ASSESSING THE IMPACT OF RAINFALL VARIABILITY ON WHEAT, BARLEY AND TEFF CROPS PRODUCTION IN THE SOUTH WOLLO ZONE OF ETHIOPIA

By: Endalamaw Wende Wasihun

A Thesis Submitted to Applied Physics Department

School of Applied Natural Science

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Applied Physics (Meteorology)

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

November, 2018

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Approval Sheet of the Board of Examiners

We, the undersigned Members of the Board Examiners of the final open defense by Endalamaw Wende Wasihun have read and evaluated his thesis entitled: “Assessing the impact of rainfall variability on three major crops Production in the South Wollo Zone of Ethiopia” and examiner the candidate. Therefore, this is to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Masters in Applied Physics (Meteorology).

Diriba Korecha (PhD)		**26/11/2018**
Major Advisor	Signature	Date
______________	__________	__________
Chairperson	Signature	Date
______________	__________	__________
Internal Examiner	Signature	Date
______________	__________	__________
External Examiner	Signature	Date

Declaration

I hereby, declare that this MSc Thesis is my own original work and that it has not be presented for a degree in any other University ,and all sources of material used for this thesis have been dully acknowledged. This thesis has been submitted in partial fulfillment of the requirement for MSc.degree in Applied Physics (Meteorology) at Adama Science and Technology University and deposited at the University library to be made available to borrowers under the rules of the Library.

Name: Endalamaw Wende Wasihun

Signature: ___________________

This MSc Thesis has been submitted for examination with my approval as Thesis advisor.

Advisor: Diriba Korecha (PhD)

Signature: ________

Date of Submission: 26/11/2018

Advisor's Approval Sheet

To: Applied Physics Department

Subject: Thesis Submission

This is to certify that the Thesis entitled "Assessing the impact of rainfall variability on three major crops Production in the South Wollo Zone of Ethiopia", submitted in partial fulfillment of the requirements for the degree of Master's in Applied Physics (Meteorology), the graduate program of the department of Applied Physics, and has been carried out by Endalamaw Wende Wasihun Id.No GSR/0205/2009, under our supervision. Therefore, we recommended that the student has fulfilled the requirements and hence here by he can submit the thesis to the department.

Endalamaw Wende Wasihun	________________	_____________
Student	signature	Date
Diriba Korecha (PhD)		**26/11/2018**
Advisor	Signature	Date

BIOGRAPH OF THE AUTHOR

The author, Endalamaw Wende, was born on January 29/1986 in Mehal Saint Woreda, South Wollo Zone of Amhara National Regional State of Ethiopia from his father Wende Wasihun and his mother Beletu Alemu. He attended his elementary and junior school at Gert and Denssa Primary and Secondary Schools, respectively. After completion of elementary and junior school, he attended grade 9-10 at SaintAdjibar high school and grade 11-12 at Borena preparatory school. After passing the Ethiopian School Leaving Certificate (ESLC) in 2004, he joined Arbaminch University in 2005 and graduated with a BSc degree in Meteorology Science in 2007. Soon after his graduation, he was employed by the National Meteorological Agency of Ethiopia (NMA) at Kombolcha Meteorological Branch Directorate. He has also a BSc degree in Civil Engineering from Wollo University in 2017 with Extension program. He served as a meteorologist until he joined the School of Graduate Studies of Adama Science and Technology University in October 2017 to pursue his MSc. study in the field of Applied physics Specialization in Meteorology.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANRS	Amhara National Regional State
ANOVA	Analysis Of Variance
CHIRPS	Climate Hazards Groups Infra-Red Precipitation with Stations
CC	Climate Change
CV	Coefficient of Variation
CSA	Central Statistics Agency
CDCC	Copping with Drought and Climate Change
DOY	Day of Year
EOS	End of Season
ENSO	El Niño Southern- Oscillation
ERSST	Extended Reconstructed Sea Surface Temperature
FAO	Food and Agricultural Organization
FMAM	February, March, Apr and May
INSTAT	Interactive Statistical Processing Package
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
ITCZ	Inter-Tropical Convergence Zone
JJAS	June, July August and September
KEOS	Kiremt End of Season
KLGP	Kiremt Length of Period
KNRD	Kiremt Number of Rainy Days
KRT	Kiremt Rainfall Total
KSOS	Kiremt Start of Season

LGP	Length of Growing Period
MoEDC	Ministry of Economic Development and Co-operation
NDD	Number of Dry Day
RF	Rain Fall
NMA	National Meteorological Agency
NMSA	National Meteorology Services Agency
NRD	Number of Rainy Day
RT	Rainfall Total
SD	Standard Deviation
SOS	Start of Season
SST	Sea Surface Temperature
SSTa	Sea Surface Temperature anomaly
SWBMLZ	South Wollo Belg-Meher Livelihood Zone
SWZ	South Wollo Zone
UN, OCHA	United Nation Office for the Coordination of Humanitarian Affairs
USAID	United States Agency for International Development
WMO	World Meteorological Organization

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Abstract

Variation in the seasonal cycle of Ethiopian rainfall is key importance for agriculture. This study was undertaken in South Wollo Zone, which is situated in the northeastern Ethiopia, to analyze the impacts of extensive seasonal rainfall variability on three wheat, barley and teff crops productivity. We use observed sea-surface temperatures (SST), satellite estimated rainfall data (CHIRPS), gauge-based observed rainfall from local meteorological stations and crop yields to explore crops productivity associated with warm phase of ENSO identified based on eastern Pacific SSTs. Standard statistical descriptors and statistical software like INSTAT V3.37, MAKESENS 1.0, XLSTAT 2014 and Arc GIS 10.3 were employed for the analysis. The results indicated that South Wollo Zone experienced moderate rainfall variability in kiremt (JJAS) season (CV=20%-30%) and high variability in belg (FMAM) season (CV>30%).The results indicated that the mean onset date of the main rain season (JJAS) for Akesta, Ambamariam and Wogdi station was 5th July and at station Haik, Tebasit and Worebabo was July 7th. Furthermore, the results of Pearson Correlation Coefficients indicated that duration of kiremt rainy season and kiremt rain fall total had strong positive, weak negative and weak positive relationship (r = 0.906, r = -0.203 and r = 0.344) with wheat, barley and teff respectively in Borena district of South Wollo Zone. The annual and seasonal rainfall trend results showed that South Wollo Zone practiced a decreasing trend. This study further showed that warm phases of ENSO are strongly related to recent droughts that induced significant crop yield reduction due to erratic and poor kiremt performance. Given that climate change is real, we suggest that recurrent and more extensive El Niño, which is responsible for recent droughts are likely to reoccur, thus we should document how historical rainfall trend explain crop yield variation so as to predict and respond to multi-year drought and substantial crop yield reduction in South Wollo Zone of Ethiopia.

Key words: Rainfall season, crop production, drought, El Niño, trend, prediction, food insecurity.

1. INTRODUCTION

1.1 Background

Rainfall is the most important climatic parameter in the semi-arid Tropical region of the world. It has a significant role in the performance of agricultural productivity, particularly over the region where agriculture heavily relies on seasonal rain. In Africa, precipitation amounts are likely to decrease for most parts of Sub-Saharan Africa, while rainfall variability is expected to increase (IPCC, 2014). Like other tropical countries, agricultural Production in Ethiopia is predominantly rain-fed whereas inter and intra-annual rainfall variability is high and droughts are recurrent in many parts of the country. Variations of rainfall in space and time affect agricultural production system and need a close study (NMSA, 2001; Woldeamlak, 2007; Rosell and Holmer, 2007). Numerous research findings revealed that global, regional and local factors are responsible to this inter-annual and seasonal rainfall variability (Mesay, 2006; Korecha and Barnston, 2007). Moreover, the threat of global climate change has caused concern among scientists to livelihoods, agricultural production and food security of the smallholders could be severely affected by changes in key climate variables.

One major implication of global warming is greater scarcity and variability of renewable resources in many parts of the world (IPCC, 2001). Agriculture, being the main source of food, fiber and jobs; and farming activities being directly dependent on climatic conditions, it is highly exposed to the effects of CC. Climate change manifest in the form of temperature increases, changes in precipitation and sea level rise, and the intensification of natural hazards, such as storms, floods, droughts and landslides (IPCC, 2007). It was affecting agriculture and its effects are unevenly distributed across the world (Porter *et al*., 2014). Though CC affects all countries globally, developing countries are the most vulnerable as they have inadequate resources to adapt. The Horn of African in general and Ethiopia in particular have for the past decades experienced unprecedented food shortages due to CC (Toulmin *et al*., 2006).Third assessment report of Intergovernmental panel on climate change (IPCC, 2001) indicates that the least developed countries have contributed the least to the emission of greenhouse gases but the impacts of climate change are expected to be more pronounced in the developing countries particularly Sub-Saharan Africa. Because of their livelihood is dependent on nature which is highly sensitive to climate change.

Indeed, many researchers pointed out that, the severity of climate variability and change-induced societal catastrophes are expected to be more pronounced over low-income countries particularly in Africa (Olsen, 2006). As many of low income countries are located in tropical, sub-tropical region, or in semi-desert zones, they are particularly vulnerable to shifting weather patterns and rising temperature (Joachin, 2008). Even though climate impacts are reverberating through the economy, threatening water availability, hydro-power generation, extreme weather impacts, sea level rise, amongst others in in both developed and developing world (WWF, 2006), Climate change and variability has potential impact in Africa in general and East Africa in particular inducing influences on different natural resources, such as water availability, which in turn greatly influences agriculture, energy, ecosystems and many other sectors (Solomon, 2007). Various studies indicate that future climate change will lead to an increase in climate variability and the frequency and intensity of extreme events (Boko et al, 2007; Stern, 2007).

Recurrent extreme climate events such as floods, storms, and droughts could be particularly damaging too many countries of Africa (HDR, 2007) such as Ethiopia, since they are, dependent on climate sensitive subsistence and rain fed agriculture. On the other hand, food insecurity, famines and droughts are prevailing phenomena (Hassan, 2006; IRI, 2007). These natural hazards are becoming more pronounced due to the fact that rainfall is highly variable both in amount and distribution across regions and seasons (Tesfaye, 2003; Tilahun, 1999; Mersha, 1999). In particular, the agricultural sectors are predominantly in the hands of small holdings mostly private peasant holdings with traditional farming depend on rainfall. Their productivities are subjected to wide variation due to variation of rainfall in magnitude and distribution both in space and time.

In Ethiopia, around 83% of the total population live in rural areas and perform agriculture practices in backward methods; and rely on what the land can produce for their income and daily food in-take. Beside, rainfall variability in daily, seasonal and inter- annual cause major socio-economic problems (Shanko and Chamberlain 1998). Thus, it led to a Production deficit (20%) and increase in poverty rates (25%) which cost the economy over one-third of its growth potential (Hagos et al., 2009; Osman and Sauer born, 2002). Moreover, the agriculture in Ethiopia is practiced under the condition of diminishing farm size, high soil degradation, inadequate and variable rainfall, imperfect agricultural markets and poor infrastructure (Degefe et al., 1999). As a result, agricultural Production in Ethiopia reveals to be very poor and highly susceptible to minor climate change that causes the occurrence of drought.

Drought is one of the utmost main disasters associated with rainfall variability, which cause instability in food Production in different parts of Ethiopia including among which northeast Ethiopia is recently becoming drought hotspots (Tessema and Lamb, 2003). The principal cause of drought in Ethiopia is asserted to be the fluctuation of the global atmospheric circulation, which is triggered by SSTa, occurring due to ENSO events that affect rainfall distribution. The phenomena have significant impact on displacement and weakening of the rain producing system in the seasons. ENSO episodes and other regional systems have impact on seasonal rainfall performance and rainfall variability over Ethiopia due to remote Tele-connections system (NMSA, 1996; Korecha and Barnston, 2007). Hence, most of the drought years including 1888 Great Ethiopian Famine were caused by El Niño episode (Nicholls, 1993) that results greatest effect in Ethiopia where about one-third of the population died (McKee, 2008; Pankhurst 1985; Webb and Braun 1994) .Next to that major droughts in Ethiopia: 1957, 1965, 1973, 1983-84, 1987, 1993-94 occurred coincide or follow El Niño events (OCHA, 2015; FAO, 2014).

South Wollo Zone, which is located in Northeastern Ethiopia, is one of the most severely affected parts of the country. Most of the woredas in the zone are affected by drought. Due to the well-known famines of 1971–74 and 1983–84, to date some households in the area have not fully recovered from the debilitating effects of the 1983–84 drought-induced crises. In addition to previous droughts and history of famines, the recent strongest El Niño, which occurred in 2015, has a great loose of life (Cattles) and property as well as strong socio-economic impact (WFP, 2015). Moreover, the delaying of onset, below normal in amount and unevenly distribution of kiremt rainfall were identified some of the key events that eventually prevailed over South Wollo Zone as a result of El Niño 2015. Thus, agricultural productivity including cereal crops became generally low over South Wollo Zone, the area which is the main focus of the present study. In this study, we attempt to evaluate empirically the influence of rainfall variability on crop production in relation to global Tele-connection indices over South Wollo Zone. This study covers a period of 1986-2016. As many of previous studies concentrated mainly on the effect of El Niño on summer (kiremt) rains at national and regional scale. We believe that the present study could fill the research gaps on local scales.

1.2 Statement of the Problem

Drought often results in famine and hunger because the subsistence nature of Ethiopian livelihoods (Bekele 2006). Even though, almost eighty-five percent of Ethiopians including South Wollo Zone are engaged in farming and eighty per cent of food is consumed on-farm (Tefera, 2004), ten per cent of the population received food aid (Makombe *et al*., 2007), and in fact Ethiopia is the largest recipient of food aid in Africa (Moges and Holden, 2007). South Wollo Zone is highly vulnerable to natural and human disasters like drought, flooding, heat waves, frost, deforestation, land degradation, and soil erosion, which are the manifested as a result of rainfall variation, temperature extremes, altitude difference, and ENSO events (Yimer *et al*., 2018). North central part of Ethiopia (where this study was conducted) is among the drought prone areas of Amhara National Regional State (ANRS) and food insecure areas of the country and farming is practiced in the context of unreliable rainfall (World Bank, 2010; Muluneh and Demeke, 2011) and has frequently suffered from recurrent drought often followed by devastating famine (Amare *et al*., 2011; Daniel, 2011). Climate variability particularly rainfall with associated drought have been major causes of food insecurity and famine in Ethiopia including South Wollo Zone (Seleshi & Zanke 2004; Thornton *et al*., 2006; NMA, 2007; Conway & Schipper, 2011; Rosell, 2011). As a result, seasonal rainfall is becoming highly variable in amount, distribution, intensity, duration, onset and cessation. These variations have imposed negative impact on socio-economic activities, particularly on agriculture productivity of major crops such as wheat, barley and teff.

In recent time, Ethiopia including South Wollo Zone has faced one of the worst droughts in its history that was driven by strong El Niño, which was the consecutive failure of two rainy seasons (WFP, 2015). As a result, smallholder farmers have encountered total failure of both belg (small rain season which lasts from February to April) and Kiremt (main rain season which lasts from June to September) of 2015/2016 harvesting year. Due to this, significant number of small holder farmers exposed to emergency of food aid (FEWSNET, 2015). FAO

(2016) also reported that because of El Niño caused drought in 2015/2016, the average number of food insecure people in Ethiopia was of more than 10 million. At that point, the Government of Ethiopia had committed US$270 million to emergency support, and the 2016 HRD estimated needs at US$1.4 billion (USAID, 2016). Farmers in affected communities reported selling livestock at markedly low prices in some areas of Ethiopia including South Wollo Zone have decreased by nearly 90 percent in recent months. Farmers have also sold plowing oxen, which will affect future productive capacity (USAID, 2015). Based on South Wollo Zone Early warning office report, the study area lost 423810 hectares crop productions due to Strongest El Niño induced drought in 2015.

The scientific problem to address in this study is therefore, the impacts of rainfall variability on crop yields not known even if low yield and droughts has been related. So, statistical analysis of crop yields and rainfall at district levels has not been conducted in the study area.

1.3 Objectives

1.3.1 General objective

The main objective of this study is to analyze intra-seasonal rainfall variability, its trend and impact of Strong El Nino during kiremt rainy season and their impacts on agricultural production of three major crops in South Wollo Zone

1.3.2 Specific Objectives of the Study

In order to achieve the general objective of the study, the following specific objectives were adopted.

- To analyses of rainfall variation in spatial and temporal scale
- To evaluate rainfall performance of kiremt season during strong El Niño events.
- To analyses annual and seasonal trend, onset and cessation date of seasonal rainfall in the study area.
- To correlate between kiremt rainfall features and major crop yields.
- To identify hotspot districts (Woredas), that are more exposed to drought.

1.4 Research Questions

In this study, the following research questions were addressed:

- Which parts of the study areas are vulnerable to different climatic extremes?
- Which climate-related disasters are more frequent in study areas?
- How does seasonal rainfall variability impact on crop production and productivity?
- What are the main footprints (effects) of El Niño in the study area?
- Does El Niño affect macro and microclimate of South Wollo Zone?
- Which parts of South Wollo Zone strongly affected by recurrent ENSO-related climatic droughts?

1.5 Scope and Limitation of the Study

This research was conduct in South Wollo Zone of Amhara Regional State of Ethiopia. The scope of this study was mainly confined to observed meteorological parameters as meteorological stations. Data analysis made using different statistical methods, characterizes the annual, and seasonal variations of rainfall, trend and its impact on three major crops production. In addition, characterize the relation between strong El Niño years using Niño 3.4 and observed stations or satellite estimated rainfall data. Moreover, the study highly considers rainfall features. However, the distribution of available meteorological stations and length of data's with this study period and the time interval of the accessed crop data in the selected districts could be the limitation of the study.

2. LITERATURE REVIEWS

2.1 Rainfall Variability in Ethiopia

Rainfall is the most important climate parameter which influences the growth characteristics of crops (Bewket 2009; Befekadu and Berhanu, 2000) and water serves as a carrier of nutrients and energy exchanger in crop development. Rainfall variability and associated droughts have been observed to be major causes of food shortages and famines in sub-Saharan countries of Africa (Wood, 1977; Pankhurst and Johnson, 1988). Agriculture production is largely undertaken by smallholder subsistence farmers who rely solely on high unpredictable and sporadic seasonal rainfall (Ndamani, 2008). Climate variability and associated droughts have been major causes of food insecurity and famine in Ethiopia (Tesfaye et al., 2017; Alemayehu and Bewket 2016). Drought originates from temporary water deficits that result in an inability to meet the demands of human activities and the environment (Smakhtin and Schipper 2008). This deficit may be related to a lack of precipitation, soil moisture, stream flow, or any combination of the three taking place at the same time. There have been notable droughts in Ethiopia throughout human history (Haile, 1988; Degefu, 1987; Nicholls, 1993; Webb and Braun 1994). In the second half of the 20th century alone, the country endured several severe droughts (1957-58, 1964-65, 1972-73, 1983-84, 1990-92 and 1993-94) that caused the loss of numerous humans and livestock (Umer, 2002).

Previous droughts and the frequency of rainfall deviation from the average suggest that drought occur every 3-5 and 6-8 years in northern Ethiopia and every 8-10 years for the whole country (Haile 1988 and 1990). Haile (1985 and 1988) believes that Ethiopian drought is caused by ENSO, along with sea surface temperature (SST) anomalies in the Southern Atlantic and Indian Oceans combined with anthropogenic activities. ENSO events and SST anomalies affect rainfall distribution in Ethiopia by displacing and weakening the rain-producing air masses. The year 1888 drought was a major ENSO year that damaged the economies of Brazil and Australia, but a great effect in Ethiopia (Nicholls, 1993). Drought struck Ethiopia in 1888, leading to the historic deadly famine of 1888/89 which cause about one-third of the population died and ninety percent of the animals perished due to render pest infestation and the drought (Webb and Braun 1994). The worst disaster in Ethiopia has experienced in 1983/84 failure of the main rainfall season, and resulted in reduction of the agricultural outputs by 21%, and GDP by 9.7% (World Bank 2006).

Many researchers including Bewket (2009) in the study area revealed that rainfall variability each seasons were affect crop production in his study period of 1975-2003. Rosell (2014) pointed out erratic rainfall of belg seasons that consequence for reducing teff production in central Highlands particularly South Wollo. Yimer et al. (2017) also revealed that South Wollo is one of the drought prone and food insecure areas of Ethiopia. Moreover, El Niño induced drought had a strong affects the academic performance of students (Amogne and Wondifraw, 2017). For detail warning, we have to do detail analysis on the relation between crop production of wheat, barley and teff, ENSO events and RF variability for each diverse microclimate zone with a certain period of time. Moreover, findings of this study can play significant role to enhance, understand and facilitate exchange of climate knowledge and information among local communities, field experts, policy makers and researchers.

2.2 Agro- Climatic Zones and Seasons in Ethiopia

As climate is rather complex, it has been the topic of many studies and several classification systems have been applied to the Ethiopian situation. The Ethiopian traditional systems uses altitude and mean daily temperature to divide the country into 5 climate zones: which are Bereha, Kola, Woyina-Dega, Dega and Wurch (Gemechu, 1977); Bereha covers the desert lowlands below 500 metres, and average annual temperatures range between 28°C and 34°C or higher; Kola includes those areas with an altitude of 500-1500 metres, and an average annual temperature range of 20-28°C; Woyna-dega covers the temperate highlands between 1,500 and 2,500 metres and an average annual temperatures vary between 16°C and 20°C; Dega includes the temperate highlands between 2500 and 3200 metres, where average temperatures range between 10°C and 16°C;Wurch covers the Afro-alpine areas on the highest plateaus between 3200 and 3500 metres; average temperatures are below 10°C.

Another broad classification can be made using the rainfall distribution though the year giving the distinction between the mono-modal, the bi-modal and a diffuse rainfall region (Haile & Yarotskaya, 1987). However, the most useful for agricultural purposes is the agro climatic zones which used the water balance concept, the length of the growing season (including onset dates) at certain probability levels (NMSA, 1996). In this way three distinct zones can be identified namely the area without a significant growing period, areas with a single growing period and area with a double growing period.

Season is defined as a period when an air mass is characterized by homogeneous weather elements such as rainfall, temperature, relative humidity, wind, etc. are dominate in a region or part of a country (NMSA, 1996). According to NMSA (1996) season classification varies with spatial location, which means central, northeastern and eastern Ethiopia have three seasons: namely, main rainy season (Kiremt) from June to September, dry season (Bega) from October to January and small rainy season (belg) from February to May (Degefu, 1987; Gissila *et al*, 2004). While, frost occurs during October to December season mainly over northeastern, central, eastern and southern high lands of the country. As a result, the occurrence of extreme minimum temperatures at night and early morning favors for frost occurrence. Belg is described by varying dry and wet days, hot days and nights. However, Kiremt is the main rainy season, occurring from June to September. During this season, about 85% to 95% of the food crops of the country are produced (Degefu, 1987; NMSA, 1996; Mesay, 2006).

2.3 Seasons and the Associated Climatic Factors in South Wollo Zone

2.3.1 Bega Seasons

Bega is the dry and cool season, running from October to January. The northern hemispheric subtropical anticyclones, the seasonal Siberian high and dry cool northeasterly monsoon are the dominant features. In bega Season most of the country is generally dry and cold Areas such as Gimba, Guguftu and Wegeltena in South Wollo Zone had occurred extreme minimum temperature (Frost) in this season (NMSA, 1996). Meher crops which are planted in kiremt season are collected in bega season in this study area. Moreover, there is an occasional unseasonal rain over northern, central, and eastern Ethiopia due to eastward traversing of mid latitude frontal systems (Kassahun, 1987; Nicholson, 2000) that results crop damage. In contrast, it is important for land preparation for belg season (belg benefited areas of South Wollo Zone), grass development and water accumulation for animals.

2.3.2 Belg Seasons

Belg is the short rainy season, from February to May. The rainfall is highly characterized by inter annual and inter seasonal variation. The seasonal and annual rainfall variations are the result of the micro-scale pressure systems and monsoon flows which are related to the changes in the pressure systems (Haile, 1986; Beltrando and Camberlin, 1993; NMSA, 1996 and Conway, 2009). The major weather producing systems during belg season are: development of thermal low (cyclone) over the south of Sudan, and winds from the Gulf of Aden and the Indian Ocean highs that are drawn towards this center and blow across central and southern Ethiopia (Kassahun, 1987; Camberlin and Philippon, 2002). These moist, easterly and southeasterly winds produce the main rains in Southern and Southeastern Ethiopia and the belg rains to the east-central part of the northwestern highlands.

Belg rain which is important not only just for the belg crops (accounting for 5-15% of the national food crop) but also for improving pasture for livestock, and for the planting of long-season crops as well as useful for land preparation for meher production and supplementing water for irrigation purposes has been decreased substantially (Eiste et al., 2012; Degefu, 1987). Later start of the short rainy season (belg) which is causing a problematic situation for the farmers to sustain a livelihood and have a secure food situation (FEWS, 2013).

In South Wollo Zone, the area used for cropping during the belg season varies between 12 and 30% of the area used for cultivation during the long rainy season (Atlas of Rural Ethiopian Economy, 2006). In belg season, short cycle crops including barley, wheat and teff in high altitude areas such as parts of Ambassel, Albuko, Legambo, Haik, Dessie Zuria and Kalu were grown (Rosell, 2007). In lowland areas, belg rains are used for the production of short cycle crops such as teff and the planting of long cycle crops (maize, sorghum, millet, etc.) that attain maturity during the main meher season in Harbu and Worebabo (Rosell, 2007). It is also important for the replenishment of pasture and water resources in the study area.

2.3.3 Kiremt Seasons

Kiremt is the main rainy season that covers the period from June to September. Major rain producing systems during kiremt season includes; northward migration of ITCZ, development and persistence of the Arabian and South Sudan thermal low, development of quasi-permanent high pressure system over south Atlantic (St.Helena high) and South Indian Oceans (Macarena high), development of tropical easterly jet and generation of low level Somali jet that enhance low level south westerly flow (Tadesse, 1994; NMSA, 1996; Segale and Lamb, 2005) and moisture advection from Congo Basin through the south westerly monsoon (Camberlin, 1997). Kiremt rain fall accounts for 50–80% of annual rainfall totals in Ethiopia, which has high contribution to agricultural productivity and major water reservoirs (Tilahun, 1999). Thus, the most severe droughts in Ethiopia are usually related to a failure of kiremt rainfall to meet the agricultural and water resource needs (Korecha and Barnston, 2007). In South Wollo Zone, the mean onset and end date of kiremt season are July 10 and September 25 (Mesay, 2006), respectively. In this season, Major socio-economic activities are performed in the study area.

2.4 Causes for Rainfall Variability in South Wollo Zone

Rainfall is highly varied in both amount and distribution across a region and seasons (Tilahun, 1999; Mersha, 1999). The most important weather systems that cause rain over Ethiopia include: Sub-Tropical Jet (STJ), ITCZ, Read Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and Somalia Jet (NMSA, 1996). The movement of ITCZ is sensitive to variations in Indian Ocean sea surface temperatures and varies from year to year; hence the start date, end date and duration of the rainfall seasons vary considerably inter-annually. In addition to the above weather producing systems, the most well documented cause of this variability is the El Niño Southern-Oscillation (ENSO). Warm phases of ENSO (El Niño) which is associated with reduced rainfall in the main rainfall season (Kiremt) in north and central Ethiopia, causing severe drought and famine, but also with enhanced rainfalls in the earlier February to April rainfall season which mainly affects the rainfall distribution in the southern Ethiopia (Korecha and Barnston, 2007; McSweeney et al., 2008). The spatial distribution of rainfall in Ethiopia is significantly influenced by local factors like topography (NMSA, 1996) which changes intensity, position and direction of movement of the rain producing systems over the country (Tadesse, 2000).

2.5 Global ENSO Phenomena Causing Rainfall Variability Over South Wollo Zone

The ENSO can be described as a phenomenon consisting of two oceanic phases. The El Niño warm phase and La Niña cold phase that are connected through a fluctuation in atmospheric pressure over the South Pacific called the Southern Oscillation (Shrestha and Kostaschuk 2005). During an ENSO event, which occurs on average every 3-7 years (Garcia *et al*. 2003), the surface temperature of Pacific Ocean on the west coast of Ecuador and Peru's abnormally high with major world-wide consequences**.** More than 100 years ago, the name El Niño 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 Niño in Spanish means the child, with specific reference to the Christ child. La Niña, baby girl in Spanish it is opposite weather condition to El Niño (Child Christ).

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). El Niño is a local warming of surface waters that take place in the entire equatorial zone of the central and eastern Pacific Ocean of the Peruvian coast and which affects the atmospheric circulation worldwide (Kiladis and Diaz, 1989). During La Niña events, the equatorial trade winds strengthen, resulting in colder water being brought up from the ocean's floor. Neutral is the term for when neither El Niño nor La Niña present in the Pacific (Trenberth, 1997). Under neutral conditions, trade winds blow from east to west near the Equator in the Pacific Ocean.

Many authors have documented ENSO events have strongly linked with various atmospheric system and rainfall distribution over Ethiopia like (Korecha and Barnston, 2007). Drought in Ethiopia is asserted by the fluctuation of the global atmospheric circulation, which is triggered by sea surface temperature (SST) anomalies, associated with ENSO events. ENSO episodes and other regional systems have impact on seasonal rainfall performance and rainfall variability over Ethiopia is due to remote Tele-connections system (NMSA, 1996; Gissila, 2001; Korecha and Barnston, 2007). The relationship between El Niño events and drought in Ethiopia has been known for many years. According to Nicholls (1993), the 1888 drought was a major ENSO year that damaged the economies of Brazil and Australia, but a great effect in Ethiopia including South Wollo Zone and that results one-third of the population died because of famine, and 90% of the animals perished due to render pest infestation and the drought (Webb and Braun, 1994). Similarly, drought in 1973 also associated with ENSO phenomena that showed signs of the distress in Wollo spilling over to the other regions in the form of migration and roadside destitution: sick and hungry people lined parts of the north-south highway through Wollo, stopping vehicles to beg for food (Girma, 1988). In this year, the real crisis of starvation and death in the Wollo famine occurred from June to August 1973, which the relief camps were simply overwhelmed by destitute people. Mortality estimates for this period vary considerably: the official estimate of the Relief and Rehabilitation Commission suggests that only 10,000 people 30 died, a UNICEF study puts the figure at between 50,000 and 100,000 (Gebre-Medhin, 1977). Besides, the drought of 1984 which caused by El Niño those results fails of kiremt rainfall that affects over all the country in particularly central highlands including Wollo (South and North Wollo) that causes 64% of its population migrate from this area and settle to other parts of the country (Girma, 1988). Moreover, Observed data indicates that the 1997 drought is associated with ENSO events. Thus, an ENSO based early warning system, used effectively by policy makers, could help to reduce the societal impacts of drought in Ethiopia (Wolde-Georgis, 1997).

2.6 Rainfall Variability and Agriculture in South Wollo Zone

Agriculture remains one of the most important sectors in the Ethiopian economy by supporting about 83% of the population in terms of employment and livelihood, contributing over 40% of the country’s gross domestic product (GDP), generating about 85% of export earnings and supplying around 73% of the raw material requirements of agro-based domestic industries, such as biofuels (MEDaC, 1999; AfDB, 2011). It is also the major source of food for the population and hence the most important sector for food security. Moreover, agriculture is playing key role in generating surplus capital to speed up the country’s overall socio-economic development (MEDaC, 1999). Ethiopia has a total land area of about 112.3 million hectares. Of this, about 14.6% (16.4 million hectares) was suitable for producing annual and perennial crops. Of the estimated arable land, about 48.8% (8.0 million hectares) are used for either crop or pasture and 35% of the arable land is used for agriculture. The percentage of the arable land under irrigation is very small, around 0.5% (World Bank.org 2013).

Studies in Ethiopia have shown that rainfall variability usually result in reduction of 20% Production and 25% raise in poverty rates in Ethiopia (Hagos *et al*., 2009; Osman and

Sauerborn, 2002). Moreover, 10% of decrease in seasonal rainfall from the long term average generally translates a 4.4% decrease in the countries food Production (Braun, 1991). Rainfall in much of the country is erratic and variable and the associated drought have historically been the major cause of food shortage and famine (Wood, 1997; Pankhart and Johnson, 1998). According to South Wollo Zone Early Warning report, drought, hailstone, pest, crop disease and excessive rainfall were loss crop production in the time period of 2006 -2015 with value of 7433040, 1683779, 1463391, 1305118 and 1288965 quntals respectively.

2.6.1 Rainfall Totals

Kiremt rainfall total was calculated by adding the monthly totals of June, July, August and September. Similarly, belg: February, March, Apr and May. Annual rainfall total was rainfall total of each month in a year. After 1996, a decline in total rainfall during the short rainy season has been identified in the central highlands of Ethiopia (Bewket 2009; Viste et al., 2012).

2.6.2 Onset of Rainy Season

Rainfall onset and cessation dates are important parameters in the agricultural calendar in most tropical regions. As defined by Odekunle *et al*. (2005), the rainfall onset is the period at the beginning of the rainy season, when rainfall distribution has become adequate for crop development. Due to the complex topography and large spatial rainfall variability with a single kiremt onset criterion could not be established for all of Ethiopia. This situation stemmed, first, from onset criteria requiring an initial wet-spell length of more than one day giving unreasonable onset dates for dry regions where wet spells often are limited to a single day low lying regions of eastern Ethiopia, northern Rift Valley, southwestern lowlands in Gambella region (Segele and Lamb, 2005).

Onset marks the beginning of a season though different researchers have put it differently. According to Tesfaye and Walker (2004) defined onset as the date in which 20 mm 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. Mamo (2005), Hadgu et al. (2013) and Taye *et al*. (2013) also followed the definition of Tesfaye and Walker (2004) but Hadgu *et al*. (2013) specified dry spells up to 10 days. For belg onset as indicated in 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.

What so ever might the definition used, a study conducted in Ethiopia by Mesay (2006) noted that northern and north eastern regions have a belg rain in April with standard deviations of 31.9- 46.1. Also, according to Ayalew *et al*. (2012) reported June 15 (167 DOY) as a mean date of onset for kiremt rainfall in the ANRS. According to Muluneh (2015), the median SOS of kiremt growing season were observed being DOY187 (Jul 5), DOY190 (Jul 8), DOY187 (Jul 5) and DOY187 (Jul 5) for Kombolcha, Kobo, Lalibela and Srinka respectively during the period 1992- 2012. Rainfall variability and its unreliable occurrences in sufficient amount and delay in onset dates caused significant reduction in crop yield with reasonable amount almost all parts of the country (Godswill *et al*., 2007).

2.6.3 End of Rainy Season

End of rainy season (EOS) marks withdrawal of rainy season. Like onset, end of rainy season is also defined differently by different authors. As defined by Odekunle *et al*., (2005) rainfall cessation or end of rainy season refers to the period, towards the end of the rainy season, when rainfall distribution may no longer sustain crop growth. But, Mesay (2006) used to determine end of belg rain with an earliest possible day of May 1, the capacities of soils to persist precipitation with water balance equal to zero. Mamo (2005), Mesay (2006) and Taye *et al*., (2013), also defined as any date when water balance reaches zero after the first date of September (for kiremt). FAO (1978) defined end of growing period when precipitation amount is below half of the reference evapotranspiration. Furthermore, Tesfaye and Walker (2004) defined end of rainy season (for kiremt) as the date when the available soil water content drops to 10 mm/m of the available water after September 11. Hadgu *et al.* (2013), Hadgu et al. (2014) and Kassie *et al*., (2014) used the same definition to determine end of rainy season). Moreover, Zargina (1987) and Benoit (1977) defined end date of growing season as the date in which the minimum daily rainfall threshold is 25 mm in which the soil is assumed to be at field capacity (100mm). On the last day of rain that is greater than 0.5 PET, provided that the date is not proceeded by a dry spell (less than 1 mm average daily rainfall) or more than five days (Mubvuma, 2013).

2.6.4 Length of Growing Period

Growing seasons can be defined as a 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., 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 the 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. Accordingly, Hadgu et al. (2013) reported that the average length of growing period in northern Ethiopia varies from 66 to 85 days depending on the location of the study area. At kombolcha, Muluneh (2015) observed the mean LGP of Kiremt were 93 days. Similarly, Ayalew et al. (2012) also reported a median length LGP during kiremt season at Kombolcha were 100 days.

2.6.5 Numbers of Rainy and Dry Days

According to NMSA (2001) definition, a rainy day is a day that accumulates 1 mm or more rainfall in its 24 hours .Thus, rainy days for kiremt season was counted starting from the first day of June to September 30 in each year; from first day of February to May 31 for belg season; and January 1 to December 31 for annual total. However, dry days are the rainfall amount is less than 1mm or no rainfall in 24 hours or more than 1 day. 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. 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.

2.6.6 Dry Spell Probability

The dry spell probabilities were determined as consecutive number of days with rainfall less than 1 mm per day exceeding 5, 7, 10 and 15 consecutive days. Dry spell length was analyzed by first order Markov Chain analysis (Stern *et al*., 2006; Stern and Cooper, 2011) using

INSTAT v3.37 software. The probability of maximum dry spells on calendar basis at lengths 5, 7, 10 and 15 days were computed and obtained an overview of dry spell risks on the yield production.

2.7 Features of Strong El Niño Years on Rainfall Variability in South Wollo Zone

2.7.1 The 1987 El Niño and Rainfall Variability in South Wollo Zone

El Niño 1986/87 and 1987/88 were two consecutive warm events without interruption that together influenced the climate for 19 months, the most prolonged period during 1984-2013 time frame. El Niño 1986 is classified as moderate while 1987 is classified as a strong one. This combination of moderate/strong El Niño has happened only once in 64 years of recording these events (1950-2013), representing a particular case. The ONI value of El Niño 1987/88 was 1.6 (FAO, 2014).

2.7.2 The 1997 El Niño and Rainfall Variability in South Wollo Zone

Intense warming of ocean waters across the eastern and central tropical Pacific developed in March 1997(WMO, 1998a). The El Niño developed very rapidly during April–May and reached a peak in June 1997. By January 1998, the El Niño began to weaken; the surface area of the warm water pool in the Pacific decreased by 40% since its maximum in the preceding November. The condition previous to El Niño 1997 was considered neutral with ONI value close to -0.5. El Niño 1997 was classified as strong in intensity, reaching the maximum ONI value of 2.4. Due to its extreme intensity, it was called the 'climate event of the century'. However, the impacts on the agriculture sector do not seem to be directly correlated with the intensity of the phenomenon.

According to the NMSA (1998), almost all parts of Ethiopia had dry spells in the Kiremt months of July and August 1997. Out of the 33 Zones in Ethiopia, 18 zones received late rainfall, affecting land preparation and sowing. The 15 Zones that had a good start in rainfall were affected by dry spells in August and September 1997, which adversely affected the maturation stage of the crops. The unseasonable rainfall in October and November 1997 led to fungal attack, slowed the rate of desiccation of the seeds, and led to the germination of the seeds before the harvest (FAO, 1997). Erratic rainfall affected the size of cultivable land by

9% from that of 1996, because of oxen with low energy levels due to less access to fodder. Poor farmers could not rent or borrow oxen at the right time because the owner gave priority to his own plot. The re-planting of the land several times following the coming and retreating of rainfall depleted the seed reserves of farmers. Yields were low because of reduced land preparation, and poor and early cessation of rainfall. Heavy rainfall that flooded farms along with pest infestation also reduced output (Wolde-Georgis et al., 2000).

2.7.3 The 2015 El Niño and Rainfall Variability in South Wollo Zone

Based on NOAA data, three month ONI value of El Niño 2015 was 2.5 that was reach maximum in October-November-December. In 2015 food security reports and humanitarian needs assessments in Ethiopia refer to failed or poor rains, which in part relate to El Niño weather events: in early June of 2015 Ethiopia's National Meteorological Agency (NMA) reported that the important belg rains of March to May had failed, and an emerging El Niño episode was associated with the delayed onset of the main kiremt rains, normally falling in June to September (OCHA, 2015). Clear evidence that the start of the kiremt rains was delayed and erratic in northern and eastern areas. Erratic kiremt rains have resulted in reduced and delayed planting, poor germination and establishment and increased incidence of pests and diseases.

According to the office of South Wollo Zone Early Warning, the belg beneficiary areas of the zone were failing and the kiremt rainfall showed delaying, erratic in nature and mostly lowland areas of the Zone were got low in amount. They also indicates that there an area there was rainfall not more than 5 days in kiremt season 2015. As a result, the long cycle meher crop productions which are sowing during belg were mostly failed and crops that are sowing in kiremt season were reduced. Beside, South Wollo Zone lost 423810 hectare crop productions with associated El Nino induced drought in the year of 2015.

2.8 Climate Change Impacts in Agricultural Production in South Wollo Zone

Climate change affects agriculture in a number of ways; including through changes in average temperatures; rainfall and climate extremes with an important impact on soil erosion (i.e. floods, drought, etc.), changes in pests and diseases, changes in atmospheric carbon dioxide, changes in the nutritional quality of some foods, changes in growing season and changes in sea level (World Bank, 2008). Crop yields show a strong correlation with temperature change and with the duration of heat or cold waves and differ based on plant maturity stages during extreme weather events (Hoffmann, 2013). According to Ignaciuk and Mason-D'Croz (2014), climate change currently decrease the yields of maize, rice, wheat, potatoes and vegetables and continue to reduce seriously by 2050 globally. MacDonald and Simon on IPCC (2007) also reported that farmers living in Ethiopia’s semi-arid and arid lowlands that have less diversified assets and are heavily reliant on rain-fed agriculture, particularly vulnerable to climate change. Climate change is also likely to affect the livestock sector both by affecting the quantity and quality of feed and by affecting the frequency and severity of extreme climate events livestock sector particularly vulnerable to the effects of climate change (Hoffmann, 2013).

Kalu Woreda is one of the climate change affected area of South Wollo Zone (CwCC, 2009). To cope or adapt drought and CC in this area, UNDP funded 995000 USD in six villages of community members of 41421(of which 21991 male and 19,430 females) were benefited through disseminating and utilizing effective early warning information to various stakeholders in the agricultural planning processing from January 2009 to December 2012 (CwDCC, 2009). UNDP also funded in the South Wollo Zone of Legambo, Mekdela and SaintAdjibar by planning food security and recovery program (BoFED, 2009).

2.9 Major crops in South Wollo Zone and their Productivity

A large number of crops are grow in Ethiopia including South Wollo Zone that contains cereals (teff, wheat, barley, corn, sorghum and millet); pulses (faba bean, chickpea, haricot bean, field pea, lentil, soybean and vetch); Oilseeds (linseed, noug, gomenzer, sesame and groundnuts), vegetables (pepper, onion, tomato, carrot, cabbage, and kale), root and tubers (potato, enset, sweet-potatoes, beets, yams); fruits (apple, peach, plum, grape, banana, citrus, papaya, pineapple, mango and avocado); fibers (cotton and sisal); stimulants (coffee, khat and tobacco) and sugarcane (EIAR, 2011). Cereals are the dominantly grown crops in Ethiopia not only in terms of the area under cultivation but also amount of production and consumption (CSA, 2014). More than 73% of the country’s cropped area and over 68% of the crop productions are contributed by cereals. From the cereals teff, maize, sorghum, wheat and barley are the main food crops in the country in terms of area of land coverage and contribution to the country's production. They are produced under rain fed farming system. Sorghum and maize are long-cycle and warm weather cereals while wheat, barley, and teff are short- cycle cool weather cereals (CSA, 2014). Barley and wheat are more frequently found at higher altitudes including South Wollo Zone (Eklundh and Pilesjö 1990; Ketema 1993). Teff is most commonly found at altitudes of 1500–2300 metres but can be grown up to 2800 m altitude (Rosell and Holmer, 2007). Based on SWBMLZ (2007), wheat, barley and teff are the dominant cereal crops supported by rearing of livestock are the main economy of smallholder farmers in South Wollo Zone.

2.9.1 Wheat (Triticum aestivum)

Wheat is an important cool weather crop grown predominantly in the Ethiopian highlands including South Wollo Zone at optimum altitude ranging from 1000 to 2300 meters above sea level. Wheat occupies large area of land and produces large amount of grain every year. It furnishes the flour to make bread and injera that is consumed throughout the country. Wheat Production receives large amount of inorganic fertilizers and herbicides; to some extent fungicides against rust diseases.

Based on CSA (1998) report on meher 1997/1998 which was manifested by strong El Nino in the country including South Wollo Zone, from the total arable land, 30,060 hectares covered with wheat and produced 345840 quintals in South Wollo Zone. Moreover, on meher 2006/2007 report, the production of wheat in South Wollo Zone was 11132329.27 quintals from 78907 hectares of land and the yield was 11.19 quintals per hectares (CSA, 2007). In 2104/2015 meher season with total cultivated area 96654.51 hectares covered with wheat and produced 1953957.03 quintals with yields of 20.21 quintal per hectare. As compared to the previous listed year, the yield of wheat in the year 2014/2015 meher season was high.

2.9.2 Barley (Hordium spp.)

Barley is a cool weather crop grown in the extreme highlands of Ethiopia with an optimum altitude range of 2000 to 3500 meters above sea level. It is used as staple diet of many Ethiopians in the highlands and is eaten in many ways and also used in the production of Tella, a locally produced beer and beer beverage as malt (input of malt factories of North

Gonder Zone and Arsi Zone as country level). Barley is a subsistence crop, grown mostly without external inputs. Pesticides are used to some extent, particularly for aphid's control.

Based on CSA (1998) report on meher1997/98 in South Wollo Zone, 23250 hectares covered with barely and produced totally 287430 quntals in total. The total barley yield which expresses quntals per hectares was 12.36. However, on meher 2006/2007 reports of CSA indicated that the total areal production of barley with 35691.57 hectares got 444126.44 quintals and showed 12.44 quntals/hectares. Similarly, in 2014/2015 meher season with 46872.57 total cultivated area of barley, 727195.03 quintals were produced and showed 15.51 quintal per hectare. In the year 2014, barley produced 727195.03 quintals from the total cultivated area of 46872.57 hectares with yield of 15.51 quintal per hectare (CSA, 2015).

2.9.3 Teff (Eragrostis teff)

Teff is a cool weather crop grown predominantly in the Ethiopian highlands at optimum altitude range of 1800 to 2200 meters but can grow up to 2800 meters (Rosell and Holmer, 2007). This crop occupies the largest area (about 1.4 million hectares of land) at country level and has relatively large amount of grain production. It is an indigenous to Ethiopia, forms the staple diet of many Ethiopians and it furnishes the flour to make injera, unleavened bread that is consumed in the highlands and in urban centers throughout the country. It is gluten-free, rich in phosphorous, copper, aluminum and thiamine and is an excellent source of protein, amino acids and carbohydrates. It is also higher in calcium, iron and zinc content than corn, wheat, or rice (Baye, 2014). Teff is, however, very delicate and fragile crop that requires a lot of work and care, and it has one of the lowest yields of the cereal crops grown in the county. The production of teff requires high external inputs, particularly fertilizers and herbicides. In South Wollo Zone , teff and Barley can grow in belg season on belg beneficiary areas such as Haik, Kutaber and Dessie Zuria district (Rosell and Holmer, 2007).

According to CSA (1998) report on meher 1997/98, from the total arable land, 65240 hectares covered by teff and produced 562070 quintals. The total yield which expresses quintals per hectares of teff was 8.62. It showed the production of teff crops was low during bad years in the study areas. However, 2006/2007 meher, from the total cultivated areas of 113828.84 hectares of land production of teff produced 1273186.14 quintals with yields of 11.19 quintal per hectare. Based on yield data and rainfall recording history, the year 2006 was good year and showed good teff production (CSA, 2007). Similarly, in 2104/2015 meher season which was reported by CSA (2015) showed 1822625.92 quintals of teff obtained from 124418.12 hectares of land with yield of 14.6 quintal per hectare. The yield of teff was good. It might be kiremt rainfall in the year 2014 was suitable for the production of teff as compared to the pervious listed (reported) years.

2.10 Relationships between Rainfall Variability with Crop Yield in South Wollo Zone

Lemi (2005) found that crops are negatively affected by rain, based on the yield and rainfall data he analyzed for four provinces of Ethiopia. The results further showed strong negative correlation between meher season rainfall and crop yield. The converse is true for the case of belg season. For instance, Meher (JJAS) rain (r = -0.161 and r = 0.479) had low to moderate negative and positive correlation with wheat yield in Harar and Gonder province in Ethiopia, respectively. On the other hand, meher rain (r = -0.009 and r= -0.255) had low positive and negative correlation at both locations in the country. Bewket (2009) also showed on the correlation between monthly, seasonal and annual areal average rainfalls and cereal production that the production of teff, barley and wheat considerably high correlations with kiremt rainfall total. But, sorghum production showed a stronger correlation with the belg rains.

Particularly in South Wollo Zone, Admassu (2004) found using climate and crop data for the period 1994-2001, total annual rainfall does not show strong correlation with the production of cereals crops such as teff, barely, wheat and maize in the study areas except for annual rainfall with wheat production. He also found that teff, barley, wheat and Maize production do not show strong correlation with kiremt rainfall. But, barley production shows strong correlation with kiremt rainfall total. On the other study, Bewket (2009) showed productions of teff, barley and wheat show stronger correlations with the kiremt rainfall while sorghum production is more strongly correlated with belg rainfall. Rosell (2014) revealed that teff production is highly correlated with belg rainfall at Haik during his study period of 1963-2003.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

South Wollo administrative Zone, which is located in North eastern portion of Ethiopia, is found between $10^{0}10'$-$11^{0}41'$N and $38^{0}25'$-$40^{0}05'$E (Figure 3.1). Its zonal capital, Dessie, is found at a distance of 400 kilometers North of Addis Ababa. South Wollo Zone are bordered on the south by North Shewa Zone and Oromia Regional state, on the west by eastern Gojjam Zone, on the northwest by South Gondar Zone, on the north by North Wollo Zone, on the northeast by Afar Regional state, and on the east by the Oromo Nation's Special Zone.

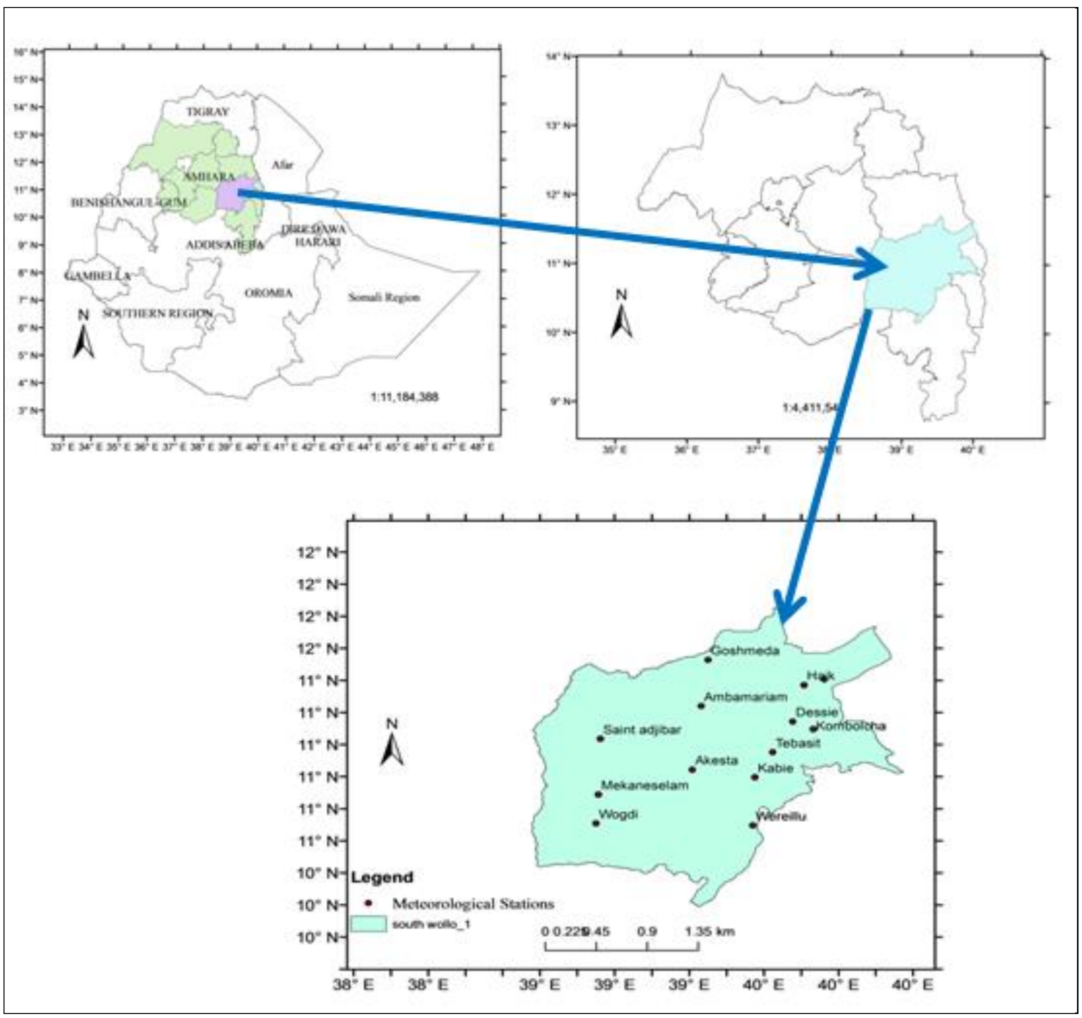


Figure 3.1: Location map of the study area.

3.1.2 Topography and Climate Characteristics

South Wollo is characterized by diverse topographic features in which high mountainous and deeply incised canyons and gorges, valleys and plateaus with steep slopes dominate its most parts (Coltortiet, 2007). The elevation ranged from the dry plains at 1000 metres altitude in the east to the high peaks above 3500 metres altitude in the west. However, highland areas ranging between 1500 and 3500 metres altitude are the dominate feature of South Wollo Zone (Rosell and Holmer, 2007).

According to South Wollo Zone Early Warning, South Wollo Zone has four agro-ecologies: 17% Kola, 46% Woyina-dega, 35% Dega and 2% Wurch. So, the agro-ecology is mainly Woyna-dega. Most parts of the Zone are mountainous and hilly. The land is highly degraded and the area is deforested in terms of indigenous trees and thus dominantly covered by substantial eucalyptus plantations. In terms of rainy season, South Wollo Zone is characterized by bimodal rainfall patterns and hence major parts of the Zone have two harvest periods. Kiremt (June-September) is the main rainy season, while in belg season (February-May) is found to be this short rainy season. In fact, belg season is very influential for mid to high latitude areas, whereas the mid lands to lowland areas mainly depend on the kiremt rain. The annual rainfall varies between 1,000 mm in the western part to 1200 mm in the eastern part. Similarly, the mean annual and seasonal for kitremt, bega and belg temperature varies from 5°C in the western highlands to 22°C in the eastern lowlands. The area is characterized by erratic rainfall and low crop productivity (Taye et al., 2013). Indeed, the crowded, steep-sloped highlands above 2000 metres including large parts of South Wollo are among the country's most famine-prone areas (Little et al., 2006). Due to this, South Wollo Zone is one of the drought-prone and aid-dependent areas in Amhara Regional State (Bewket and Conway, 2007; Yimer et al., 2017). However, the South Wollo Belg livelihood Zone is mainly confined in parts of Tenta, Legambo, Kalu, Legehida, Dessie Zuria, Kutaber and Ambassel woredas.

3.1.3 Population and Socio-economic Activities

The total number of people lived in South Wollo Zone was 2518862 (CSA, 2007). Out of this total population, people lived in rural and urban areas are 88% and 12% respectively, of which the urban dwellers were lower than the national average (BoFED, 2009). Population density was high with 150-250 persons per km^2 in the areas. The largest ethnic group in South Wollo

Zone was Amhara (99.33%); all other ethnic groups made up 0.67% of the population. Amharic is spoken as a first language by 98.65%; the remaining 1.35% spoke all other primary languages reported. 70.89% were Muslim, and 28.8% of the populations practice Ethiopian Orthodox Christianity (CSA, 2007).

Rain-fed agriculture is predominant in the study area. Major crops such as, cereals (teff, barley, wheat, maize, sorghum and millet), pulses (horse beans, chickpea and lentil) and oil crops (sesame, ground nuts, sunflowers and noug) are the major crops grown in the study area (CSA, 2011). Agriculture in the area is constrained by poor soil fertility, soil degradation and erratic rainfall (Rosell, 2014); as a result, most parts of South Wollo are chronically food insecure (Amare et al., 2011; Kahsay, 2013; SWDoFED 2014; Kebede and Zewdu, 2014). As in most other drought-affected areas, food security in South Wollo Zone is precarious due to a high population density, small land holdings per household, heavy reliance on (often erratic) rain, high soil erosion and decreasing soil fertility (AMAREW, 2007; Yimer et al, 2017). It is structurally food deficit, with much of the population chronically dependent on food aid.

Khat is an important cash crop particularly in Tehuledere and Worebabo woredas. Eucalyptus is also another source of income in the study area; the trees are sold for construction and firewood. Many farmers supplement subsistence agriculture with cash income from seasonal labor, the sale of firewood or charcoal and, the less poor, hiring out animals for transporting or ploughing. Poor households in the rural economy are susceptible to natural disasters, even if households are not directly involved in agricultural production. This is due to the fact that many rural poor communities have income sources that are tied to the success of agricultural production or are otherwise susceptible to extreme weather events (Barnett and Mahul, 2007; Dyer et al. 2005). In times of stress, coping mechanisms include the sale of small livestock, productive assets such pack animals and oxen and seasonal out-migration. Since the area is characterized by quasi bimodal rainfall pattern (Mesay, 2005; Segele and Lamp, 2005; Viste et al., 2012), some of the crops are planted and harvested in the main rainy season (Kiremt), while some of them in belg while others (long maturing crops and delaying of belg rain) planted in the belg and harvested in kiremt (e.g., barley, sorghum, millet and maize).

3.2 Data Sources and Methods

3.2.1. Observed and Satellite-estimate Rainfall data

In order to analyze rainfall variability and its trend, long term daily gauge rainfall data and some stations gridded rainfall data were obtained from NMA, Ethiopia. Based on the availability and quality, and relative length of time, thirteen meteorological stations were select for this study with a reasonably good geographic distribution in the study area. Out of thirteen stations, some stations have missed data and filled with satellite-estimated rainfall data.

Table 3.1: Locations of meteorological stations used in this study

Station Name	Longitude (degree)	Latitude (degree)	Altitude (m.a.s.l.)	Length of record	Woreda
Akesta	39.18	10.87	3086	1986-2016	Legambo
Ambamariam	39.22	11.20	2990	1986-2016	Tenta
Dessie	39.63	11.12	2553	1986-2016	Dessie Zuria
Haik	39.68	11.31	1985	1986-2016	Tehuledere
Goshmeda	39.25	10.44	2261	1986-2016	Mekdela
Kabie	39.46	10.83	2879	1986-2016	Wereillu
Kombolcha	39.72	11.08	1857	1986-2016	Kombolcha
Mekaneselam	38.76	10.74	2605	1986-2016	Borena
SaintAdjibar	38.77	11.03	2844	1986-2016	Saint
Tebasit	39.54	10.96	3302	1986-2016	Dessie Zuria
Woreillu	39.45	10.58	2690	1986-2016	Wereillu
Wogdi	38.76	10.59	2405	1986-2016	Wogdi
Worebabo	39.77	11.34	2378	1986-2016	Worebabo

The rainfall data used in this study are in daily, monthly, seasonal and annual forms for the period 1986 to 2016. Prior to analyzing gauge-based daily rainfall, the data inspected carefully for their completeness and quality as well as detecting outliers.

3.2.2 Sea Surface Temperature (SST) data

Sea Surface Temperature (SST) data is downloaded from the most recent version of the Extended Reconstructed Sea Surface Temperature dataset (NOAA NCDC ERSSTv2) from http:// iridl.ldeo.columbia.edu/ to analyses the ENSO features.

3.2.3 Crop Yield Data

In this study, crop yield data obtained from South Wollo Zone Early Warning Office from 2011 to 2016. These data contained three major cereal crops that are usually grow in different districts of the Zone. Therefore, the selected crops and districts were wheat, barley and teff from Tenta, Tehuledere, Borena, Wogdi and Worebabo respectively. Crop yield data were expressed in quintals (qt) over cultivated land in hectare (ha).

3.3 Data Analysis Method

Various data analysis methods are employed for this study. Multivariate statistical techniques were used to characterize how rainfall, sea surface temperature and crop yield data are inter-linked. Specific statistical parameters are used; such as long-term mean values and indices for variability like standard deviation, coefficients of variation, precipitation concentration Index and Man-Kendal trend were compute at seasonal and annual time scales.

3.3.1 Data Quality Check

To avoid potential problems in the analysis of climatic records a number of pre-scrutiny of historical data can be made. For instance, rainfall data were plotted for visual inspection and detection of outliers. Identification of outlier values should be done carefully to make sure that the detected outliers would truly be erroneous and is not naturally extreme values (Abbas et al., 2013). A standard outlier threshold, which is defined using inter-quartile range (IQR), was used for this study (Gonzalez-Rouco et al, 2001). Mathematically, it is defined by formula as:

$$\text{Threshold} = (Q_1 - 3*IQR, Q_3 + 3*IQR) \qquad [3.1]$$

Where, Q_1 is first quartile, Q_3 is third quartile and IQR is an inter-quartile range (which is the difference of Q3 and Q1). The inter-quartile range method is known as a technique which is resistance to outliers but still keep the information of extremes. The detected outlier values were then removed and substituted by outlier threshold (SUPARI, 2012).

3.3.2 Inter-Seasonal to Seasonal Climate Variability Analysis

Seasonal and annual rainfall and crop yield indices were analyzed using the coefficient of variation (CV), standard deviation (SD), mean, precipitation anomaly, and Precipitation concentration Index (PCI).Scientifically, CV can be computed as:

$$\mathrm{CV}\,\% = \left(\frac{\mathrm{SD}}{\bar{\mathrm{X}}}\right) * 100 \qquad [3.2]$$

Where, $\bar{\mathrm{X}}$ and SD are the average and standard deviation of parameters, respectively over the given Period. According to Hare (1983), CV (%) values are classified as follows: < 20% as less variable, 20- 30% as moderately variable and > 30% as highly variable.

On the other hand, standard deviation is computed as the square root of variance. Using the classification of Reddy (1990), the stability of rainfall is examined as follows: when standard deviation <10 as very high stability, 10-20 as high stability and 20-40 as moderate stability and >40 as less stability. Statically, SD can be computed as:

$$\mathrm{SD} = \sqrt{\sum_{i=1}^{n} \frac{(\mathrm{Xi}-\bar{\mathrm{X}})^2}{n}} \qquad [3.3]$$

Rainfall anomaly was also used to examine the nature of rainfall over the period of Observation and to determine dry and wet years in the record. As in Agnew and Chappel (1999), the Standardized Rainfall Anomalies (SRA) were calculated and graphically presented to evaluate inter-annual fluctuations of rainfall in the study area over the period of observation. SRA is expressed as:

$$\mathrm{SRA} = \frac{(\mathrm{Xi}-\bar{\mathrm{X}})}{\mathrm{SD}} \qquad [3.4]$$

Where, $\bar{\mathrm{X}}$ is the long term mean, n is total number of years, Xi is the rainfall amount in each time of year i.

The same method was used by Ayalew et al. (2012) and Hadgu *et al*. (2013) to identify dry and wet years in their study.

Another method of rainfall variability analysis used was precipitation concentration Index (PCI). Oliver (1980), proposed the Precipitation Concentration Index (PCI) as an indicator of rainfall concentration and rainfall erosivity. Michiels *et al*. (1992) evaluated the PCI and calculated its values on annual and seasonal scale.

$$\text{PCI Annual} = 100 * \frac{\sum(\text{Pi})^2}{(\sum \text{Pi})^2} \qquad [3.5]$$

Rainfall during a year occurs in different seasons, three seasons are known in Ethiopia, namely bega, belg and kiremt (NMA, 2007). So, PCI on seasonal scale also calculated as:

$$\text{PCI seasonal} = \frac{100}{3} * \frac{\sum(\text{Pi})2}{(\sum \text{Pi})2} \qquad [3.6]$$

Where, Pi is rainfall amount of the i^{th} month and $\sum$ is summation over the number of months being assessed. Based on PCI values, we can be generalizing the rainfall distribution. When PCI value is less than 10, there is Uniform precipitation distribution. PCI is between 11 and16, moderate precipitation distribution. When the PCI value is found between 16 and 20, there was an irregular monthly distribution. Finally, strong irregular precipitation distribution occurred when PCI value is greater than 20. Tsegaye et al. (2015) and Luis *et al*. (2011) used the same method for calculating seasonal PCI.

3.3.3 Annual and Seasonal Trend Analysis

In this study, Mann-Kendall test used to show the trend of rainfall pattern by using the sign of the difference between later-measured data and earlier-measured data seasonally and annually. The Mann-Kendall's test statistic was given as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \text{sign}(\text{Xj} - \text{Xi}) \qquad [3.7]$$

Where S is the Mann-Kendall statistics; Xj and Xi is the sequential rainfall values in years j and i (j>i) respectively and N is the length of the time series. The sign function was computed as:

$$\text{Sign (Xj} - \text{Xi)} = \begin{cases} +1 \rightarrow \text{if (Xj} - \text{Xi)} > 0 \\ 0 \rightarrow \text{if (Xj} - \text{Xi)} = 0 \\ -1 \rightarrow \text{if (Xj} - \text{Xi)} < 0 \end{cases} \qquad [3.8]$$

Sign (X_j- X_i), is equal to +1, 0, or -1 as indicated above. When S is a large positive number, later-measured values tend to be larger than earlier values and an upward trend is indicated. When S is a large negative number, later values tend to be smaller than earlier values and a downward trend is indicated. When the absolute value of S is small, no trend is indicated. Trends considered at the study sites were tested for significance. The variance of S, for the situation where there may be ties (that is, equal values) in the x values is given by:

$$\mathrm{Var}(S) = \frac{1}{18}\left[N\,(N-1)\,(2N+5) - \sum_{i=1}^{m} ti(ti-1)(2ti+5)\right] \qquad [3.9]$$

Where, m was the number of tied groups in the data set and ti was the number of data points in the i^{th} tied group. For N larger than 10, Z_{MK} approximates the standard normal distribution (Yenigun et al., 2008) and computed as follows:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{Var}(S)}} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{Var}(S)}} \text{ if } S < 0 \end{cases} \qquad [3.10]$$

Statistically, significant trend was evaluated using the Z_{MK} value. In a two sided test for trend, the null hypothesis Ho was accepted if $|ZMK| < Z_{1-\alpha/2}$ at a given level of significance. $Z_{1-\alpha/2}$ was the critical value of Z_{MK} from the standard normal table. A positive value of Z_{MK} indicates an increasing trend while a negative value indicates a decreasing trend. In this study, the significance of the observed change was examined at 0.05 significance levels. MAKESENS 1.0 was used to perform two types of statistical analyses. First, the presence of a monotonic increasing or decreasing trend was tested with the nonparametric Mann-Kendall test and secondly the true slope of the existing linear trend (as change per year) was estimated with the nonparametric Sen's method (Gilbert, 1987).

3.3.4 Crop data Analysis using Correlation and Regression

Correlation and regressions techniques are important in showing the relationship between climatic parameters and crop Production, and to identify the most predictor variable. To analysis crop data (wheat, barley and teff) in relation to rainfall characteristics, Correlation and multiple linear regression methods were used. The regression equation was:

$$Y=a+b_1x_1+b_2x_2+b_3x_3\dots b_nx_n+e \qquad [3.11]$$

Where, Y is the value of the dependent variable (wheat yield in qt or qt/ha); a is Y intercept and b_1, b_2, b_3, b_4 … b_n are regression coefficients x_1, x_2, x_3, x_4… x_n are the independent variables (rainfall characteristics such as rainfall onset, cessation, duration, seasonal rainfall total and number of rain days, respectively); and e is the error of estimate or residuals of the regression. Correlation coefficient (r) analyses were used to analyze the correlation between crop yields (Wheat, Barley and Teff yield expressed in qt/ha) with rainfall characteristics. Value of 'r' ranges between -1 to +1, a correlation coefficient close to +1 indicates a strong positive correlation; a correlation coefficient close to -1 indicates a strong negative correlation similarly a correlation coefficient of 0 indicates no correlation.

The other formula used to determine the percentage of variation between rainfall charactestics and yields of selected crops is coefficients of multiple determinations (R^2). The formula is written as follows.

$$R^2=\left[\frac{n\sum_{i=1}^{n}XiYi-(\sum_{i=1}^{n}Xi)(\sum_{i=1}^{n}Yi)}{\sqrt{[n\sum_{i=1}^{n}Xi^2-(\sum_{i=1}^{n}Xi)^2]\,[n\sum_{i=1}^{n}Yi^2-(\sum_{i=1}^{n}Yi)^2]}}\right]^2 \qquad [3.12]$$

Where, n is number of years, Xi is rainfall amount in millimeter (mm) in the i^{th} year and Yi is amount of yield production in the i^{th} year in quntals. Lemi (2005); Bewket (2009); and Akinseye et al. (2013) used the same methodology in their study of the relationship between climate variables and crop production.

3.4 Determination of Rainfall Characteristics

The Start and End of the Growing Period

In setting an onset date of the past records, many different criteria could be used for different crops exhibiting different maturity plus drought tolerance levels and soil types. Here, the one with 20 mm of total rainfall received over three consecutive days that were not followed by greater than 10 days of dry spell length within 30 days from planting was adopted (Raman, 1974). This criterion was also used by Mamo (2005) and Fitsum (2015) for determining the start of rainy seasons. On the other hand, the end of growing season is mainly dictated by the water stored in soil and its availability to the crop after the rain stops. The growing periods for most crops continue beyond the rainy season and crops often mature on soil moisture reserves. Soil moisture must, therefore, be considered for determining LGP. However, data on soil moisture is not easily available in Ethiopia. Hence based on an experimental evidence from Africa (FAO, 1978), 100 mm of soil water is added during the rainy season, to determine the end of the growing period. As result, the present study used 100 mm/meter of the plant available water holding capacity to the soil on INSTAT v 3.7 software applications.

4. RESULTS AND DISCUSSIONS

4.1 Annual Rainfall Variability in South Wollo Zone

As depicted in Table 4.1, the long term mean annual of South Wollo Zone rainfall ranges was fall 641.8(at Goshmeda) -1251.5mm(at Worebabo) in the period of observation (1986-2016), with standard deviation of 123.7mm (at Wogdi) and 346.0mm (at Ambamariam) and a coefficient of variability 14.1% and 34.0%, respectively. Out of thirteen stations, seven stations (Ambamariam, Dessie, Haik, Kombolcha, SaintAdjibar, Tebasit and Worebabo) received 1014.3mm to 1251.7 mm of annual rainfall per year. High mean annual rainfall were recorded at Worebabo, Haik and Dessie with amount of 1251.7, 1219.8 and 1191.3 mm respectively and the annual maximum rainfall was recorded in Ambamariam with 2377.1mm .However, the lowest mean annual rainfall was recorded at Goshmeda of 633.3mm and the annual minimum rainfall was observed at Goshmeda with 257.0 mm (Table 4.1). Generally, the annual mean rainfall was much more in eastern part than in western parts of South Wollo Zone (Figure 4.2). In line with the present study, Yimer *et al* (2017) showed similar thought on the Meteorological drought assessment in north east highlands of Ethiopia, from 1984-2014.

According to Hare (1983), the calculated annual coefficient of variation ranges from 14.1% (at Wogdi) to 34% (at Ambamariam) and the annual rainfall variability of SaintAdjibar and Tebasit were categorized as moderately variable and Ambamariam was highly variable. However, the remaining stations were experienced less annual variable. The calculated annual PCI showed rainfall in South Wollo Zone is generally characterized by high to very high monthly concentration (PCI values ranged from 19.5% in Mekaneselam to 69.7% in Haik). According to Oliver (1983), all stations except Mekaneselam (which showed moderately monthly precipitation distribution) received strong irregular monthly precipitation distribution (which has values greater than 20%).

Table 4.1: Annual rainfall variability in South Wollo Zone, during 1986-2016

Stations	Min (mm)	Max (mm)	Mean (mm)	SD (mm)	CV%	PCI%
Akesta	661.1	1255.8	914.1	146.1	16.0	25.9
Ambamariam	654.3	2377.1	1019.3	346.3	34.0	21.3
Dessie	810.7	1612.6	1191.3	209.7	17.6	23.2
Haik	633.5	1825.3	1219.8	213.2	17.5	22.4
Goshmeda	257.0	973.8	641.8	184.9	28.8	27.8
Kabie	436.6	1374.6	886.7	173.5	19.6	33.4
Kombolcha	725.1	1361.6	1035.1	154.9	15.0	24.3
Mekaneselam	633.5	1323.9	859.4	167.0	19.4	19.5
SaintAdjibar	679.5	1521.1	1014.3	203.8	20.1	22.6
Tebasit	539.0	1829.9	1037.3	298.3	28.8	26.3
Woreillu	467.6	1146.2	860.2	164.7	18.3	30.2
Wogdi	644.0	1139.1	906.0	127.3	14.1	22.0
Worebabo	619.7	1673.1	1251.7	211.4	16.9	24.3

Monthly rainfall has its own contribution to annual total rainfall. As figure 4.1 shown, the type of rainfall was bimodal and their maximum peak monthly rainfalls were recorded in July and August. In belg season of FMAM, monthly peak rainfalls were recorded in the month of March and April at Akesta, Ambamariam, Dessie and Kombolcha. While in Mekaneselam and Worebabo, belg rainfall peaks in the month of March and May.

On the other hand, kiremt season JJAS, all stations were recorded maximum rainfall in the months of July and August in the range of 235.6 mm at Akesta to 327.5mm at Tebasit and 204.8 mm at Akesta to 320.1 mm at Dessie respectively. As compared to the two months, out of thirteen stations, eight stations (at Ambamariam, Kabie, Kombolcha, Mekaneselam, Saint Adijibar, Tebasit and Woreilu) had higher monthly average rainfall in July. The remaining stations were recorded monthly peak average rainfall in August. The month September has also good contribution to Annual rainfall as well as kiremt seasonal rainfall. In general the failure of rain in March, April, July and August has caused many socio-economic problems in South Wollo Zone.

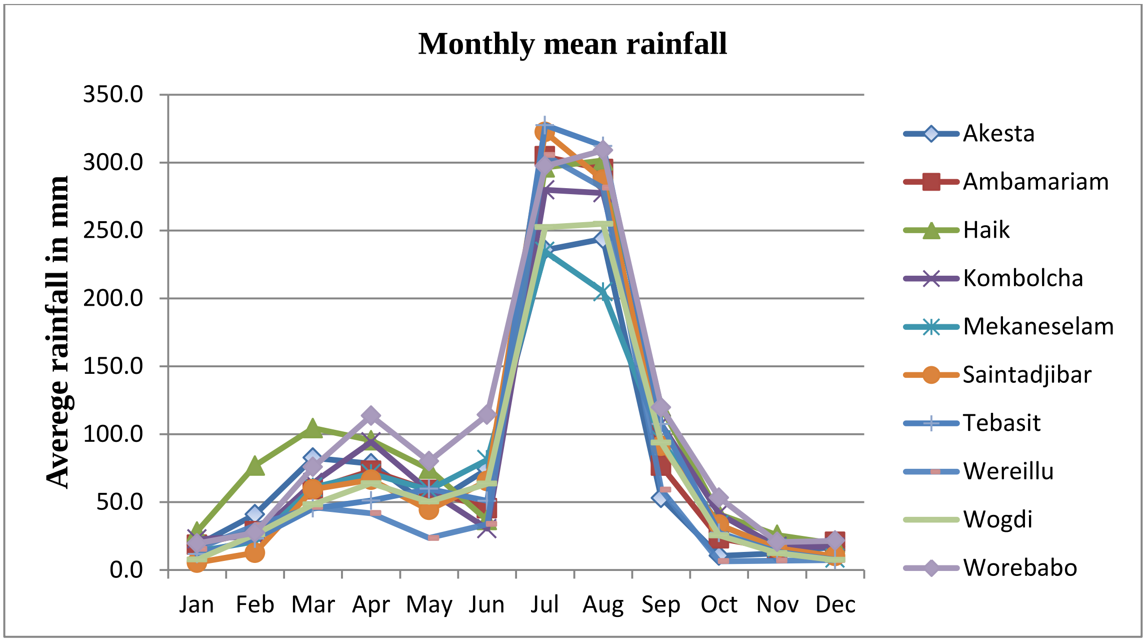


Figure 4.1: Mean monthly rainfall (mm) for the stations under study area.

4.2 Seasonal Rainfall Variability

The study area heavily experiences high rainfall during kiremt (main rainy from June to September) season. This season contributes from 61.8% (at Haik) to 79% (at Woreillu) to mean annual rainfall in South Wollo Zone (Table 4.2). Similar result was also reported by Muluneh (2015) with contribution of seasonal kiremt rainfall to annual total rainfall varied from 60% at Srinka to 76% at Lalibela including Kombolcha with 64.2% contribution of Northern East Amhara during the period of 1992-2012. Also, reported by Bewuket (2009), the contribution of kiremt rainfall to the annual rainfall totals ranged from 64% (at Kombolcha) to 85% in Amhara region for the period of 1975-2003. Likewise, Alemayehu and Bewket (2016) found that kiremt rainfall contributed from 65.8% to 73% in the North Shewa during 1983-2013.

The mean rainfall of kiremt season in the study area was varied 487.3 (at Goshmeda) to 840.3 mm (at Worebabo) of the South Wollo Zone, CV ranged from 16.3 % (at Wogdi) to 30.6% (at Tebasit) and SD ranged from 108.3 mm to 244.3 mm, respectively (Table 4.2). The result showed that, the study area mostly experienced moderate rainfall variability and less stability of rainfall during kiremt season. This less stability showed that the kiremt rainfall totals were not easily predictable and could result in difficult decision regarding rain fed crop production during the study period. Similar results were also reported by Muluneh (2015), Hadgu et al. (2013) and Bewket (2009) in the north and north eastern parts of Ethiopia. The calculated PCI showed that rainfall in the South Wollo Zone is generally characterized by very low to low monthly concentration. That means, from uniform monthly distribution to moderate monthly precipitation distribution (PCI values ranged from 10.5% at Mekaneselam to 13.5% in Wereillu) that indicates the monthly rainfall distribution was moderate. In the present study, PCI and CT values of kiremt at Kombolcha station was 12.4 and 67.1% respectively. Similarly Ayalew (2012) showed on his study on variability of rainfall and its current trend in Amhara region from 1979-2008 found PCI and CT values in the same season at Kombolcha were 15.3 and 64.87% respectively.

Table 4.2: Kiremt seasonal rainfall means (mm), coefficient of variation (CV), Precipitation Concentration Index (PCI) and contribution to total rainfall (CT), 1986-2016.

	Kiremt						
Stations	min(mm)	max(mm)	mean(mm)	SD(mm)	CV%	PCI	CT%
Akesta	391.3	807.9	606.7	111.9	18.5	12.2	66.4
Ambamariam	445.5	995.4	721.7	151.3	21.0	13.0	70.8
Dessie	449.0	1196.7	815.3	181.6	22.3	11.8	68.4
Haik	386.9	1218.6	754.3	180.8	24.0	12.1	61.8
Goshmeda	219.5	761.6	487.3	136.7	28.1	13.3	77.0
Kabie	106.4	963.9	663.3	164.0	24.7	12.9	74.8
Kombolcha	379.2	962.5	695.0	137.5	19.8	12.4	67.1
Mekaneselam	390.7	1113.0	616.1	136.9	22.2	10.5	67.8
SaintAdjibar	365.7	1214.0	766.4	181.2	23.6	10.8	73.9
Tebasit	411.2	1287.6	797.9	244.3	30.6	12.4	76.9
Woreillu	302.9	1056.0	679.7	173.8	25.6	13.5	79.0
Wogdi	452.1	858.9	664.3	108.3	16.3	11.4	73.3
Worebabo	321.8	1287.2	840.3	182.6	21.7	10.9	67.1

On the other hand, belg season (February-May) rainfall plays a vital role to the contribution of the annual total precipitation in all the 13 stations and varied from 17.3% at Tebasit to 28.8%

at Haik (Table 4.3). This indicates that the contribution of the seasonal belg rainfall to the annual total is less than half of the contribution of the seasonal Kiremt rainfall. In line of the present study, NMSA (2005) also noted that over the north, northeastern (including South Wollo Zone) and eastern parts of Ethiopia, the contribution of seasonal belg rainfall to the annual total range from 5% - 30%. In a similar study, Taye *et al*. (2012) also found 20% - 30% contribution of the seasonal belg rainfall in the same region during 1979-2008.

The observed mean seasonal belg rainfall totals ranged from 133.5mm at Goshmeda to 351.1mm at Haik station of the study area with CV ranged from 37.1% to 67.5%, and the SD value ranged from 84.0-142.1mm respectively (Table 43). This implies that the seasonal belg rainfall was characterized by high variability as the classification of Hare (1983). Similar result were reported by Rosell and Holmer (2007) with mean belg rainfall and CV of Haik, Dessie and Kombolcha were 341, 276 and 242 mm and CV of 37%, 41% and 40% for the period 1984-2003 respectively. In line with the present study, Bewket (2009) also revealed that the mean belg rainfall amount was 251 mm at Dessie and 230 mm at kombolcha and CV of 44% and 40% respectively for the period 1975- 2003. Likewise, high seasonal belg rainfall variability was reported by Ayalew *et al*. (2012) over Amhara Region, and Alemayehu and Bewket (2016) over North Shewa for the time period of 1975-2003, 1979-2008 and 1983-2013, respectively.

The PCI value of the belg seasons varied between 10.8 and 13.0, that indicates the Zone received normal amount rainfall with moderate monthly rainfall distribution in the study period (Table 4.3). The small amount rainfall observed with less stability and high variability indicates that the rainfall was not dependable and easily predictable, and the seasons were unlikely to sustain agricultural crop Production on rainfall during 1986-2016. In general, seasonal and annual rainfall variation in South Wollo Zone has its own role for crop and livestock Production and productivity.

Table 4.3**:** Belg seasonal rainfalls mean (mm), coefficient of variation (CV), Precipitation Concentration Index (PCI) and contribution of total rainfall (CT), 1986-2016.

			Belg				
Stations	Min (mm)	Max (mm)	Mean (mm)	SD (mm)	CV%	PCI	CT%
Akesta	29.3	552.1	258.0	115.1	44.6	10.8	28.2
Ambamariam	19.0	823.1	219.5	142.1	64.8	11.0	21.5
Dessie	77.7	521.9	258.9	111.9	43.2	11.6	21.7
Haik	84.1	623.4	351.1	130.1	37.1	11.4	28.8
Goshmeda	10.6	311.2	133.5	86.7	65.0	11.5	20.8
Kabie	26.7	434.4	181.5	91.6	50.5	12.1	20.5
Kombolcha	48.2	541.0	241.8	104.8	43.0	12.2	23.4
Mekaneselam	47.3	411.8	211.8	85.4	40.3	11.8	23.4
Saint Adjibar	29.5	425.8	182.2	84.2	44.6	10.8	18.2
Tebasit	26.8	513.6	179.1	97.2	54.2	11.6	17.3
Woreillu	8.4	614.1	160.0	108.1	67.5	12.6	18.0
Wogdi	52.2	356.7	188.7	84.0	44.5	11.2	20.8
Worebabo	68.1	539.9	296.7	112.0	37.8	13.0	23.7

As zone in general, rainfall amount in kiremt, belg and annual was higher in the eastern than in western part (Figure 4.2).

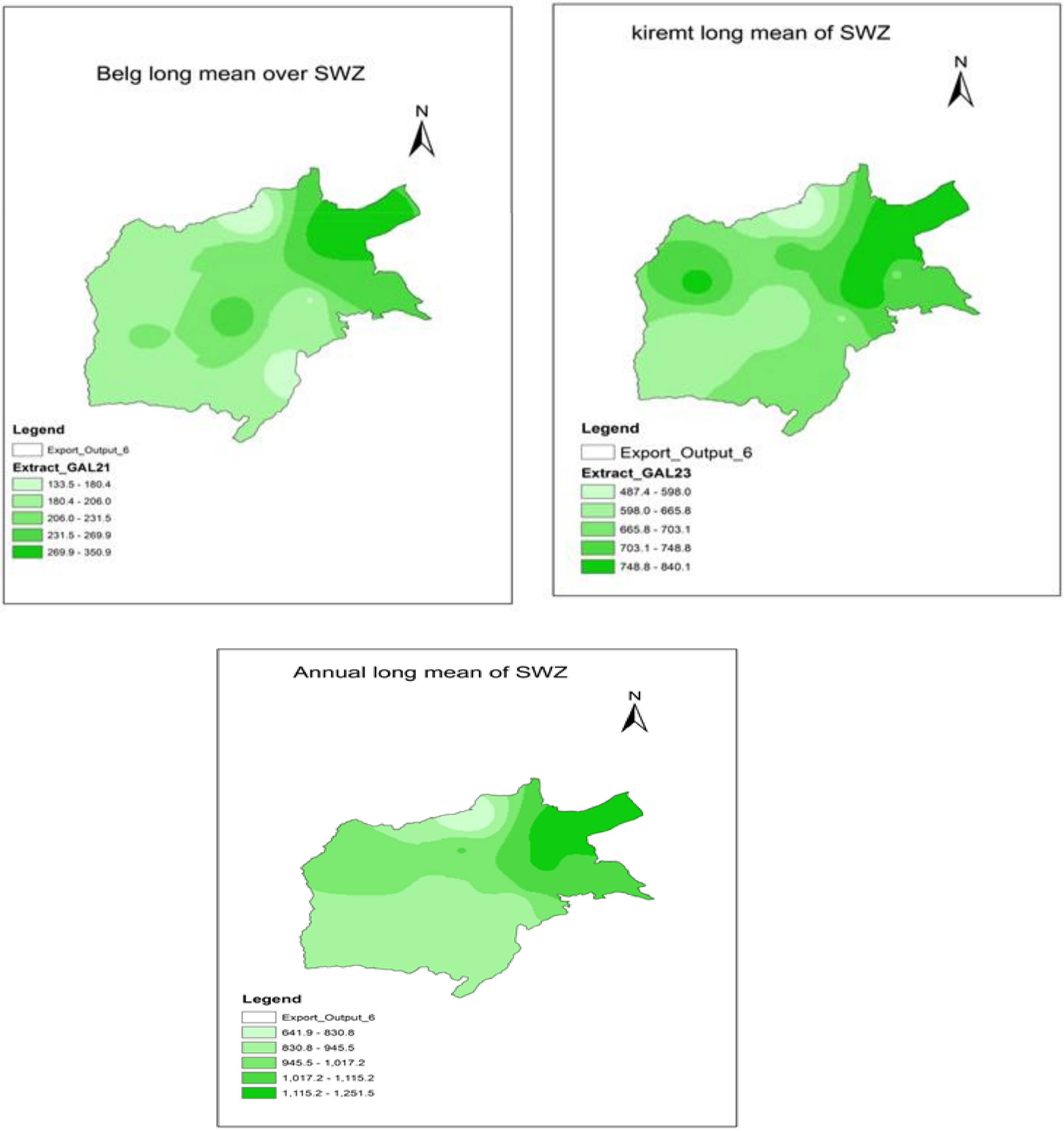


Figure 4.2: Spatial rainfall variation on kiremt, belg and Annual in south Woll Zone from 1986-2016

4.3 Annual and Seasonal Rainfall Anomaly in South Wollo Zone

Figure 4.3 showed that the standard anomaly of rainfall in annual and seasonal time scale in the study period in three listed stations. Rainfall anomalies generally characterize inter-annual and inter-seasonal rainfall variability as prevailed in South Wollo Zone. The positive anomaly represented by wet meteorological climate condition. While dry climate represented by negative anomaly. There was also a normal climate condition that the anomaly was zero.

Annual rainfall anomaly: the annual rainfall anomaly of different stations in South Wollo Zone is characterized by fluctuating of dry and wet conditions. There is high inter annual variability of rainfall in time period of 1986-2016. Mekaneselam was wetter than the others in the cumulative of annual rainfall anomaly. However, the year 2015 (strongest El Niño) was the only year that in all stations of South Wollo Zone occurred negative anomaly. Moreover, 1997, 1999, 2002, 2003, 2004, 2007, 2008, and 2009 were mostly dryer years. However, 1986, 1988, 1996 and 2016 were wetter years. In line with present study, NMA (2007) listed that 1991, 1994, 1999 and 2002 were dry while 1993, 1996, 1998 and 2006 were wet years.

According to Agew and Chappel (1999), in the year 2004, Akesta, Kombolcha and Mekaneselam were in the influence of moderate dry condition. In addition, Kombolcha was under very dry in the year 2008. But, Akesta was in extremely dry. Moreover, Akesta was experienced moderate dry and Kombolcha was in the effect of extremely dry in 2015 strong El Nino year. Similar to present result, Korecha (2013) reported that 1990, 1994 and 2009 were drier years and 1988, 1993, 1996 and 1998 were wettest years overall the country. Likewise, Bewket (2009) revealed that rainfall has shown some recovery since the 1990s, from the low values of the 1980s, but drier conditions have been experienced in 2002 and 2003.Yimer *et al*. (2017) reported that years of 1984, 1987, 2004, 2008 and 2009 were characterized by occurrence of drought in South Wollo Zone at stations of Ambamariam, Kombolcha, Woreillu, Dessie, Haik and Mekaneselam.

Kiremt and Belg season anomaly: Even though**,** Kiremt rainfall plays vital role on socio-economic activities in most parts of the country including South Wollo Zone, its seasonal anomaly depends their activities. Figure 4.3 revealed that the calculated kiremt season (June-September) rainfall anomaly of South Wollo Zone from 1986-2016. At station level, Akesta in the years of 1987, 1993, 1995, 1997, 2003 and 2009 was dryer kiremt seasons. Similarly, in

1987, 1990, 1991, 1992 and 2015 at Kombolcha were dryer years in kiremt seasons. Likewise, 1988, 1989, 1992-1994, 1997 and 2015 at Mekaneselam were the dryer kiremt years. The above listed stations were happened some signals of drought in each selected years. In line with the present study, Yimer *et al.* (2017) revealed that drought occurred across the study area (South Wollo Zone) in 1987, 1992-1993, 2004 and 2008. In contrast 1988, 1998, 1999, 2007 and 2010 were wetter standard anomaly.

On the other hand, belg season (FMAM) rainfall characteristics over 31years had its own fluctuation in the study area. From the given period, 1999, 2000, 2003, 2008, 2013 and 2015 were the drier belg seasons in the study area. In some parts of those above listed years were below normal rainfall with different stage. For Example, the standard anomaly of Akesta, kombolcha and Mekaneselam was -1.99, -1.84 and -1.42 with extreme dry, extreme and very dry in the year 1999 respectively. In line with the present study, Yimer *et al*. (2017) revealed that 1988, 1999, 2004 and 2007-2009 were drought years at Ambamariam, Dessie, Kombolcha, Haik, Mekaneselam and Wereillu stations. However, in the years of 1988, 1990, 1993, 1998, 2000, 2007 and 2010 were recorded wetter belg seasonal anomaly in the study areas (Figure 4.3)

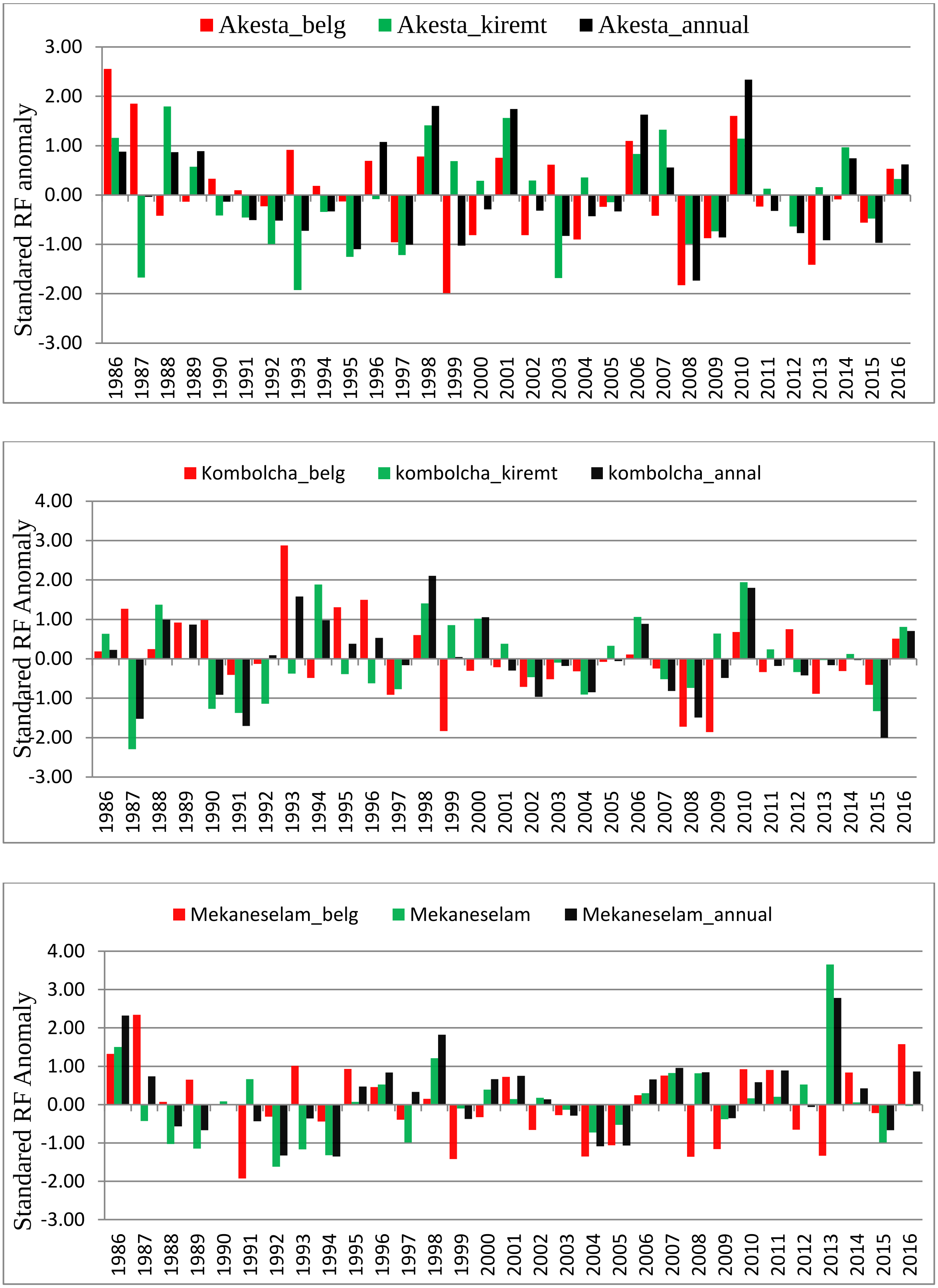


Figure 4.3: Annual and seasonal (belg and kiremt) rainfall anomalies

4.4 Annual and Seasonal Rainfall Trend

The Mann-Kendall trend test showed a decreasing trend of annual rainfall in South Wollo Zone (Table 4.4). In the last three decades, at stations Akesta, Dessie, Haik, Goshmeda, Kombolcha, Wogdi and Worebabo, the annual rainfall decreased by 2.00, 6.16, 3.04, 6.12, 2.78, 9.34 and 4.51 mm per year respectively. However, at stations of Ambamariam, Kabie, Mekaneselam, SaintAdjibar, Tebasit and Wereillu showed a slightly increasing trend of annual rainfall with 1.26, 2.30, 3.21, 0.60, 4.73 and 0.19 mm per year respectively. In most stations, except Goshmeda, Wogdi and Tebasit, the decreasing and increasing annual rainfall trend were not statistically significant at 0.05 significant levels. This might be due to large inter-annual fluctuation of rainfall in the South Wollo Zone. In line with this study, Mohammed *et al*. (2018) revealed that there was an increasing trend at Wereillu station and a decreasing annual trend at kombolcha during 1984-2014.

Table 4.4: Trend of annual and seasonal rainfall at South Wollo Zone, during 1986-2016

	Annual		kiremt		Belg	
Station	Z_{MK}	slope	Z_{MK}	slope	Z_{MK}	slope
Akesta	-0.92 ^{ns}	-2.00	0.61 ^{ns}	2.10	-1.46 ^{ns}	-3.49
Ambamariam	0.31 ^{ns}	1.26	0.68 ^{ns}	2.43	-0.37 ^{ns}	-0.97
Dessie	-1.36 ^{ns}	-6.16	-0.32 ^{ns}	-0.85	-0.92 ^{ns}	-2.53
Haik	-0.85 ^{ns}	-3.04	0.82 ^{ns}	2.35	-1.60 ^{ns}	-4.51
Goshmeda	-3.52 ^{c}	-6.12	-3.26 ^{c}	-8.45	-2.60 ^{c}	-5.69
Kabie	0.51 ^{ns}	2.30	1.36 ^{ns}	4.66	-1.94c	-4.10
Kombolcha	-0.99 ^{ns}	-2.78	0.78 ^{ns}	3.24	-1.90 ^{c}	-3.39
M/selam	1.22 ^{ns}	3.21	1.22 ^{ns}	3.52	-0.75 ^{ns}	-1.85
SaintAdjibar	0.10 ^{ns}	0.60	0.58 ^{ns}	2.34	-1.22 ^{ns}	-1.78
Tebasit	2.96 ^{c}	4.73	3.88 ^{c}	5.68	-0.24 ^{ns}	-0.49
Wereillu	0.14 ^{ns}	0.19	2.52 ^{c}	5.38	-3.16 ^{c}	-4.36
Wogdi	-3.13 ^{c}	-9.34	-2.14 ^{c}	5.69	-2.31 ^{c}	-4.21
Worebabo	-1.26 ^{ns}	-4.51	-0.17	-0.68	-1.90 ^{c}	-4.55

Where, Slope (Sen's slope) is the rate of change mm/year, ns is non-significant and c is significant at 0.05 significance level.

Likewise, stations of Dessie, Goshmeda, Wogdi and Worebabo showed a decreasing trend on kiremt seasonal rainfall totals. However, Akesta, Ambamariam, Haik, Kabie, Kombolcha, Mekaneselam, SaintAdjibar, Tebasit and Wereillu had shown an increasing trend. There were a significant increasing trend at Tebasit and Wereillu and decreasing trend at Goshmeda and Wogdi. The results of this study agree with the findings of Bewket & Conway (2007) and Rosell (2007) that reported increasing trends in summer rainfall. It also agrees with the findings of Muluneh (2015) who reported the increasing trends of kiremt rainfall across the North East Amhara during 1992-2012.

On the other hand, all stations during belg season showed a decreasing trend of 5% significant level (Table 4.4). Out of the study stations, Goshmeda, Kabie, Kombolcha, Wereillu, Wogdi and Worebabo stations showed significant decreasing trend of belg rainfall. In line with the present study, Asfaw (2017) revealed that belg rainfall has been decreased in three stations (Mekaneselam, Kabie and Wereillu) and the trend was statistically significant at Woreillu during 1901-2013 in Woleka sub-basins. Muluneh (2015) also found that belg rainfall has shown a declining trend across the North East Amhara.

4.5 Rainfall Characterization

Rainfall is characterized by its onset, cessation, total rainfall, and number of rainy days, Length of growing period and yearly annuals and dry spell probability. So, its characteristic's discussed one by one in the following sub topics.

4.5.1 Onset and Cessation of Rainy Season

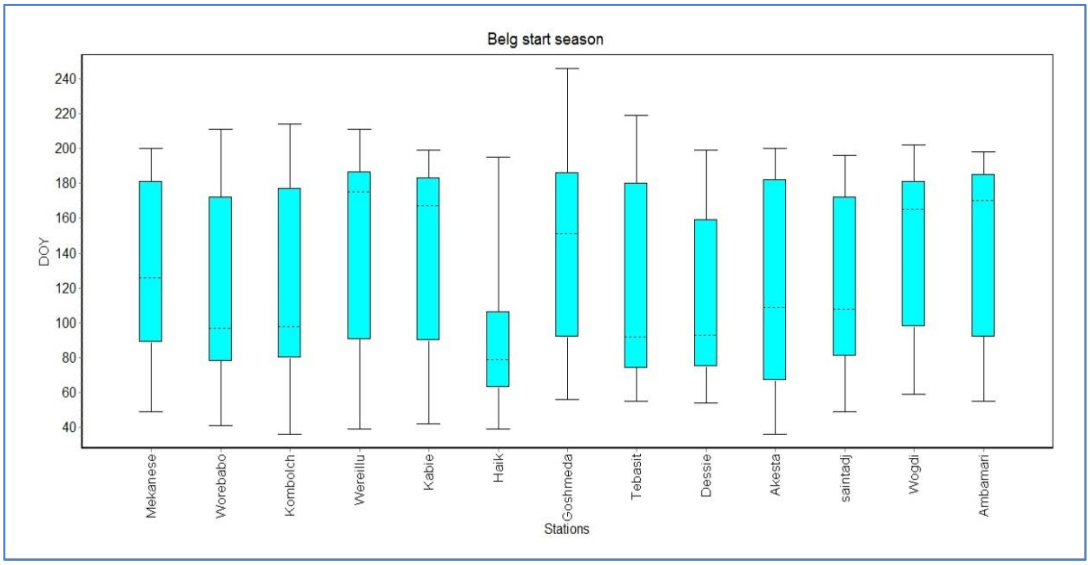
4.5.1.1 Onset and cessation of Belg Season

Belg seasonal rainfall onset date in the selected stations of SWZ was varied as shown in Table 4.5 and Figure 4.4.The median of the start of belg season showed that the onset date on DOY, 109 (Apr 18) at Akesta, 170 (Jun18) at Ambamariam, 93 (April 2) at Dessie, 110 (May 19) at Haik, 98 (April 7) at Kombolcha, 108 (Apr 17) at SaintAdjibar, 91(April 1) at Tebasit and 97 (April 6) at Worebabo. While the remaining stations: Akesta, Goshmeda, Kabie, Mekaneselam and Wogdi were merging to Kiremt start of season. However, the mean onset date of belg seasons 120 DOY (April 29), 118 DOY (April 27), 116 DOY (April 25), 115 DOY (April 24), 110 DOY (April 19), 93 DOY (April 2) at Akesta, Kombolcha, Tebasit, Worebabo, Dessie and Haik respectively. Besides, Wogdi, Kabie, Woreilu, Ambamariam, Goshmeda, Mekaneselam and SaintAdjibar on 144 DOY (May23), 141 DOY (May20), 141 DOY (May20), 140 DOY (May 19), 140DOY (May19), 134 DOY (May13), 122 DOY (May1) respectively (Table 4.5). Moreover, the third Quartile (75 Percentile) of belg start season date showed the belg rain disclose with kiremt Start of season. In line with this study, Rosell and Holmer (2007) observed the median start time of belg season was on March and April in his selected stations of Kombolcha, Haik, Kutaber, and Dessie. On the other hand, the cessation date of belg season normally from first to second decade of May (10May-20 May) at Akesta ,Ambamariam , Dessie, SaintAdjibar, Tebasit and Wogdi. However, at Haik, Kombolcha, Mekaneselam, Woreillu, Goshmeda and Worebabo, the belg rainfall ended between on the dates of second and third dekade of May.

Table 4.5: Onset season of belg in the South Wollo Zone, from 1986-2016

			Statistics in DOY			
Stations	Early	1st Quartile	Median	3rd Quartile	Late	Mean
Akesta	36(Feb 5)	66(Mar 6)	109(Apr 18)	181(Jun 29)	200(Jul18)	120(Apr 29)
A/mariam	55(Feb 24)	96(Mar 31)	170(Jun18)	185(Jul 3)	198(Jul 16)	140(May 19)
Dessie	54(Feb 2)	74(Mar 14)	93(Apr 2)	120(Apr 29)	199(Jul 17)	110(Apr 19)
Haik	39 (Feb 8)	62(Mar 2)	110(May 19)	182(Jun 30)	195(Jul 13)	93(Apr 2)
Goshmeda	56(Feb 25)	91(Mar 31)	151(May 30)	186(Jul 4)	228(Aug 15)	140(May19)
Kabie	42(Feb 11)	62(Mar 2)	167(Jun 15)	182(Jun 30)	199(Jul 17)	141(May 20)
Kombolcha	36(Feb 5)	78(Mar 18)	98(Apr 7)	177(Jun 25)	214(Aug 1)	118(Apr 27)
M/selam	49(Feb 18)	88(Mar 28)	126(May 5)	181(Jun 29)	200(Jul 18)	134(May 13)
S/Adjibar	49(Feb 18)	81(Mar 21)	108(Apr17)	171(Jun 19)	196(Jul 14)	122(May 1)
Tebasit	55(Feb 24)	73(Mar 13)	91(Apr 1)	180(Jun 28)	219(Aug 6)	116(Apr 25)
Wereillu	39(Feb 8)	90 Mar 30	175(Jun 23)	188(Jul 5)	211(Jul 29)	141(May 20)
Wogdi	59(Feb 28)	94(Apr 3)	166(Jun 13)	181(Jun 29)	202(Jul 20)	144(May 23)
Worebabo	41(Feb10)	78(Mar 18)	97(Apr 6)	169(Jun 17)	211(Jul 29)	115(Apr 24)

Note: A/mariam is Ambamariam, M/selam is Mekaneselam and S/adjibar is SaintAdjibar.



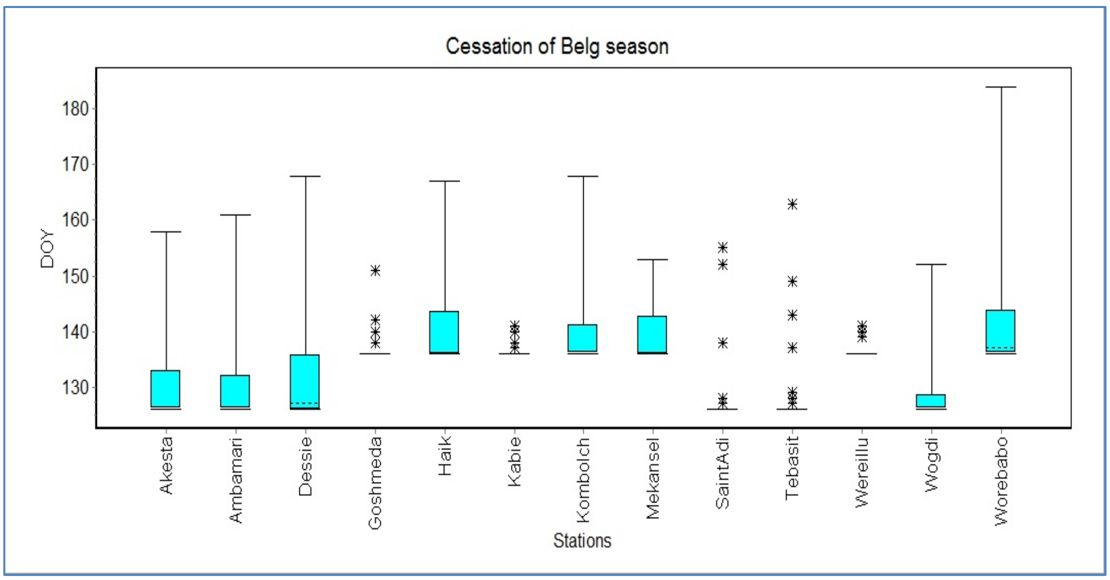


Figure 4.4: Box and whisker plots that represent the onset and cessation of belg rainfall season.

Note: The box indicates the location of the medians while the whisker indicates the lower and the upper quartile date of belg season. * Means the onset and cessation of belg season were around common dates.

4.5.1.2 Onset and Cessation of Kiremt Season along with Length of Growing Period

As shown in Table 4.6, the early onset dates of kiremt rainfall in South Wollo Zone of selected stations mostly on 172 and 173 DOY (Jun 20 and 21) respectively. However, the median onset date of the main rainfall season (kiremt) was at Mekaneselam on 183 DOY (July 1), SaintAdjibar on 184 DOY (July 2), Wogdi on 186 DOY (July 4), Akesta, Ambamariam, Dessie, Kabie and Woreillu on 187 DOY (July 5), Worebabo on 188 DOY (July 6), Haik on 190 DOY (July 8) and Goshmeda on 192 DOY (July 10). In line with the present result, Ayalew *et al*., (2012) also found DOY 189 (July 9) and DOY 186 (July 4) as the median SOS of the Kiremt growing season at Srinka and Kombolcha, respectively, for the period 1978-2008. On another study, Araya and Stroosnijider (2011) and Hadgu et al., (2013) noticed comparable findings of the SOS of Kiremt growing season being between 1st week of July and 3rd week of July in northern Ethiopia.

Table 4.6: Summary of onset dates of kiremt season in South Wollo Zone from 1986-2016

	Summary of DOY Statistics					
Stations	Early	1st Quartile	Median	3rd Quartile	Late	Mean
Akesta	172(Jun 20)	183(Jul 1)	187(Jul 5)	193(Jul 11)	215(Aug 2)	187(Jul 5)
Ambamariam	173(Jun 21)	180(Jun 28)	187(Jul 5)	192(Jul 10)	210(Jul 28)	187(Jul 5)
Dessie	173(Jun 21)	183(Jul 1)	187(Jul 5)	189(Jul 7)	214(Aug 1)	186(Jul 4)
Haik	173(Jun 21)	184(Jul 2)	190(Jul 8)	194(Jul 12)	227(Aug 14)	189(Jul 7)
Goshmeda	177(Jun 25)	188(Jul 6)	192(Jul 10)	195(Jul 13)	227(Aug 14)	198(Jul 16)
Kabie	172(Jun 20)	179(Jun 29)	187(Jul 5)	190(Jul 8)	230(Aug17)	198(Jul 16)
Kombolcha	173(Jun 21)	185(Jul 3)	189(Jul 7)	193(Jul 11)	214 (Aug 1)	190(Jul 8)
Mekaneselam	172(Jun 20)	178(Jun 26)	183(Jul 1)	189(Jul 7)	228(Aug 15)	186(Jul 4)
SaintAdjibar	172(Jun 20)	179(Jun 27)	184(Jul 2)	193(Jul 11)	211(Jul 29)	185(Jul 3)
Tebasit	173(Jun 21)	182 (Jun 30)	189 (Jul 7)	192(Jul 10)	221(Aug 8)	189 (Jul 7)
Wereillu	175(Jun 23)	182 (Jun 30)	187(Jul5)	192(Jul 10)	220(Aug 7)	188(Jul 6)
Wogdi	172(Jun 20)	179 (Jun 27)	186 (Jul 4)	193 (Jul 11)	216(Aug 3)	187(Jul 5)
Worebabo	172(Jun 20)	179 (Jun 27)	188(Jul 6)	194 (Jul 12)	216(Aug 3)	189(Jul 7)

Similarly, the observed median end date of Kiremt growing season (EOS) was seen being DOY269 (September 25) at Akesta, DOY 273 (September 29) at Ambamariam, DOY 289 (October 15) at Dessie, DOY284 (October 10) at Haik, kombolcha and Mekaneselam, DOY 265 (Sep 21) at Goshmeda, DOY 273 (Sep 29) at Kabie, DOY 274 (September 30) at SaintAdjibar, DOY 281 (October 7) at Tebasit, DOY277 (October 3) at Wogdi and DOY 272 (September 28) at Wereillu (Table 4.7). Due to the observed median EOS of kiremt, out of thirteen stations six of them were terminated their seasonal rainfall earlier than 1 October (DOY 275).

Table 4.7: Summary of cessation dates of kiremt season in South Wollo Zone from 1986-2016

	Summary of DOY Statistics					
Stations	Early	1st Quartile	Median	3rd Quartile	Late	Mean
Akesta	264(Sep 20)	264(Sep 20)	269(Sep 25)	275(Oct 1)	281(Oct 7)	270(Sep 26)
A/mariam	263(Sep 19)	270(Sep 26)	273(Sep 29)	276(Oct 2)	286(Oct 12)	273(Sep 29)
Dessie	271(Sep 27)	299(Oct 25)	289(Oct 15)	295(Oct 21)	313(Nov 8)	289(Oct 15)
Haik	267(Sep23)	277(Oct 3)	284(Oct 10)	294(Oct 20)	312(Nov 2)	285(Oct 11)
G/meda	264(Sep 20)	264(Sep 20)	264(Sep 21)	270(Sep 26)	276(Oct 2)	267(Sep 23)
Kabie	265(Sep 21)	269(Sep 25)	273(Sep 29)	275(Oct 1)	276(Oct 2)	272(Sep 28)
K/cha	265(Sep 21)	276(Oct 2)	284(Oct 10)	291(Oct 17)	310(Nov 5)	285(Oct 11)
M/selam	265(Sep 21)	275(Oct1)	284(Oct10)	291(Oct17)	326(Nov 21)	284(Oct 10)
S/Adjibar	264(Sep 20)	265(Sep 21)	274(Sep 30)	283(Oct 9)	306(Nov 1)	277(Oct 3)
Tebasit	264(Sep 20)	274(Sep 30)	281(Oct 7)	290(Oct 16)	303(Oct 29)	283(Oct 9)
Wereillu	265(Sep 21)	269(Sep 25)	272(Sep 28)	275(Oct 1)	279(Oct 5)	271(Sep 27)
Wogdi	264(Sep 20)	271(Sep 27)	277(Oct 3)	284(Oct 10)	302(Oct 28)	279(Oct 5)
Worebabo	265(Sep 21)	275(Oct10)	285(Oct11)	294(Oct 20)	335(Nov30)	287(Oct13)

Note: A/mariam means Ambamariam, K/cha means Kombolcha and S/Adjibar means SaintAdjibar.

Summary statistics for the length of kiremt growing period (LGP) during 1986-2016 at thirteen stations in South Wollo Zone is depicted in Table 4.8. From this study, planting earlier than 2 July (DOY 184) was possible once in four years on 1 July (DOY 183) at Akesta and Dessie, June 28 (DOY 180) at Ambamariam, 2 July (DOY184) at Haik, 6 July (DOY 188) at

Goshmeda, 29 June (DOY181) at Kabie, 3 July (DOY 185) at Kombolcha, 26 June (DOY178) at Mekaneselam, 27 June (DOY 179) at SaintAdjibar, Wogdi and Worebabo, and 30 June (DOY182) at Tebasit and Wereillu. On the other hand, planting earlier than 11 July (DOY 193) at Akesta, kombolcha, Wogdi and SaintAdjibar. While at Ambamariam and Wereillu on July 10 (DOY 192) and it was also possible on 7 July (DOY 189) at Dessie and Mekaneselam, on 12 July (DOY 194) at Haik and Worebabo, on 13 July (DOY 195) at Goshmeda. Moreover, on 8 July (190) at Kabie and 10 July (DOY192) at Tebasit is possible three times in four years. During the study period, the median SOS of Kiremt growing season was observed DOY 187 (July 5) at Akesta, Ambamariam, Dessie, Kabie and Wereillu, DOY190 (July 8) at Haik, DOY192 (July 10) at Goshmeda and DOY 187 (July 7) at Kombolcha and Tebasit, DOY183 (July1) at Mekaneselam, DOY184 (July 2) at SaintAdjibar, DOY186 (July 4) at Wogdi and DOY188 (July 6) at Worebabo. The upper quartile (75% ile) of the kiremt starting season on the stations varied in the range of 7 July (DOY189) at Worebabo to 12 July (DOY 194) at Wereillu. There is also an observed late onset on kiremt rainy days such as Akesta on DOY 215 (August 2), Ambamariam on DOY 210 (July 28), Dessie on DOY 214 (August 1), Haik and Goshmeda on DOY227 (August 14), Kabie on DOY230 (August 17), Kombolcha on DOY214 (August 1), Mekaneselam on DOY 228 (August 15), SaintAdjibar and Tebasit on DOY211 (July 29), Wogdi and Worebabo on DOY 216 (August 3) and Wereillu on DOY 220 (August 7). The late onset date of the season, the length of growing period was short. Thus, late onset of kiremt rainfall has affected the growing season of crops. In general, to know the onset and cessation of each season in particular area is important to decide when to land preparation, sowing and harvest and to select the type of crops to plant.

Table 4.8: Length of Growing Period during kiremt season in South Wollo Zone, 1986-2016

	LGP of Kiremt				
Stations	Min	Max	Mean	SD	CV%
Akesta	49	104	82.3	10.5	12.8
Ambamariam	53	105	86.1	10.5	12.2
Dessie	62	129	101.6	15.3	15.0
Haik	55	123	95.1	15.1	15.9
Goshmeda	52	97	75.8	8.5	11.2
Kabie	50	110	85.0	11.8	13.9
Kombolcha	54	126	94.8	14.9	15.7
Mekaneselam	71	122	98.1	13.8	14.1
SaintAdjibar	53	134	91.6	17.3	18.8
Tebasit	60	119	93.1	13.4	14.4
Wereillu	48	100	82.9	11.4	13.7
Wogdi	48	118	91.2	14.7	16.1
Worebabo	52	148	97.8	19.1	19.5

4.5.2. Number of Rainy and Dry Days

The number of rainy and dry days during both belg and kiremt seasons as recorded over thirteen stations of South Wollo Zone are summarized in Table 4.9. The observed number of rainy days (NRD) during belg season varied from 1 day at Wereillu to 53 days at Tebasit and Worebabo. On average, Wereillu and Goshmeda received measurable rainfall amounts for less number of rainy days as compared to other stations. However, Haik had more NRD with average days of 29.3. The observed CV values also showed that there were high variability (CV>30%) in the NRD at all stations from smallest value 32.3% at Haik to highest value 47.6% at Goshmeda during 1986-2016. It indicates the NRD during belg season was highly variable and less dependable in selected stations of the study area. Moreover, the observed seasonal Belg NDD varied from 62 days at Haik to 120 days at Wereillu.

Table 4.9: Number of rainy days in South Wollo Zone from 1986-2016 in both seasons.

	Belg NRD					Kiremt NRD				
Station	Min	Max	Mean	SD	CV%	Min	Max	Mean	SD	CV%
Akesta	5	49	27.5	11.8	42.9	33	71	56.4	9.6	17.1
Ambamariam	3	42	22.0	8.1	37.0	33	72	59.4	8.7	14.7
Dessie	10	50	26.6	11.0	41.4	31	75	58.2	9.9	17.0
Haik	10	44	29.2	9.4	32.3	35	75	58.6	8.5	14.5
Goshmeda	3	31	17.8	8.5	47.6	23	70	49.0	9.5	19.4
Kabie	5	41	22.2	8.9	40.0	40	84	61.0	12.1	19.8
Kombolcha	9	45	23.3	9.6	36.1	40	71	59.3	7.5	12.6
Mekaneselam	10	46	26.1	9.0	34.4	41	90	74.0	9.3	12.6
SaintAdjibar	5	45	22.6	8.9	39.2	44	87	68.5	9.5	13.5
Tebasit	7	53	26.6	10.9	41.0	44	90	68.3	11.0	16.0
Wereillu	1	33	17.7	7.6	43.1	35	72	56.9	9.0	15.7
Wogdi	6	42	22.5	8.7	38.7	43	80	68.2	8.4	12.3
Worebabo	7	53	26.8	9.7	36.1	30	66	53.4	8.0	15.0

Moreover, the observed kiremt NRD varied from 23 days at Goshmeda to 90 days at Mekaneselam and Tebasit (Table 4.9). The observed CV values also showed that there was more variability in the NRD at Kabie and conversely, less at Wogdi than the other selected stations during 1986 -2016. On the other hand, the observed extreme minimum and maximum number of Kiremt dry days (NDD) varied from 22 days at Akesta to 92 days at Worebabo respectively. On average, there were more kiremt NDD at Kombolcha than the rest of the studied stations (Table 4.10). The observed CV of Kiremt NDD in the present study also indicated that there was relatively more inter annual variability of seasonal Kiremt NDD at Mekaneselam and Tebasit. However, in belg season the numbers of dry days were more common than kiremt. In line with the present study, Zanke and Seleshi (2004) reported comparable result in NDD for Belg and Kiremt seasons at Kombolcha for the study period of 1965-2002.

Table 4.10: Summary of number of dry days during belg and kiremt season in South Wollo Zone from 1986 to 2016

	Belg NDD					Kiremt NDD				
Stations	Min	Max	Mean	SD	CV%	Min	Max	Mean	SD	CV%
Akesta	72	116	93.9	12.1	12.9	22	89	65.8	12.1	12.9
Ambamariam	79	118	98.8	8.3	8.4	50	89	62.5	8.7	14.0
Dessie	71	111	93.5	11.1	11.9	50	87	62.7	8.9	14.0
Haik	2	111	90.8	9.7	10.7	47	80	62.5	8.2	13.1
Goshmeda	87	118	103.2	8.5	8.2	52	89	73.0	9.6	13.1
Kabie	80	116	98.8	8.9	9.0	38	82	61.0	12.1	19.8
Kombolcha	76	112	93.8	10.1	10.7	51	82	82.6	7.5	12.0
Mekaneselam	75	111	94.9	9.0	9.4	32	85	49.4	11.3	22.9
SaintAdjibar	76	116	98.3	8.9	9.0	35	78	53.5	9.5	17.8
Tebasit	68	114	94.4	10.9	11.6	32	78	53.7	11.0	20.4
Wogdi	79	115	98.5	8.7	8.8	42	72	53.8	8.4	15.5
Worebabo	68	114	94.2	9.7	10.3	56	92	68.8	8.0	11.7
Wereillu	88	120	103.3	7.6	7.4	50	87	65.1	9.0	13.8

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 during belg season could pose a great problem for farmers who lack instruments to quantify rainfall amount but rather depend on number of rainy days to plan cropping calendar.

4.5.3 Trend Analysis on Number of Rainy and Dry Days

From 1986-2016, Ambamariam, Dessie, Haik, Goshmeda, Kabie, Kombolcha, Mekaneselam, SaintAdjibar, Tebasit and Wereillu are showed an increasing rainy day at kiremt season. However, Akesta, Wogdi and Worebabo showed decreasing trend. Of those selected stations of South Wollo Zone, Dessie, Haik and Wereillu showed significantly increasing trend while Worebabo showed significantly decreasing in KNRD. The other remaining stations, the observed trends were not statistically significant. On the other hand, number of dry days

(NDD) showed a tendency of decreasing trends in 10 stations (except Akesta, Wogdi and Worebabo). Wereillu and Worebabo stations were showed statistical significant decreasing and increasing trend respectively. While, the remaining 11 stations trend change were not significant (Table 4.11). In line with this, Muluneh (2015) reported a tendency of increasing trends at Srinka and Kobo. Conversely, non-significant decreasing trends at Kombolcha and Lalibela stations indicated lack of consistent trend in NDD for kiremt growing season in North eastern Amhara during 1992-2012. Similarly, Zanke and Seleshi (2004) reported comparable result that NRD and NDD showed decreasing and increasing change, respectively, over Ethiopia. An increasing change in NDD indicates that rain fed crop Production in the study area was at risk of soil moisture stress which resulted in crop failure (Zanke and Seleshi, 2004).

Table 4.11: Trends of number of rainy and dry days during kiremt and belg seasons in South Wollo Zone, from1986-2016.

	Kiremt				Belg			
	NRD		NDD		NRD		NDD	
Station	Z_{MK}	slope	Z_{MK}	slope	Z_{MK}	slope	Z_{MK}	slope
Akesta	-0.31	-0.105	1.28	0.333	0.34	0.095	0.00	0.000
Ambamariam	1.70	0.333	-1.67	-0.333	-0.58	-0.111	0.58	0.111
Dessie	2.11^{c}	0.429	-1.84	-0.333	-0.49	-0.111	0.68	0.167
Haik	2.42^{c}	0.318	-1.72	-0.222	-1.65	-0.333	2.18^{c}	0.455
Goshmeda	0.31	0.077	-0.31	-0.222	-2.92^{c}	-0.500	2.92^{c}	0.500
Kabie	0.49	0.105	-0.49	-0.111	-1.45	-0.250	1.45	0.250
Kombolcha	1.53	0.286	-1.48	-0.273	-2.10^{c}	-0.381	1.69	0.333
Mekaneselam	1.57	0.267	-0.70	-0.167	-0.37	-0.080	0.58	0.111
SaintAdjibar	0.10	0.000	-0.10	0.000	0.05	0.000	-0.07	0.000
Tebasit	1.92	0.500	-1.92	-0.500	-0.24	-0.067	0.24	0.067
Wereillu	2.09^{c}	0.400	-2.09^{c}	-0.400	-1.45	-0.238	1.45	0.238
Wogdi	-1.21	-0.143	1.21	0.143	-1.40	-0.300	1.40	0.300
Worebabo	-2.20^{c}	-0.333	2.20^{c}	0.333	-2.50^{c}	-0.409	2.50^{c}	0.409

Where, Slope (Sen's slope) is the rate of change of rainfall amounts as expressed in mm/year, c is a significant trend in 0.05 levels of significance.

Moreover, seasonal belg NRD have also shown tendency of non-significant declining trends at Ambamariam, Dessie, Haik, Kabie, Mekaneselam, Tebasit, Wogdi and Wereillu. Conversely only Akesta showed increasing trend. However, at Goshmeda, Kombolcha and Worebabo showed significant decreasing trend. Furthermore, the observed increasing change in the NDD of the belg growing season was significant at Haik, Goshmeda and Worebabo. Similar to the present study result, Muluneh (2015) reported belg NRD have also shown none significant declining trends at Kombolcha in Kobo and Lalibela while increasing trend at Srinka in belg NRD while in belg NDD decreasing trend were observed at Kombolcha, Kobo and Lalibela during 1992-2012. Similarly Hadgu et al. (2013) found variable and non-significant trends in NRD and NDD among four studied stations in the nearby areas of northern Ethiopia.

4.5.4 Probability of Dry Spell Length

Probability of dry spells exceeding 5, 7, 10 and 15 days length based on the fitted first order Markov Chain probability values at five stations in the South Wollo Zone during 1986-2016 is depicted in figure 4.5. It showed that the probability of dry spells occurrence for belg season differs among stations. For instance, The probability of dry spell occurrence at 5 days length was above 60% at Haik , above 95% at Ambamariam, Mekaneselam, Wogdi and Worebabo stations during the Peak rainfall months of belg season DOY 80 (the end of 1st week of March) to DOY115 (April 24). Whereas, the probability of dry spell occurrence of 7 days was greater than 40% at Haik, above 80% at Ambamariam and Worebabo, and above 85% at Mekaneselam. Similarly the probability of dry spell occurrence of 10 days was 60% at Ambamariam, Mekaneselam and Wogdi, 20% at Haik, and 48% at Worebabo in peak belg rainfall season(March and April) between 80 DOY(end of second dekade of march) and 115 DOY(Apr 24), respectively. It indicates that the risk of dry spell occurrence of 5, 7 and 10 days were greater than the above listed percentage values in each stations. On the other hands, the observed dry spell occurrence of 15 day was above 10% at Worebabo, above 5% at Haik, above 20% at Ambamariam, Mekaneselam and Wogdi in the belg season of March and April.

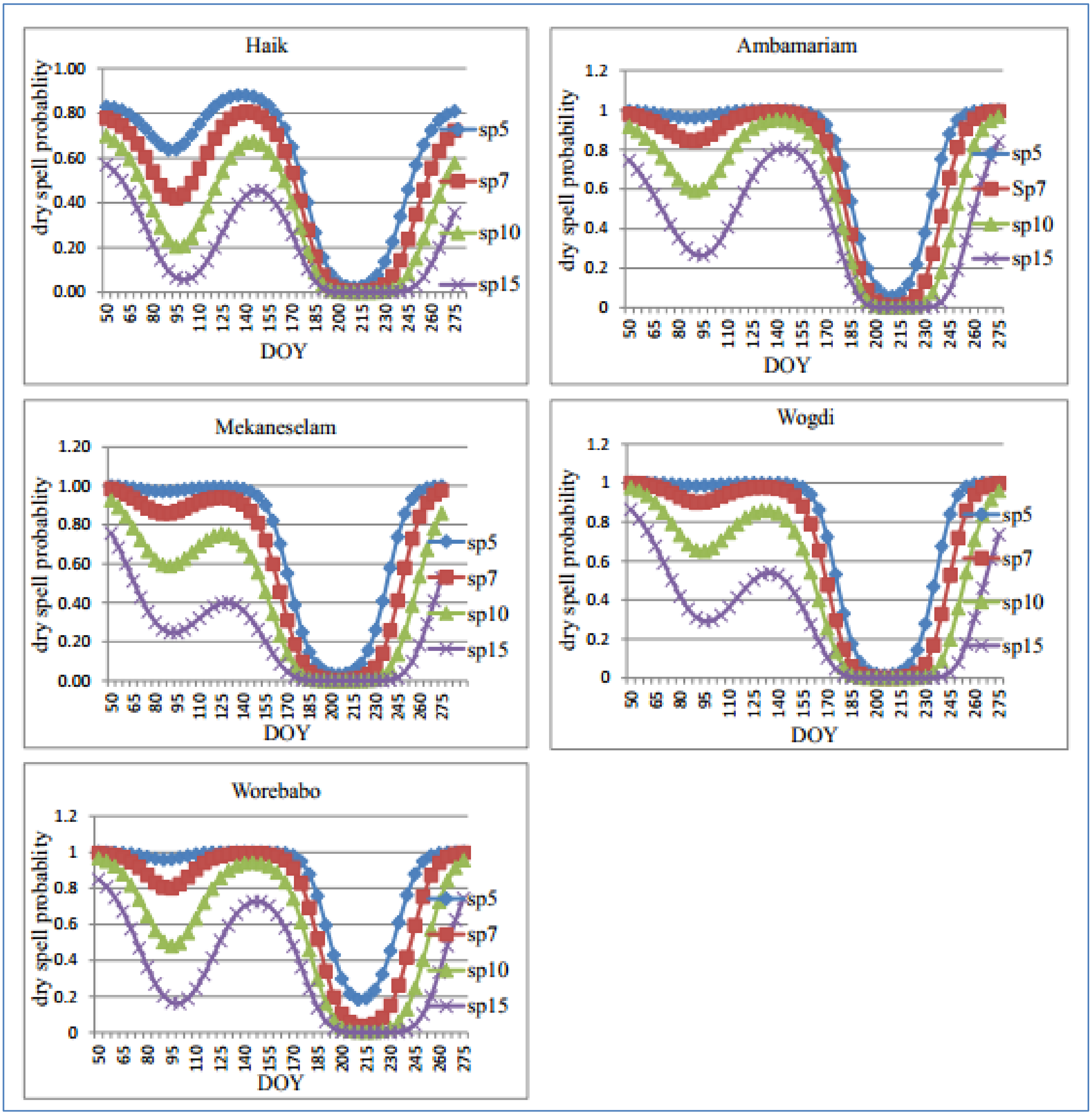


Figure 4.5: Probabilities of dry spells at 5, 7, 10 and 15 days' length in the South Wollo Zone, during 1986-2016.

From the dry spell graphs , there was no chance for the occurrence of dry spell at greater than 7, 10 and 15 days lengths during the peak months of main (Kiremt) rain season(July and August).However, in most of the selected station there was 5 days dry with a small percentage except Worebabo (it shows above 15%). This implies that the predictability of dry spells occurrence at greater than 7 days length were easy for decision makers. As the length of dry spell threshold becomes short, the probability of dry spell occurrence increases. Conversely, as the dry spells threshold becomes longer, the probability of dry spells occurrence decreases with-in the growing seasons. As indicated by Tesfaye and Walker (2004), these types of dry spell analysis are important for on farm level agricultural decisions like choice of crop or variety (short, medium, long maturing, drought tolerant or susceptible) and crop management practices (supplemental irrigation, fertilizer and insecticide application).

Generally, at all the selected locations, curves of dry spells probability at different lengths converge to their minimum during months of peak rainfall periods and turn upward again from the 2nd week of September, signaling end of the growing season. This suggests that standing crops after this time will face increasingly greater risk of water shortage in the study area. This information is very important to farmers in the study area to decide on crop types to be cultivated and on planning sowing dates as a function of observed from the onset dates. In rain-fed farming, the intermittent dry spell becomes critical, particularly for the seedling establishment during the first 30 days or so after planting. In fact, a dry spell of any length could occur at any stage of crop growth. However, it is potentially damaging if it coincides with the most sensitive stages such as flowering and grain filling (Stern and Coe, 1984).

4.6 Characterizing Kiremt Rainfall Performance during Strong El Niño Years in South Wollo Zone

Based on Oceanic Nino Index (ONI) values of Niño 3.4, the four monthly averages of JJAS recorded values indicates less than -0.5 is La Niña condition, between -0.5 to 0.5 neutral condition and greater than 0.5 El Niño condition. However, when the ONI values greater than 1.5, and shows strong El Niño event. Based on figure 4.6, 1987, 1997 and 2015 were categorized under strong El Niño.

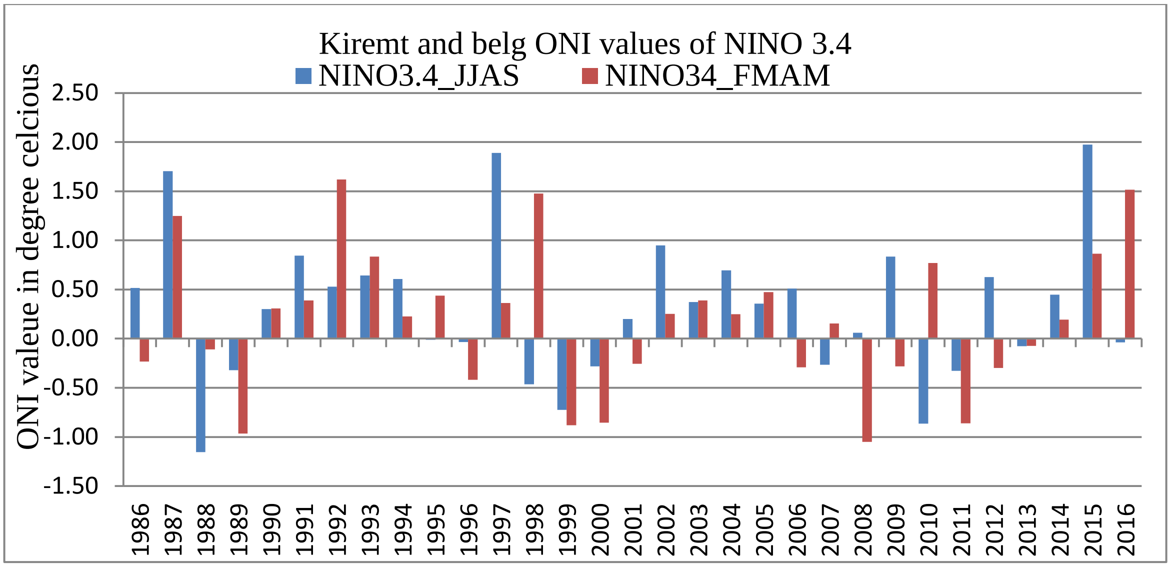


Figure 4.6: Representation of various phase of ENSO as averaged index for belg and kiremt using ONI- NINO 3.4, from 1986-2016.

As depicted in Table 4.12, in most stations (districts) the starting dates of 1987 kiremt were characterized by late onset. Besides, the starting date of kiremt 1987 at Akesta on August 2, Ambamariam on July 28, Dessie on July 28, Goshmeda on July 30, Haik on July 30, Kabie on August 17, Kombolcha on July 29. However, the 1997 kiremt started in most station of South Wollo Zone were between June 26 (at Akesta) to July 5(at Dessie and Kombolcha). Moreover, the KSOS of 2015 also show late onset in the study area. Generally, out of 3 strong years, 1987 and 2015 showed late start of kiremt season in South Wollo Zone.

In the case of KEOS, most stations showed normal end dating in both years of 1987 and 1997. But, the year 2015 showed late cessation date. On the other comparison of KLGP, 1987 was very short as compared to 1997 and 2015 LGP (Table 20). Table 4.13 showed that, 1987 NRD was the lowest as compared to the other selected strong El Niño years. But, the 1997 KNRD, all stations in the study areas except Mekaneselam were got more than long mean KNRD. Similarly, all stations were got more than long mean KNRD in 2015. On the other hand, the 1987 KTR was lowest as compared to other selected Strong years and long mean rainfall total. Even though 2015 rainfall total was better than 1987, lower to 1997 and long mean. However, the 1997 kiremt rainfall total was highest as other strong El Niño years but less than long mean. In general, out of three strong El Niño years, two of them showed late start of kiremt season, normal cessation, short length of growing period, less number of rainy days and less amount of total rainfall. The above parameters influence the agricultural production and productivity. So, strong El Niño event happened directly affect rainfall characteristics in South Wollo Zone.

Table 4.12: kiremt Rainfall features (KSOS, KEOS, and KLGP) during strong El Niño years (1987, 1997 and 2015) in South Wollo Zone.

Station	KSOS			KEOS			KLGP		
	1987	1997	2015	1987	1997	2015	1987	1997	2015
Akesta	Aug 2	Jun26	Jul13	Sep20	Sep20	Oct1	49	86	80
Ambamariam	Jul 28	Jun25	Jul14	Sep19	Sep23	Sep23	53	90	71
Dessie	Jul 28	Jul5	Aug1	Sep28	Sep28	Oct13	62	85	73
Goshmeda	Jul 30	Jun29	Aug14	Sep20	Sep20	Sep20	52	83	74
Haik	Jul 30	Jul3	Jul31	Sep23	Oct8	Oct2	55	97	63
Kabie	Aug 17	Jun30	Aug6	Sep21	Sep25	Oct2	35	87	57
Kombolcha	Jul 29	Jul5	Aug1	Sep21	Sep25	Oct8	54	82	68
Mekaneselam	Jul16	Jul1	Jul14	Oct24	Sep21	Oct5	100	82	83
Saint Adjibar	Jul29	Jun26	Jul13	Sep20	Sep20	Oct5	53	86	84
Tebasit	Jul30	Jun27	Aug8	Sep28	Sep20	Oct16	60	85	69
Wereillu	Aug 7	Jun27	Jul13	Sep26	Sep21	Oct5	50	86	84
Wogdi	Aug 3	Jul1	Jun24	Sep20	Sep20	Sep24	48	81	90
Worebabo	Jul 29	Jul5	Aug3	Oct19	Nov30	Sep24	82	148	52

Where, KSOS is kiremt start of season, KEOS is kiremt end of season and KLGP is kiremt Length of Growing Period.

Moreover, the correlation between kiremt rainfall totals and the strong El Nino years, in the stations such as: SaintAdjibar, Wogdi, Kombolcha, Kabie, and Akesta were experienced positive correlation from strong to strong with correlation values of 0.73, 0.74, 0.76, 0.80, and 0.95 respectively. Similarly, there were a medium positive correlation at Dessie and Wereillu with its values of 0.60 and 0.36. However, Haik and Tebasit stations are experienced positive weak correlation. On the other hand, at Mekaneselam showed negative strong correlation.

Worebabo and Goshmeda stations also showed negative weak correlation. The only station, Ambamariam showed no correlation between kiremt rainfall total and El Niño events (Table 4.13). In general, the amount of kiremt rainfall in South Wollo Zone had greatly connection with El Niño. In line with this study, Korecha (2013) reported that rainfall variability in the north and north east Ethiopia is highly correlated with ENSO and sea surface temperature.

Table 4.13: Comparison of kiremt Rainfall features of KNRD and KRT with long mean during strong El Niño years in South Wollo Zone.

	KNRD				KRT				
Stations	1987	1997	2015	mean	1987	1997	2015	mean	correlation
Akesta	33	58	53	56.4	419.6	470.4	553.2	606.7	0.95
Ambamariam	33	70	49	59.4	487.1	657.0	445.5	721.7	0.00
Dessie	31	70	58	58.2	449.0	688.8	553.4	815.3	0.60
Goshmeda	23	54	37	49	340.5	485.7	265.0	487.3	-0.15
Haik	35	75	42	58.6	411.3	740.0	414.9	754.3	0.20
Kabie	16	69	40	61	106.4	539.1	401.1	663.3	0.80
Kombolcha	40	65	51	59.3	379.2	588.6	512.0	695.0	0.76
Mekaneselam	59	68	62	74	554.1	477.6	477.7	616.1	-0.95
Saint Adjibar	44	73	52	68.5	365.7	700.1	564.9	766.5	0.73
Tebasit	45	71	50	68.3	430.8	611.4	411.2	797.9	0.10
Wereillu	35	68	50	56.9	369.3	580.9	410.0	679.7	0.36
Wogdi	43	69	55	68.2	452.1	523.1	495.2	664.3	0.74
Worebabo	39	63	30	53.4	689.1	813.1	595.5	840.3	-0.25

Where, KNRD is Kiremt Number of Rainy Day and KRT is kiremt rainfall total

4.7 Variability of Wheat, Barley and Teff in South Wollo Zone

Wheat yield showed on Table 4.14, highly variable during 2011-2016. The mean yield of wheat in qt/ha were 17.2, 22.7, 19.8, 35.0 and 18.2 at Tenta, Tehuledere, Borena, Wogdi and Worebabo respectively. Its yield of coefficient of variation (CV) was 40.8% at all selected districts of South Wollo Zone. On the other hand, the mean yield of Barley were 15.7, 21.0, 13.7, 19.7 and 13.6 quintals per hectare and the calculated CV were 12.1, 42.4, 14.8, 25.7 and 19.9% at Tenta, Tehuledere ,Borena, Wogdi and Worebabo respectively. However, the mean yield of teff in quintal/hectare was 11.9, 14.4, 11.9, 19.8 and 11.6 at Tenta, Tehuledere, Borena, Wogdi and Worebabo respectively. The range of CV varied from 22.1% at Worebabo to 33.4% at Debresina with SD of ± 2.6 and ± 4.0 quintals per year respectively (Table 4.14).

Table 4.14: Summary of statistics on wheat, barley and teff production South Wollo Zone, from 2011-2016.

Districts	crops	min(qt/ha)	max(qt/ha)	mean(qt/ha)	SD(qt/year)	CV %
Borena	Wheat	15.3	26.3	19.8	8.1	40.8
	Barley	11.0	16.0	13.7	2.0	14.8
	Teff	6.0	17.0	11.9	4.0	33.4
Tehuledere	Wheat	13.0	30.0	22.7	9.3	40.8
	Barley	5.0	35.0	21.0	8.9	42.4
	Teff	8.0	22.0	14.4	4.5	31.3
Tenta	Wheat	13.0	21.0	17.2	7.0	40.8
	Barley	12.0	18.0	15.7	1.9	12.1
	Teff	7.5	15.9	11.9	2.8	23.1
Wogdi	Wheat	24.8	47.0	35.0	14.3	40.8
	Barley	14.0	30.0	19.7	5.1	25.7
	Teff	13.0	29.0	19.8	5.5	27.6
Worebabo	Wheat	11.0	29.0	18.2	7.4	40.8
	Barley	10.0	18.0	13.6	2.7	19.9
	Teff	7.1	14.5	11.6	2.6	22.1

4.7.1 Correlation Analysis between Rainfall and Wheat, Barley and Teff Yields.

As presented in Table 4.14, the correlation coefficients computed between yields and climate features for the SOUTH WOLLO ZONE showed that kiremt (JJAS) start of season (r = -0.365, -0.389, -0.246, 0.095 and -0.124), End of date of the rainy season (r = 0.408, 0.279, -0.058, 0.021 and -0.253), rainfall total (r =0.906, 0.245, -0.124, -0.406 and 0.197) , length of growing period (r = 0.876, 0.496, 0.105, -0.071 and -0.029) and number of rainy day (r =

0.757, 0.0.519, -0.075, -0.084 and 0.476) had positive and negative correlation with wheat yields at Tenta, Tehuledere, Borena, Wogdi and Worebabo respectively. At Tenta, the kiremt start season was the only negative (moderately) correlated as compared to others climate features. But, KLGP, KRT and KNRD had strong positive correlation. But, KEOS had moderately correlated with wheat yields. KSOS at all districts (except Wogdi) had negative correlation with wheat yields. At Borena, Wogdi and Worebabo, the correlation between rainfall characteristics (except KRND at Worebabo, KRT at Wogdi) and wheat yield had weak (positive and negative) correlation (Table 4.15).

On the other crop, which is barley, the start of the season (r = 0.212, -0.006, -0.442, -0.666 and -0.573), end of date of the season (r = 0.015, 0.006, -0.847,-0.522 and 0.619), rainfall total (r = -0.203, -0.222, 0.661, 124, -0.615 and 0.441), length of growing period (r = -0.268, 0.008, 0.878, and 0.003 and -0.679) and number of rainy day (r = -0.448, -0.036, 0.595, -0.485 and 0.425) showed positive and negative(weak to strong) correlation at Tenta, Tehuledere, Borena, Wogdi and Worebabo respectively. At Borena district all rainfall features except KSOS (had moderately negative correlation) showed moderate to strong positive correlation with Barley yield. Borena and Worebabo districts had shown good correction of barley yield as compared to other districts (Table 4.16).

Teff (Eragrostis teff), the correlation with start of kiremt season (r = 0.688, -0.197, -0.554, 0.352 and 0.210), end of date of the rainy season (r = 0.886, 0.199, 0.698, -0.061 and 0.250), rainfall total (r = 0.344, 0.056, 0.745, -0.362 and 0.231), length of growing period (r = -0.061, 0.291, 0.838, -0.446 and -0.033) and number of rainy day (r= 0.358, 0.279, 0.821, -0.069 and 0.047) at Tenta, Tehuledere, Borena, Wogdi and Worebabo respectively were showed weak to strong positive and weak to moderate negative. At Tenta, KSOS and KEOS had strong positive correlation and KRT and KNRD showed moderately positive correlation. Whereas, KLGP had weak negative correlation with teff yields. However, teff yield at Tehuledere district had weak correlation with all rainfall features. There was a strong positive correlation in all features (except KSOS with negative moderate correlation) at Borena. There were also negative corrections from weak to moderate in all rainfall features except KSOS at Wogdi (Table 4.17).

Table 4.15: Pearson's correlation of kiremt rainfall features and wheat yields in South Wollo Zone, during 2011-2016

RF features	Wheat				
	Tenta	Tehuledere	Borena	Wogdi	Worebabo
KSOS	-0.365	-0.389	-0.246	0.095	-0.124
KEOS	0.408	0.279	-0.058	0.021	-0.253
KLGP	0.876	0.496	0.105	-0.071	-0.029
KRT	0.906	0.245	-0.124	-0.406	0.197
KNRD	0.757	0.519	-0.075	-0.084	0.476

Table 4.16: Pearson's correlation of kiremt rainfall features and barley yields in South Wollo Zone, during 2011-2016

RF features	Barley				
	Tenta	Tehuledere	Borena	Wogdi	Worebabo
KSOS	0.212	-0.006	-0.442	-0.666	-0.573
KEOS	0.015	0.006	0.847	-0.522	0.619
KLGP	-0.268	0.008	0.878	0.003	0.679
KRT	-0.203	-0.222	0.661	-0.615	0.441
KNRD	-0.448	-0.036	0.595	-0.485	0.425

Table 4.17: Pearson's correlation of kiremt rainfall features and teff yields in South Wollo Zone, during 2011-2016

RF features	Teff				
	Tenta	Tehuledere	Borena	Wogdi	Worebabo
KSOS	0.688	-0.197	-0.554	0.352	0.210
KEOS	0.886	0.199	0.698	-0.061	0.250
KLGP	-0.061	0.291	0.838	-0.446	-0.033
KRT	0.344	0.056	0.745	-0.362	0.231
KNRD	0.358	0.279	0.821	-0.069	-0.047

4.7.2 Coefficient of Determination of Rainfall Features on Wheat, Barley and Teff Yields

Table 4.17, 4.18 and 4.19, showed highest variation in yields of wheat, barley and teff during kiremt season with each rainfall characteristics (SOS, EOS, LGP, NRD, and RT). For the Production of wheat, the end of kiremt season, length of growing period, number of rainy day and total rainfalls were the most deterministic factors in all districts of the study area. That means, to produce more wheat yield, KNRD at Tehuledere, LGP at Wogdi, and KEOS and KNRD at Worebabo. Similarly, KEOS and LGP at Borena, KNRD at Tehuledere, KEOs at Wogdi and KNRD at Worebabo district are the deterministic factors. On the other hand, more teff Production LGP at Wogdi, KEOS at Borena and both KEOS and KNRD at Worebabo district are main climatic features.

The computed values of coefficient of determinations (R^2) at Borena, Tenta, Tehuledere, Wogdi and Worebabo district for wheat yield were R^2= 0.95, 0.99, 0.93, 0.91 and 0.58. For barley R^2 = 0.99, 0.48, 0.58, 1.00, 0.93 and teff R^2= 0.81, 0.98, 0.54, 0.56 and 0.99 respectively (Table 4.18, 4.19 and 4.20). The coefficient of determination was more than 0.90 showed the listed rainfall factors were the deterministic factors to produce good yields of the selected crops. Which means the predicted yield and the actual data showed strong correlation. For instance, Kiremt rainfall total and length of growing period were the dominant factors of the 95% yield production of wheat at Borena district. But, the lower coefficient of determination such as 0.48-0.58 showed medium correlation between the observed and the predicted data. It might be other controls like minimum and maximum temperature, Soil type, fertilizers etc. rather than the above rainfall features in the study area. As use of modern inputs and farm tools is limited in Amhara region (Bewket, 2009) and national level application of chemical fertilizers, improved seeds and high return technologies are also limited (Dercon and Hill, 2009), rainfall variability explained 84.1–93.1% of production variability in the study area, while temperature accounts from 0.4% to 9% of total variability in production of crops.

Table 4.18: Regression model as developed for wheat yields with rainfall features as explanatory variables

District	Equation of Model	model goodness of fit statistics		ANOVA for regression models				
		R^2	$AdjR^2$	Source	DF	Fcal	F tab 5%	F tab 1%
Borena	Y=891.93-3.51*KEOS+ 2.27*LGP+0.08*KRT-2.01*KNRD	0.95	0.75	Model	4	247.3	225	5625
				Error	1	S		
				Total	5			
Tenta	Y=83.71+0.22*KEOS+ 0.72*LGP-0.02*KRT-2.01*KNRD	0.99	0.95	Model	4	247.3	225	5625
				Error	1	S		
				Total	5			
Tehuledere	Y=184.37-0.77*KSOS-0.12*KRT+ 1.22*KNRD	0.93	0.84	Model	3	19.52	19.26	99.17
				Error	2	S		
				Total	5			
Wogdi	Y=173.53+0.94* KEOS+ 0.59*KLGP-0.23*KRT+0.45* KNRD	0.91	0.52	Model	4	23.83	225	5625
				Error	1	NS		
				Total	5			
Worebabo	Y=-136.82+0.49* KSOS+1.38*KNRD	0.58	0.3	Model	2	7.07	9.55	30.8
				Error	3	NS		
				Total	5			

Where, KSOS, KEOS, KRT, KNRD, KLGP is Kiremt start of season, Kiremt End of Season, Kiremt Rainfall Total, Kiremt Number of Rainy Day, Kiremt Length of Growing Period respectively, Y is yield qt/ha, DF is degree of freedom, Ftab is F tabulated found from degree of freedom Table. S is significant and NS is none significant at 95% confidence level.

Table 4.19: Regression model as developed for barley yields with Rainfall features as explanatory variables

District	Equation of Model	model goodness of fit statistics		ANOVA for regression models				
		R^2	$AdjR^2$	Source	DF	Fcal	F tabulated	
							5%	1%
Borena	Y=252.41+0.99* KEOS-0.38*LGP-0.02*KRT+0.46* KNRD	0.99	0.97	Model Error Total	4 1 5	232.2 S	225	5625
Tenta	Y=21.08+0.01*KRT-0.15*KNRD	0.48	-0.28	Model Error Total	2 3 5	3.54 NS	9.55	30.8
Tehuledere	Y=254.62-0.99* KSOS-0.15*KRT+ 1.23*KNRD	0.52	-0.19	Model Error Total	3 2 5	0.73 NS	19.2	99.2
Wogdi	Y=19.16+0.69*LGP-0.09*KRT-0.13 *KNRD	0.995	0.99	Model Error Total	3 2 5	442.2 S	19.2	99.17
Worebabo	Y=292.86+1.17*KEOS-0.35*LGP-0.05 *KRT+1.14*KNRD	0.93	0.66	Model Error Total	4 1 5	345.1 S	225	5625

Where, KSOS, KEOS, KRT, KNRD, KLGP is Kiremt start of season, Kiremt End of Season, Kiremt Rainfall Total, Kiremt Number of Rainy Day, Kiremt Length of Growing Period respectively, Y is yield qt/ha, DF is degree of freedom, Ftab is F tabulated found from degree of freedom Table. S is significant and NS is none significant at 95% confidence level.

Table 4.20: Regression model as developed for teff yields with rainfall features as explanatory variables

District	Equation of Model	Model goodness of fit statistics		ANOVA for regression models				
		R^2	$AdjR^2$	Source	DF	Fcal	F tab	
							5%	1%
Borena	Y=-73.48+0.22*KEOS+ 0.29* KNRD	0.81	0.69	Model Error Total	2 3 5	13.52 S	9.55	30.82
Tenta	Y=-56.30+0.30*KSOS+ 0.01*KRT+0.08*KNRD	0.98	0.95	Model Error Total	3 2 5	32.52 S	19.16	99.17
Tehuledere	Y=113.49-0.45*KSOS- 0.07*KRT+0.69*KNRD	0.54	-0.14	Model Error Total	3 2 5	2.89 NS	19.16	99.17
Wogdi	Y=-17.04+0.29*KSOS- 0.03*KRT	0.56	-0.05	Model Error Total	2 3 5	11.03 S	9.55	30.82
Worebabo	Y=379.91+1.50*KEOS- 0.69*LGP-0.04*KRT +1.49*KNRD	0.99	0.95	Model Error Total	4 1 5	242.1 S	225	5625

Where, KSOS, KEOS, KRT, KNRD, KLGP is Kiremt start of season, Kiremt End of Season, Kiremt Rainfall Total, Kiremt Number of Rainy Day, Kiremt Length of Growing Period respectively, Y is yield qt/ha, DF is degree of freedom, Ftab is F tabulated found from degree of freedom Table. S is significant and NS is none significant at 95% confidence level.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusions

This study was undertaken to analyze the characteristic of historical rainfall (rain gauge and gridded) data to investigate the variability and trend in associated with its global governing factors of Strong El Niño and its relation with major cereal crops including wheat, barley and teff in South Wollo Zone of ANRS .Analysis of climate characteristics for the study area 1986-2016 using 13 meteorological stations and in relation to crops, used 5 districts of wheat, barley and teff yields from 2011-2016 with Pearson's correlation and multiple regression model.

South Wollo Zone received, on average between 648.9-1251.5 mm, from which kiremt rainfall contributes about 61.8% to 79.0% with PCI from 10.5 (at Mekaneselam) to 13.5 (at Wereillu) and CV of 16.3% (at Wogdi) to 30.6% (at Tebasit) and belg rainfall from 17.3% to 28.8% with PCI values ranged from 10.8% at Akesta and SaintAdjibar to 13.0% at Worebabo and CV values from 37.1% at Haik to 67.5% at Woreillu. The area received mean total rainfall in kiremt season varied from 487.4mm to 840.1mm and in belg season it received varied from 133.5 mm to 350.9 mm respectively during 1986-2016.

In all stations drought occurred in different time scales with different magnitude based on standard rainfall anomaly measurement. Though almost all stations in the study area suffer from drought, it is important to consider that all of the stations did not experience well-defined drought episode during the same periods. In other words, temporal distribution and frequency of droughts varied markedly among each station. In most of the stations, 1987 and 2015 years of kiremt season were the common drought years with in different magnitude in the study areas.

The past 31years annual rainfall increased by 1.26, 2.30, 3.21, 0.60, 18.86 and 0.19 mm per year at Ambamariam, Kabie, Mekaneselam, SaintAdjibar, Tebasit and Wereillu respectively. However, at Akesta, Dessie, Haik, Goshmeda, Kombolcha, Wogdi and Worebabo stations were decreased by 2.00, 6.16, 3.04, 13.97, 2.78, 9.34 and 6.45 mm per year respectively. Even though Dessie, Goshmeda, Wogdi and Worebabo station showed a decreasing trend on kiremt rainfall totals, Akesta, Ambamariam, Haik, Kabie, Kombolcha, Mekaneselam, SaintAdjibar, Tebasit and Wereillu showed an increasing trend. Principally, there were a significant increasing kiremt rainfall trends at Tebasit and Wereillu, and decreasing trend at Goshmeda and Wogdi. Moreover, all stations during belg season showed decreasing rainfall trend.

The onsets of the rainy seasons are the most important for agricultural activities and sowing different type of crops. As a result, the rainfall characteristics that expressed in descriptive statistics that the mean onset date of the short rainy seasons in the study areas were 120 DOY (April 29), 118 DOY (April 27), 116 DOY (April 25), 115 DOY (April 24), 110 DOY (April 19), 93 DOY (April 2) at Akesta, Kombolcha, Tebasit, Worebabo, Dessie and Haik respectively. In addition, Wogdi, Kabie, Woreilu, Ambamariam, Goshmeda, Mekaneselam and SaintAdjibar; on 144 DOY (May 23), 141 DOY (May 20), 141 DOY (May 20), 140DOY (May 19), 140 DOY (May 19), 134DOY (May 13), 122 DOY (May 1) respectively. On the other hand, the median onset date of the main rainfall season (kiremt) was at Mekaneselam on 183DOY (July1), SaintAdjibar on 184 DOY (July 2), Wogdi on 186 DOY (July 4), Akesta, Ambamariam, Dessie, Kabie and Woreillu on 187DOY (July 5), Worebabo on 188 DOY (July 6), Haik on 190 DOY (July 8) and Goshmeda on 192 DOY (July 10). On other hand, the observed median end date of Kiremt growing season (EOS) was seen being DOY269 (Sep 25) at Akesta, DOY 273 (September 29) at Ambamariam, DOY 289 (Oct 15) at Dessie, DOY 284 (Oct 10) at Haik, kombolcha and Mekaneselam, DOY 265 (September 21) at Goshmeda, DOY 273 (September 29) at Kabie, DOY 274 (September 30) at SaintAdjibar, DOY 281(October 7) at Tebasit, DOY277 (October 3) at Wogdi and DOY 272 (September 28) at Wereillu. The variability of LGP ranges from 11.2% at Goshmeda to 19.5% at Worebabo and NRD ranges from 12.3% at Wogdi to 19.8 % at Kabie of the study area. Due to the fact that kiremt rainfall onset in the study area can be easily predictable while it can’t be easily understood the end date of kiremt season. In the case of KNRD, the trend from 1986-2016, South Wollo Zone except Akesta, Wogdi and Worebabo, showed an increasing trend. Of those selected stations of South Wollo Zone; Dessie, Haik and Wereillu showed significant increasing trend. But, Worebabo showed significant decreasing trend.

The correlation coefficients computed between yields and climate features South Wollo Zone showed that kiremt (JJAS) start of season (r = from -0.389 to 0.095), End of season (r = from -0.253 to 0.408), rainfall total (r = from -0.406 to 0.906), length of growing period (r = from -

0.071 to 0.876) and number of rainy day (r = from -0.084 to 0.757) had weak negative and strong positive correlation with wheat yields. Similarly, barley yields has weak negative to moderate positive correlation. Moreover, teff yield showed weak - moderate negative correlation to weak- strong positive correlation on the study area.

The 1987 strong El Niño years characterized as Late on set of kiremt rainfall in the study area and normal ending date. While the number of rainy day and length of Growing Period was lowest as compared to other two Strong El Niño years. However, 1997 showed late onset and normal end date. Also, more number of rainy days and length of growing period in 1997 from long mean in the study area. The 2015, the recent strong El Niño, indicated late start and end of kiremt season in South Wollo Zone and small number of rainy days and length of growing Period. In general, South Wollo Zone is considered as drought prone region, where El Niño induces unbearable impacts on seasonal rainfall performance. It affects the production and productivity of different types of crops from the preparation of land, sowing period, development and harvesting period. It results food insecurity and dependent on food aid.

5.2 Recommendations

This study only considered only rainfall parameters in relation to wheat, barley and teff yields. Hence, inclusion of other climatic (climate information and access to climate information) and non-climatic (application of fertilizer, seed variety and farming methods) factors might enhance the visibility of boundaries up to some levels can influence crop performance. By using district level seasonal climate information that regularly issued by NMA of Ethiopia and the farmers are encouraged to benefit from this service and apply such information for farm level decision that ultimately enhance their crop yield under variability's of climate.

South Wollo Zone is considered as drought prone areas widely affected emerging of strong El Niño events. To minimize such effect, the local policy makers should be integrate efficient agricultural water management practices with productivity-enhancing interventions; promote not only short period growing cereals but also new drought-tolerant cereals seeds of wheat, barley and teff varieties distribute to the local farmers; and also promote farming of dairy animals favorable districts in the Zone. The local policy makers, Kebele leaders, NGOs, local donors, Zonal disaster protections, and service providing institutions should be integrate in order to design adaptation strategies and setting agenda for development policies. The federal and regional government also should be big attention to the areas by assigning NGOs and funds to further works and studies on climate change and variability as well as extreme climate events, crop pests and disease, water and land management system, rehabilitation of soil and forests.

6. REFERENCES

Abbas, F., Ahmad, A., Safeeq, M., Ali, S., Saleem, F., Hammad, H.M., Farhad, W. 2013. Changes in precipitation extremes over arid to semiarid and sub humid Punjab, Pakistan. Theor.Appl.Climatol. Doi: 10.1007/s00704-013-0988-8.

AfDB (African Development Bank). 2011. Federal Democratic Republic of Ethiopia: Country Strategy Paper 2011-15, Apr.

Alemayehu, A., Bewket, W. 2016. Local climate variability and crop Production in the central Highlands of Ethiopia. Environ Dev. 19:36–48

Agnew, CT., Chappel A. 1999. Drought in the Sahel. Geo J., 48: 299-311.

Amare, B., Hurni, H., Gete, Z. 2011. Responses of rural households to the impacts of population and land-use changes along the Eastern Escarpment of Wollo, Ethiopia. Nor. J. Geogr. 65, 42–53. https://doi.org/10.1080/00291951.2010.549954.

Amhara Micro-enterprise Development, Agricultural Research, Extension, and Water shed management (AMAREW) Project. 2007. Annual Work Plan Bahirdar, Ethiopia.

Akinseye, F., Ajayi, V., Oladitan, T. 2013. Assessing the impacts of climate variability on crop yield over Sudano- Sahelian zone in Nigeria. Access Int. J. Agric. Sci., 1(7), 91-98

Amogne Asfaw and Wondifraw Workineh. 2017. Effect of El Niño induced drought on students ’academic performance: a case study in Borena Woreda of South Wollo Zone, Ethiopia. International Journal of Academic Research in Education and Review. Vol. 5(2), pp. 37-47.

Asfaw, A., Simane, B., Hassen, A., Bantider, A. 2017.Variablity and time series trend analysis of rainfall and temperature in northern Ethiopia: A case study in Woleka sub-basin. Weather and Climate Extremes 19(2018) 29-41.

Atlas of Rural Ethiopian Economy. 2006. International Food Policy Research Institute and the central statistical agency Addis Ababa, Ethiopia, Washington.

Ayalew, M. (Former Head of The Early Warning and Planning Department, The Relief and Rehabilitation Commission), 1996: Addis Ababa, Ethiopia. Letter, August 26.

Ayalew Dereje, Kindie Tesfaye, Girma Mamo, Birru Yitaferu and Wondimu Bayu. 2012. Variability of rainfall and its current trend in Amhara Region, Ethiopia. African Journal of Agricultural Research,7(10):1475–1486.

Barnett, B., Mahul, O., 2007.Weather index insurance for agriculture and rural areas in lower-income countries. American Journal of Agricultural Economics. 89, 1241-1247

Bewket, W. And Conway, D. 2007. A note on the temporal and spatial variability of rainfall. International Journal of Climatology, 27:1467–1477.

Bewket, W. 2009. Rainfall variability and crop Production in Ethiopia Case study in the Amhara region.

Befekadu Degefe and Berhanu Nega (eds.). 2000. Annual report on the Ethiopian economy, 1999/2000. Ethiopian Economic Association, Addis Ababa.

BoFED.2009. Development indicators of the Amhara national regional state of the year 2008. 6th edition; Bahir Dar, Ethiopia

Boko, M., Niang, I., Nyong, A.,VogeL, C., Githeko, A., Medany, M., Osman-elasha, B., Tabo, R. &Y and A, P., 2007. African Climate Change. 2007. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change(Eds M. L. Parry, O. F. Canziani,J. P. Palutikof, P. J. van der Linden & C. E. Hanson), pp. 433–467. Cambridge, UK: Cambridge University Press.

Borrell, A., E.V. Oosterom, H. Graeme, J. David & H. Bob. 2003. Using science to combat drought: a case study of stay-green in sorghum. Science for Drought. Proceedings of the National Drought Forum. p120-123.

Conway, A. 2009. The science of climate change in Africa: impacts and adaptation. Grantham Institute for Climate Change Discussion paper No 1, Pp 24.

Conway, D. and Schipper, E.L.F., 2011. Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. Global Environment Change 21:227–237.

Coltorti, M., Dramis, F. and Ollier, C.D., 2007. Plantation surfaces in northern Ethiopia. Geomorphology, Vol. 89 Nos 3/4, pp. 287-296.

Cooper, P. J. M., Coe, R. 2011. Assessing and addressing climate-induced risk in Sub-Saharan rain fed agriculture. Experimental Agriculture 477: 179.

Dercon, S., and R.V.Hill. 2009. Growth from Agriculture in Ethiopia: Identifying key constraints. Paper prepared as a part of a study on agriculture and growth in Ethiopia for the United Kingdom Department for International Development (DFID).Oxford University, Oxford, UK.

Dyer, N.G, Paul J. Hangesa, Rosalie J. Hall. 2005. Applying multilevel confirmatory factor analysis techniques to the study of leadership. Department of psychology, University of Maryland, College Park, MD 20742, United States. The Leadership Quarterly 16 (2005) 149–167.

CSA. 1998. "Agricultural Sample Survey 1997/98 (1992 E.C.):, Report on Farm Management Practices (Private Peasant Holdings, Meher Season)," Statistical Bulletin". The Federal Democratic Republic of Ethiopia, Addis Ababa.

Central Statistics Agency (CSA). 2007. Census 2007 Tables: Amhara Region, Tables 2.1, 2.4, 2.5, 3.1, 3.2 and 3.4.

Central Statistics Agency(CSA).1994, Population and Housing Census of Ethiopia: Results for Amhara Region, Vol. 1, part 1, Tables 2.1, 2.11, 2.14, 2.17 (accessed 6 Apr 2009).

Central Statistics Agency (CSA) .2014. Area and production of major crops 2014 / 2015 (2007 E.C.). Federal Democratic Republic of Ethiopia, Central statistical agency agricultural sample survey. Volume I.

Degefe, B. & Nega B.1999.Annual report on the Ethiopian economy. The Ethiopian Economic Association.Vol.1. 1999/2000.

Degefu, W. 1987. Some aspects of meteorological drought in Ethiopia. Drought and hunger in Africa. Denying famine a future. M.H. Glantz. Cambridge, Press Syndicate of the University of Cambridge.

Dyer, G., Taylor, G. E., Yunez-Naude, A. 2005. Disaggregated rural economy-wide models for policy analysis. World Development. (33)10, 1671-1688.

Eiste, E., Diriba, K., Sorteberg, A. 2012. Recent drought and precipitation tendencies in Ethiopia. Theoretical Applied climatology, 112 (3–4), pp.535-551.

Eklundh, L. and Pilesjö, P. 1990. Regionalization and spatial estimation of Ethiopian mean rainfall. International Journal of Climatology, 10: 473–494.

FAO.2014. Understanding the drought impact of El Niño on the global agricultural areas, ISBN 978-92-5-108671-1.

FEWSNET. 2015. Food Security Outlook Ethiopia July-December 2015.

Folland, C.K., J. Owen, Ward, M.N., and Colman, A. 1991. Prediction of seasonal rainfall in the Sahel region using empirical and dynamical methods. Journal of Forecasting, 10 (21).

Garcia, A.M., Vieira, J.P., and Wine miller, K.O. 2003. Effects of 1997-1998 El Niño on the dynamics of the shallow water fish assemblage of the Patos Lagoon Estuary (Brazil). Estuarine, Coastal and Shelf Science, 57, 489–500.

Gebre-Medhin, M. and Vahlquist, B. 1977. Famine in Ethiopia: the Period 1973-75, Nutrition Reviews, 35.

Gilbert, RO., 1987. Statistical methods for environmental pollution monitoring. Van Nostr and Reinhold; 1–334.

Girma, A. 1988. Drought and Famine in Ethiopia and the Effort to Overcome It, 3 Notre Dame J.L. Ethics & Pub. Policy 71.

Gissila, T., E. Black, D. I. F. Grimes, and J. M. Slingo, 2004. Seasonal forecasting of the Ethiopian summer rains. International Journal of Climatology.24, 1345–1358.

Godswill, M., Dawit, K. and Dejene, A. 2007.A comparative analysis of rain fed and irrigated agricultural production in Ethiopia. Journal of Irrigation and Drainage. Vol 21 No 1.Springer Netherlands.

Gonzalez-Rouco JF, JL Jimenez, V Quesada and F Valero, 2001. Quality control and Homogeneity of Precipitation Data in the South West of Europe. Journal of Climate.14.pages: 967-978.

Hadgu, G., Tesfaye, K., Mamo, G., and Kassa, B. 2013. Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception. Academically Journal Environmental Science 1(8): 159-171.

Hadgu, G., Kindie Tesfaye and Girma Mamo. 2014. Analysis of climate change in Northern Ethiopia: implications for agricultural production. Theoretical and Applied Climatology ISSN 0177798X.Vol.117: P 3-17.

Hagos, F., Makombe, G., Namara, R.E. and Awulachew, S.B. 2009. Importance of irrigated agriculture to the Ethiopian economy: Capturing the direct net benefits of irrigation. Colombo, Sri Lanka: International Water Manage. Inst. p.37.

Haile, T. 1988. Causes and Characteristics of Drought in Ethiopia. Ethiopian Journal of Agricultural Sciences.10, 85 – 97.

Hare, F.K. 1983. Climate and Desertification. Revised analysis (WMO-UNDP) WCP-44 pp5-20. Geneva, Switzerland.

Hassan, R.,2006. Climate change and African agricultures, Policy Note.

Hoffmann, U. 2013. Section B: Agriculture: a key driver and a major victim of global warming, in: Lead Article, in: Chapter 1, in Hoffmann 2013, pp.3-5.

HDR (Human Development Report). 2007. Climate Change and Human Development in Africa: Assessing the Risks and Vulnerability of Climate Change in Kenya, Malawi and Ethiopia. By IGAD Climate Prediction and Applications Centre (ICPAC).

Helsel, D.R. and R.M. Hirsch. 1992. Statistical methods in water resources. Studies in Environmental Science 49. New York: Elsevier. (Available on-line as a pdf file at: http://water.usgs.gov/pubs/twri/twri4a3/) [Accessed 9-15-2011].

Ignaciuk A, Mason-D'Croz D.2014. Modeling Adaptation to Climate Change in Agriculture. OECD Food, Agriculture and Fisheries Papers 70: 58.

IPCC. 2001.Climate change: Impact Adaptation and vulnerability. Cambridge University press, Cambridge, UK.

IPCC. 2007. Climate change: The physical science basis, contribution of Working Group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, UK and New York. Cambridge University Press

IPCC. 2007. Climate Change, Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [https://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html].

IPCC. 2014. Summary for Policymakers in Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Joachin, G. 2008. The ultra-poor neglected resource, future potential. International Journal for rural development. Rural 21 volume 43.No.5/2008ISSN: 1866-8011.D20506F http:// www.rural21.com.

Kassahun, B. 1987. Weather systems over Ethiopia. Procedures of first Technical Conference on Meteorological Research in Eastern and Southern Africa, Nairobi, Kenya, UCAR, 53–57.

Kassa, F. 2015. Ethiopian seasonal rainfall variability and prediction using canonical correlation Analysis (CCA) Earth Science., 4(3) (2015), pp. 112-119.

Kassie, B. T., Rotter, R. P., Hengsdijk, H., Asseng, S., Vanittersum, M.K., Kahiluoto, H. and Van Keulen, H. 2014. Climate variability and change in the central Rift Valley of Ethiopia: challenges for rain fed crop production. Journal of Agricultural Science, 152: 58-74.

Kebede Kassa and Zewdu Eshetu. 2014. Situation analysis of rural livelihoods and socio-economic dynamics for sustainable rural development: The case of Legehida Woreda (District), South Wollo of Ethiopia Research Journal of Agriculture and Environmental Management. Vol. 3(3), pp. 201-208.

Ketema, S. 1993. Teff, breeding, genetic resources, agronomy, utilization and role in Ethiopian agriculture. Institute of Agricultural Research. Addis Ababa. p102 .

Kiladis, G. & Diaz H. 1989. Global climatic anomalies associated with extremes in the southern oscillation. Journal of Climate, 2: 1069–1090.

Khan, S. 2008. Managing climate risks in Australia: options for water policy and irrigation management. Aust J Exp Agric; 48:265–73.

Korecha, D. and A.G. Barnston. 2007. Predictability of June-September Rainfall in Ethiopia. Monthly Weather Review 135(2): 628–650.

Korecha, D. 2013. Characterizing the predictability of seasonal climate in Ethiopia. Doctoral dissertation in meteorology. University of Bergen, Norway.

Lemi, A. 2005. Rainfall probability and agricultural yield in Ethiopia, Eastern Africa social science review, volume 21, number 1, pp.57-96

Little, P.D., Stone, M.P., Mogues, T., Castro, A.P. and Negatu, W. 2006. Moving in place: drought and poverty dynamics in South Wollo, Ethiopia, Journal of Development Studies, Vol. 42 No. 2, pp. 200-225

Luis, M., Gonz J.C., alez-Hidalgo, Brunetti M., and Longares L.A. 2011. Precipitation concentration changes in Spain. Natural Hazards Earth System. Science., 11: 1259–1265.

Makombe, Godswill, Kelemework, D. and Aredo, D. 2007. A comparative analysis of rain fed and irrigated agricultural Production in Ethiopia. Irrigation & Drainage Systems 21(1):35-44.

Mamo Girma. 2005. Using seasonal climate outlook to advice on sorghum production in the Central Rift Valley of Ethiopia. Doctoral Dissertation in Agro-meteorology. University of the Free State, Bloemfontein, South Africa. p171

McKee, J. 2008. Deconstructing some myths about climate change adaptation and mitigation, In: Green Forum (ed.), Climate change a burning issue for Ethiopia: proceedings of the 2nd Green Forum Conference held in Addis Ababa, 31 October –2 November 2007 (Addis Ababa: Green Forum), pp111–135

McSweeney, C., New, M., Lizcano G. and UNDP. 2008. Climate change country profiles: Ethiopia. (http://country-profiles.geography.ox.accadamy.uk). Accessed on October 1, 2014.

MEDaC (Ministry of Economic Development and Co-operation). 1999. Survey of the Ethiopian Economy: Review of Post-Reform Developments, 1992/93-1997/98. Addis Ababa, MEDaC.

Mesay, A. 2006. The Onset, Cessation and Dry Spells of the Small Rainy Season (Belg) of Ethiopia. National Meteorological Agency of Ethiopia, Addis Ababa. p10-13.

Moges, A. and N.M. Holden. 2007. Farmers' perceptions of soil erosion and soil fertility loss in Southern Ethiopia. Land Degradation Development, 18: 543-554.

Mohammed, Y., Yimer, F., Tadesse, M., et al. 2018. Variability and trends of rainfall extreme events in north east highlands of Ethiopia. Int.J.Hydro.2 (5):594–605.

Mubvuma, M. T. 2013. Climate change: Matching Growing Season Length with Maize Crop Varietal Life Cycles in Semi-Arid Regions of Zimbabwe. Greener Journal of Agricultural Sciences ISSN: 2276-7770. 3 (12): 809-816.

Muluneh, W., Demeke, H. 2011. Climate change and its variability: its impact on rural livelihoods, local coping and adaptation strategies in Wereillu Woreda, Northeastern Ethiopia. J. Dev. Res. 33(1), 29-59.

Muluneh Getahune. 2015. Analysis of past and future intra-seasonal rainfall variability and its implications for crop production in the North Eastern Amhara Region, MSc. Thesis Haramaya University, Haramaya, Ethiopia.

NMSA. 1996. Climate & agro climate resources of Ethiopia. NMSA Meteorological Research Report Series, Vol.1, No.1, and Addis Ababa.

NMSA. 2001. Report submitted to initial national communication of Ethiopia to the United Nations Framework Convention on Climate Change, Addis Ababa, Ethiopia.

Nicholls, N. 1993. What are the potential contributions of El Niño - Southern Oscillation Research to Early Warning of Potential Acute Food-deficit Situations? In M. H. Glantz (Ed.), Workshop on Usable Science: Food Security, Early Warning and El Niño, 25-28 October, Budapest, Hungary, Boulder: National Center for Atmospheric Research, 169-177.

Nicholson, S. E. 2000. The nature of rainfall variability over Africa on time scales of decades to millennia, Global Planet. Change, 26, 137–158.

OCHA (Office for the Coordination of Humanitarian Affairs by United Nation). 2015. Annual report on areas affected by 2015/2016 El Niño.

Oliver, J. E. 1980. Monthly precipitation distribution: a comparative index. Professional Geographer 32: 300-309.

Osman, M., Sauerborn P. 2002. A preliminary assessment of characteristics and long-term variability of rainfall in Ethiopia basis for sustainable land use and resources management. Conference on International Agricultural Research for Development, Deutscher Tropentag 2002, Witzenhausen, Germany October, pp. 9-11.

Pankhurst, R. 1985. The history of famine and epidemics in Ethiopia prior to the twentieth century. Addis Ababa: Relief and Rehabilitation Commission

Pankhurst, R., Johnson, D.H.1988. The great drought and famine of 1888-92 in northeast Africa. In The ecology of survival: case studies from northeast African history (pp. 47-72), Johnson DH, Anderson DM (eds.). Lester Crook Academic Publishing, London.

Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell, and M.I. Travasso. 2014. Food Security and Food Production Systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectorial Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Chan. P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York.

Quisumbin, A. R. 2003. Food Aid and Child Nutrition in Rural Ethiopia. World Development 31(7): 1309-1324.

Reddy, G.V.S., Bhaskar, S.R., Purohit, R.C. and Chittora, A. K., 2008. Markov chain Model probability of dry, wet weeks and statistical analysis of weekly rain fall for agricultural planning at Bagalore and Kamataka. Journal of Agricultural Science21 (1), 12-16.

Rosell, S. and Holmer, B. 2007. Rainfall change and its implications for spring harvest in South Wollo, Ethiopia. Geografiska Annaler, Vol. 89 No. 4, pp. 287-299.

Rosell, S. 2011. Regional perspective on rainfall change and variability in the central highlands of Ethiopia, 1978-2007. Applied Geography 31, 329-338.

Segele, Z. T., and P. J. Lamb. 2005. Characterization and variability of Kiremt rainy season over Ethiopia. Meteor. Atmos. Phys., 89, 153-180.

Shanko, D. and Chamberlain, P. 1998. The effects of the southwest Indian Ocean tropical cyclones on Ethiopian drought. International Journal of Climatology, 18: 1373–1388.

Shrestha, A. and Kostaschuk, R.A. 2005. El Niño Southern Oscillation (ENSO)-related variability in mean-monthly stream flow in Nepal. Journal of Hydrology, 308, 33–49.

Smakhtin, V.U., and E.L.F. Schipper. 2008. Droughts: the impact of semantics and Perceptions. Water Policy, 10, 131–143,doi:10.2166/wp.2008.036.

Solomon, S., D. Qin, M. Manning, Z. Chen, and M. Marquis. 2007. Regional Climate Projection in Climate Change. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Stern, N. H. 2007. The Economics of Climate Change: The Stern Review. Cambridge, UK: Cambridge University Press.

Stern, R.D., Cooper, P. J. M. 2011. Assessing climate risk and climate change using rainfall data -a case study from Zambia. Journal of Experimental Agriculture 47, 241-266.

SUPARI. 2012. Spatio-temporal Characteristics of Extreme Rainfall Events over Java Island. Submitted to MSc. Program. Faculty of Geo-Information and Earth Observation, University of Twente.

Taddesse, T. 1994. Summer monsoon seasonal rain fall of Ethiopia in ENSO episodic years.

Taddesse, T. 2000. Drought and its predictability in Ethiopia. In: Wilhite, D.A. (Ed.), Drought: A Global Assessment, Vol. I. Routledge, pp. 135-142.

Tesfaye, K. And S. Walker. 2004. Matching of crop and environment for optimal water use: The case of Ethiopia. Physics and Chemistry of the Earth, 29: 1061-1067.

Tilahun, k. 1999. Test of homogeneity, frequency analysis of rainfall data and estimate of drought probabilities in Dire-Dawa, Eastern Ethiopia. Ethiopian Journal of Natural Resources1: 125-136.

Thornton, P.K., Jones, Owiyo., P.G. Kruska, T.M.,Herrero, S.V.and Kelkar, U. 2006. Mapping climate vulnerability and poverty in Africa: Report to the Department for International Development. ILRI, Nairobi, Kenya, pp.171.

Trenberth, K.E. 1997. The Definition of El Nino. Bulletin of American Meteorological Society: 78, 2771-2777.

Tsegaye, G., Guta, W., G.N. Rao, Tessema, A. 2015. The current and future trend of Rainfall and its variability in Adami-Tulu Jido-KombolchaWoreda, Central Rift Valley of Ethiopia. Journal of Environment and Earth Science ISSN, 2224-3216 (Paper) ISSN 2225-0948 (Online) Vol.5, No.22.

Toulmin, C. and Huq, S. 2006. Africa and climate change in sustainable development opinion. International Institute for Environment and Development. London, UK.

USID, 2016. Ethiopia Agriculture Knowledge, Learning, Documentation and Policy Project Contract number: AID-663-C-14-00002.

Viste, E., Korecha, D. and Sorteberg, A. 2012. Recent drought and precipitation tendencies

in Ethiopia. Theor. Appl. Climatol. DOI 10.1007/ s00704-0120746-3.

WMO, 1998a. 1998. El Niño Updates (1–5). [http://www.wmo.ch.]

Wolde-Georgis, T. 1997. El Niño and Drought Early Warning in Ethiopia. Internet Journal of African Studies, http://www.bradford.ac.uk/research-old/ijas/ijasno2/Georgis.html accessed January 2016.

Wolde-Georgis, T., Aweke, D. and Hagos, Y. 2000. The Case of Ethiopia - Reducing the impacts of environmental emergencies through early warning and preparedness: the case of the 1997-98 El Niño.

World Bank. 2006. Four Ethiopia's: A Regional Characterization (accessed 23 March 2006).

World Bank. 2008. World Bank data on agricultural value added as a share of GDP in 2008.

World Food Program (WFP). 2015. Belg- producing areas: SNNPR, North Eastern Amhara, Southern Tigray and some areas in Central and Eastern Oromia.

Wood, A. 1977. A preliminary chronology of Ethiopian droughts. In Drought in Africa, vol. 2 (pp.68-73), Dalby D, Church RJH, Bezzaz F (eds.). International African Institute, London. (Journal Articles).

WWF (World Wildlife Fund). 2006 .Climate Change Impact in East Africa: A Review of The Scientific Literature.

Yimer Mohammed., Fantaw Yimer., Menfese Tadesse, Kindie Tesfaye, 2017. Meteorological drought assessment in north east highlands of Ethiopia, International Journal of Climate Change Strategies and Management, https://doi.org/10.1108/IJCCSM-12-2016-0179.

Yimer Mohammed., Fantaw Yimer., Menfese Tadesse, Kindie Tesfaye, 2018. Variability and trends of rainfall extreme events in north east highlands of Ethiopia, International Journal of Hydrology,

Zargina, A.B., 1987. Onset of effective rainfall and characteristics of dry spell in Nigeria savanna. Unpublished B.Sc. Project Report, Department of Geography, Ahmadu Bello University, Zaria, Nigeria, pp. 1-20.

7. APPENDICES

Figure 1: Landslides and erosion by flood in Kalu, kiremt 2014

(Source: South Wollo Early warning department)

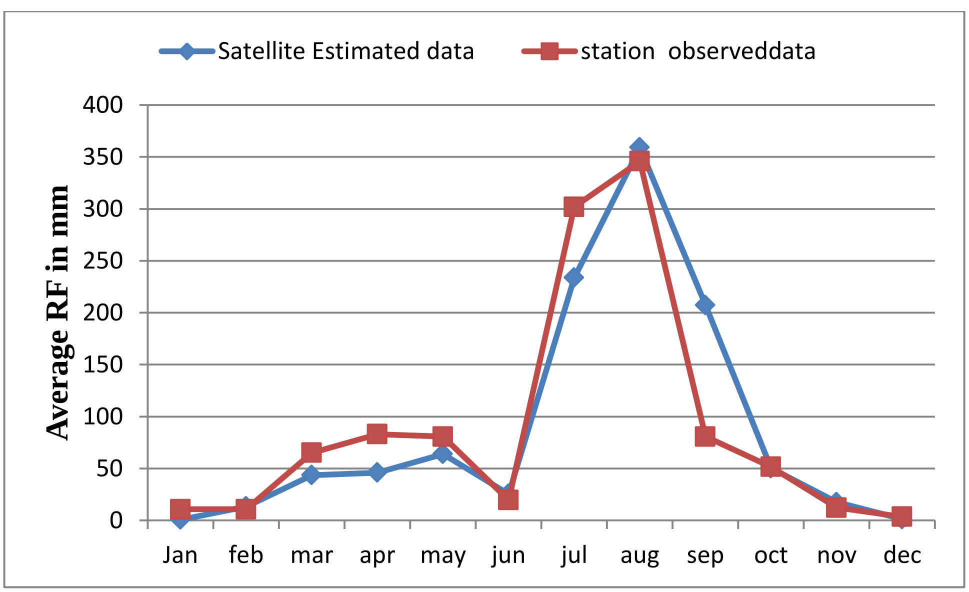


Figure 2: Kombolcha station VS satellite estimated monthly Rainfall data from 2010-2014.

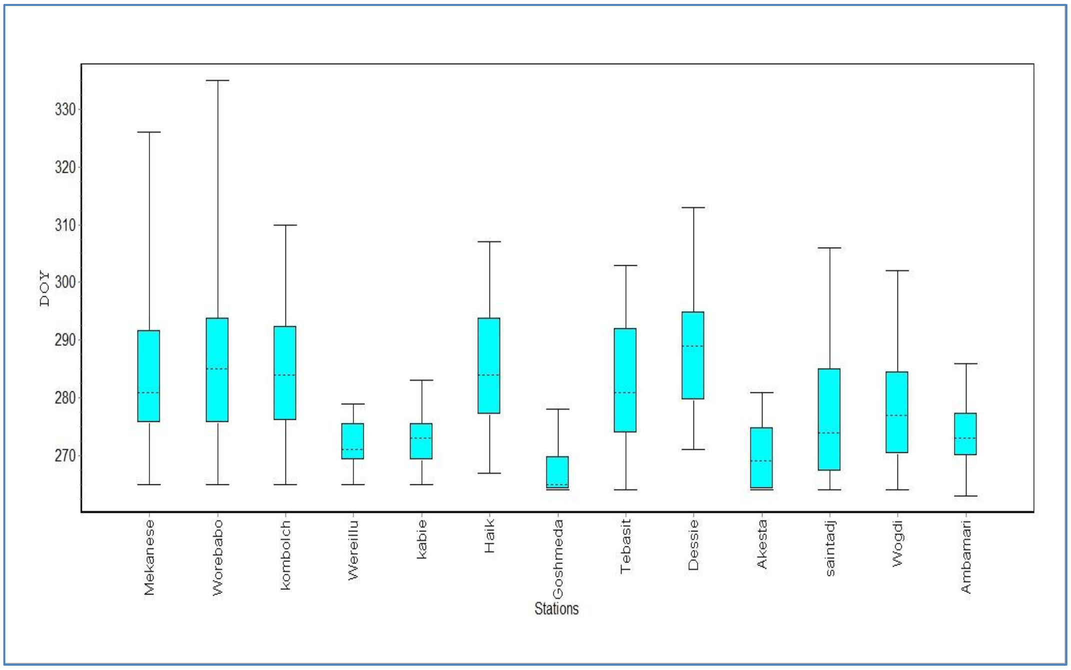


Figure 3: Kiremt onset date using Box and Whisker plot from 1986-2016

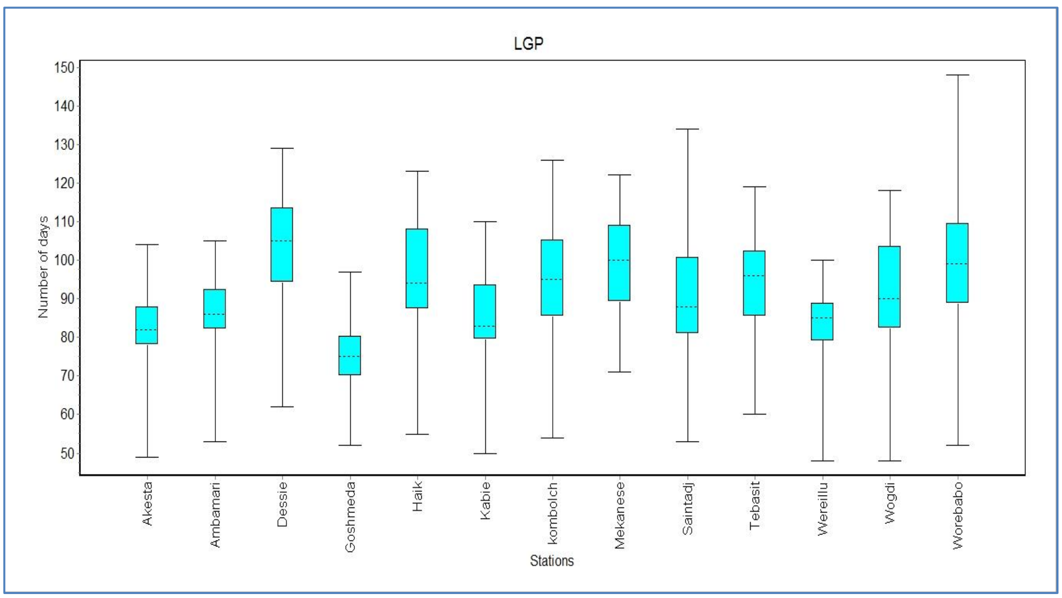
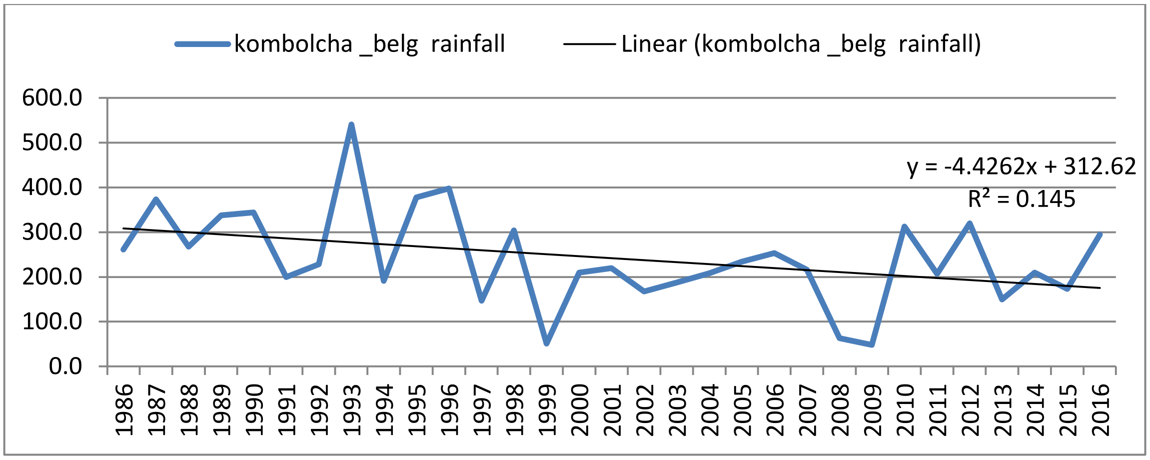
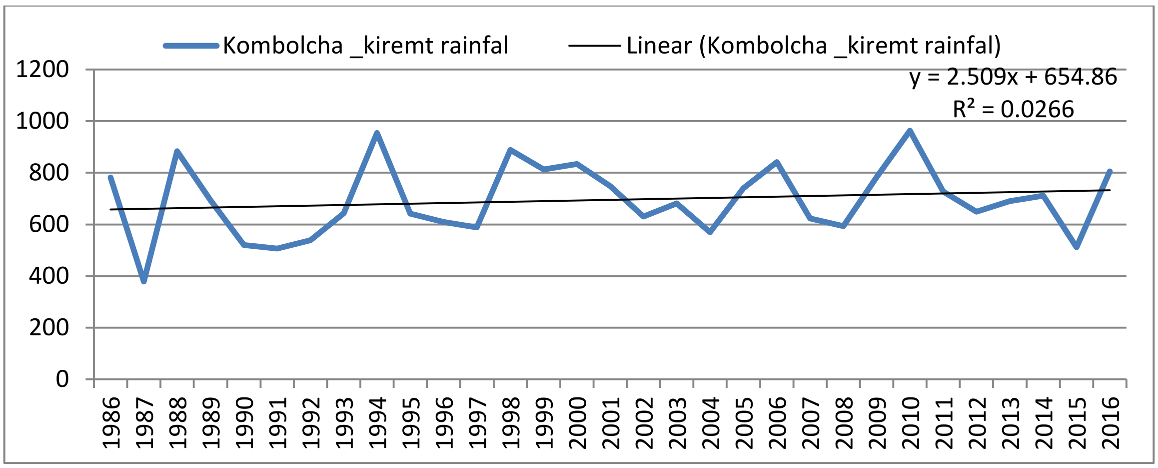


Figure 4: Length of Growing Period using Box and Whisker plot





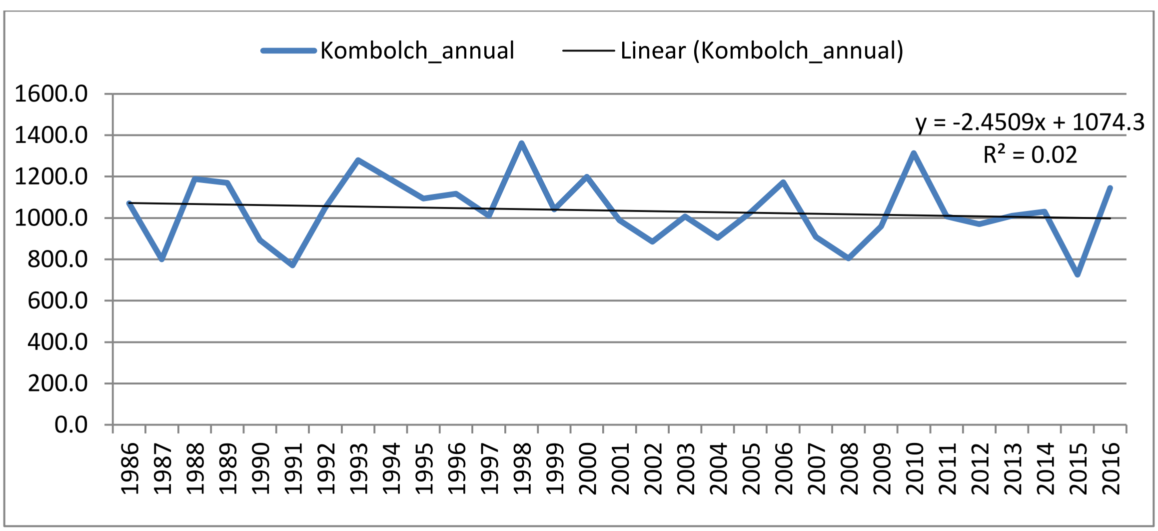


Figure 5: Trend of rainfall during belg, kiremt and annual at Kombolcha station.

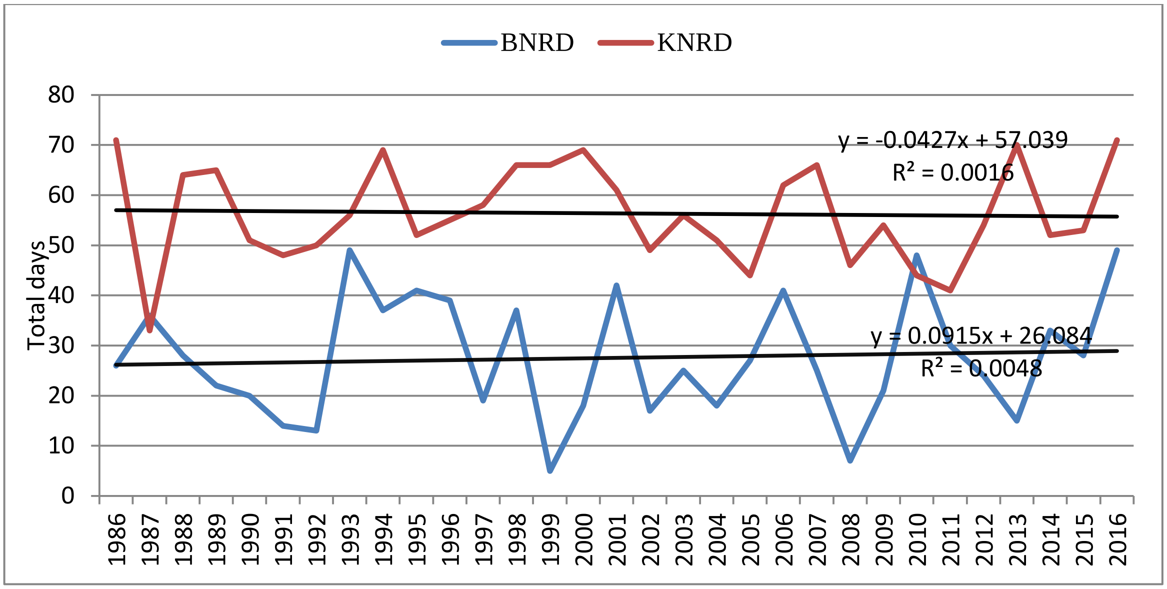


Figure 6: Trends of kiremt and Belg number of rainy day at Akesta from 1986-2016.

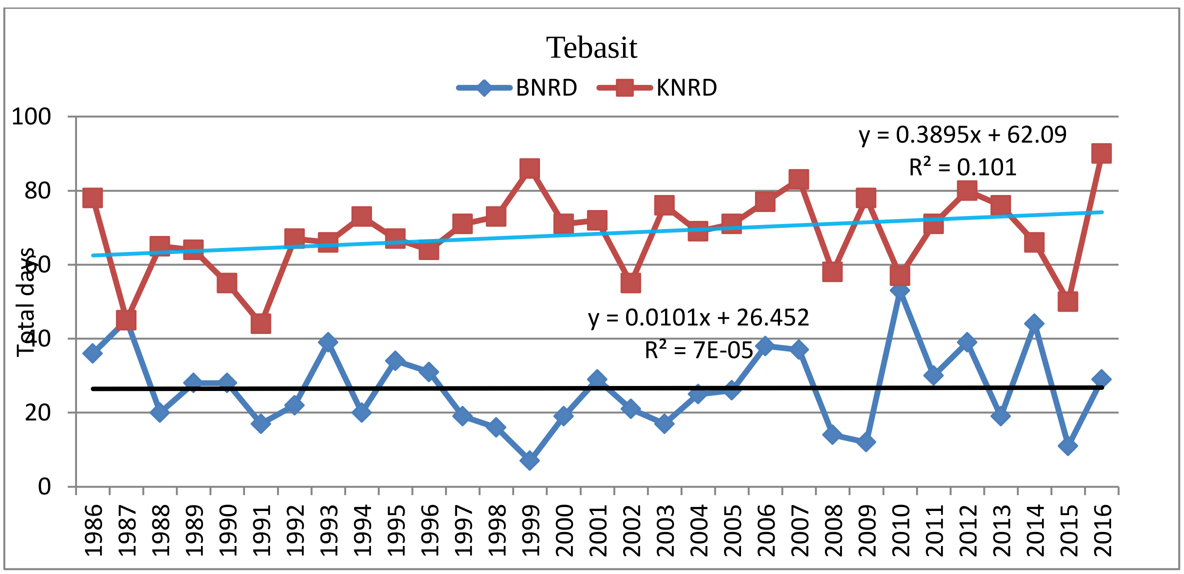


Figure 7: Trends of kiremt and Belg number of rainy day at Tebasit from 1986-2016.

Table 1: Dry spell probability at Ambamariam and Haik

DOY	Ambamariam				Haik			
	SP5	Sp7	sp10	sp15	sp5	sp7	sp10	sp15
50	1.00	0.98	0.92	0.74	0.83	0.78	0.70	0.57
60	0.99	0.96	0.86	0.64	0.81	0.74	0.64	0.50
70	0.98	0.92	0.76	0.49	0.77	0.66	0.53	0.37
80	0.96	0.86	0.65	0.35	0.69	0.54	0.37	0.21
90	0.96	0.84	0.59	0.27	0.64	0.43	0.23	0.09
100	0.97	0.88	0.64	0.28	0.66	0.44	0.21	0.06
110	0.99	0.94	0.76	0.41	0.75	0.55	0.30	0.09
120	1.00	0.97	0.87	0.58	0.83	0.69	0.46	0.20
130	1.00	0.99	0.93	0.73	0.87	0.77	0.60	0.34
140	1.00	0.99	0.95	0.80	0.88	0.81	0.67	0.43
150	1.00	0.98	0.94	0.80	0.86	0.79	0.66	0.45
160	0.98	0.96	0.88	0.71	0.79	0.70	0.57	0.39
170	0.92	0.85	0.71	0.52	0.65	0.53	0.40	0.26
180	0.72	0.56	0.40	0.25	0.40	0.28	0.18	0.10
190	0.35	0.20	0.11	0.05	0.15	0.07	0.03	0.01
200	0.11	0.03	0.01	0.00	0.04	0.01	0.00	0.00
210	0.05	0.01	0.00	0.00	0.02	0.00	0.00	0.00
220	0.12	0.02	0.00	0.00	0.04	0.01	0.00	0.00
230	0.38	0.13	0.02	0.00	0.14	0.03	0.00	0.00
240	0.75	0.46	0.18	0.03	0.34	0.14	0.03	0.00
250	0.95	0.81	0.53	0.19	0.57	0.35	0.15	0.03
260	0.99	0.96	0.82	0.50	0.72	0.55	0.34	0.13
270	1.00	0.99	0.94	0.76	0.79	0.69	0.51	0.28

Where, Sp is spell length

Table 2: Crop data of wheat, barley and teff in at Borena and Tehuledere from 2011-2016

years	Crop	Borena			Tehuledere		
		Wheat	Barley	Teff	Wheat	Barley	Teff
2011	Area Cultivated (ha)	15596	1841	9760	1749	1242	2222
	Production (quintals)	282674	25199	79365	23382	21114	24141
	Yield (Q/ha)	18.1	13.7	8.1	13.4	17.0	10.9
2012	Area Cultivated (ha)	15613	1462	10371	1575	950	2292
	Production (quintals)	239514	20923	161507	42850	20900	34474
	Yield (Q/ha)	15.3	14.3	15.6	27.2	22.0	15.0
2013	Area Cultivated (ha)	18445	1634	10986	2410	1119	3463
	Production (quintals)	343719	25711	190807	72060	39165	77117
	Yield (Q/ha)	18.6	15.7	17.4	29.9	35.0	22.3
2014	Area Cultivated (ha)	18585	1410	10626	2159	1114	3298
	Production (quintals)	412582	22249	146843	60683	26880	58134
	Yield (Q/ha)	22.2	15.8	13.8	28.1	24.1	17.6
2015	Area Cultivated (ha)	21753	173	11569	1643	462	3867
	Production (quintals)	393446	1897	69813	34674	10754	48997
	Yield (Q/ha)	18.1	11.0	6.0	21.1	23.3	12.7
2016	Area Cultivated (ha)	18684	684	9686	1740	410	4086
	Production (quintals)	482785	7860	103621	28760	1880	32849
	Yield (Q/ha)	25.8	11.5	10.7	16.5	4.6	8.0

Table 3: Crop data of wheat, barley and teff in at Tenta and Wogdi from 2011-2016

years	Crop data	Tenta			Wogdi		
		Wheat	Barley	Teff	Wheat	Barley	Teff
2011	Area Cultivated (ha)	5226	6505.5	6606.5	3242	854	12020
	Production (quintals)	74018	115830	69291	81292	12134	152224
	Yield (Q/ha)	14.2	17.8	10.5	25.1	14.2	12.7
2012	Area Cultivated (ha)	5693	1432	6955	3998	710	13457
	Production (quintals)	105464	22788	52064	99201	12598	245276
	Yield (Q/ha)	18.5	15.9	7.5	24.8	17.7	18.2
2013	Area Cultivated (ha)	6245.25	3290.6	7690.25	4230	621	13376
	Production (quintals)	112176	56060	108988	165350	10393	255001
	Yield (Q/ha)	18.0	17.0	14.2	39.1	16.7	19.1
2014	Area Cultivated (ha)	6178	1214	7100	4970	160	13180
	Production (quintals)	114652	19869	112861	174928	2928	296073
	Yield (Q/ha)	18.6	16.4	15.9	35.2	18.3	22.5
2015	Area Cultivated (ha)	6964	2971	6943	5380	78.5	13762.4
	Production (quintals)	92572	45430	78090	208184	2352	211620
	Yield (Q/ha)	13.3	15.3	11.2	38.7	30.0	15.4
2016	Area Cultivated (ha)	6175	2234	5705	5407	193	13515
	Production (quintals)	132127	27301	76996	252649	4017	395774
	Yield (Q/ha)	21.4	12.2	13.5	46.7	20.8	29.3

Table 4: Crop data of wheat, barley and teff in at Worebabo from 2011-2016

years	Crop	Worebabo		
		Wheat	Barley	Teff
2011	Area Cultivated (ha)	325	226	1624
	Production (quintals)	5590	3348	22481
	Yield (Q/ha)	17.2	14.8	13.8
2012	Area Cultivated (ha)	1057	193	1050
	Production (quintals)	22258	2123	7493
	Yield (Q/ha)	21.1	11.0	7.1
2013	Area Cultivated (ha)	855	316	950
	Production (quintals)	25216	4148	12050
	Yield (Q/ha)	29.5	13.1	12.7
2014	Area Cultivated (ha)	555	326	792
	Production (quintals)	10712	5101	11476
	Yield (Q/ha)	19.3	15.6	14.5
2015	Area Cultivated (ha)	360.8	165.9	549.8
	Production (quintals)	4195.5	1737.5	5583
	Yield (Q/ha)	11.6	10.5	10.2
2016	Area Cultivated (ha)	505.5	123	1009
	Production (quintals)	5345.5	2235	10656
	Yield (Q/ha)	10.6	18.2	10.6

Source: South Wollo Zone Early Warning office

Table 5: Correlation between rainfall and crop yields (Source: Lemi, 2005)

Province	Crops	Annual RF	kiremt RF	Belg RF
Gojjam	Cereal	0.105	-0.083	0.286
	Teff	-0.001	0.277	-0.283
	Wheat	0.249	0.053	0.048
	Barley	-0.013	0.055	-0.012
	Maize	-0.131	-0.191	0.034
	Sorghum	0.061	-0.218	0.658
Gonder	Cereal	0.176	0.202	-0.286
	Teff	0.013	0.034	-0.083
	Wheat	0.401	0.479	-0.042
	Barley	0.037	0.009	-0.219
	Maize	0.115	0.16	-0.187
	Sorghum	-0.329	-0.359	0.156
Harar	Cereal	0.033	-0.009	-0.129
	Teff	0.006	0.044	-0.173
	Wheat	0.020	-0.161	0.055
	Barley	0.056	-0.255	0.096

Table 6: correlation matrix of rainfall and crops at Mekaneselam using ANOVA

Variables	KSOS	KEOS	LGP	KRT	KNRD	Wheat
KSOS	**1.0000**	-0.1331	-0.6974	-0.1101	-0.7958	-0.2456
KEOS	-0.1331	**1.0000**	0.8032	0.8892	0.4421	-0.0584
LGP	-0.6974	0.8032	**1.0000**	0.7092	0.7981	0.1054
KRT	-0.1101	0.8892	0.7092	**1.0000**	0.6009	-0.1246
KNRD	-0.7958	0.4421	0.7981	0.6009	**1.0000**	-0.0754
Wheat	-0.2456	-0.0584	0.1054	-0.1246	-0.0754	**1.0000**
Variables	KSOS	KEOS	LGP	KRT	KNRD	Barley
KSOS	**1.0000**	-0.1331	-0.6974	-0.1101	-0.7958	-0.4421
KEOS	-0.1331	**1.0000**	0.8032	0.8892	0.4421	0.8469
LGP	-0.6974	0.8032	**1.0000**	0.7092	0.7981	0.8782
KRT	-0.1101	0.8892	0.7092	**1.0000**	0.6009	0.6611
KNRD	-0.7958	0.4421	0.7981	0.6009	**1.0000**	0.5951
Barley	-0.4421	0.8469	0.8782	0.6611	0.5951	**1.0000**
Variables	KSOS	KEOS	LGP	KRT	KNRD	Teff
KSOS	**1.0000**	-0.1331	-0.6974	-0.1101	-0.7958	-0.5539
KEOS	-0.1331	**1.0000**	0.8032	0.8892	0.4421	0.6979
LGP	-0.6974	0.8032	**1.0000**	0.7092	0.7981	0.8377
KRT	-0.1101	0.8892	0.7092	**1.0000**	0.6009	0.7447
KNRD	-0.7958	0.4421	0.7981	0.6009	**1.0000**	0.8205
Teff	-0.5539	0.6979	0.8377	0.7447	0.8205	**1.0000**

Table 7: Crop damage with different factors in SOUTH WOLLO ZONE , during 2006-2015

Years	Cause of crop disease and lost in Quntals in each year								
	Drought	Excessive RF	Pest	Crop disease	Hail storm	Flood	Frost	Weed	Land side
2006	221734	174072	61971	16765	55982	28447	925	16659	1507
2007	118182	49473	177955	13250	101427	17189	38907	36153	655
2008	588431	132016	96918	47066	62121	19492	38242	37795	493
2009	778811	322491	182358	68840	49706	27808	78742	27522	35
2010	433760	465503	123512	472634	221547	314142	69439	11480	54950
2011	59666	2426	195375	275737	60936	89340	17023	21206	1499
2012	691415	59223	368602	161766	399307	38575	77741	17457	1710
2013	151719	54800	89404	128573	328088	71368	0	7291	9755
2014	151218	28961	102428	111313	271573	100978	0	7762	6207
2015	4238104	0	64868	9174	133092	18507	2649677	8321	0

Source: South Wollo Zone Early Warning Office.

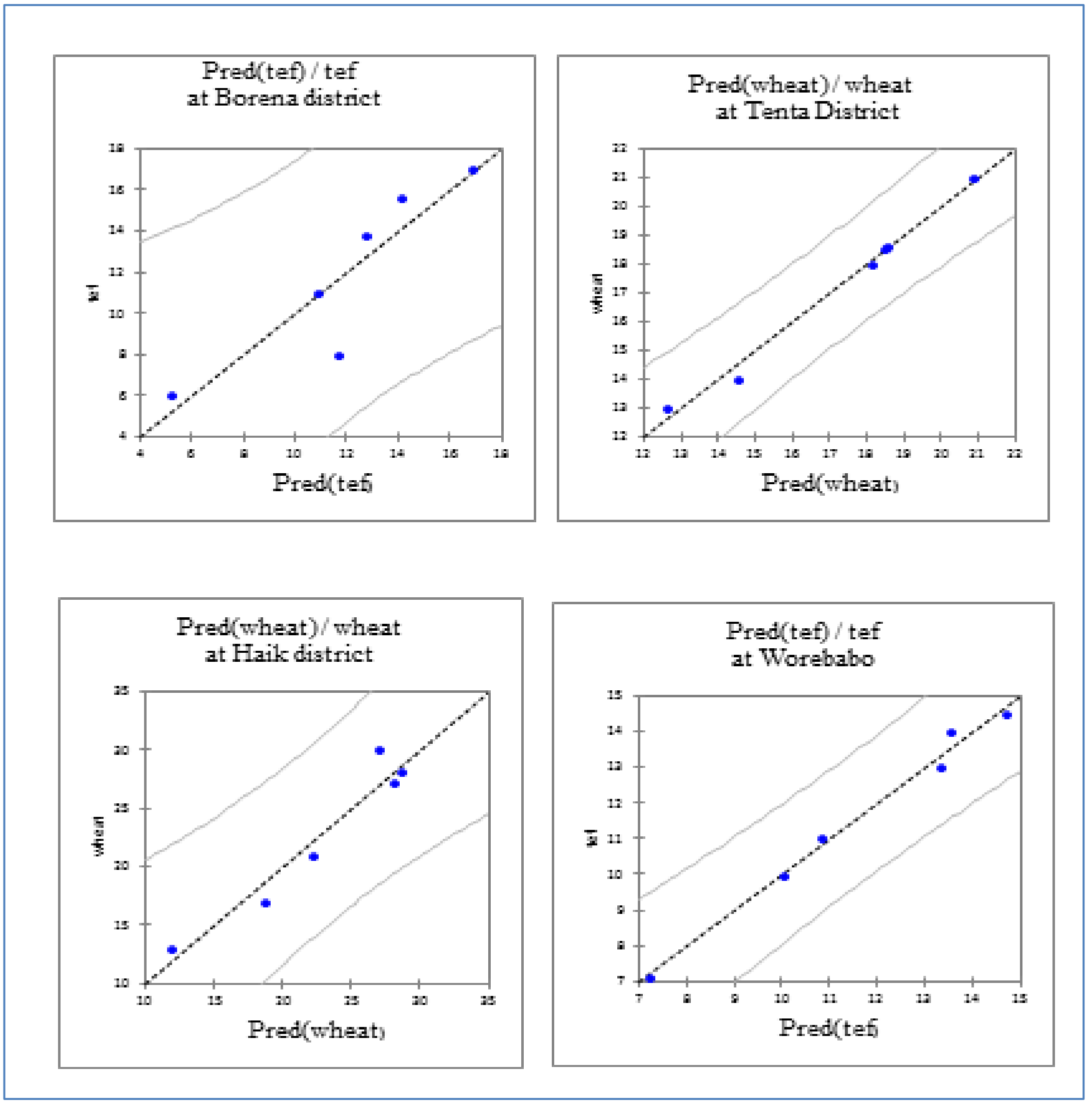


Figure 8: summary of prediction outputs of crops in different districts using ANOVA