long term mean). At Aje and Kofele in years 2007 and 2013 indicated extreme negative anomalies were observed (Figure 14). On the other hand, at Kofele years 1987, 2009, 2015 and at Aje and 1998 and 2015 were extreme positive anomalies years (Figure.16). In short when mean temperature indicated negative anomaly or decreasing both GDD and crops yield showed negative anomalies and deviation below normal as illustrated in 2013 (Figure.14). This process needs warming practice to reduce heat deficit that cause decline in crops yield. Contrary to this in warmers years when mean temperature is exceeds long years mean crops suffer excess heat that shorten LGP and need cooling management to reduce risk on yield.

The monthly mean degree day totals, cumulative monthly mean and annual cumulative degree-days were illustrated in (Table 20a to d and Figures 14, 15). The GDD was positively correlated with mean temperature and temperature anomalies indicated in (Figure15). The total degree day of selected crops for study were demThis result indicated that crops face heat deficit which elongated LGP and implicate decreasing in GDD and crops yield. onstrated for comparison as follows , 638- 1631 for tef, 1538-2000 for wheat, 800-3000 for maize, 1100-2450 for haricot bean, growing degree day of onion is not available and 3655 for potato Jasper W. (2005). Onion photoperiod requirement was not satisfied prior to the accumulation of 600degreedays (Lancaster, *et al*.1996).This study revealed a cumulative degree day variation from 1000 to 6000 (Figure 14).

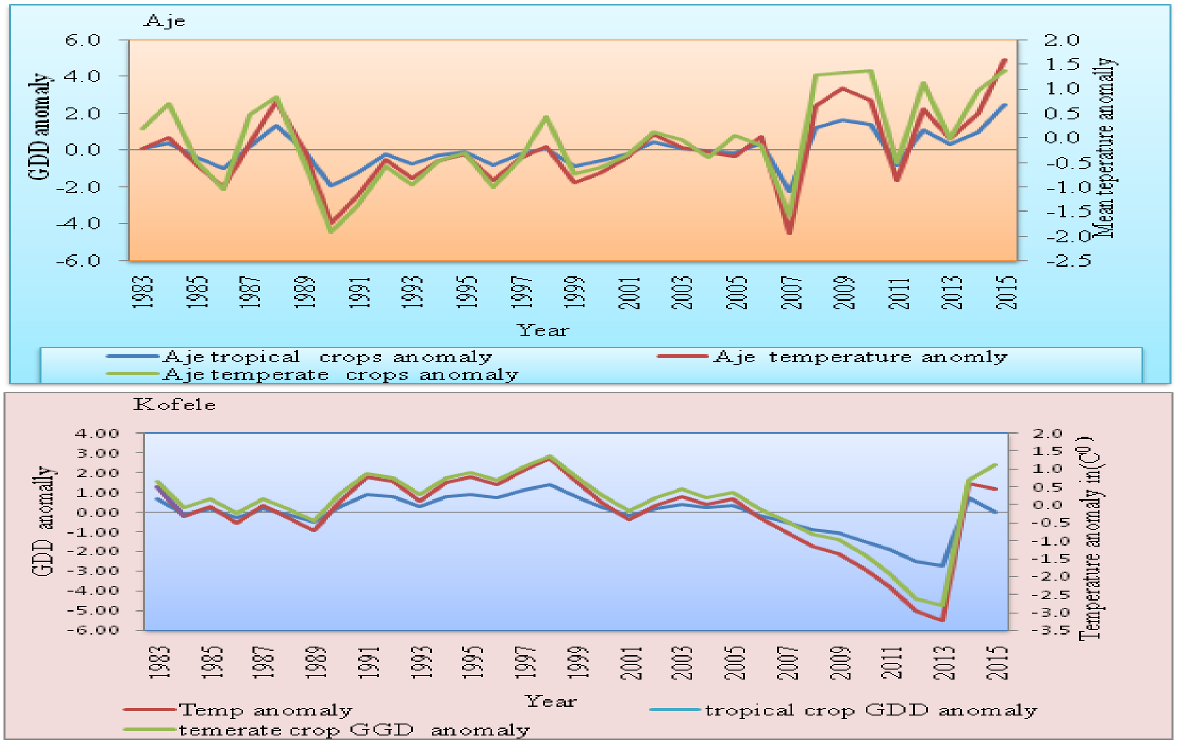


Figure 14. Annual mean temperature and GDD anomalies of selected crops at Aje and Kofele(1983 to 2015)

Table 20a. Monthly growth degree day of crops with base temperature of $5.5^{0}$C at Aje (1983-2015).

| | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 427 | 405 | 475 | 453 | 462 | 437 | 429 | 421 | 413 | 424 | 409 | 439 |
| SD | 27 | 26 | 36 | 24 | 20 | 29 | 28 | 21 | 19 | 22 | 28 | 30 |
| CV | 11 | 58 | 59 | 59 | 57 | 57 | 57 | 57 | 58 | 58 | 58 | 55 |
| Median | 423 | 412 | 474 | 447 | 463 | 433 | 427 | 418 | 413 | 424 | 403 | 439 |
| Max | 487 | 446 | 568 | 517 | 508 | 505 | 486 | 476 | 454 | 483 | 481 | 496 |
| Min | 370 | 336 | 382 | 404 | 418 | 355 | 371 | 385 | 354 | 389 | 366 | 360 |

Table 20b. Monthly Growth degree Day for crops with base temperature of $10^0C$ at Aje(1983-2015).

| | Jan | Feb | March | April | May | June | July | August | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 288 | 279 | 336 | 318 | 323 | 302 | 290 | 282 | 278 | 284 | 274 | 299 |
| SD | 28 | 25 | 36 | 24 | 20 | 29 | 28 | 21 | 19 | 22 | 28 | 31 |
| CV | 10 | 9 | 11 | 8 | 6 | 10 | 10 | 8 | 7 | 8 | 10 | 10 |
| max | 347 | 316 | 428 | 382 | 369 | 370 | 347 | 336 | 319 | 343 | 346 | 357 |
| MIN | 231 | 210 | 243 | 269 | 278 | 220 | 231 | 246 | 219 | 249 | 231 | 220 |

Table 20c. Monthly growth degree days of crops for base temperature of $5.5^0C$ at Kofele (1983-2015)

| | Jan | Feb | March | April | May | June | July | August | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 232 | 253 | 303 | 307 | 318 | 313 | 324 | 341 | 358 | 379 | 382 | 196 |
| SD | 89 | 143 | 197 | 259 | 317 | 380 | 441 | 505 | 569 | 629 | 691 | 62 |
| CV | 38 | 57 | 65 | 84 | 99 | 121 | 136 | 148 | 159 | 166 | 181 | 32 |
| Median | 235 | 238 | 279 | 263 | 265 | 233 | 230 | 230 | 228 | 237 | 217 | 215 |
| Max | 461 | 741 | 1007 | 1272 | 1509 | 1738 | 1968 | 2196 | 2426 | 2640 | 2871 | 264 |
| Min | 13 | 12 | 11 | 11 | 13 | 13 | 16 | 15 | 14 | 14 | 14 | 13 |

Table 20d. Monthly Growth degree Day for crops with base temperature of $10^0C$ at Kofele (1983-2015)

| | Jan | Feb | March | April | May | June | July | August | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 96 | 113 | 141 | 130 | 126 | 102 | 91 | 91 | 93 | 91 | 79 | 80 |
| SD | 30 | 29 | 32 | 29 | 34 | 31 | 34 | 33 | 32 | 32 | 30 | 28 |
| CV | 31 | 25 | 22 | 23 | 27 | 31 | 37 | 36 | 34 | 35 | 37 | 35 |
| Median | 101 | 118 | 146 | 134 | 135 | 107 | 99 | 94 | 97 | 97 | 83 | 81 |
| Max | 146 | 165 | 192 | 192 | 181 | 147 | 149 | 137 | 140 | 144 | 146 | 125 |
| Min | 30 | 41 | 63 | 46 | 20 | 12 | 4 | 4 | 8 | 10 | 14 | 19 |

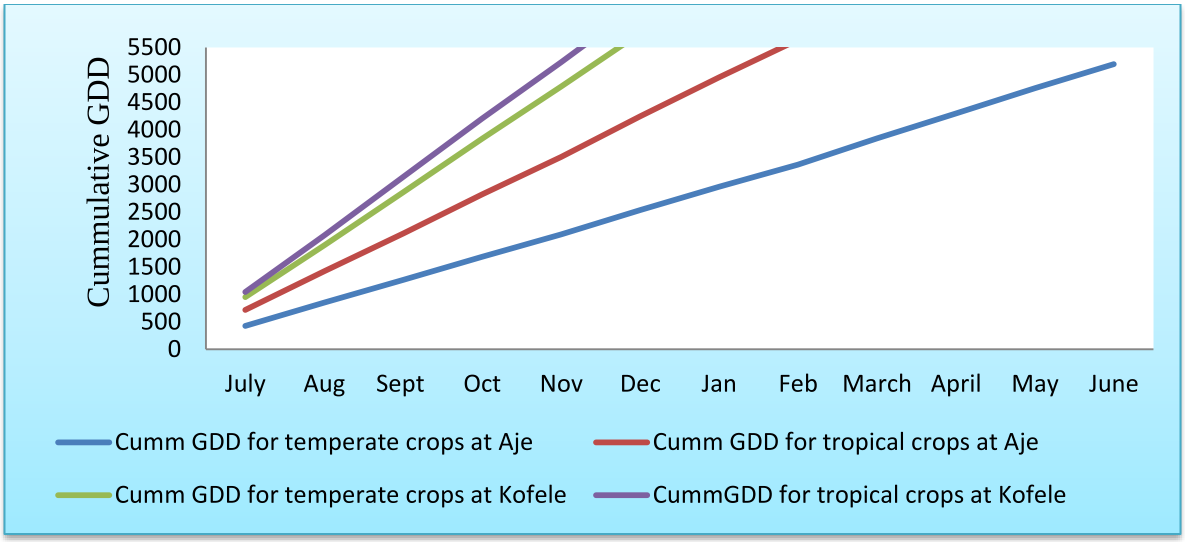


Figure 15.Monthly cumulative mean growing degree day at Aje and Kofele

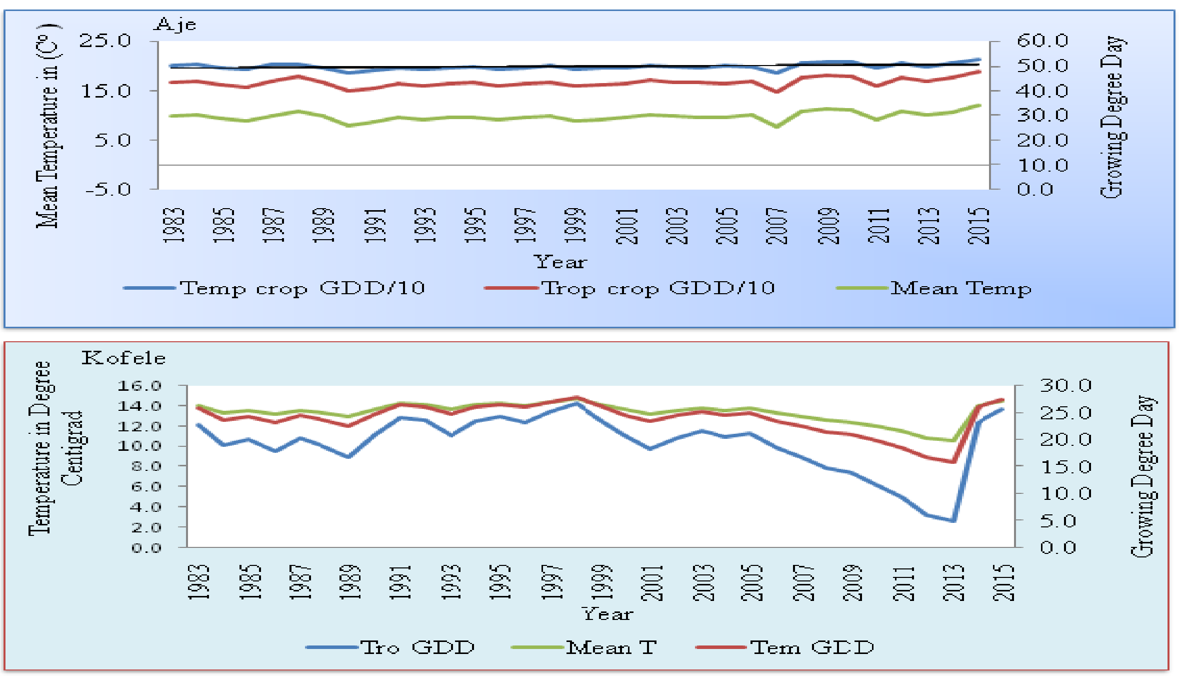


Figure 16. Annual mean temperature and mean growing degree days of crops in tenth at Aje and Kofele (1983-2015).

## 4.9. Agro meteorological Advisory to Mitigate Impact on Crops Yield under Different ENSO Phases

Unstable patterns in rainfall seasonality underscore the importance of improving access to current agro meteorological information, forecasts and advisories to inform farm level decision making and to maximize their production and reduce climate related production losses. The emerging ability to provide timely, skilful climate forecasts offers the potential to reduce human vulnerability to agricultural impacts of climate variability through improved agricultural decision making, to either prepare for expected adverse conditions or take advantage of expected favorable conditions as climate is a constraint (have certain threshold suitable for specific crop), climate is hazard (extreme cases) and climate is a resource (that can be used as in put like other natural resources).

Thus, it requires improving of agro meteorological information, forecasts and advisories, including a critical review of the status of agro meteorological services in the country, as there is a strong need for capacity building in this area. Finally, a general framework was given on how agro meteorological advisory service in recent future can be integrated with agricultural extension services package so that it can be an important component of the climate variability mitigation tool.

In order to plan seasonal agricultural cropping; the following five key factors need to be characterize a rainfall season for crop production; Onset ,cessation dates, rainfall amount, distribution of rainfall over the seasons duration (patchiness, including dry spells and their lengths) and rainfall intensities, frequency of rain days, average daily rates of precipitation appear to be of interest to farmers.

### 4.9.1. Crop planning during *Kiremt* El nino and *Belg* La Nina phases

Both of these phases suppress seasonal rainfall and result in inadequate moisture or below normal rainfall and some places may be get much below normal or pocket areas may face serious moisture stress. Keeping in view of the below normal rainfall during coming *Kiremt* El Nino and *Belg* La Nina seasons, farmers are advised to cultivate less area for crops need of *tef* and onion and potato with keeping in mind possibility of supplementary irrigation either from rain or other moisture source and plant less maize and haricot bean .Plant more of early maturing or short cycle varieties. Reduce or avoid late maturing long cycle and more water demanding maize varieties and cultivars particularly over the low lands. Farmers are also advised to diversify these crops into extensive and intensive farming to manage water stress or reduce risk. This is not to mean potato and vegetable are more tolerant to moisture stress but they are more suitable for mater management. For instance when onset is too late it is possible to Keep horticultural crops (onion) seed seedling in nursery until rain comes or in those areas where irrigation facilities are available is crucial for drought risk management. Moreover, Farmers are also advised to procure good quality seeds from certified sources. Therefore, where irrigation facilities are available, onion and potato are good candidates for irrigation and intensive farming and should expand. Haricot bean need more normal condition and area to be planted should reduced and moisture tolerant early maturing short cycle varieties should be planted. Moderately decrease in amount of fertilizer to be used and reducing frequency of tillage during field preparation help for on time sowing of crops and moisture conservation. Appropriate agricultural practices and water conserving mechanisms such as in-situe and ex-situe should practice to reduce moisture losses.

Generally, *tef* crop is more tolerant to moisture stress than other cereals particularly at later time of growth and should expand. Moreover, onion is high value and it is suitable for irrigation and should be intensify more than cereals to minimize risk of prevailed drought.

Thus, to reduce moisture stress during cropping season onion and potato are more suitable for water management as they are high value crops and yield per unit area is very high. Therefore, crop planning during different ENSO phases should give due attention to onion and during El Nino and need more of these crops as expense of cereals with appropriate agronomic practice, moisture conservation structures or mechanisms and supplementary irrigation should be practice. As the study resulted showed, the determining climatic factors were temporal and spatial distribution of rainfall than amount received.

#### 4.9.2. Crop planning during *Kiremt* La nina and *Belg* El Nino phases

Both of these phases or situations are accelerate or intensify seasonal rainfall. Above normal rainfall expected during *Belg* facilitate planting of more of excess tolerant crops varieties maize.

Planting onion and potato also good as high value are high value vegetables and suitable harvesting than the rest. Contrary to this, planting these vegetables during *Kiremt* is risk due excess moisture and related problems. Reduce planting excess moisture sensitive crops such as haricot bean and wheat and increase excess moisture tolerant cereal crops such as *tef*. Because of excess moisture prevalence during this period, slight increase in amount of input utilization is paramount important. Adjusting proper time of planting is critical in order to balance or reduce more vegetative growth as expense of reproductive growth. Increase density of planting is also help to reduce excess moisture. Avoid planting of water logging sensitive crops at low laying farms and making channel to around the farm protect excess run off entering into the farm. Therefore, at the time of La Nina period during *Kiremt* more of cereals as expense of vegetables should be planted with proper excess moisture draining mechanisms and agronomic practices. However, since very high rainfall is expected in these areas during July and August and also the *Kiremt tef* production is preferable because of better excess moisture tolerance than other crops. *Tef* is more suitable to both conditions moisture stress and excess condition than the rest.

### 4.9.3. Crop planning during normal or neutral phase

When normal or close to normal rainfall will anticipated, adequate or moderate conditions will expect. More or less near normal agricultural practices, cropping and activities should be done. During this period, before decide what to plant, when to plant and how to plant it is quite important to determine economic importance or cost benefit analysis should be considered to select crop to plant. This is to say more of high yielding should be selected. Hence, crops like wheat, *tef*, and haricot bean which need moderate water have medium life cycle varieties should be expanded. Since during normal years rainfall is normal and suitable for all crops; selection of more profitable crops should be performed with caution.

Sequential cropping; planting onion, potato and haricot bean and green maize during *Belg* and *avoiding tef* and wheat to reduce harvesting risk. Inversely, plating *tef* and wheat during *Kiremt* and reducing onion and potato reduce pest and disease attack .For plating maize over high land (Kofele) heat stress tolerant varieties should be selected. Similarly, when need arise to plant wheat over the low lands (Aje) excess moisture resistant cultivar must be selected.

#### 4.9.4. Temperature

Although, impact of temperature is not significant compared with rainfall, it is clear that during rainy season associated with cloudy condition cold temperature can affect crops heat requirement (GDD) and crops yield. Contrary to this condition, dry and sunny condition can create excess heat and unfavorable condition that aggravate moisture stress. Therefore, all possible warming and cooling mechanisms should be used to reduce unfavorable extremes on crops growth.

#### 4.9.5. Agro meteorological advisory to Mitigate or reduce crops failure risks for forecast combinations of *Belg* and *Kiremt* seasons

As this study demonstrate in drought frequency and intensity occurrence, extremes cases were rare while, none extreme combination were frequently occurred. Thus, it is very crucial to give some important agro meteorological advisories to reduce impact on crops yield.

4.9.5.1. When dry *Belg* forecasted and dry *Kiremt* is prospected

During these period both seasons are dry and make copying mechanisms very difficult as it usually expose community to hanger. If other source of moisture other than rain is available, the first choice is onion growing as intensive farming with supplementary irrigation and staying in nursery with relatively small amount. Depending on degree and intensity of dry condition short cycle moisture stress tolerant *tef*, haricot bean is second choice if certain amount of moisture is received.

4.9.5.2. When dry *Belg* forecasted and normal *Kiremt* is prospected

The same procedure should be followed as mention above during *Belg*. But during the main rainy season it needs intensive moisture conservation practices. On top of this, since this situation is conducive or favorable for all six crops, crop selection is function of selecting crops that can compensate loss occurred during *Belg*. Thus, onion, potato and maize should be first choice as yield per unit area and price is high. All planting should be done as soon as possible. Proper moisture conservation agronomic practices can assist moisture loving crops; such as maize to fulfill water requirement.

4.9.5.3. When dry *Belg* forecasted and wet *Kiremt* is prospected

Again, chance of cropping is also low and force to use supplementary irrigation if moisture source rather than rain is not limiting factor. This condition also force to give due attention for supplementary irrigation which make to select onion because of its conducive for irrigation and high yield per unit area. During *Kiremt* season wet condition favored growing moisture loving and excess moisture tolerant short cycle crops. Therefore, short or three month maize varieties and *tef* should be selected increase in area of production. Onion and potato area should be decreased or omitted. Crop like wheat and haricot bean also can be planted by avoiding planting on flood prone low laying areas. In general, very important thing that one should keep in mind before decision making what to plant is that crops will be selected must be compensate loss occurred previous season.

4.9.5.4. When wet *Belg* forecasted and dry *Kiremt* is prospected

This situation is also need careful decision making in crop selection as moisture stress is expected in coming season at critical crops growth phase. Thus, planting long cycle maize variety that transit to second season must avoid. Focus should be on short cycle varieties of *tef*, wheat, haricot bean and maize with proper site selection and excess moisture management agronomic practices. Planting of vegetables (onion and potato not recommended as theses crops are more sensitive to excess moisture and susceptible pests and diseases.

4.9.5.5. When wet *Belg* forecasted and normal *Kiremt* is prospected

At this time, wet *Belg* is more favorable for planting long cycle maize varieties and situation in coming main season is also promising and heisting in decision making to plant maize is not recommended because its high yield per unit area compared to the rest cereals. Planting onion and potato during *Belg* is not risk free, but considering sunny condition in interval of time compared *Kiremt* and high yield per unit area can attract farmers to cove certain amount of land with these crops. Monitoring pest and disease early in the morning and evening should be an avoidable task. Normal condition during main season can attract farmers to plant any of six crops. But to exploit chance of favorable condition crops of more yields are preferable.

4.9.5.6. When wet *Belg* forecasted and wet *Kiremt* is prospected

This condition is a time of more excess moisture is available in both seasons.

Hence, conservation and management water should be done. This can even enable to conserve more water that can be used during long dry *Bega* season with proper irrigation conservation methods. Moreover, it is a time to make care full site selection to avoid water logging sensitive crops planting in flood prone areas. Increasing area of *tef* and maize during main season than any other time is highly recommended as this situation is unfavorable to onion and potato. Moreover, these situations are also very conducive for diseases and pests than rest of combinations. Thus, diseases and pest monitoring must be mandatory.

4.9.5.7. When normal *Belg* forecasted and normal *Kiremt* is prospected

Both normal conditions are favorable for all six crops. Risk of crop failure due to extremes is moderate. Crop selection during theses time is depending on interest and income it can generate. Crop selected during these times should be medium cycle and high yielding crops of under consideration. The normal condition is not meaning any chance of moisture stress. Hence, time of planting is very crucial to reduce moisture stress that might expect during the end of the season.

4.9.5.8. When normal *Belg* forecasted and dry *Kiremt* is prospected

This situation force effective use of wet season as food security can only fulfill by combination harvest of both seasons. Thus, what produced in wet season should overcome what expected to loss in dry season. Therefore, decision making what to plant at these times is very decisive to avoid weather information gap that might expect. As a result of these, more attention and priority should be given to high yielding crops (onion and potato). Planting long cycle maize varieties which need two consecutive seasons is full of risk as crops face moisture at critical moisture requirement growth phase. Therefore, anybody who missed weather forecast and agro meteorological advisory costs a lot.

4.9.5.9. When normal *Belg* forecasted and wet *Kiremt* is prospected

The last combination is not the least and not very difficult situation in decision making processes.

Thus, these situations are among the most conducive once for growing maize of long cycle maize varieties. Since, these varieties are high yielding, increasing in area of production is very crucial. In addition to these, growing concerned vegetables and haricot bean during *Belg* is recommended and profitable. Growing *tef and* wheat during *Belg* has high risk because of difficulty in harvesting under rainy condition. Similarly growing onion, potato, haricot bean and wheat during main season again has a chance of expose to risk. Since, *tef* is more tolerant to both extremes than rest five crops planting and increasing area of this crop is less risk and also highly recommendable. Short cycle maize varieties can also planted. To sum up, water conservation mechanisms, moisture management agronomic practices should be done during this period as well.

# 5. SUMMARY AND CONCLUSION

Identifying impacts of climate variability contributes in factoring and resolving challenges of food security in livelihood zone. Besides, better understanding of climate systems and crop production risk and its management is important to help farmers to make pre-informed and critical decisions about their crops to withstand the risk of crop loss. The analysis of variability of rainfall and temperature enables to provide policy direction for planning and management of water resource and agricultural practices. This research paper envisaged to present a comprehensive analysis of the impact of climate systems and variability on key crop performance along the SKV Potato –Vegetables production livelihood zone.

The coefficient of variation of annual rainfall varied from less to highly variable over high and lowlands, respectively. The calculated variability using rainfall index and CV showed good agreement in evaluating the variability, which indicated that there was high variation in rainfall during *Belg, Kiremt* and annual timescale, respectively in decreasing order. Much of the rainfall was concentrated in the three and four months of (MAM and JJAS) respectively

Precipitation concentration index (PCI) is characterized by less to high monthly concentration over Kofele and Aje, respectively. The short rainy season (MAM) contributes about 34-38% and *Kiremt* (JJAS) 46% to 49% to the annual total crop production while contribution of *Bega* is more at Kofele and reach up to 20%. Therefore, any fail or sort of change on pattern of the two seasons seriously affects food security of livelihood. High variability of season onset, cessation length of growing period, number of rainy days and dry spell of different length were identified as major constraints of crop production in SKV livelihood zone. As correlation of SOS, EOS and LGP indicates changes in length of growing period of *Belg* explained more by variability of onset, while main rainy season was influenced more by variability of cessation. In order to demonstrate how dependable rainfall amount prolonged over the time, number of rainy days was computed for both short and long rainy seasons. The impact of the current climate variability on crop production has been clearly seen through its effects on crop planting times, length of growing season.

Evidences revealed that the crop yield in the study livelihood zone were highly correlated with the rainfall patterns, and as a result reduction in crop productivity and substantial crop failures recurrently observed as a result of declining of rainfall amount, spatial and temporal distribution over time.

It was observed that the lowest probabilities of occurrence of dry-spells of all durations were recorded in the month of April and July. Indeed, months of April and August coincided with the peak of rainfall amounts for both SR and LR growing seasons in the livelihood zone. High probabilities for occurrence of dry-spells that often exceeded the normal durations induced high risks and vulnerability on rain-fed smallholder farmers, which are predisposed to the study area. In terms of probability of occurrence of dry-spells of various durations the results showed that there was substantial month to month variation during the SR and LR growing seasons. For instance, there were high probabilities of dry-spells during the start of *Belg* season (March 0.47 to 0.90) and end of the *Kiremt* season (September; 0.4 to 0.80).

In this regard, one of the findings deducted from the present study dictated that even though few of pounced droughts during the study period were unmanageable, due to their severity, majority of drought prevailed were mild drought leading to moderate drought were manageable. Indeed, number of mild to moderate droughts was more outperformed as compared to intensive droughts. From temporal perspective, intensity and frequency of drought were more prevalent over lowlands (Aje).

The linear correlation analysis showed that there was strong negative and positive relationship between *Kiremt* rains which demonstrated that El Nino and La Nina significantly suppresses and enhances seasonal rainfall performance, respectively. The results as deduced from the present study demonstrated how seasonal rainfall and cropping systems became the victim of teleconnection such as El Nino and La Nina episodes.

Inter-annual and seasonal variability of rainfall is the major causes of fluctuations in crop yield in the livelihood zone over the period 1995-2014.The patterns of inter-annual variability against productivity of the major six crops and vegetables, noticeably *tef*, wheat, maize, haricot bean, potato and onion of the livelihood zone showed similar patterns of inter-annual variability in the seasonal or annual scales.

In this perspective, both growing degree day (GDD) and crops yield indicated direct relationship with mean temperature in similar pattern. *Tef* and wheat crops correlated with (-

0.25 and -0.4) with the *Kiremt* rainfall. In contrast, being it is long-cycle crop; maize appeared to require evenly distribution of rainfall throughout the *Belg* and *Kiremts* season, consecutively.

The result showed that high value of degree-day in Aje and low value over the Kofele help to determine what to grow when to grow and where to grow. The value of degree day also helps to illustrates how to determine dates of attainment of critical phenological phase and harvesting. Degree-day can be used where warmth is the only limiting factor.

The mean monthly temperature and GDD for selected stations and crops can be used degree day as decision support tool in agriculture. The long term mean is useful if the user wishes to compare current use against long term average conditions, or wishes to set energy budgets against such conditions. Growing degree days, which are based on actual temperatures, are a simple and accurate way to predict when a certain plant stage will occur. The processing and analyzing of precipitation, minimum and maximum temperature data help to determine length of growing period and preparing for major crops for both *Belg* and *Kiremt* seasons is very important for crop planning.

Depending on the result obtained in this study, the following useful points are recommended;

The central piece of this study is that in a multiple-crop system, the combination of crops chosen should not be sensitive to weather risk.

Knowledge of lengths of dry-spells and the probability of their occurrence can aid in planning for supplementary risk aversion strategies through prediction of high water demand spells. Therefore, high rainfall variability and chances of prolonged dry-spells established in this study demand farmers ought to keenly select crop varieties and types based on the degree of their tolerance to drought.

Based on these findings, it is apparent that farmers at Aje (Siraro and Shala) districts are encouraged to plant moisture stress resistant and short cycle *tef*, haricot bean and maize varieties with proper time of planting and appropriate agronomic practices and management.

Moreover, in lowlands of Aje (Siraro and Shalla) districts planting crops before second dekad of March is risky and crops need LGP more than 70 and 90 days during *Belg* and *Kiremt*, respectively should not be planted.

The discussions in this paper have illustrated those areas where degree-days can be used for various purposes. These may include but not limited to selection of suitable crops for a particular area, strategic agricultural planning like designing of crop calendar, consideration during crop planning.

It is recommended that climate information should be considered as resource should be incorporate and packaging with other extensions services to reduce climate related crop production risk and help to exploit favorable climate condition as well.

More specifically, intensive climatic research has to be made or highly recommendable to develop and strengthen in order to address knowledge gaps and investing more to improve agriculture extension services.

Finally, the findings deduced from the present study in fact would help practitioners, particularly water resource managers, agricultural development planners and ecosystems managers, with their strategic planning and decision making processes and researchers as well.

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