ANALYSIS OF SPATIAL-TEMPORAL RAINFALL VARIABILITY AND ITS RELATIONSHIP WITH SEA SURFACE TEMPERATURE OVER WESTERN OROMIA.

BY

KEFIYALEW AYELE ALANDU

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE MASTERS IN APPLIED PHYSICS (METEOROLOGY)

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the project entitled "Analysis of spatial-temporal rainfall variability and its relationship with sea surface temperature over Western Oromia" in partial fulfillment of the requirement for the award of the degree of Masters Science in Applied physics (Meteorology) in an authentic record of my own work carried out from February, 2018 to September, 2018 under the supervision of Dr. Tadesse Terefe and Dr. Mesfin Asfaw, Department of Applied Physics, Adama science and Technology University, Ethiopia.

The matter embodied in this project has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this project have been duly acknowledged.

Kefiyalew Ayele Alandu ____________________ __________________

Student Signature Date

This is to certify that the above statement made by the candidate is correct to the best of my Knowledge and belief. This project has been submitted for examination with my approval.

Dr. Tadesse Terefe ______________ ______________

Advisor Signature Date

Dr. Mesfin Asfaw ______________ ______________

Co-Advisor Signature Date

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF APPLIED NATURAL SCIENCES

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Approved by Board of Examiners

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ANALYSIS OF SPATIAL-TEMPORAL RAINFALL VARIABILITY AND ITS RELATIONSHIP WITH SEA SURFACE TEMPERATURE OVER WESTERN OROMIA.

ABSTRACT

All rural livelihood systems in Ethiopia are highly sensitive to climate. Rainfall is the primary climatic factor that directly affects Agriculture, hydrological dynamics and driver of food insecurity and that shows variations across time and space. The main objective of this study was to analyses the spatial-temporal variability of rainfall and its correlation with SSTs by using statistical method for period from 1985 to 2016 over western Oromia of southwestern Ethiopia. Mean annual rainfall distribution increases toward the central portion of the area from the east and west over Western Oromia. Inter-annual rainfall and Kiremt season variability varies from low to moderate (CV%=11 to 24%) and unimodal type. The MK-trend test show an increasing trend change in annual and seasonal rainfall and onset of rainy season is moderate, more variable than cessation and late one to two week from previous studies. This may be a signal of climate change impact on the region. Belg season Precipitation anomalies with SSTs correlation showed statically significant positive relationship over north eastern tropical Pacific (Niño regions -160^{0}W ─ -100^{0}W), south western part of Atlantic and Indian Ocean. Parts of western Atlantic Ocean and north western Pacific Ocean also show negative correlation coefficients with rainfall anomaly during the belg season. Kiremt season anomalies to SSTs in the region show a positive relationship over south eastern tropical Pacific, central and south western part of Atlantic Ocean. Western parts of Equatorial Atlantic Ocean and central and north western Pacific Ocean (Niño regions-160^{0}W ─-100^{0}W) also show negative correlation coefficients with kiremt season rainfall anomalies over Western Oromia.

Key words: Ethiopia, SSTs, climate change, Climatic variability, Trend, season, Interpolation.

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ACRONYMS AND ABBREVIATIONS

CC	Climate change
CV	Coefficient of Variability
GDP	Gross domestic product
EALLJ	East African Low Level Jet
ENSO	ELI Niño southern Oscillation
FAO	Food and Agricultural Organization
GHGs	Green House Gases
IRI	International Research Institute
IPCC	Intergovernmental panel on climate change
ITCZ	Inter Tropical Convergence Zone
NMSA	National Meteorological Service Agency
NMA	National Meteorological Agency
NASA	National Aeronautics and space Administration
SSTs	Sea Surface Temperatures
SORS	Start of Rainy Season
TEJ	Tropical Easterly Jet
USAID	United States Agency for International Development
WMO	World Meteorological Organization

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CHAPTER ONE

1. INTRODUCTION

This section contains introduction background of study, explains about the motivation, rational and objectives of the study.

1.1 Background of study

Climate change is recognized as one of the most serious global environmental challenges of the 21 century. (Houghton, 2002; Agatsiva, 2010). A Global climate change is undeniably clear with impacts already affecting basic human support systems such as agricultural production, forests, water resources, ecosystem and biodiversity. The raising temperatures and variability of RF (amount and distribution), sea level rise, and the intensification of natural hazards, such as storms, floods, droughts and landslides are indicators of CC (IPCC, 2014; Birhanu, 2014). One of the most widespread and potentially devastating impacts of climate change in East Africa will be changes in the frequency, intensity, and unpredictability of precipitation and temperature (Taye, 2013). Rainfall is the primary climatic factor that directly affects Agriculture and hydrological dynamics and varies significantly in amount and distribution from different regions of Ethiopia. In fact, there is signal for increasing/ decreasing trend on rainfall, while significantly increasing of temperature. Recent detection of increasing trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (IPCC, 2014). And also due to high rainfall variability, early/late onset and cessation of rainfall is becoming common now.

In both developed and developing countries, climate impacts are reverberating through the economy. Though CC affects all countries globally, it will have a disproportionately harmful effect on developing countries, particularly in poor communities as they have inadequate resources to adapt (Houghton, 2002). In some countries, climate impacts affect the ecosystem services that communities are largely dependent upon, threatening development and economic stability. Rural livelihood systems of Ethiopia are highly sensitive to climate. As livelihood depends on rainfall, rainfall variability and the recurrent associated droughts, have been major causes of food insecurity and famine, due to its great reliance on climate-sensitive industries, particularly agriculture and affects the lives of millions of people (Tossou et al., 2017; Viste et al, 2012). 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. Therefore, Climate variability plays a great role in agricultural production having a direct impact upon operational practices from the start of land preparation to the final harvest. It also influences crop and livestock production, hydrologic balances, input supplies and other components of agricultural systems (IPCC, 2007; Tesso, 2012).

The impact of climate change and variability on human health has received increasing recognition (Degefu, 2017). Global warming and increased rainfall contribute to extreme events for instances Variable rainfall patterns and floods can contaminate freshwater supplies, heighten the risk of waterborne diseases such as diarrhea and the abundance and distribution of vectors like mosquitoes by providing breeding grounds (Degefu, 2017). Furthermore, it is altering the incidence, seasonal transmission, and geographic range of diseases.

Climate variability and change, therefore, has the potential to hold back economic progress, or reverse the gains made in Ethiopia's development and could exacerbate social and economic problems (USAID and Chemonics, 2015).Therefore, local specific knowledge of rainfall climatology, distribution pattern and as well as variability in various rainfall properties, including onset date, duration, end of the season, dry spell and rainfall amount is very important for crop planning and managing the extreme events like floods, droughts and severe storms. In spite of different studies were done in rainfall variability at national level (Abebe, 2006 ; NMSA, 1996; SELESHI, 2004; Wagesho et al, 2013), regional based detail spatial and temporal variability and SST associations over Western Oromia are still limited. In addition, an onset and cessation of seasonal rainfall vary in Ethiopia, considerably within few kilometers distance due to altitudinal variations, orientation of mountain chains and their physical influence on atmospheric flow (Legese, 2018). Therefore, it is essential to assess the temporal and spatial distribution pattern, trends and variability of rainfall and its correlation with SSTs within the period under study by using statistical method in the area. This is helps to improve decision-making in the sustainable management and planning of water resources and agriculture sectors being more and more related to watersheds climatic conditions by contributing to current knowledge on rainfall variability and distribution across western Oromia.

1.2 Statement of the problem

The diverse topography and various atmospheric systems affecting the Ethiopian climate, in turn, resulted in varying climatic conditions across the country. Rainfall distribution patterns are highly complex due to the varied topography of the country: the seasonality, duration, and regularity of rainfall vary by both latitude and longitude. The future of precipitation for the region in a changing climate is uncertain. Despite these uncertainties, it is clear that in the future, significant increases in climate variability and extreme events such as droughts and floods can be expected. Changes in rainfall patterns, including decreased reliability and less predictability.

The country is highly dependent on the rain-fed agricultural sector for income, foreign currency, and food security, a state which renders Ethiopia highly vulnerable to climate variability (as seen during past persistent drought), and thus to climate change. Impacts of climate change and variability lead to human suffering, particularly for the poor as witnessed, for example, during the prevalent droughts and floods in the Ethiopia. Rural livelihood systems of Ethiopia, crop cultivation, pastoralism and agro-pastoralism, are highly sensitive to climate. Food insecurity patterns are seasonal and linked to rainfall patterns, with hunger trends declining significantly after the rainy seasons. The increasing year-to-year climate variability and increases in both droughts and heavy precipitation events lower agricultural production with negative effects on food security (Conway, 2011). Analysis of changes in extreme climate events, therefore, is important due to the potentially high social, economic and ecological impact of such events and historical climate trends can provide useful insights into the current trajectory of various climate variables, particularly on shorter-term planning.

1.3 Significance of the study

The research paper will have both academic and applied expected outcomes for different sectors. It may has significance for the readers by providing with some basic information. It also helps responsible bodies on the area of education, agriculture and water resource management and to get information as an input for the economic growth and development of an individual and a country from socio-cultural, political, and economic perspective.

Although the study will be carried out for academic purpose, the findings shall contribute to the knowledge of local on climate and rainfall variability in the study area in particular and relevant to the water resources management and rainfall-related agricultural operations monitoring for land preparation, sowing, crop planting, weeding, fertilizer applications, harvesting and post-harvest handling activities.

Identify the various climate situations and characteristics of the area of study during that event and to highlight the general rainfall distribution (trends, variability, extremes(flooding and drought), etc.), the shifts between dry-humid seasons and to assess their space and time dimension; such information stand as the basic elements for a deeper reflexion on the phenomena that contribute Governmental bodies, policy-makers and other stakeholders such as investors and farmers in formulating viable policies and intervention programs for the strategic approaches in accordance with the given situation at a particular time and place to remedy the problem to the fight against climate change (Tossou et al., 2017). Farther more, the operational seasonal forecasts for Ethiopia are based on analogue methods relying mainly on sea surface temperature (SST) indices. A better understanding of the rainfall variability and physical links between Ethiopian rainfall and SST may help to improve forecasts and to achieve food security, reliable hydroelectric power in most parts of the country (Gleixner et al, 2016).

Therefore, The findings of this research will presents a detail account of the climate results for possible application to sectors like education and research, agriculture water resources, health, and other sectors are using and sensitive for weather and climate data.

1.4 Rationale of the study

All rural livelihood systems in Ethiopia are highly sensitive to climate. Agriculture and allied sectors is most susceptible and highly dependence on temperature and precipitation. Rainfall and its variability is the primary climatic factor that directly affects Agriculture, hydrological dynamics and driver of food insecurity. Ethiopia's agricultural sector makes up the largest share of the country's economy (close to 50% of GDP), 80% exports and occupies 80% of the labor force and it is almost entirely rain fed (NMA, 2015). In the western Oromia, agriculture is the main economic activities and is dominated by small-scale mixed farmers. The increasing year-to-year climate variability and increases in both droughts and heavy precipitation events lower agricultural production with negative effects on food security. Clear understanding of the key intra seasonal rainfall variations is crucial for planning and management purposes especially to farmers and water managers. Advance information of appearing wet/dry spells could be used to strategize on agricultural and water management policies as well as mitigating the adverse effects of recurring extreme climate.

1.5 Objective of the study

1.5.1 General objective of the study

The main objective of this work is to study spatial- temporal rainfall variability and its relationships with SSTs for the last 31 years from 1985 to 2016 over Western Oromia.

1.5.2 Specific objectives of the study

Therefore, the specific objectives of this research are to:

- To analyze the spatial distribution of annual and seasonal rainfall over Western Oromia.
- To determine the dates for rainfall onset, cessation, the length of the rainy season and dry spell and their variability over the Western Oromia Climate
- To quantify the trends of annual and seasonal rainfall
- To assess seasonal and annual variability as well as reliability.
- To determine relationship between seasonal rainfall anomalies and SSTs.

CHAPTER TWO

2. LITERATURE REVIEW

This section reviews the key findings, theoretical and methodological contributions by past studies on climate (rainfall) variability in Ethiopia. It comprise of an overview on physics of climate Chang and variability and its methodological analyses, and the impacts of sea surface temperature (SST) on seasonal rainfall are also presented.

2.1 Climate and Rainfall Variability of Ethiopia

2.1.1 Climate of Ethiopia

Ethiopia has one of the extremely variable and most complex climates in East Africa. Because of this complexity, climatology may differ from those observed at larger spatial scales. (IRI, 2016; Degefu, 2017). This complex spatiotemporal variability of climate over Ethiopia is influenced by different local, regional and global rain-bearing systems and factors. Altitude greatly influences the climate of Ethiopia, with the creation of microclimates ranging from cool highlands to hot desert climate (SELESHI, 2004). The major drivers of the climate system over Ethiopia include the dynamics of the ITCZ, subtropical high pressure systems (St. Helena, Masccharin, Azores, Sahara and Arabian high), tropical cyclones (Indian and Pacific oceans) and tropical pacific ocean SST (MISGANAW, 2014). Over most of Ethiopia are causing most of the inter-annual variability in rainfall over Ethiopia and are known to be linked to El Niño occurrence. The principal cause of drought in Ethiopia is asserted to be the fluctuation of the global atmospheric circulation, which is triggered by SSTa, occurring according to ENSO events. El Nino episodes tend to suppress the Kiremt (June-September) rainfall and enhance Belg (February-May) rainfall. To the contrary, La Nina conditions over the eastern tropical Pacific Ocean tend to enhance Kiremt rainfall and depress Belg rainfall. (Ogallo, 1988; Korecha, 2007; NMSA, 1996; Gissila, 2004). The inter-seasonal East African Low Level Jet (EALLJ) or Somali Jet, Tropical Easterly Jet (TEJ) and inter-annual variation of the strength of the monsoon over the Arabian Peninsula are affects climate of Ethiopia. (Degefu, 2017; SELESHI, 2004; Korecha, 2007).

2.1.2 Rainfall and its variability in Ethiopia

Rainfall is the most important climate element that shows variations. The mean annual rainfall ranges from 2700 mm or more in the southwest highlands, steadily reducing in the north to less than 200mm, northeast to less than 100 mm and south east to less than 200 mm. The seasonality

of rainfall varies in different areas of Ethiopia. Ethiopia receives most of its rain between March and September. Rainfall variability has always been a major climatic challenge to Ethiopia. Segele and Lamb (2005) note that the characteristics of the main rainy season (Kiremt) rainfall are the most important determinants for agricultural activity from the perspective of its amount and geographical coverage. Kiremt rainfall is less variable in most parts of the country compared to the short rainy season (Belg) which is highly variable (Shanko, 1998; Bewket, 2007) On the other hand, the frequent droughts in the past 50 years were caused by shortages of rainfall. The seasons over Ethiopia are classified as 'Belg' (February – May), 'Kiremt' (June –September) and 'Bega' (October to January of the subsequent year) as they are locally referred. (Birhanu, 2014; Seleshi, 2004; Korecha, 2007). Recent climate trends show that rainfall is decreasing in the south-central, southeastern, and northern parts of the country, while the western parts of the country have been receiving more rainfall potentially increasing the magnitude of droughts and floods.
According to the NMA, both seasonal and annual rainfall has exhibited high variability throughout country. The western half of the country, with one dry and one wet season in a year, receives the highest amount of rainfall in Kiremt season. Description of homogeneous regimes for southwestern Ethiopia regime rain usually falls from March and continue without prolonged dry spells up to October/mid-November. Ethiopian teff-farmers depend on the short duration(the belg season) and relatively invariable amount rainfall. And Belg season rain especially contribute to land preparation, planting/sowing of long-cycle (6 months) crops (e.g., maize, sorghum), and to contribute for extension of long rainy season (Pedreros, 2017; Abebe, 2006). Even though it didn't studied monthly and seasonal variability, the study by Seleshi and Zanke 2004 identified significant recent declines in the annual and kiremt rainfalls in south western Ethiopia and rainfall and rainy days in Ethiopia showed southwestern included only two stations (Gore and Jimma, the wettest part of Ethiopia), however, have relatively low variability (CV=0.2) and also the variability pattern of rainy days closely matches the variability pattern of rainfall totals (Seleshi, 2004).

It has been determined that Ethiopia has nine homogeneous rainfall regimes with distinct times of peak rainfall and duration of rainy seasons. Moreover, the variability of monthly rainfall, for instance in the dominant rainy season (JJAS) over western Ethiopia (categorized as subregions R-

1, R-8, and R-9) accounts for; 65%–85% of the total rainfall variability over these regions and reaches its peak in July. The remaining variability of the monthly rainfall is due to rainfalls in the other months as these regions get rainfall throughout nearly the whole year (Tsidu, 2012). The studies have identified that South west regime of Ethiopia receives up to 30% of their annual rainfall totals from Belg rainfall. The sources for Belg rainfall is partly from Congo forest basin and partly from the Indian Ocean (Abebe, 2006). Belg rains usually fall from March and continue without prolonged dry spells up to October/mid-November. Belg rains especially contribute to land preparation, planting/sowing of long-cycle (6 months) crops (e.g., maize, sorghum), and to contribute for extension of long rainy season that usually spans from March to November. Information about the start of the rains is important for appropriate agricultural decision making so that reduction in yield of the crops is avoided by taking appropriate action. Haile, 1988 and Abebe, 2006 did a comprehensive work on the onset and cessation of the kiremt and Belg season respectively for Ethiopia by making use of the statistical packages. But on local scale, including analysis of rainy days, were also not done. The goals of this study are to determine the onset and cessation of the rainy season.

In Ethiopia rainfall projections are uncertain, although most models suggest a gradual increase in rainfall over the coming decades, at least in the south of the country. What is clearer is that Ethiopia will experience a more unpredictable and variable climate, exacerbating a number of existing risks: Floods have also caused major economic and social disruption over recent decades, displacing people and damaging infrastructure, increase the risk of contamination of water sources and cause land degradation that can indirectly threaten water resources (Conway D., 2011). Droughts, or periodic decreases in runoff and recharge, can reduce water availability, precipitate mechanical breakdowns and lead to system and/or source failure. It has affected most parts of Ethiopia with strong impacts on livelihood and economic development of the country for a long period and appear to be increasingly frequent and heavy rainfall events appear to be increasingly frequent, with changes in rainfall patterns, including decreased reliability and less predictability. In Ethiopia, among major droughts that have occurred the recent drought years of 1983–84, 1987–88, 1997 and most recently 2015-16 resulted in low agricultural production and affected millions of rural poor farmers, pastoralists, domestic and wild animals, with serious degradation of the environment (USAID and Chemonics, 2015; Terefe, 2013). Inter-annual and seasonal rainfall variability is high and droughts are frequent in many parts of the country (Bank, 2010). GDP in Ethiopia rises or falls about a year behind changes in average rainfall. With agriculture accounting for half of GDP and 80% of jobs, the Ethiopian economy is sensitive to climate variability, particularly variations in rainfall (Taye M., 2013). These risks are already apparent, with a growing body of evidence indicating that existing climate variability rather than longer term change.

The annual rainfall distribution over Ethiopia is higher in the western half of the country compared to the eastern half of the country. The eastern and southeastern low lands of the country receive small amount of rainfall throughout the year (MISGANAW, 2014).

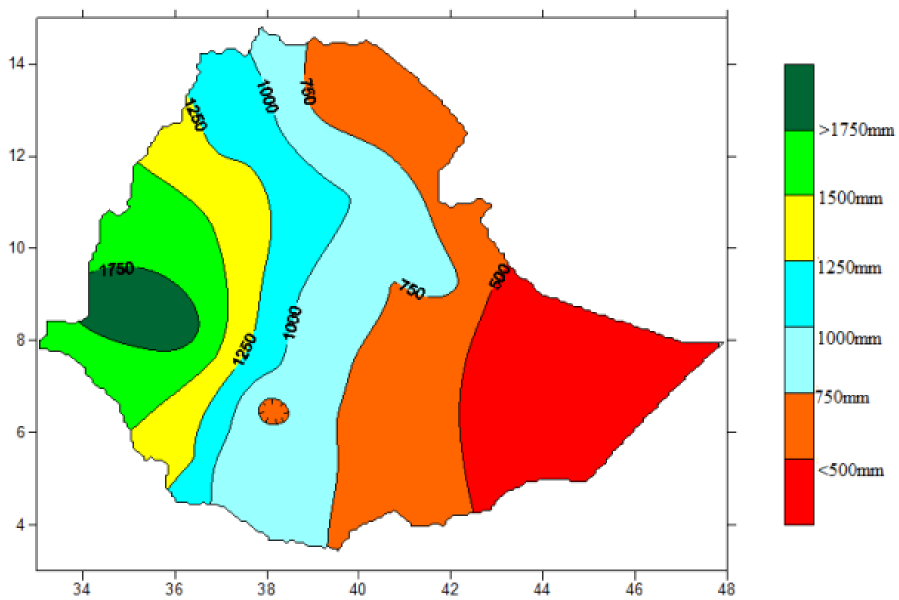


Figure 1. Annual rainfall distribution over Ethiopia (1980-2013 mean). (MISGANAW, 2014)

2.2 Effects of Climate variability and change on rainfall of Ethiopia.

Climate change (CC) manifest in the form of changes in precipitation (IPCC, 2007) Patterns (Changes to timing and amount of seasonal rains, Rainfall patterns increasingly more erratic, with decreased reliability and failure of Belg rains):

- ✓ Drought frequency and intensity (low amounts of seasonal rains rainfall, delay of onset and early set-off of rainfall, Increasingly erratic rainfall, and shortened rainy seasons)
- ✓ Heavy rainfall (frequent, flash floods and unseasonal rains)

Summary of regional trends in rainfall showed that a mixed but tentative signal of increased rainfall (west Oromia) during the March-May seasonal rainfall, but a stronger message of increased rainfall and intensity during the October-December seasonal rainfall (USAID and Chemonics, 2015).

2.2 Variability of Onset, Cessation of the Season and Length of Growing Period

The time of agricultural activities, from land preparation, through crop selection and planting, to the time of harvesting for a developing countries, is rainfall dependent. In Ethiopia, onset and cessation of seasonal rainfall vary considerably within a few kilometers distance due to altitudinal variations as well as orientation of mountain chains and their physical influence on atmospheric flow. In the 50th assessment report of the IPCC, an intensification in the frequency of extreme rainfall events during the present century due to climate variability and change has been predicted (IPCC, 2014). These changes in climatic patterns will have a direct impact on the onset, duration and cessation of rainfall which affect productivities. The assessment and prediction of the onset and cessation dates of the rainy season is therefore crucial to the success of agricultural activities. In addition, rainy season onset and cessation dates affect the transmission of vector-borne diseases, as the life cycle of the disease transmission vectors is sensitive to the variability rainfall.

Different methods have been employed to determine the onset and cessation of rainy season in different parts of Ethiopia. Onset of the rain season(ORS) is defined the time when the first wet-spell of the year occurs when the rain accumulated in the three consecutive days is at least 20 mm and no dry spell of more than eight or more days in the next 30-days periods (NMA, 2015). Segele and Lamb (2005) defined Cessation of rainy season as the first day of a dry-spell (<0.1mm per day) of at least 20 days duration that occurred after onset. This study incorporate the Food and Agricultural Organization (FAO) threshold of at least 25 mm of rainfall (FAO., 1977) in five consecutive days and 0.25 mm threshold for a rainy day. This criteria reduces the chance of a false start of rain characterized by early rainfall followed by long dry spells. The length of growing period (LGP) is the difference between the start date and end date of growing season.

2.3 Probability of dry spell occurrence

Dry spell occurrence is a result of meteorological conditions, i.e., rainfall or no rainfall, uneven distribution incurs periods of dry spells within rainfall season so-called Meteorological droughts or agricultural dry spell occurrence, which is linked to crop, soil and rainfall conditions at a site. Estimation of the probability of dry spell length becomes critical in rain-fed agriculture for agriculture planning and in rainfall water resource management (LUPI, 2015). In humid countries the success or failure of the crops, particularly under rainy conditions is highly related with the distribution of dry spells. Moreover, in the southwest of Ethiopia, rainfall persists relatively less erratic on annual scale, but what a limiting factor is the unexpected occurrence of the dry spell during some of the most important crop development stages and high intensity of rainfall in the middle of the season causing runoff and subsequently damaging the crops in the field. According to NMSA (2001), a day is said to be dry if it accumulate rainfall <1 mm and dry spell length is the maximum number of consecutive dry days with rainfall less than 1 mm per day exceeding 5, 7, 10, and 15. In this study, Markov chains model, has been used to investigate the wet and dry weather patterns observed

2.4 SST relationship to rainfall variability and droughts

Annual rainfall seasonal patterns in Ethiopia (and more generally in the Greater Horn of Africa) and historical droughts in Ethiopia had been linked with regional and global sea surface temperatures (SSTs) ENSO events in the past (Souverijns., 2016; Yirgaw, 2011). The global SST like tropical Pacific SST enhance or depresses the Kiremt and Belg rains over Ethiopia. And also Haile (1988, 85) 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. Furthermore other climatic events like the occurrence of El Niño and La Niña affects the climate since the rainfall in Ethiopia is related to the El Niño–Southern Oscillation index. During El Niño below average precipitation in the Kiremt period is received (Seleshi, 2004). In contrast, during La Niña the mean monthly Kiremt rainfalls seem to be increased (Korecha and Barnston, 2007). ENSO events and SST anomalies affect rainfall distribution in Ethiopia by displacing and weakening the rain-producing air masses (Haile, 1988). Numerous studies have revealed the relationship between ENSO and Ethiopian rainfall in all seasons. Degefu 1987, 2017 showed statistically significant negative correlations with Nino3.4 and the IOD with JAS is the main rainfall season over central and western Ethiopia (CW-Ethiopia). The SST correlations with MAM and ON rainfalls are not significant. The studies showed strong coupling between the short rainy season in the neighboring East African countries, and both the ENSO and the east – west circulation over the Indian Ocean (Ogallo, 1988). However, other studies have contradicted similar findings. Studies imply that the SSTs-to-rainfall correlation in Ethiopia are both temporally and spatially complex and not yet well understood. So understanding their association is potentially important for prediction purposes (Degefu, 1987). The El Niño and La Niña (ENSO) events are the main causes and also only one of several complex climatological factors which influence rainfall patterns in the country. Therefore, the study of the local impacts of the relationship between ENSO and rainfall variability has importance in many different aspects over western Oromia of southwest Ethiopia. There are no climatological studies that have approached SST induced precipitation influences over Western Oromia up to now. Therefore, these study fill gaps by investigating potential SST (ENSO) driven precipitation anomalies of the local impacts of the relationship in spatial and seasonal aspects over western Oromia from 1985 to 2016.

CHAPTER THREE

3. DATA AND METHODOLOGY

This chapter describes about the study area, the datasets and methodologies applied to achieve the objectives of the study. It provides the details of the data source, describes the several climate indices and also overview of different techniques used to investigate variability and the correlation between the SSTs and precipitation over study area.

3.1 Description of the study Area

The study was focused on the five Zones of western Oromia (Jimma, Illubabor, Bedele, East and West Wolega), in the Southwestern part of Ethiopia. It is located between 7.2 ^{o} to 10.5^{o} North latitudes and 38.2^{o} to 34.2^{o} East longitudes (Figure1). The study area is characterized by a tropical high land climate with heavy rain fall, warm temperature and long wet period. It is the parts of the country experience a unimodal rainfall pattern and annual mean rainfall exceeds 1500mm.

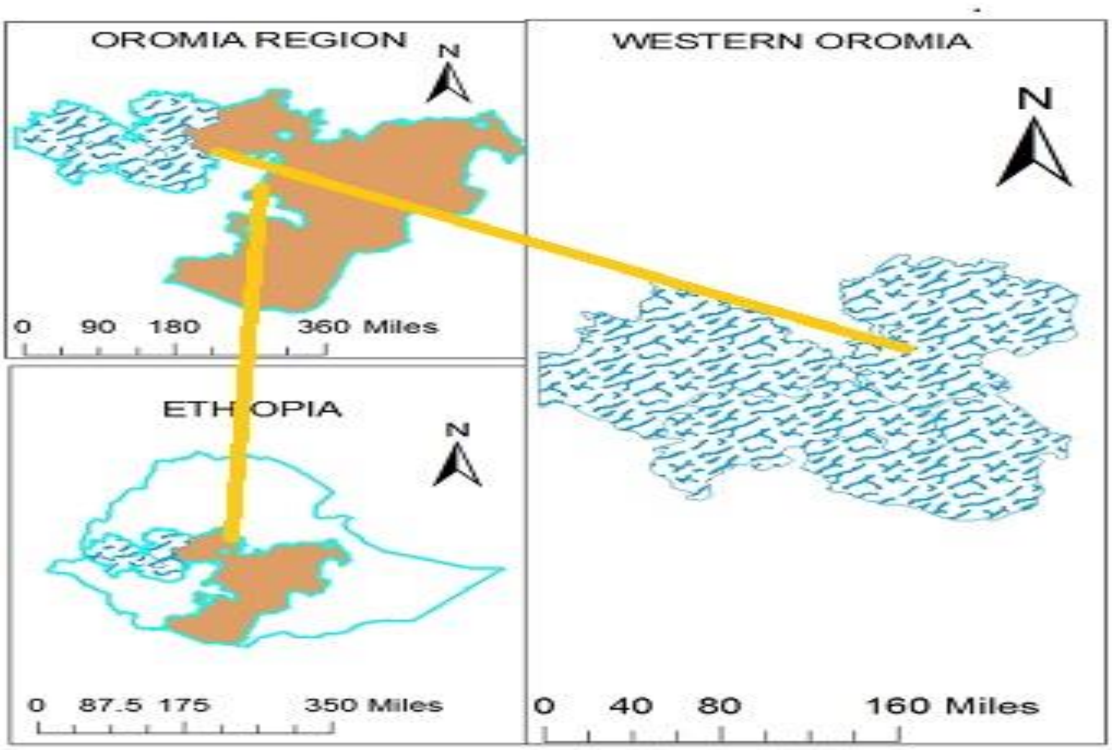


Figure 2. The location of study area

Western Oromia as a part of the southwestern Ethiopia, It doesn’t follow the three-season patternsof the country, because there it rains from February to November. The ecology of the study area is dominated by forest and fruits while the farming system is mixed farming system i.e., an agrarian system which comprises farming along with the raising of livestock simultaneously. Agriculture is the main economic activities and is dominated by small-scale farmers. Coffee plays a major role in income generation in the areas. Teff (short cycle or Belg crop), Maize and sorghum (their growing season extends throughout the main rainy season, called Meher Crops) are the major crops. Pulses crops, such as, beans and pea are also grown to a lesser extent (Abebe, 2006 ; Teshome, 2015).

3.2. Data

The daily gauge rainfall data measured at surface based observing of 13 stations were obtained by from National Meteorological Agency (NMA) of Ethiopia. The list of rainfall stations zones of Western Oromia (WO) are given in Table 1.

Table 1 Description of the study meteorological stations

Zone	S N$_{\underline{o}}$	Station	Latitude	Longitude	Elevation (m.a.s.l)	Rainfall database Available
East wollega	1	Arjo	8.75	36.50	2565	1989-2016
	2	Shambu	9.57	37.12	2460	1987-2016
	3	Nekemte	9.08	36.46	2080	1985-2016
West wollega	4	Ayira	9.10	35.55	1555	1988-2016
	5	Gimbi	9.17	35.78	1970	1985-2016
	6	Dembidolo	8.52	34.80	1850	1987-2016
Illubabor	7	Bedele	8.45	36.33	2011	1985-2016
	8	Gore	8.13	35.53	2033	1985-2016
Jimma	9	Chira	7.73	36.23	2095	1985-2016
	10	Jimma	7.67	36.82	1718	1985-2016
	11	Limu Genet	8.07	36.95	1766	1985-2016
	12	Sekoru	7.92	37.42	1928	1985-2016
	13	Gatira	7.98	36.2	2358	1985-2016

Data were captured into Microsoft Excel 2013 following the days of year entry format and stack using Instat Statistical software Version 3.37. The quality was controlled missing data is filled using arithmetic mean method. The Hadley Centre SST dataset of the Met Office Hadley Centre for climate prediction are used to obtained SST (Rayner, et al., 2003) from: https://www.metoffice.gov.uk/hadobs/hadisst/

3.3 Analysis of data

There are different statistical techniques and indices that used to assess trend, onset, duration, ends of rainy season, dry spell and variability of rainfall and its relationships with SSTs both in time and space. Annual and seasonal variability of rainfall of stations in the study area were analyzed using coefficient of variations (equation 10 & 3 respectively) and normalized anomaly. The trends of annual and seasonal rainfall were analyzed by Mann Kendall trend test was used to detect the significance of the trends. The Mann Kendall trend test were calculated by trend software XLSTAT2014. Statistical computations and interpolation were performed with INSTAT Vs3.37 statistical software and ArcGIS 10.3.1 respectively.

3 .4 Methods of Assessing Rainfall Variability.

3.4.1 Method of determination of Onset and Cessation Rainy Season

Onset and cessation of rainfall date is analyzed using an Instat version 3.37 package. The onset date of the rainy season for individual years is therefore determined using the following criteria: the one with 20mm of total rainfall received over three consecutive days that were not followed by greater than ten days of dry spell length within 30 days from planting was adopted (Raman, 1974) as a rainy season. To define the date of cessation of the rainy season satisfies the following conditions; based on water balance the end of growing season occurs any day after the first of September when the water stored in the soil has been used, rather than when the rainfall stops. In addition, a fixed average 5 mm of evapo-transpiration per day, and 100 mm/meter of the maximum soil water holding capacity of the area were considered. The LGP was determined by subtracting onset date from end date. (Legese, 2018).

3.4.2 Analysis of spatiotemporal rainfall variability

The monthly rainfall series of all the stations used to calculate an areal average rainfall for the region as follows (Nicholson, 1985);

$$R_j = I_j^{-1} \sum_{k=1}^{j} X_{ij} ----------------------- (1)$$

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

Geostatistical interpolation techniques are valuable tools for spatial interpolation of the attributes considered and provide important dataset relationship information to agricultural sector and risk management. Spatial interpolation can be used to estimate precipitation variables at other locations. The spatial interpolation of mean annual and seasonal rainfall were studied using geo-statistical method; Inverse Distance Weighting to characterize rainfall spatial distribution in the study area, The inverse distance weighting (IDW) method estimates the values of an attribute at unsampled points using a linear combination of values at sampled points weighted by an inverse function of the distance from the point of interest to the sampled points using ArcGIS 10.3.1. It can be expressed as:

$$\lambda_i = \frac{(1/d_i^p)}{\left(\sum_{j=1}^{n} 1/d_i^p\right)} --- (2)$$

Where di is the distance between x_0 and x_i, p is a power parameter, and n represents the number of sampled points used for the estimation. The main factor affecting the accuracy of IDW is the value of the power parameter. Weights diminish as the distance increases; especially when the value of the power parameter increases, so nearby samples have a heavier weight and have more influence on the estimation and the resultant spatial interpolation is local.

Coefficient of Variability (CV)

Coefficient of variation (CV) is calculated to evaluate the inter-annual variability of monthly, seasonal and annual rainfall, by dividing the standard deviation of the event to its mean.

$$CV = \left(\frac{\sigma}{\mu}\right) x100\% ------------------------ (3)$$

Where μ: the average rainfall; $\sigma = \sqrt{((1/n-1) \sum (X_i-\mu)^2)}$: the standard deviation, and X_i: rainfall of the year i. CV<20% indicate low variability, CV between 20% and 30% indicate moderate rainfall variability, CV>30% indicate high, CV>40% very high and CV>70% indicate extremely high inter-annual variability of rainfall. The reliability of annual and seasonal stations rainfall records were examined using method of coefficient of variation. High coefficient of variability means that low reliability of rainfall and vice versa is true. Reliability (R) is given by the formula;

$$\mathrm{R} = 100 - \mathrm{CV} - (4)$$

3.4.3 Methods trend detection

In this particular study, Mann-Kendall’s test was employed to detect trends and other changes in hydrologic and climatic variable. It is commonly used and suitable to identify trends in hydrological data as it is not affected by the distribution, outliers and missing values of time series data. (Legese, 2018) In this study, two non-parametric methods (Mann-Kendall and Sen's slope estimator) were used to detect the meteorological variables' trends using XLSTAT software. The Man-Kendall’s test statistics is given as:

$$\mathrm{S} = \sum_{\mathrm{i}-1}^{\mathrm{n}-1} \sum_{\mathrm{j}=\mathrm{i}+1}^{\mathrm{n}} \mathrm{sgn}(\mathrm{xj} - \mathrm{xi}) - - - - - - - - - - - - - - - - - - (5)$$

,where, S is the Mann-Kendall’s test statistics; xi and xj are the sequential rainfall values in the year i and j (j>i), and n is the length of the time series. The Sgn (xj −xi) is an indicator function that results in the values−1, 0, or 1, where j>i and it is calculated as:

$$\mathrm{sgn}(\mathrm{xj} - \mathrm{xi} = \begin{Bmatrix} +1 & \text{if} & \mathrm{xj} - \mathrm{xi} > 0, \\ 0 & \text{if} & \mathrm{xj} - \mathrm{xi} = 0, \\ -1 & \text{if} & \mathrm{xj} - \mathrm{xi} < 0. \end{Bmatrix} - - - - - - - - - - - - - - - - - - (6)$$

The variance (Var(s)) of S-statistics, for the situation where there may be ties (same values) in the x values, is given by:

$$\mathrm{Var}(\mathrm{S}) = \frac{1}{18}\left[\mathrm{n}(\mathrm{n}-1)(2\mathrm{n}+5) - \sum_{\mathrm{i}=1}^{\mathrm{m}} \mathrm{ti}(\mathrm{ti}-1)(2\mathrm{ti}+5\right) - - - - - - - - (7)$$

Where m is the number of tied groups in the data set and it is the number of data points in the ith tied group. For the sample size n≥10, the standard test statistic Zis calculated as follows:

$$Zmk = \begin{cases} \frac{s-1}{\sqrt{Var(s)}} \text{ if } s > 0 \\ 0 \text{ if } s = 0 \\ \frac{s+1}{\sqrt{var(s)}} \text{ if } s < 0 \end{cases} -------------------- (8)$$

Z_{mk} approximates standard normal distribution and it is used to evaluate whether the trend is statistically significant or not. Positive values of Z_{MK} indicate increasing trends, while negative Z_{MK} values reflect decreasing trends. The presence of a statistically significant trend is evaluated using the Z_{MK} value. $Z_{1-\alpha/2}$ is the critical value of Z_{MK} from the standard normal table. For 5% and 10% significance level, the value of $Z1\text{-}\alpha/2$ is 1.96 and 1.64 respectively (0.05 in this study). The Sen's estimator of slope: The test is applied where the trend is assumed to be linear. It is not affected by missing data, insensitivity to extreme values and better performance even for normally distributed data. Then, the slope (change per unit time) was calculated as:

$$Q = \frac{Xj - Xi}{i - j}, i \neq j -------------------(9)$$

Where, X_i and X_j are data values at times i and j (j>i), respectively. The median of these n values of Q is Sen's estimator of slop. Based on the above procedure, trends of current and future climate element (rainfall) were determined (Wagesho, 2013).

Standardized anomaly index (SAI)

Standardized anomaly index (SAI) which is also called precipitation index widely used in studies on precipitation variations and has a number of important statistical properties. SAI is defined as the average of the normalized station time series of seasonal average over the M stations. (Mathbout, 2015) It is constructed from the station average of the standardized rainfall anomalies, a powerful, flexible index and precipitation is the only required input parameter that is simple to calculate. Positive SAI values indicate greater than mean precipitation, and negative values indicate less than mean precipitation. Drought starts when the SAI value is equal or below -1.0 and ends when the value becomes positive (WMO, 2012). SAI can be calculated at various time scales on which precipitation deficits/surpluses can affect different aspects of the hydrologic cycle, which is the main advantage of the SAI can reflect the effects of drought on water resources components (groundwater, reservoir storage, soil moisture, stream flow) to precipitation anomalies. It also used to assess frequency and severity of droughts (Mckee et al, 1993). It is constructed from the station average of the standard rainfall anomalies

$$\mathrm{SAIi} = \frac{1}{\mathrm{M}}\sum_{\mathrm{j}=1}^{\mathrm{M}}\frac{\mathrm{Pt}-\mathrm{Pm}}{\sigma} ---------------------- (10)$$

Where, SAI= standardized Anomaly Index, i…n =denote the year, j---M= the station, Pt= annual rainfall in year t, Pm= long-term mean annual rainfall over a given period of observation and σ= standard deviation of rainfall over the period of observation

In order to capture current and future climate variability we use the following classification of history and simulated meteorology years are grouped into 5 categories using the standard annual rainfall index against years. The year were grouped using the SAI as follows. The classes are (SAI >2) extremely wet, (1.5 to 1.99) Very wet, (1.0 to 1.49) moderately wet 0.99 to -0.99 near normal (-1 to -1.49) moderately dry, (-1.5 to-1.99) severely dry and (<-2) extremely dry. (According to Mckee et al., 1993, applied by Manacelli, 2005).

3.4.5 Rainfall and SST Correlation

The four study sites located in each zones Western Oromia were used to assess SST and rainfall relationships in this study. Then the monthly rainfall data anomalies and the SSTs were used for identifying relationships. The correlation method using in the study was Pearson's correlation coefficient (r) which was calculated by equation:

$$\mathrm{r} = \frac{\sum_{\mathrm{i}=1}^{\mathrm{n}}(\mathrm{x_i}-\mathrm{x_\mu})(\mathrm{y_i}-\mathrm{y_\mu})}{\sqrt{\sum_{\mathrm{i}=1}^{\mathrm{n}}(\mathrm{x_i}-\mathrm{x_\mu})^2(\mathrm{y_i}-\mathrm{y_\mu})^2}} -------------- (11)$$

Where r was Pearson's correlation coefficient; x_i and y_i were the values of SSTs and rainfall respectively at the time i; (x_μ) and (y_μ) was the average of the SSTs and rainfall; and n was the total number of year. The t-test was used to test for the statistical significant of the correlation coefficients calculated as the equation:

$\mathrm{t} = \frac{\mathrm{r}\sqrt{\mathrm{n}-2}}{\sqrt{1-\mathrm{r}^2}}$ .The $t_{(n-1),\ 0.5}$ was considered for determination significant of r values by comparison with the critical value at $t_{(n-1),\ 0.5}$.

3.5 Summary of data and methodological flow of the study

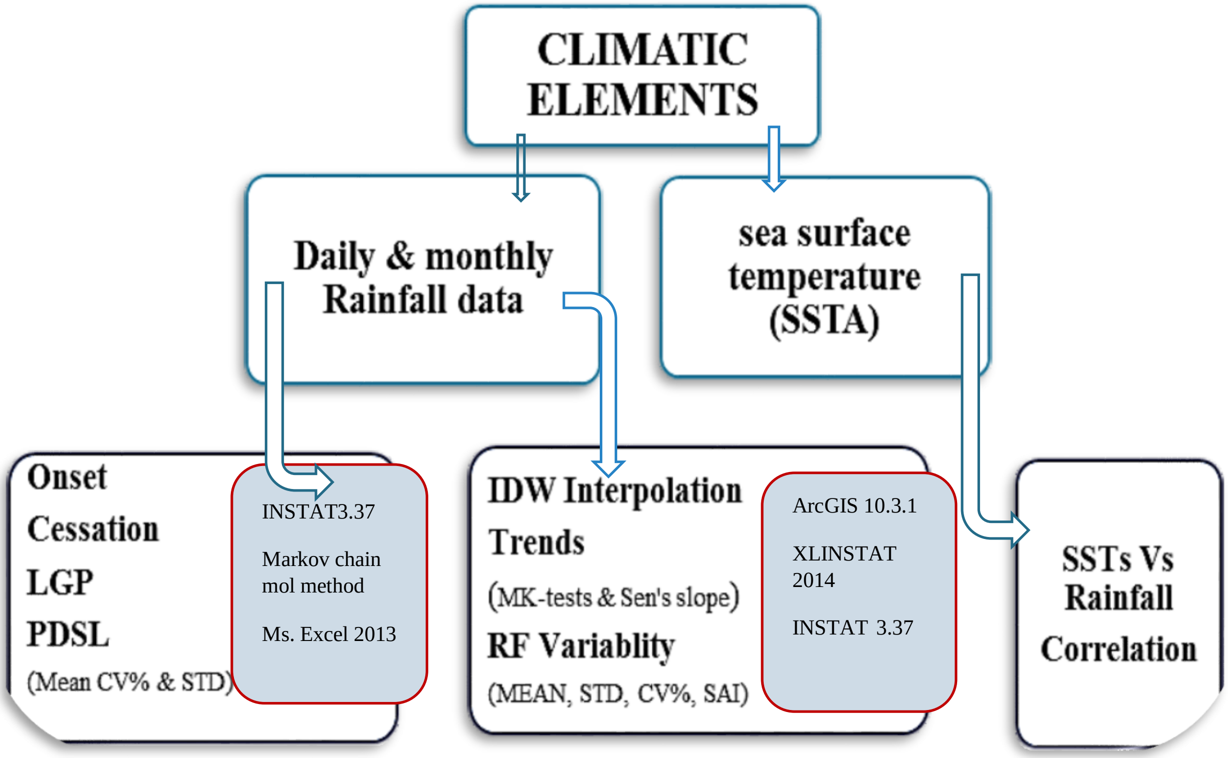


Figure 3 Outline of the methodology.

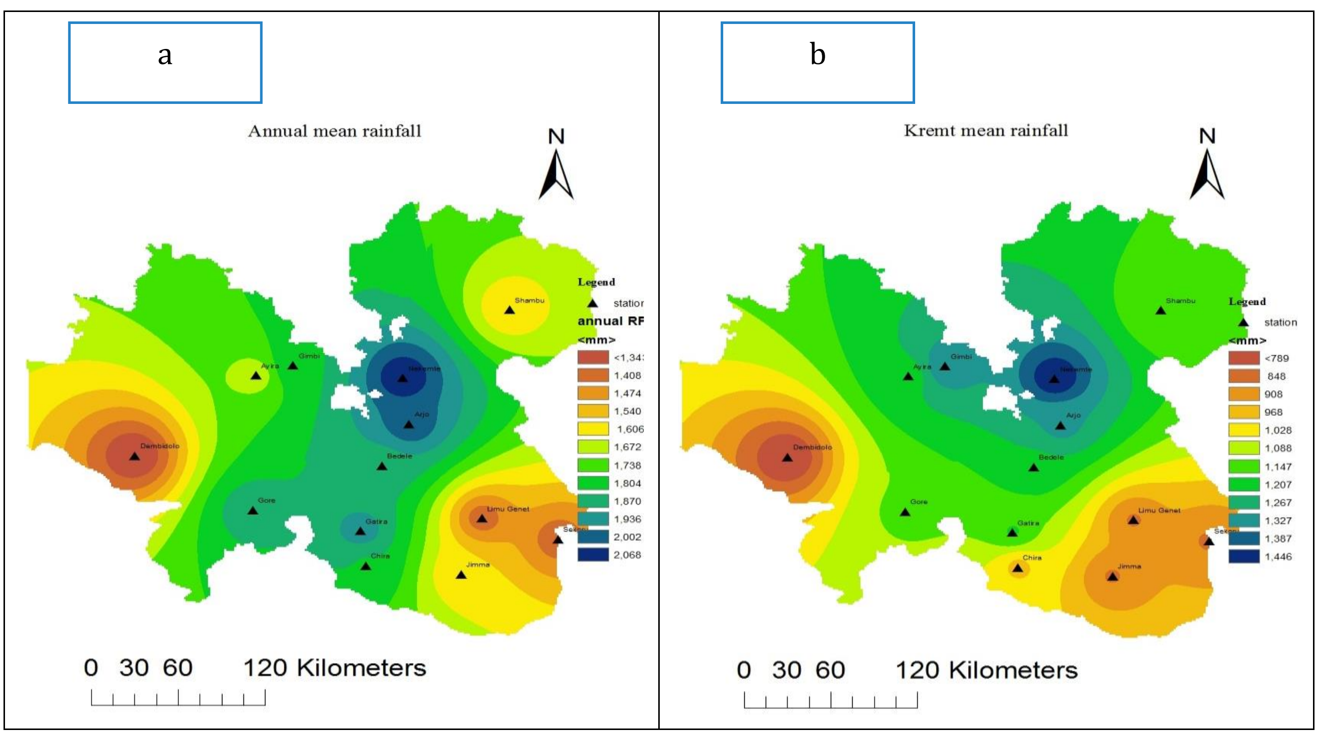
CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Annual, Monthly and Seasonal rainfall climatology

4.1.1 The spatial distribution of annual and seasonal rainfall climatology

The temporal and spatial distribution of rainfall over the study region was investigated. Mean annual rainfall distribution over Western Oromia increases toward the central portion of the area from the east and west because of the local topography and monsoon climate. The annual rainfall climatology is characterized by large spatial variations which range from less than 1277mm/year over West Wollega to 2070mm/year over East Wollega zone and 1723 mm/year areal average. Seasonally, 291.8 to 532.9 mm, 729.3 to 1325.6 mm and 144.2 to 317.7 mm contribution come from Belg, kiremit and bega respectively (Table 4). During the Kiremt season (JJAS), the central parts of the study area received high rainfall up to 78% (around Nekemt) of the annual rainfall and its distributions decreases to 53% over the southward parts both from the east and west (Illubabor & jimma zones. The rainfall distribution of Kiremt season is almost similar like that of the annual distribution. Inversely, Belg (FMAM) & Bega (ONDJ) seasonal rainfall appeared to be high over southward from east and west (Illubabor & jimma zones) upto 30% and 17% of the annual rainfall respectively. Figures 2 clearly displays the pattern of mean precipitation of study area



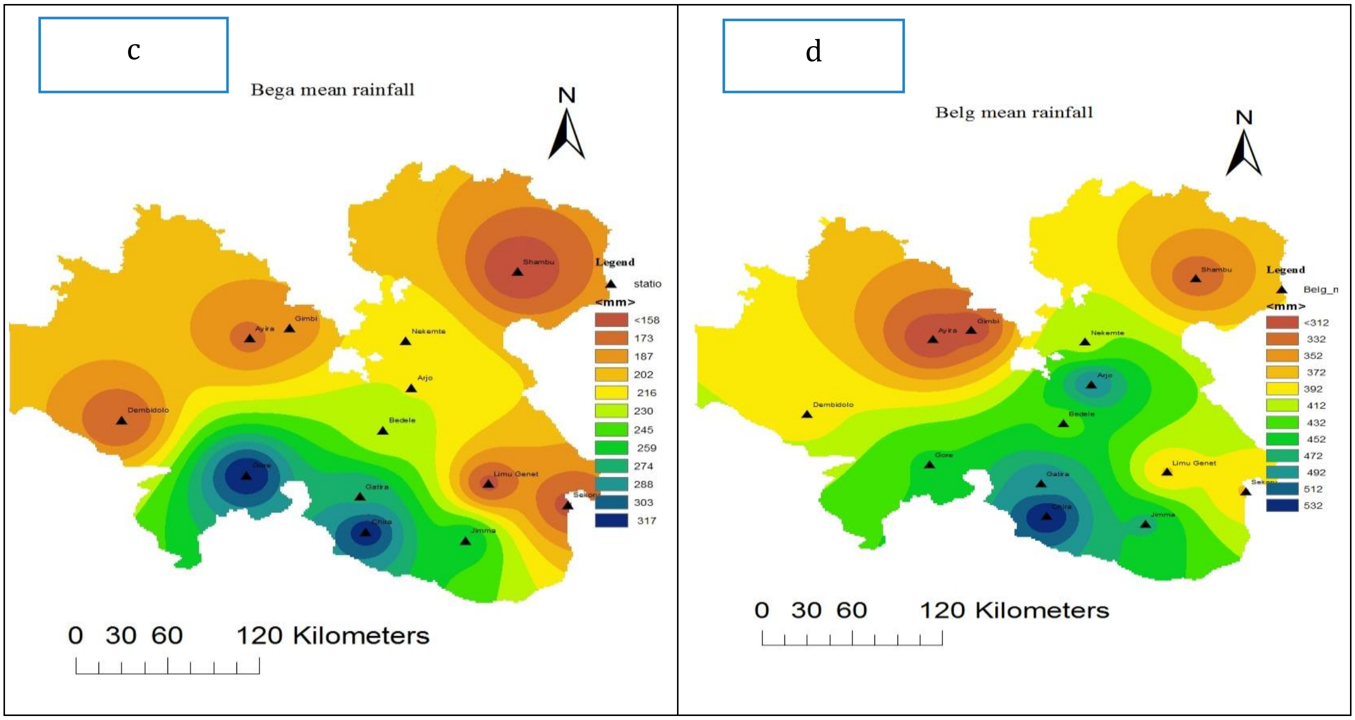
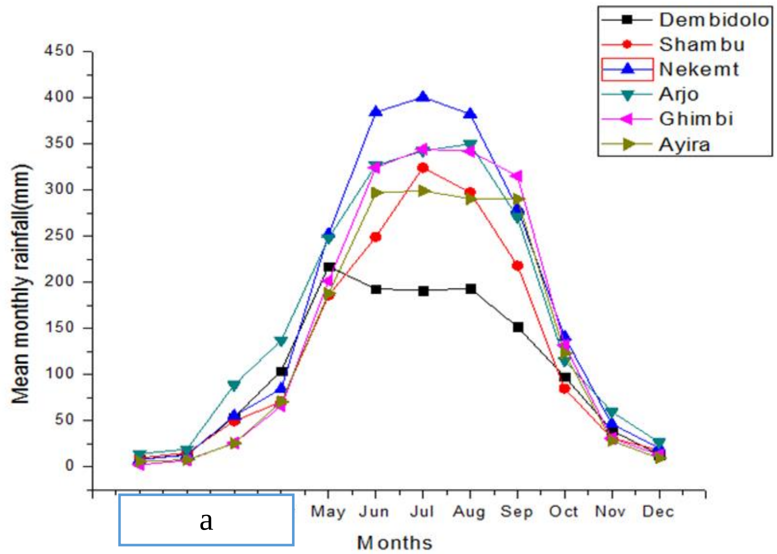


Figure 4 Spatial and temporal distributions mean annual and seasonal RF over WO (1985-2016).

From figures 4c & d, it is observed that the mean Belg and Bega rainfall in Western zone varies from 320mm (at WW &EW) to 530mm (at Jimma & Illubabor) and from140mm to 317mmover the Wollega and Jimma and illubabor areas, respectively. In addition, the mean Belg and Bega rainfall in Jimma & Illubabor zones is higher than the main rainy season fall in the lowland areas of Ethiopia similar studies by Wagesho, 2013 and MISGANAW, 2014.

4.1.2 Pattern of monthly rainfall climatology

Temporal analysis of mean monthly rainfall distribution by graphical method over all parts of western Oromia was found to be unimodal type with maximum precipitation peaking in July and august months except Dembidolo, its peak in May



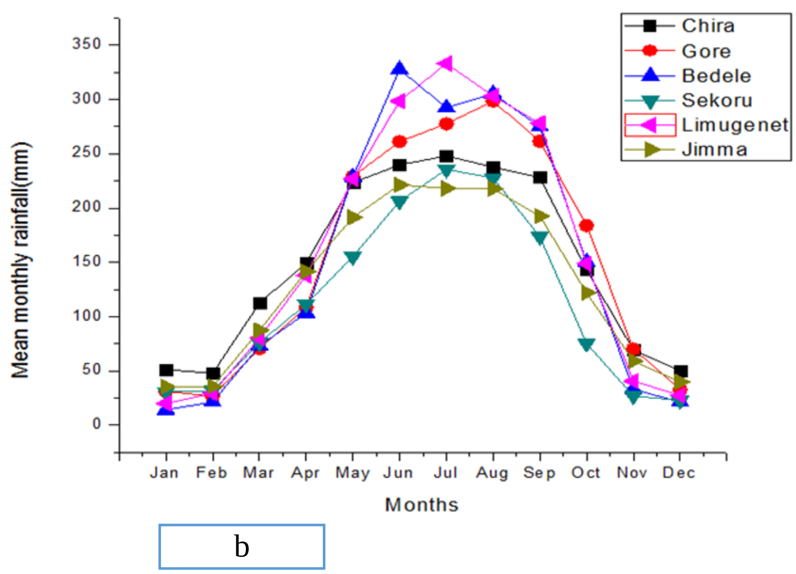


Figure 5a & b Mean monthly rainfall pattern over WO (1985-2016

4.2 Onset, cessation of rainy season and Length of the Growing Period

The variability of seasonal rainfall in terms of onset, cessation date, and length of rainy period for 12 stations were discussed in this section over WO.

4.2.1 Variability of onset of rainy season

The mean onset date of the rainy season in the WO varied from March 26(84 DOY) at Jimma to May 10(130 DOY) at Ghimbi). The CV for the start of the season (SORS) ranged from 16.4% to

24.7%. The mean onset of the rainy season is late one to two decades with the previous work of Abebe, 2006 studied over all Ethiopia which represent by Jimma, Chira and Bedele stations only from 1971 to 2004 their study.

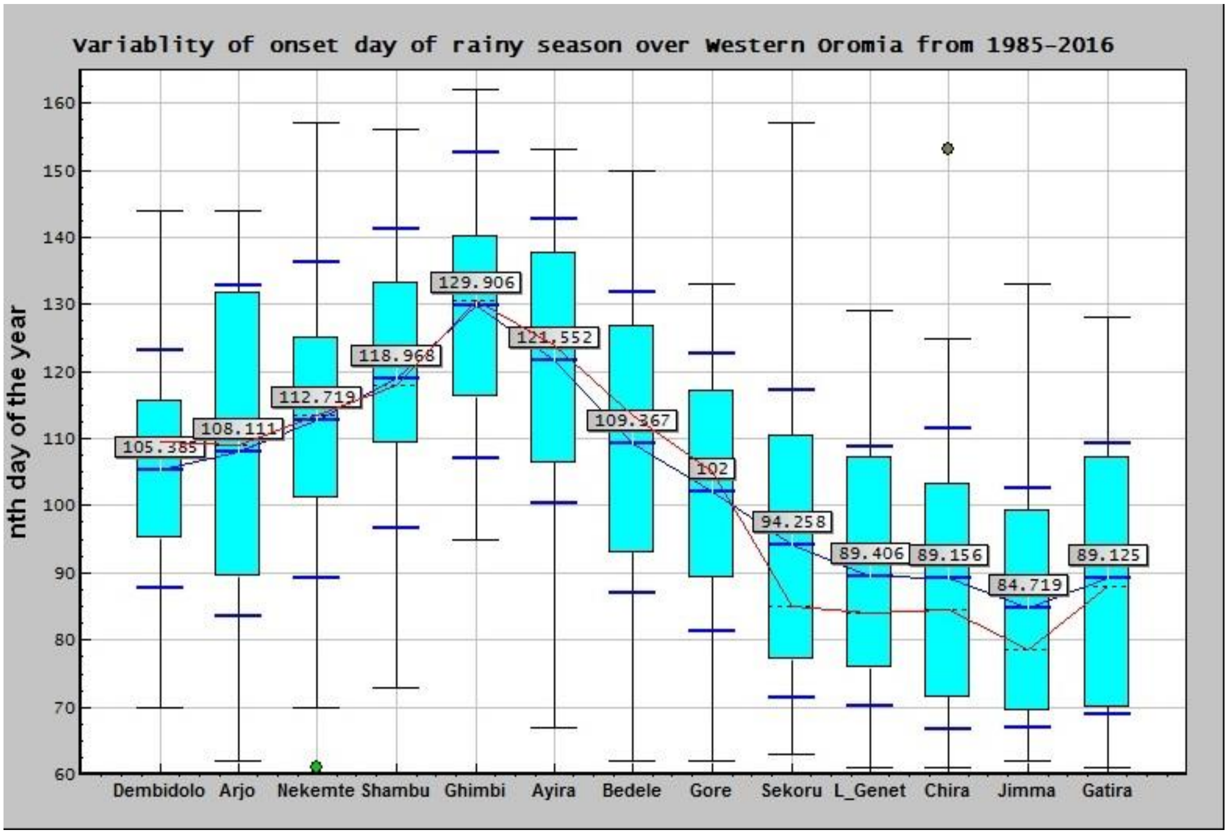


Figure 6 Boxplot explaining Variability of onset of rainy season over WO stations (1985-2016)

4.2.2 Variability of cessation of rainy season

The variability of seasonal rainfall in terms of cessation date and number of rainy days were discussed. The mean cessation date of the rainy season (CORS) for the study area ranged from days October 30 to November 25 with a CV of 3.5–7.2%.

The mean cessation date of the rainy season (CORS) for the study area ranged from days October 30 to November 25 with a CV of 3.5–7.2%.

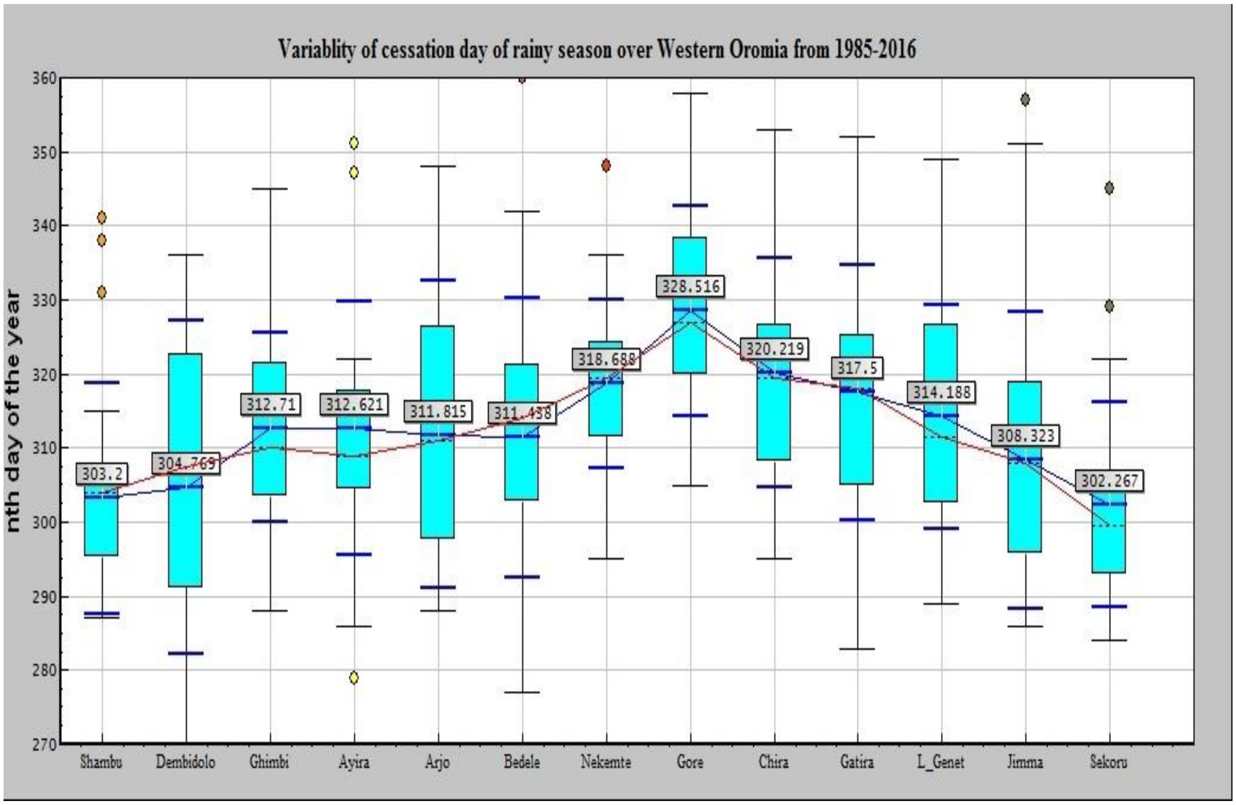


Figure 7 Boxplot explaining variability of cessation of rainy season over WO (1985-2016).

4.2.3 Variability of Length of growing Period (LGP)

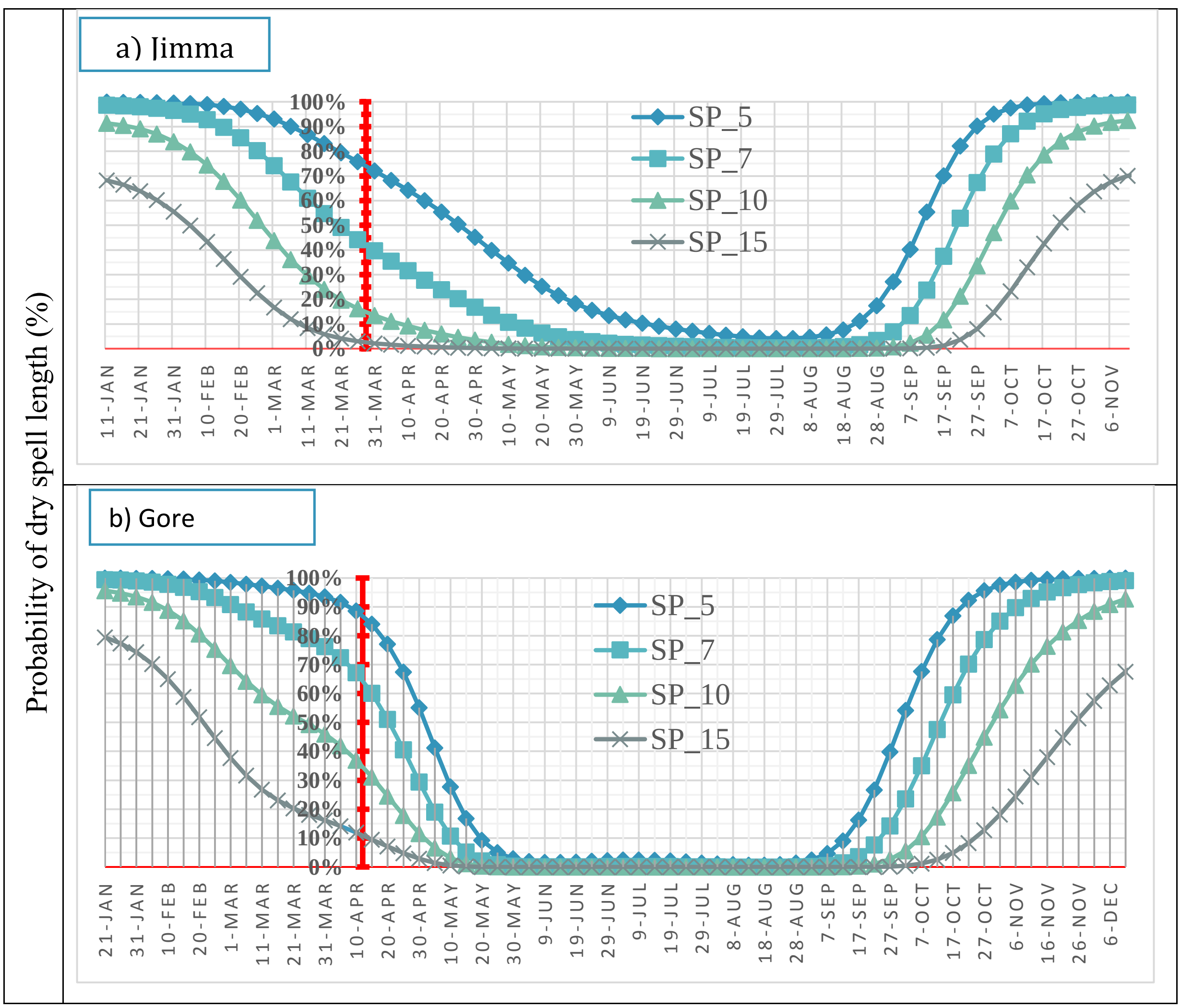
Figure 8 and table2 showed on the whole, earliest onsets were observed at stations in Jimma zone, which have mean onset in the end of last decade of March and the latest onsets were at stations in west Wollega in the first decade of May, have the moderately variability having standard deviation of 17.3 to 24.2. From table 2, it can be seen that Dembidolo/ Arjo has the lowest/highest standard deviation of the onset days. The mean rainfall retreat dates were determined to be within November and less variable in the WO. With respect to cessation Nekemte/Dembidolo has the lowest (highest) standard deviation of the cessation onset days. The mean length rainy season (LGP) over of 13 stations in the study area varied from 173 at Dembidolo to 231 days at Chira. General, Illubabor and Jimma zones have the long mean growing season and part of west and east Wollega have the short mean growing period as shown in Table2. The study shows that there is more variability in the onset of the rainy season than in its cessation.

Table 2 Descriptive statistics on onset, cessation of rainy season and Length of growing period (LGP) from 1985 to 2016 over study site.

	Mean Onset date			Mean Cessation date			LGP (No of Days)		
Stations	Mean date(DOY)	Mean STD	CV%	Mean date(DOY)	mean STD	CV%	Mean No of days	Mean STD	CV%
Nekemte	April 23(113)	23.2	20.5	Nov 15(319)	11.2	3.5	206	26.1	12.7
Shambu	April 29(119)	21.9	18.4	Oct 30(303)	15.4	5.1	185	26.1	14.1
Ghimbi	May 10(130)	22.4	17.3	Nov 9(313)	12.6	4.0	185	20.0	10.8
Arjo	April 18(108)	24.2	22.4	Nov 8(312)	20.3	6.5	199	29.6	14.8
Ayira	May 2(122)	20.8	17.1	Nov 9(313)	16.8	5.4	204	28.7	14.1
Dembidolo	April 15(105)	17.3	16.4	Nov 1(305)	22.1	7.2	173	62.9	36.3
Bedele	April 19(109)	22.0	20.1	Nov 7(307)	18.6	6.0	209	37.8	18.1
Gore	April 12(102)	20.3	19.9	Nov 24(328)	13.9	4.2	229	28.4	12.4
Sekoru	April 4(94)	22.6	24.0	Nov 29(333)	13.6	4.5	198	54.1	27.3
L/Genet	March 30(89)	19.1	21.3	Nov 10(314)	14.8	4.7	225	17.7	7.9
Chira	March 31(90)	22.1	24.7	Nov 16(320)	15.2	4.8	231	27.1	11.7
Jimma	March 26(85)	17.5	20.6	Nov 4(308)	19.8	6.4	223	28.9	13.0
Gatira	March 30(89)	20.0	22.3	Nov 13(317)	17	5.3	228	26.0	11.6
Mean(WO)	April 14(104)	21.0	20.4	Nov 9(313)	16.3	5.2	207.4	31.8	15.7

4.2.4 Probability Dry spell length

Figure 8 showed the probability of dry spells lengths of sp5, sp7, sp10 and sp15 days of the study sites. The graph indicated that the probability of occurrence of dry spell of all lengths is less than 20% at the growing season from 3rd decade of May to 1st decade of September in all study areas. From the graph that the probability of 10 and 15 days dry spell lengths were fall below 5% after 120 DOY (April 30th) at Jimma and after 140 DOY (May 20th) at Gore, Nekemte and Ghimbi. One also can see (Figure 8). that there was less or no chance for the occurrence of dry spell at all dry spell probability curves during the peak months of main (Kiremt) rain season except for Jimma, that the probability of dry spells of 5 days is <10% during periods from early June to 2nd decade of September is the signaling end of the growing season. Therefore, crop is less likely affected by moisture stress. The Belg (FMAM) season has higher probability of dry spells than the Kiremt (JJAS) and is liable to meteorological drought. The challenges of risk of dry spell were more at Jimma as compared to other three stations. Hence crop production during this particular period needs a due attention and monitoring of planted crops. Generally, at all the studied locations, curves of dry spells probability at shorter lengths (sp5 &sp7) decrease rapidly in the 1st decade April, good indicator of onset of rainy season (except for Jimma) and also curves of dry spells probability at longer length (sp15) turn upward rapidly from the last decade of September, signaling end of the growing season.



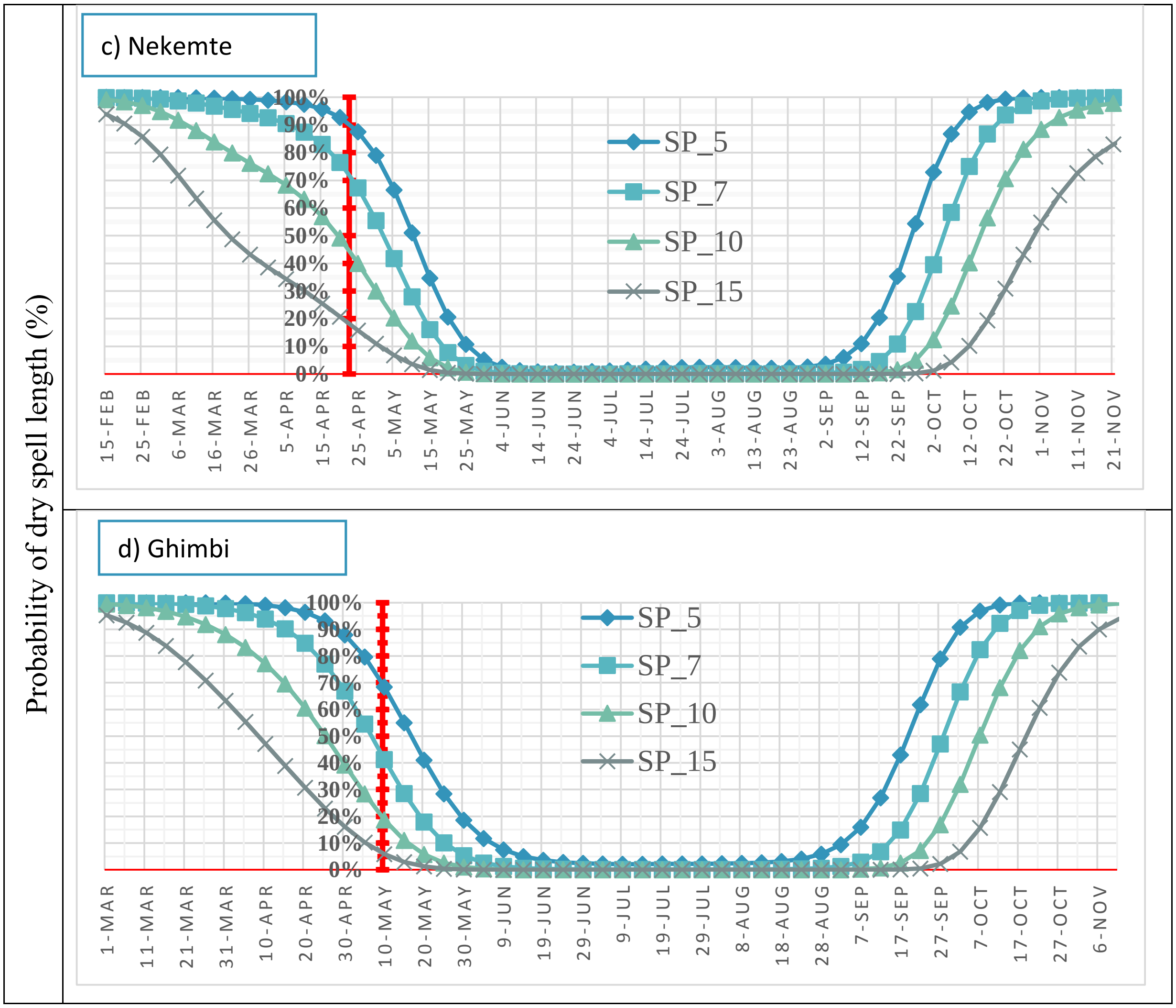


Figure 8 Markov-Chain model output Probabilities' of dry spells length longer than 5, 7, 10 and 15 days within 30 days after starting date at four stations in WO, southwestern Ethiopia for the period of 1985-2016.

Dry spells were occurring more at Jimma when comparing to the other three stations. At start of the rainy season in 3rd decade of March (26-Mar) at jimma area, the probabilities of getting dry spell length of 5, 7, and 10 days is 75, 44 and 16% which gradually decreases to 18, 5, and 0% at the end of Belg, respectively. This implies that the risk of planting long cycle before the 3rd dekade of March is below 50% (Figure). Moreover, the probabilities of all dry spell length is very low in Kiremt. The probability of two week (15 day long) dry spell occurrence is found to be below 50% from February to 2nd decade of October (Figure 8). This indicates probability wet spell of the conducive environment for crops with no risk of water shortage in the study site. This condition is inappropriate for maturity and harvesting of crops. Planning for use of agricultural water resources and flood management in kiremt season excess (intense) rainfall and also important to control effects from early/late cessation can cause serious destruction of some crops in the time harvesting as Study by Segele and Lamb (2005) indicated that wet/dry spells length is one of the major causes of crop failure in rain fed farming systems of Ethiopia.

4.3 Trend Analysis of Annual and Seasonal Rainfall

The Mann-Kendall trend analysis indicated that the annual and seasonal rainfall data have shown increasing and decreasing trend in the study area. The results of the trend test show an increasing trend in annual rainfall in (Arjo, Ghimbi, Dembidolo, Nekemte, Gore, Gatira, Jimma, Bedele and Chira) out of the 13 meteorological stations and the rest showed decreasing trends. From these increasing trend, Arjo, Jimma and Limugenet stations are statistically significant. The increasing trend of Kiremt rainfall is statistically significant in Arjo. Dembidolo and Limugenet and decreasing trend of Kiremt rainfall is statistically significant in Gore. During Belg, rainfall shows an increasing significant trend only in Ayira (bold values in Table3). This result is line with the studies conducted using some stations by Woldeamlak and Conway (2007) in (Northwestern Ethiopia), Seleshi and Zanke (2004) and Conway et al. (2004) in the central Ethiopian highlands, analysis of rainfall trend in Ethiopia by H.Seid and Admasu, 2006 and Girma Eshetu et al.(2018) Climate Variability and Small-Scale Farmer Adaptation Strategy in Setema-Gatira Area of Jimma and Conway (2000) in northeastern Ethiopian highlands agreed that there is non-significant and clear trend of annual and seasonal rainfall totals in WO, southwest Ethiopia. On the other hand, Bega season trend was not done by previous studies, show positive trends at 9 stations and also show significant change at Arjo and Gatira.

General, the MK-trend test show an increasing trend change in annual and seasonal rainfall and however, significant trend change should be checked and investigated further other near stations.

Table 3 Trends analysis with Mann-Kendall test and Sen's slope of annual and seasonal rainfall totals in Western Oromia, Southwest Ethiopia for the period 1985 to 2016 at a significance level of 5% and 10%.

Station	Belg (FMAM) season		Kiremt (JJAS) season		Bega (ONDJ) season		Annual	
	Z_{MK} test	Sen's slope	Z_{MK} test	Sen's slope	Z_{MK} test	Sen's slope	Z_{MK} test	Sen's slope
Arjo	1.44	8.36	**3.47**	**21.06**	**1.82***	**6.83**	**3.34**	**33.75**
Shmbu	-0.395	-0.976	-1.509	-4.707	-0.467	-0.914	-1.473	-7.158
Nekemte	0.956	4.278	0.47	2.802	0.664	1.22	1.25	6.934
Ayira	**2.021**	**5.308**	-0.34	-1.297	-1.14	-2.079	-0.46	-2.919
Ghimbi	1.297	3.089	0.308	0.562	-0.6	-1.116	0.697	4.31
Dembidolo	1.563	3.973	**1.96**	**8.854**	-0.918	-1.89	1.563	11.198
Bedele	0.995	1.625	0.668	2.716	0.571	1.296	1.093	4.815
Gore	0.421	0.687	**-2.124**	**-7.356**	0.308	0.717	-1.216	-6.881
Chira	-0.918	-1.792	-0.068	-0.216	0.578	0.76	-0.102	-0.421
Jimma	0.665	1.336	0.989	2.572	1.087	1.356	**1.64***	**6.126**
Limugenet	-0.172	-0.569	**1.89***	**10.527**	0.34	0.415	**1.80***	**11.148**
Sekoru	0.31	0.669	-0.73	-1.261	0.86	1.26	-0.37	-1.509
Gatira	0.308	0.812	0.697	1.92	**1.64***	**3.77**	1.22	6.18

Z_{MK} is Mann–Kendall trend test, Slope (Sen's slope) is the change (mm)/annual (season), ***** = for significance level 10%.

Rainfall is highly influenced by local- and synoptic-scale meteorological forcing's. Seasonal and annual amount and coefficient of variability have been analyzed for all the 13 rain gauge stations located in the study area. The coefficient of variation in stations revealed that rainfall in the region has low to moderate and comparable inter-annual and kiremt seasonal variability (Table 4 and figure 9). The result indicated that inter-annual rainfall variability varies from low to moderate (CV%=11 to 24%). Rainfall variability on Belg seasonal basis in the study area (Table 2) has varied between 12% at Chira and 43% at Arjo (low to very high variability). Bega seasonal rainfall has high CV%, which ranged from moderately high CV% of 31 %(at chira) to Extermely high 77% (at Ghimb). The coefficient variation indicates that Belg and Bega season rainfall of Western Oromia was highly variable than Kiremt rainfall in which the coefficient variation is low during study period. This is supported by Taye et al (2013) in their study that analyzed 5 stations in the

Western Amhara and noted that the Belg and the Bega rainfalls are found much more variation (>40%) than the kiremt rainfall in which the coefficient of variation is lower than >20%. (Taye, 2013). In general, the variability is higher in the area of lower and higher annual rain. As shown in Table 4, small rainy seasons are unreliable in the area (CV >40%) due to the effect of lesser amount of rainfall.

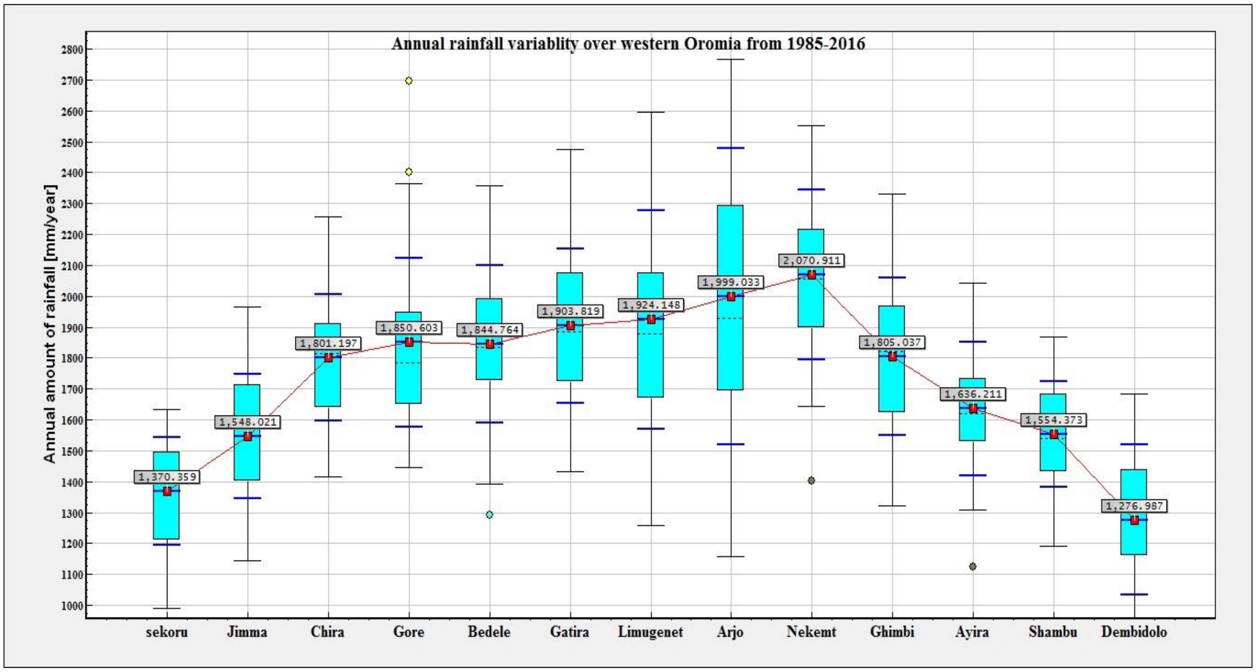
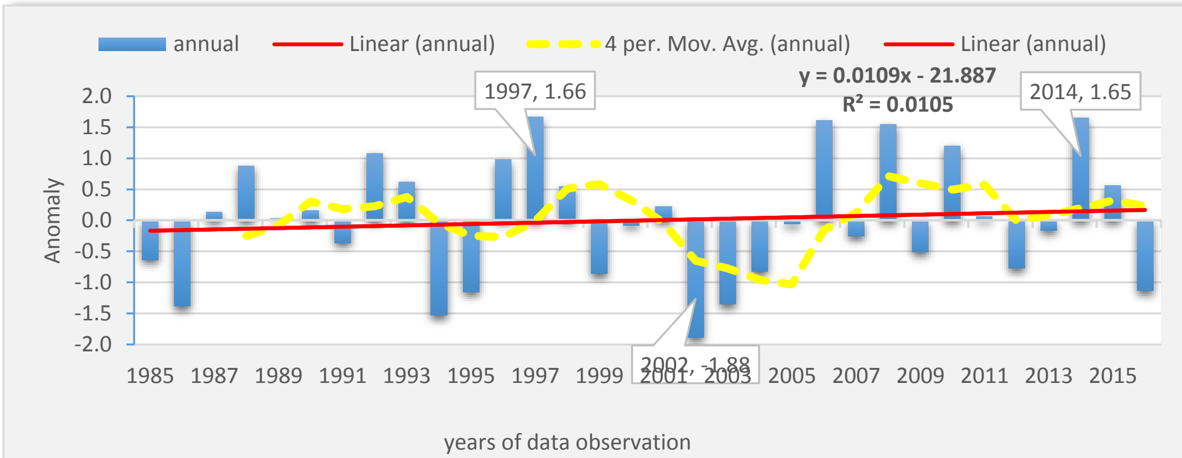
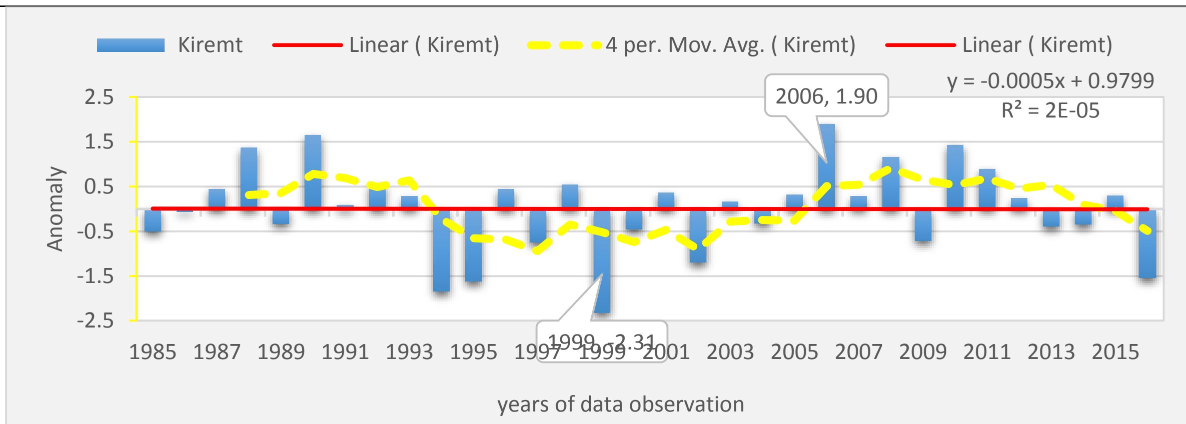


Figure 9 Boxplot intern-annual rainfall variability over Western Oromia from 1985-2016

4.4. Analysis of Inter Annual Anomaly of Rainfall

The seasonal and annual rainfall standardized anomaly (SAI) shows high inter-seasonal and inter-annual variability in the study area (figures 9) for the study period. It showed that by the periodic oscillation between consecutive positive and consecutive negative anomaly years, this means on average 2-3years with a positive anomaly tends to be followed by 2-3 year with a negative anomaly. Annual and Belg seasonal rainfall anomaly have 54.8% negative years and also kiremt season has 45.2% negative years of the total years of observation. From the 4 year moving averages, it can be seen in Figure 9 that above normal rainfall dominates the period 1985–1992 and 2006–2014 for kiremt season rainfall anomaly for the Western Oromia where the period 1993–2005 is dominated by below normal rainfall values. There were six very dry (1986, 1994, 1995, 2002, 2003 and 2016), and three moderate (1985, 1999, 2004 and 2012) drought years, which together represent 31.3% of the total number of observations. Once again, the year 2002 stands out as the strongest year, with a standardized rainfall anomaly of -1.88. In contrast, 1996 was the wettest year in the WO over the period of record following the year 2014.This results agreed with the findings (Yirgaw, 2011) conducted on climate variability over drought prone area in northern Ethiopia. The linear regression trend confirms that there was positive slope and no significance in the annual and seasonal rainfall anomaly during 1985–2016. And also years of driest and wettest anomalies was conceded with strong ENSO events in the period of study.





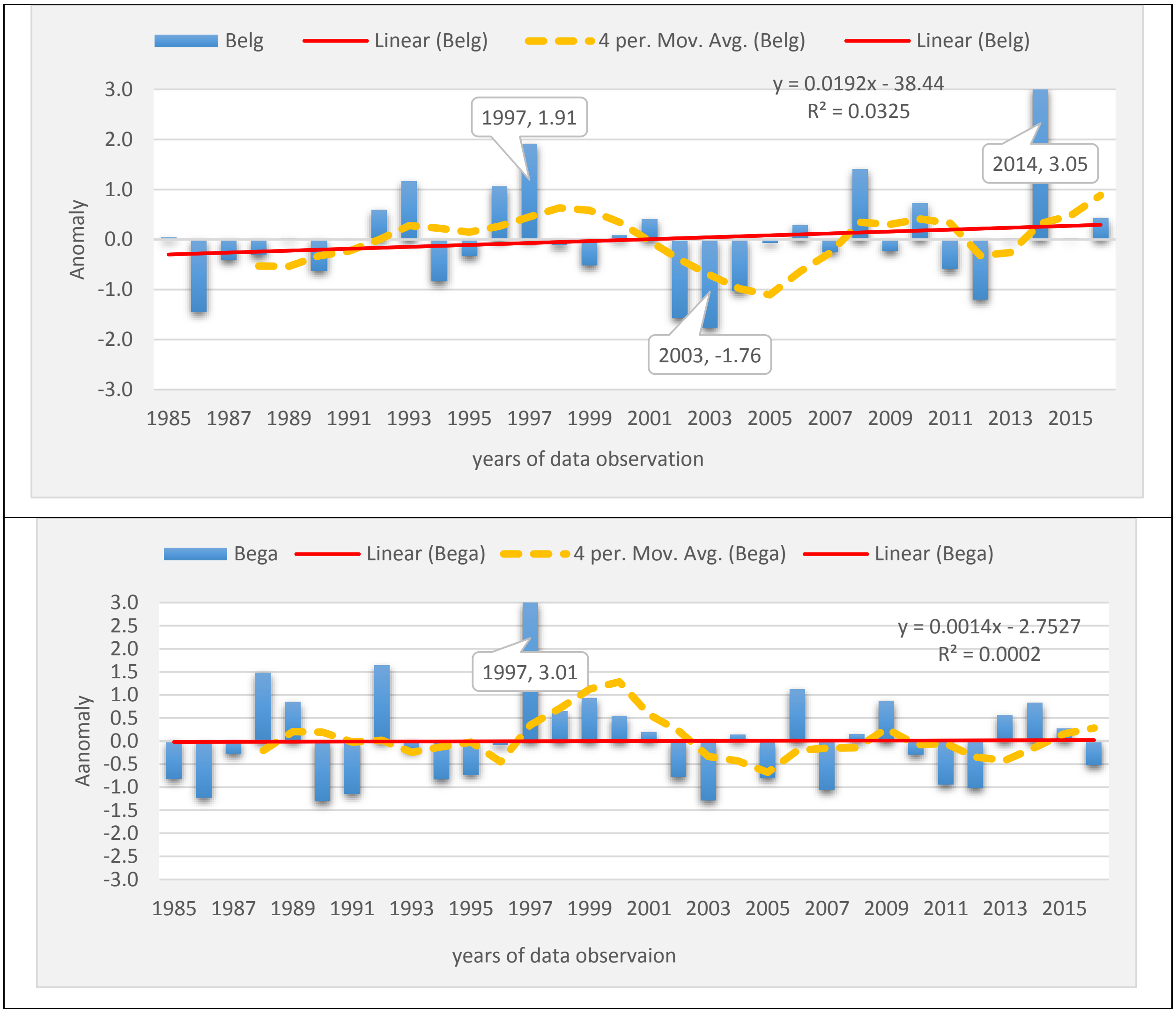


Figure 10 Standardized rainfall anomaly from long-term average, linear regression trend, 4-year moving average line and extremes to the seasonal and annual rainfall anomalies over WO(1985-2016).

4.5 Correlation of Rainfall to SST

Previous different studies have demonstrated that there is influence of anomalies in sea surface temperature on precipitation variability (Zaroug, 2014). In this study, we focused on analyzing the influence of global scale SST patterns on seasonal and annual rainfall anomaly. The significant tropical ocean parts that show strong correlation with Belg and Kiremt seasonal rainfall anomaly include equatorial eastern, western and central Pacific, central and south eastern Atlantic and most part of the Indian Ocean. Accordingly, it is found that there is correlation between rainfall in western Oromia and SSTs in various parts of the tropical Pacific, Indian and

Atlantic oceans. Belg season Precipitation anomalies to SSTs in the region show a statically significant positive relationship over north eastern tropical Pacific (Niño regions -160^{0}W - 100^{0}W), south western part of Atlantic and souteast Indian Ocean (Figure 10(a)). And parts of western Atlantic Ocean, southeast Indian Ocean and north western Pacific Ocean also show negative correlation coefficients with Belg season rainfall anomalies.

Kiremt season anomalies to SSTs in the region show a positive relationship over south eastern tropical Pacific, central and south western part of Atlantic Ocean (Figure 10 (a)). And western parts of Equatorial Atlantic Ocean and central and north western Pacific Ocean (Niño regions_160^{0}W - -100^{0}W) also show negative correlation coefficients with kiremt season rainfall anomalies.

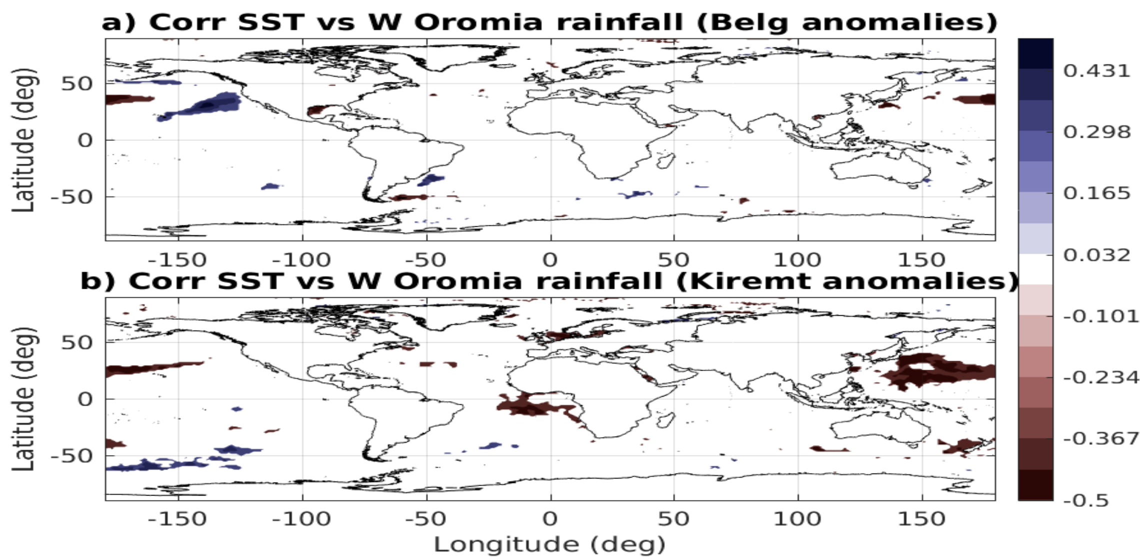


Figure 10(a).seasonal rainfall correlation to the observed SST (averaged mean 50^{0}N - 50^0 S, 150^0 E - 150^0 W) over WO (1985-2016).

Three Stations based seasonal rainfall anomalies to SSTs relationships showed similar association in both Kiremt and Belg season associations but statically significant positive for spatially larger area of North eastern Pacific Ocean (Nino regions) (figure 10(b), 10(c) and 10(d) and negative for north western Pacific and eastern Indian Ocean for Jimma Belg season anomalies. And also kiremt seasonal anomalies negatively correlated with western Atlantic SSTs anomalies Except for Station Gore which has negative significant relation with north eastern Atlantic and larger area Over north western tropical Pacific SSTs anomalies.

Jimma Station seasonal rainfall anomalies to SSTs relationships showed association in both Kiremt and Belg seasons. Association is statically significant positive for spatially larger area of North central eastern Pacific Ocean (Niño regions) (figure 10(b) and negative for patches of north western central Pacific and eastern Indian Ocean for Jimma Belg season anomalies. And also kiremt seasonal anomalies negatively correlated with eastern Atlantic and west central Pacific SSTs anomalies and positive for area of central eastern Pacific, central Indian and Atlantic Ocean.

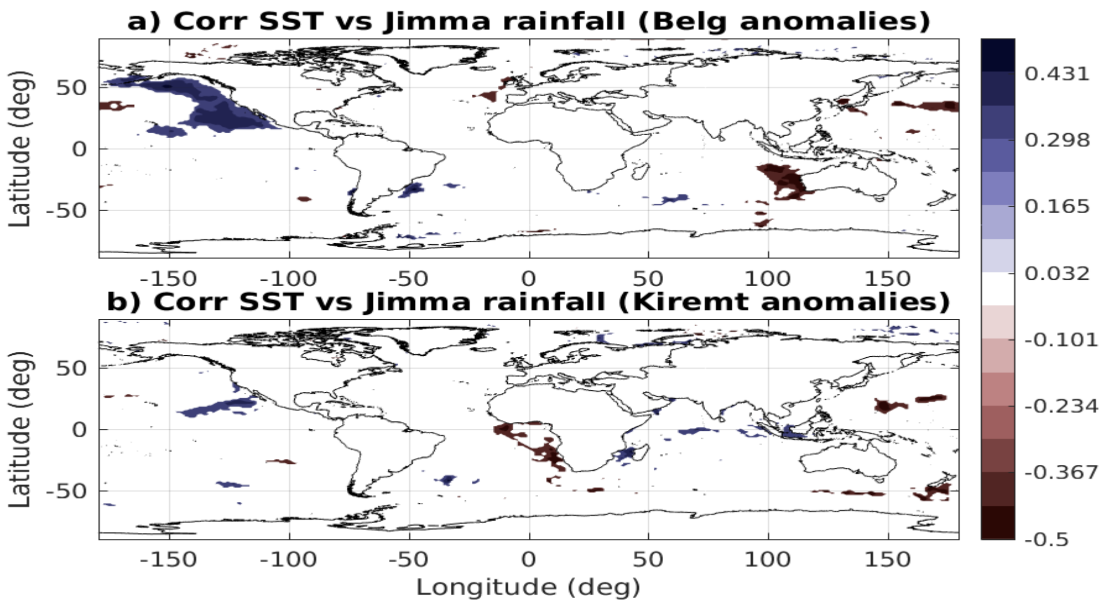


Figure10 (b) Jimma station Belg and Kiremt season rainfall anomalies correlation to the observed SST (averaged mean 50^0N - 50^0 S, 150^0 E - 150^0 W) over WO (1985-2016).

Gore station Belg season rainfall anomalies to SSTs showed association significant positive for area of north central eastern Pacific Ocean (figure 10(c). And also kiremt seasonal anomalies negatively correlated with large area of north eastern Atlantic and west central Pacific SSTs anomalies.

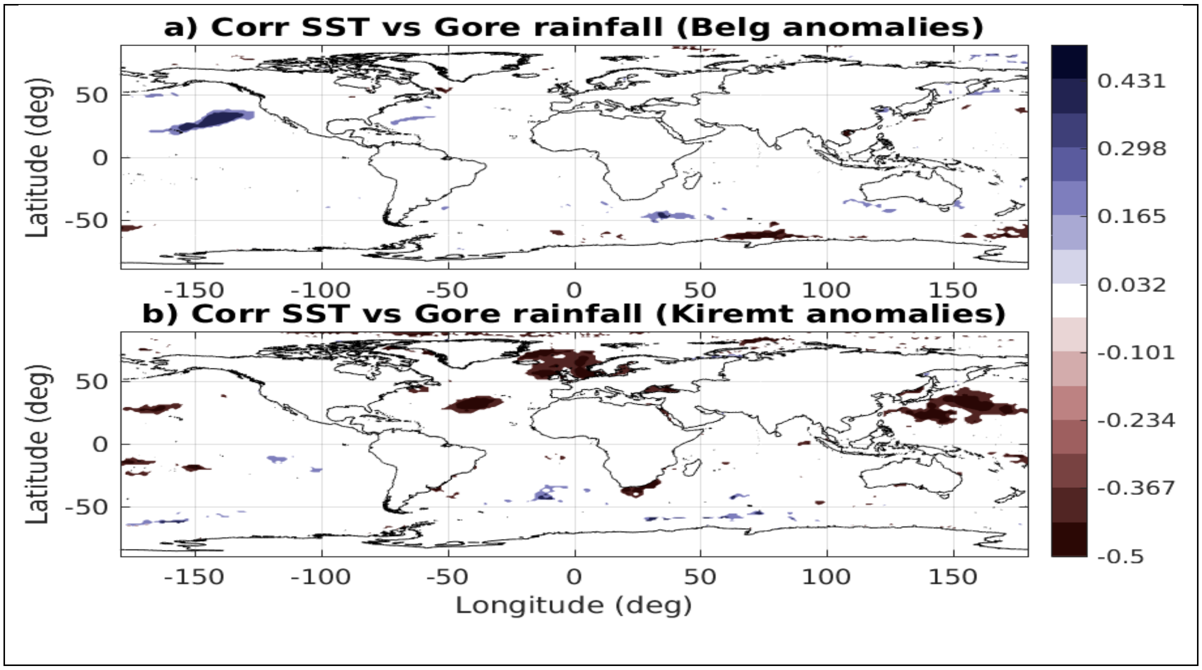


Figure Figure 10(c).1 Gore Station Belg and Kirent season rainfall anomalies correlation to the observed SST (averaged mean 50^0N - 50^0 S, 150^0 E - 150^0 W) over WO (1985-2016).

Nekemte station Belg season rainfall anomalies to SSTs showed association non-significant positive except for patches of north western central Pacific Ocean (figure 10(d) and negatively correlated for small areas of Northwest central Pacific Ocean and south east Atlantic ocean. And also kiremt seasonal anomalies negatively correlated with large area of north eastern Atlantic and west central Pacific SSTs anomalies and positive for area of central eastern Pacific, central Indian and Atlantic Ocean.

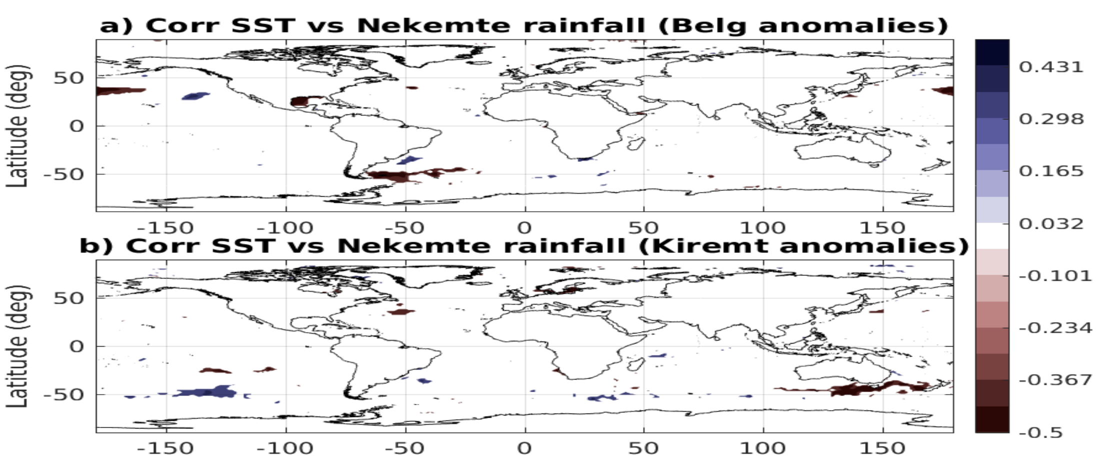


Figure10 (d). Nekemt season Belg and kiremt rainfall Anomalies correlation to the observed SST (averaged mean 50^0N - 50^0 S, 150^0 E - 150^0 W) over WO (1985-2016).

General, seasonal relationships of rainfall to SST correlation varies station to station to the parts of global oceans.

- ⇨ Belg rainfall anomaly is positively correlated with northeast central Pacific, Southeastern Indian and southwest Atlantic Ocean and negatively with Western Pacific Ocean.
- ⇨ Kiremt rainfall anomaly is positively Associated with Eastern central pacific (Niño regions) central Atlantic and Indian Ocean and negatively with Western pacific.

CHAPTER FIVE

5 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSION

Rainfall is the most important climate element that shows variations across time and space. In the western Oromia rainfall information about the spatial distribution, the seasonality of rainfall (onset, Cessation, LGP and dry spell probability), trends and its relationship with SSTs is crucial for agricultural hydrological activities and it varies from season to season and area to areas in the region.

The spatial distribution of mean annual rainfall distribution increases toward the central portion of the area from the east and west. The climate is characterized by large spatial variations which range from less than 1277mm/year over West Wollega (Dembidolo) to 2070mm/year over zone of East Wollega (Nekemte) and 1723 mm/year areal average. Seasonal Rainfall exhibited different spatial distribution in the study area. During the Kiremt season (JJAS), the central parts of the study area received high rainfall up to 78% of the annual rainfall and its distributions decreases to 53% over the southward parts both from the east and west (Illubabor and jimma zones. Inversely, Belg (FMAM) and Bega (ONDJ) seasonal rainfall appeared to be high over southward from east and west (Illubabor and jimma zones) upto 30% and 17% of the annual rainfall respectively. And mean monthly rainfall distribution over all parts of western Oromia was found to be unimodal type with maximum precipitation peaking in July and august months except Dembidolo, its peak in May.

The mean onset date of the rainy season in the WO varied from March 26(84 DOY) to May 10(130 DOY) with the CV of 16.4% to 24.7%. The mean onset of the rainy season is late one to two decades with the previous work of (Abebe, 2006) studied over all Ethiopia which represent by Jimma, Chira and Bedele stations only from 1971 to 2004 their study. The mean cessation date of the rainy season (CORS) for the study area ranged from days October 30 to November 25 with a CV of 3.5–7.2%. The study shows that there is more variability in the onset of the rainy season than in its cessation. The curves of dry spells probability at shorter lengths (sp5 &sp7) decrease rapidly in the 1st decade April, good indicator of onset of rainy season (except for Jimma) and also curves of dry spells probability at longer length (sp15) turn upward rapidly from the last decade of September, signaling end of the growing season.

The results of the trend test show an increasing trend in annual rainfall in 9 out of the 13 meteorological stations and the rest showed decreasing trends. This may be a signal for impact of cc in the region even though the trend were not statistically significant in all meteorological stations except the increasing trend of annual rainfall is statistically significant in Arjo station. The increasing trend of Kiremt rainfall is statistically significant in Arjo. Dembidolo and decreasing trend of Kiremt rainfall is statistically significant in Gore. During Belg, rainfall shows an increasing significant trend only in Arjo

Belg season Precipitation anomalies to SSTS correlation showed statically significant positive relationship over north eastern tropical Pacific (Niño regions -160^{0}W ─ -100^{0}W), south western part of Atlantic and Indian Ocean and parts of western Atlantic Ocean and north western Pacific Ocean also show negative correlation coefficients. Kiremt season anomalies to SSTs in the region show a positive relationship over south eastern tropical Pacific, central and south western part of Atlantic Ocean. And western parts of Equatorial Atlantic Ocean and central and north western Pacific Ocean (Niño regions-160^{0}W ─-100^{0}W) also show negative correlation coefficients with kiremt season rainfall anomalies over Western Oromia.

Seasonal relationships of rainfall to SST correlation varies station to station to the parts of global oceans.

- ⇨ Belg rainfall anomaly is positively correlated with northeast central Pacific, Southeastern Indian and southwest Atlantic Ocean and negatively with Western Pacific Ocean.
- ⇨ Kiremt rainfall anomaly is positively Associated with Eastern central pacific (Niño regions) central Atlantic and Indian Ocean and negatively with Western pacific.

5.2. Recommendations

This research can provide some information to the regional government and community of Western Oromia on the variability of rainfall the following useful points are being forwarded as recommendation;

To recommend the planners should design strategies and plans by taking into account increasing annual, Belg and Kiremt rainfall trends, anomalies and increasing variability of onset of rain impacts on rural livelihoods and floods may increase under climate change in the region. Floods may be major environmental challenge that exacerbated incidences of disease outbreaks, resulting in loss of lives and livelihoods in the main rainy season.

- ⇨ The planting time for long cycle crops like maize and sorghum around jimma and area of western Oromia is good if it is performed after the onset of rainy season and be adjusted farm operations to avert and minimize risk of wet spell and variability of rainfall in time of harvesting.
- ⇨ Further studies should be conducted to consider more characteristics of rainfall variability due to influence of regional features such as topography, land cover and/or use as well as other climate variables.

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APPENDICES

Table 4 Climatic Annual and seasonal mean rainfall (mm), percent contributions (%), standard deviation (mm) and their coefficient of variation (CV (%)), Reliability (R %) and the average contribution of these seasons (in percent) for stations over western Oromia for the period of study.

Stations		Annual	Seasons		
			Bega season	Belg season	kiremt season
Arjo (1989-2016)	Mean	1999.0	216.4(11%)	493.3(25%)	1289.4(65%)
	SD	479.375	121.411	214.099	281.591
	CV (%)	0.240(24%)	0.561(56.1%)	0.434(43.4%)	0.218(21.8%)
	R %	76	43.9	56.6	78.2
Ayira (1988-2015)	Mean	1636.2	167.5(10%)	291.9(18%)	1176.8(78%)
	SD	215.9	107.6	110.0524	164.5091
	CV (%)	0.132(13.2%)	0.643(64.3%)	0.377(37.7%)	0.140(14%)
	R %	86.8	35.7	62.3	86.0
Bedele (1985-2016)	Mean	1844.8	218.8(12%)	425.9(23%)	1200.0(65%)
	SD	255.4	107.1	114.6	154.1
	CV (%)	0.138(13.8%)	0.489(48.9%)	0.269(26.9%)	0.128(12.8%)
	R %	86.2	51.1	73.1	87.2
Chira (1985-2016)	Mean	1800.2	313.8(17%)	532.9(30%)	953.5(53%)
	SD	203.9	96.8	95.9	118.8
	CV (%)	0.113(11.3%)	0.308(30.8%)	0.180(18.0%)	0.125(12.5%)
	R %	88.7	69.2	82	87.5
Dembidolo (1987-2016)	Mean	1276.4	159.3(12%)	388.3(30%)	729.4(57%)
	SD	242.3	66.2	80.5	157.1
	CV (%)	0.190(19%)	0.415(41.5%)	0.207(20.7%)	0.215(21.5%)
	R %	81	59.5	79.3	78.5
Ghimbi (1985-2016)	Mean	1805.0	178.9(10%)	300.5(17%)	1325.6(73%)
	SD	254.7	138.7	123.108	206.5
	CV (%)	0.141(14.1%)	0.775(77.5%)	0.410	0.156(15.6%)
	R %	85.9	22.5	59.0	84.4

Gore (1980-2016)	Mean	1850.6	317.7(17.4%)	434.3(29.6%)	1098.6(53.0%)
	SD	272.7	106.5	115.0	175.7
	CV (%)	0.147(14.7%)	0.335(33.5%)	0.265(26.5%)	0.160(16.0%)
	R %	85.3	66.5	73.5	84.0
Jimma (1980-2016)	Mean(mm)	1548.0	256.4(16%)	455.8(30%)	843.7(54%)
	SD	201.0	112.1	100.0	118.8
	CV (%)	0.13(13%)	0.437 (43.7%)	0.219(21.9%)	0.141(14.1%)
	R %	87.0	56.3	78.1	85.9
Limugenet (1985-2016)	Mean	1924.2	237.06(12%)	474.33(25%)	1212.76(63%)
	SD	352.81	111.72	142.28	289.41
	CV (%)	0.183(18.3%)	0.471(47.1%)	0.300(30%)	0.239(23.9%)
	R %	81.7	52.9	70	74.1
Nekemt (1985-2016)	Mean	2070.9	152.8(7.4%)	498.7(24.1%)	1447.1(69.9%)
	SD	274.5	74.4	126.2	191.6
	CV (%)	0.13(13%)	0.49(49%)	0.25(25%)	0.13(13%)
	R %	87	51	75	87
Sekoru (1985-2016)	Mean	1368.7	154.59(11%)	370.98(27%)	843.09(63%)
	SD	174.1	87.34	101.49	115.74
	CV (%)	0.127(12.7%)	0.565(56.5%)	0.274(27.4%)	0.137(13.7%)
	R %	87.3	43.5	73.6	86.3
Shambu (1989-2016)	Mean	1554.4	144.2(9.28%)	321.4(20.7%)	1088.8(70.0%)
	SD	170.2	88.3	94.5	135.6
	CV (%)	0.110(11.0%)	0.612(61.2%)	0.294(29.4%)	0.125(12.5%)
	R %	89.0	38.8	70.6	87.5
Gatira (1985-2016)	Mean	1914.5	273.6	487.819	1153.0
	SD	249.7	103.3	105.402	170.445
	CV (%)	0.13(13.0)	0.378(37.8)	0.216(21.6)	0.148(14.8)
	R %	87	62.2	78.4	85.2