NMA ብሔራዊ ሚቲዎሮሎጂ ኤጀንሲ
NATIONAL METEOROLOGY AGENCY

Joint Scientific Journal of National Meteorological Agency (NMA) and Ethiopian Meteorological Society (EtMS)

Ethiopian Meteorological Research Series, First Series

April 2020
Addis Ababa, Ethiopia

Disclaimer

These research output are entirely done by NMA experts and published on Joint Scientific Journal of National Meteorological Agency of Ethiopia and Ethiopian Meteorological Society. For this reason, only NMA and EtMS are responsible for any enquiry.

Cover page design and description

The cover page was designed by Mr. Fitsum Bekele and Mr. Abate Getachew to indicate the content of the research mainly climate change and variability, climate and health, climate and agriculture and others.

Citation: This research book series can be cited as:

National Meteorological Agency (NMA) and Ethiopian Meteorological Society (EtMS). (2020). *Joint Scientific Journal of National Meteorological Agency (NMA) and Ethiopian Meteorological Society (EtMS), Ethiopian Meteorological Research Series, First Series,* Addis Ababa: Facil Printing Press, and can be downloaded from http://www.ethiomet.gov.et web site.

Reviewed by:

Edited by: NMA Research Editorial Board

Foreword

The core business of National Meteorological Agency of Ethiopia (NMA) is to provide essential Weather, Climate and Early Warning services that contribute to socio-economic activities of the Nation and protect lives and property. This is achieved by collecting, analyzing forecasting and communicating Meteorological and related information to users.

In provision of weather, climate and environment related services it is essential to put the users first and fully understanding why they need our services in their respective decision making systems. As clearly stipulated in the proclamation of NMA establishment, the main duties and responsibilities of NMA is to establish and operate national network of meteorological stations, collect all meteorological data and exchange in accordance of international agreement. Besides to this the Agency is also responsible to publish and disseminate meteorological information and forecast, provide early warning and advice on adverse weather and climate conditions and undertake meteorological research and studies.

Therefore, conducting research and studies in the field of meteorology and applied sciences, which support the operational activities of the Agency and socio-economic development of the country, is among the mandates given to NMA by the Government of Ethiopia by proclamation number 201/1980s.

By taking into account the country's Second Growth and Transformation Plan (GTP II), NMA has developed sector-specific GTP II (2008-2012 Ethiopian Calendar) among other plans, publishing eleven research papers that enhances the Agency to provide timely and accurate weather information and climate services. For this reason, this research book, which has two chapters, is intended to support operational activities of the Agency and deliver effective meteorological services for the wider range of multi sector institutions, disaster risk managers, research communities and general public in Ethiopia.

NMA has published a number of research series publications so far, but this Research Book is different among others since it encompasses different research findings of our users.

Last but not least, NMA will continue to produce and disseminate research in order to deliver quality services to key socio economic sectors as well as to meet our customer's satisfaction.

Fetene Teshome

Director General, National Meteorological Agency of Ethiopia

Preface

One of the key targets of National Meteorological Agency (NMA) of Ethiopia via Meteorological Research and Study Directorate in the Second Growth and Transformation Plan (GTP II), which spans from the period 2008 to 2012 Ethiopian calendar, is to produce eleven research findings and publish these research products and others in the field of Meteorology and [related] applied sciences. Therefore, this research book has been designed to meet the requirements of our users with the following main objectives: -

- To improve weather and climate services of the Agency
- To support sustainable economic and social development of the country
- To document and disseminate research outputs for internal and external users of the Agency

Based on the contents of the outputs this Research Book is divided in to two chapters. The first chapter contains research outputs from Meteorological data and Climatology, Meteorological Electronic and ICT and Meteorological Instrument and Civil Works Services provision. The second chapter focuses on improving Forecast, Early Warning and Applied Meteorological Services.

In the process of publication of this research outputs contribution of individuals and society plays unreserved effort. In view of this, Meteorological Research and Study Directorate would like to thank all those who contributed by any means, particularly during the review and editorial process of the manuscript: Special thanks go to Research Editorial Board, Senior scientists of NMA experts; Directors of Head Quarter Directorate and Regional Meteorological Services Centers and special recognition for the research experts. Finally, Meteorological Research and Study Directorate would like to acknowledge Mr. Fetene Teshome Director General of NMA and Mr. Kinfe H/Mariam Deputy Director General of NMA for their unreserved support and curiosity to see this research book series.

Fitsum Bekele

Acting directorate director of Meteorological Research and Study of NMA

Table of Contents

Part one: Research Outputs to Improve Data Service Provision

NATIONAL METEOROLOGICAL AGENCY

Inter-Comparison of Observation between Parallel Conventional and Automated Weather Observatoion in Ethiopia

Yosef Tesfaye[1] and Kinfe Hailemariam[2]

[1]Email:NMA (matyyos@gmail.com),

[2]Email: NMA (kinfe_hm@yahoo.com),
P. o. Box 1090

JUNE, 2019

ADDIS ABABA, ETHIOPIA

Acronyms and Abbreviations

AWS	Automated Weather Station
CWS	Conventional Station
CLIDATA	Climate Database
GCOS	Global Climate Observing System
GIS	Geographic Information System
GPRS	General Packet Radio Service
GTS	Global Telecommunication System
KOICA	Koran International Cooperation Agency
IRI	Internation Research Institiute
LST	Local Standard Time
MaxT	Maximum surface Air Temperature
MinT	Minimum surface Air Temperature
NMA	National Meteorological Agency
Rf	Rainfall
RTU	Remote Telemetry Unit
UNDP	United Nation Development Program
UTC	Coordinated Universal Time
WMO	World Meteorological Organization

Abstract

The observational system of manned conventional and automated stations are completely different, so, an attempt has been made to analyze the measured data difference between two types of stations, installed at the same geo-location, for temperature and rainfall variables from 40 pair of stations in the period of 2012-2017 over Ethiopia. Data collected from stations are statistically analyzed in order to authenticate the similarity and difference of observations. The hypothesis is that mechanical sensors have a slower response time than the electronic ones, which leads to difference in observed values. The result shows MaxT, MinT and rainfall paired correlations range from 0.78-0.99, 0.65-0.97 and 0.74-0.99 respectively. For most stations studied automated products show higher correlation coefficients with the conventional data, however, correlation is low for Jigjig and Neghele stations. The Root Mean Absolute Error is better for MaxT and MinT; but bad for Debark, Dilla, and Negelle stations. Also, it is bad for Hawasa, Dubti, Ginir, Metehara, Neghele, and Yabello rainfall observations. Likewise, Efficiency Coefficient is lower for Hawasa, Dilla, Jigjig, Negelle, and Yabello stations and the result of Bias was better. Outcomes show coefficients determination range between 0.61 to 0.98, 0.42 to 0.93 and 0.57 to 0.98 for MaxT, MinT and rainfall, respectively. Additionally, the study found reading and cleaning is the sources of error in meteorological measurements are discussed. Therefore, study found statistically insignificant differences between collocated conventional and automated observations for rainfall and temperature. Thus, it is possible to substitute the conventional stations with automated ones without major error on data homogeneity. Finally, the study recommends consideration for adopting of the expansion of the automated weather stations. Furthermore, the result indicates that automatic weather station sensors used are in a sufficient accuracy, robust, operate in wide temperature range, low power consumption; little drift over time, simple installation and low maintenance.

Key words: Automated, Conventional, Inter-comparison

1. Introduction

1.1. Background

Climate data is critical for the climate modeling, prediction and the early warning, and is used to determine the climate baseline, variability and extremes (Ogallo, 2010). Furthermore, climate variability persisting for more than a season and becoming a drought puts great pressure on land and vegetation (Harpal and Graeme, 2004). Though, African countries often have limited capacity to develop, generate, disseminate and effectively use climate data and information in climate risk reduction and management (Carberry, 2008). For example, it has an inadequate number of meteorological stations for climate data collection, and much of the data that exists has not been digitized (UNFCC, 2007). As noted by WMO (2003) meteorological station belongs to principal, ordinary, auxiliary and the spatial agricultural meteorological station and most countries the majority of meteorological stations belong to these categories. Therefore, modernization of observation networks is important for predicting and understanding the Africa's unique climate (UNDP, 2011). Besides, the number of weather stations throughout Africa is small and an unevenly distributed (Dinku, 2007). Meteorological observations made for a real-time preparation for local weather dependent operations (WMO, 2008). The purpose of this study is to support these activities by giving advice on good practices for meteorological measurements and observations. The study area Ethiopia is located in the eastern part of Africa and it covers a land area of one million square km and water area 104,300 square km bounded by 33E to 49E longitude and 3N to 15N latitude (CSA, 2016). Thus, topography plays a significant role in the climate of Ethiopia, creating diverse microclimates ranging from hot deserts over the lowlands to cool highlands (Dinku, 2007). NMA is sole public institution to provide climate service in Ethiopia. The mission of NMA is collecting and providing information on the adverse effect of climate over the country (www.ethiomet.gov.et). But, the data gap happens in some cases and to fill this gap we must find out an option. It has one headquarter, 11 national sub-offices with more than 1200 conventional meteorological stations and one radar station and satellite receiver across the country (www.ethiomet.gov.et). The network of 250 automatic weather stations (ADCON, VAISALA and JUBIX made) has been installed by NMA since 2010. The AWS data are configured to be measured every fifteen minutes and are automatically collected at a central server based availability of on GPRS connection (Adcon, 2010).

The major objective of this study is to investigate the inter-comparison of observation between parallel conventional and automated weather observatory based on observed meteorological data at the stations. Since the functioning of the automated weather station is different from conventional observation, inter-comparison studies on the difference between automated stations data and data from conventional stations are very crucial to identify the systematic difference or similarity. Many researchers have been conducted on the difference between AWS and CWS observation in the world.

For instance, in India, a study conducted by Vashistha et al. (2005) found the AWS data within WMO accuracy limit but another study Amudha et al., (2008) identified the marked deviation in surface air temperature data at 03 UTC. Similarly, a few stations of China systematic error in MaxT and MinT with AWS values a little higher than CWS observation. Nonetheless, so far, inter-comparison of conventional and automated stations has not been carried out in Ethiopia. Hence, in this paper, an attempt has been made to study inter-comparison between automated and conventional observed data of daily surface air temperature and rainfall. In CWS, surface air temperature is measured with liquid in glass thermometers housed in the wooden Stevenson screen and rainfall measurement is done with 20cm diameter manual rain gauge (Enric, 2013).

For AWS, surface air temperature is measured with sensors mounted inside thermoplastic radiation shield and most common types of thermometers used in an AWS are pure metal resistance thermometers or thermistors (CIMO, 2014; Adcon, 2010). In general, for research and studies according to WMO, 2012, one year of parallel measurement is not enough; three years is a minimum, and five is preferable. So, an attempt has been made to compare the measurement difference between co-located conventional and the automated observational data of temperature and rainfall for over five years. This study covers on 40 selected ADCON made AWS with CWS so; they are a parallel station at the same longitude and latitude location. The reason is VAISALA, and JUBIX made stations were installed at least five kilometers far from the conventional station.

1.2. Statement of the Problem

Due to the difference between observational system of conventional and automated stations, it is essential to compare the accuracy of AWS data with the CWS (Giri, 2015). Several studies for inter-comparison of AWS data with the CWS observations have been done in the past by Geeta and Panda (2014) for Karnatka region and Mohapatra et al. (2011) for its utility in study the synoptic disturbances

(Giri et al., 2015). However, such studies have not accomplished in Ethiopia and differentiate errors and similarities between them are not yet known.

1.3. Significance of the Study

The keen interest and significance of this study is to identify the advantage, disadvantage and similarity of the conventional station with automated weather station by compare and contrast based on observed data and history of instruments. After this, the study concludes which type of station is beneficial and functional for collecting meteorological data accurately at real time from both in remote and accessible area of Ethiopia. As a result, study develops and encourages the sustainability of the best-selected weather stations in Ethiopia. It will also help the acceleration of NMA modernization effort through the replacement of manned stations with automated ones. The result shall indicate if there are gaps in AWS installation, operation and maintenance that affect data quality and homogeneity.

1.4. General Objectives

The objective of this study is to inter-compare meteorological data observed by AWS and CWS, in order to verify and identify the statistical difference of measurements due to sensor types. The general hypothesis is that mechanical sensors have slower response time than the electronic ones and this could lead to different values of the observed meteorological elements, in particular rainfall and temperatures. So, the specific hypotheses were tested in the existing work if there is no statistically significant difference between the meteorological data measured on conventional (CWS) and automated weather stations (AWS).

1.5 Scope

The inter-comparison is restricted to rainfall and air temperature data for the 2012-2017 period because rainfall and temperature are the dominant factors in socio activities planning; because of its links with pasture and crop growth. Chapter 1 and 2 introduction and Literature review about CWS and AWS. In addition, Chapter 3 defines data and methodology. Chapter 4 will present results and discussion of inter-comparison and an exploration of factors that may affect the differences between CWS and AWS. Chapter 5 will present conclusions and recommendations.

2. Literature Review

Climate information is the key component of the policy and strategic planning activities in the country. Due to highly variable in space and time as the heterogeneities on a local scale in land surface features rivers, vegetation, etc. affect its distribution (Holder, 2006; Giri et al., 2015). Accordingly, observation of the earth system is important for understanding the weather and climate of countries (Kidd et al., 2012). These observations are the precondition for all socioeconomic activity to the preparation of model initial conditions through data integration; because climate plays the dominant role in agriculture (Kidd and Huffman, 2011). So, climate information is used to improve decision making in agriculture used in three main ways as, strategic purposes, tactical purposes and building resilience (Harpal and Graeme, 2004). NMA of Ethiopia has provided early warning information for more than three decades using weather and climate data collected from weather stations (Patt, 2007). Nevertheless, most meteorological instruments are in continuous use, meaning that immediate repair or adjustment is not always possible at some sites. Accordingly, a simple, strong structure along with the easy operation and maintenance are important factors. A robust structure is especially important for instruments installed outdoors. Although the equipment used for such units may be expensive, offer better observation results at a lower cost in the long run (JMA, 2013).

2.1. Status of Conventional Weather Stations in NMA of Ethiopia

Meteorological observations are carried out in principle as a continuous process, in which the frequency of observation can vary from a fraction of an hour up to periods of 24 hours (WMO, 2008). Observations are made using instruments, visually and by hearing. All value is not directly determined for a number of meteorological variables but is rather derived from other variables that have been directly observed (Jose et al., 2013). The objective of observation to record the status of observational dataset availability for climate monitoring, for future attribution, and for forecast evaluation both on seasonal timescales and at the much higher temporal resolution required for onset, duration and dry spell assessments (David et al., 2011). NMA has collected climate data and disseminated products to support socio-economic activities in the country (Dinku et al., 2013). Thus, four types of stations have been established by NMA following the main roads and towns, where infrastructure is available. Over ten weather variables are observed from synoptic and principal stations, while, MaxT, MinT, and Rf data are collected from third class stations and only rainfall from fourth class stations.

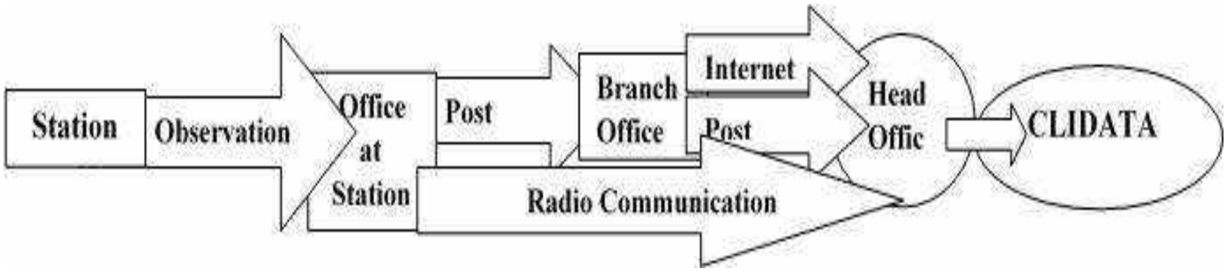


Figure 1. Flow chart for Communication between Conventional stations and head office

Figure 1. Flow chart for Communication between Conventional stations and head office

In general, from conventional observatories the parameters daily MinT and MaxT observations are taken by WMO standard synoptic hour, i.e. 0900 UTC and 1800 UTC from minimum and maximum thermometer with alcohol thermometers and mercury in glass thermometer housed in wooden Stevenson screen, respectively (WMO, 2008). In addition, daily rainfall an observation is taken by 0900 UTC standard synoptic hour from rain gauge of each day has been used for this study. Figure 1 showed the complex communication system from CWS to branch and head office. This system offers one-way communication but often require manual initiation.

2.1.1. Manual Recording of Meteorological Data

Surface weather reports are prepared and exchanged throughout the world in an international code developed and agreed upon by member states of the World Meteorological Organization (WMO, 2008). Observation with instruments which do not have self-recording instruments is taken manually, by a weather observer at given observation times. These readings are written into an appropriately designed observation book. This book has to be designed in accordance with the observation programme. For stations which do not have self-recording devices, the observation book constitutes the basic document and it is extremely important that it is properly kept (MANOBS, 2015). From this basic document, data can be transferred to dekadal, monthly, annual summaries and be extracted for special analysis.

2.1.2. Mechanical Recording Instruments

There are physical principles available for measuring meteorological parameters, which result in changes in the length of the sensing element or where the sensor exerts a force. This can be transmitted mechanically with or without amplification to a recording system, which is usually based on a clock is driven paper strip, either of the drum or endless belt type (WMO, 2008). With regard to the magnitude of the movements and the exerted forces and the technical possibilities for mechanical amplification, mechanical recorders have limited accuracy and the distance between sensing element and recording device has to be kept small (Wikipedia.org). The main advantages of mechanical recorders are the relatively low cost, easy maintenance and their independence from an external power supply. The variations over time of the parameter to be measured are displayed in graphical form on diagram chart. Generally, these charts have an appropriate time unit imprint to facilitate the analysis. As in most cases, this chart analysis is carried out manually and considerable manpower input has to be considered (Darnhofer, 1985).

2.1.3. Distribution of CWS in NMA of Ethiopia

The stations types classified as per number of instruments that installed at the station and time of observation. Those meteorological instruments are manufactured from the international factories such as Casella in London, Lambrecht in Germany, Siap in Italy and Japan that are recognized by WMO. Observation from instruments divide in to direct reading and self-recording instruments, also these all are operated, processed and key entry to database manually with WMO standard. Recently NMA has more than 50 years' data collection experience. Thus, it has 28 synoptic stations are land-based meteorological stations that report surface synoptic observations every three hours within 24 hours via the GTS in near real time (David et al., 2011).

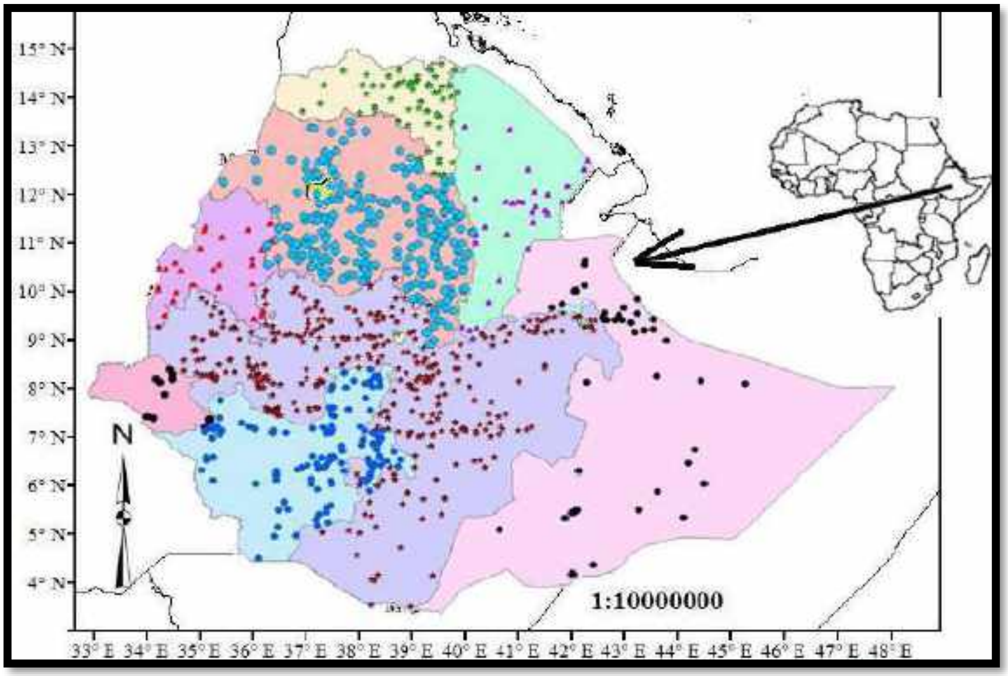


Figure 2. Distribution of Conventional Stations over Ethiopia

In addition, about 209 principal stations operated by full time meteorological observers, then observation taken every three hours within 12 hours of day time. Furthermore, 754 third class stations and 403 fourth class stations operated by part time workers and collecting daily surface air temperature and rainfall data once a day (www.ethiomet.gov.et). Merely, through these years there are many data gap due to different grounds. These grounds are: shortage (accessibility) of spare instrument, employees not observed at time of observation, observation skill, key entry error, less frequent station visit and maintenance due to remoteness of the country and vehicles limitations. As shown in Figure 2 distribution of the stations is not evenly distributed, especially in the remote peripheral areas. Therefore, distribution of conventional meteorological stations has a problem based on the above mentioned grounds. This involves spatial distribution of stations, as well as data completeness.

2.2. Status of Automatic Weather Stations in NMA in NMA of Ethiopia

An automated weather station (AWS) is defined as meteorological station at which observations are made and transmitted automatically using General Packet Radio Service (GPRS) and internet network (WMO, 1992a). GPRS is a method of enhancing phones to enable them to send and receive data more rapidly (Adcon, 2009). The layout of an AWS typically consists of a standard observing area, preferably no smaller than 25m x 25m a series of automated sensors sited at the recommended positions and interconnected to one or more data collection units using interfaces (WMO, 2012).

They are becoming increasingly popular in many applications owing to their becoming more affordable, reliable and through the growth in personal computing bringing sophisticated data manipulation and archiving within the reach of all (Andrew, 2009). Recently, NMA of Ethiopia has been using automated weather stations are product of ADCON Telemetry of Austria, and VISALA of Finlan and Jubix of South Korea. So, ADCON Company initially established in 1992 by using the core technology low power ultra-high frequency radio (Adcon, 2009). This study used output of ADCON stations; because more number of AWS are installed by NMA. RTU, A850Telemetry Gateway and AddVANTAGE Pro are the three basic components in ADCON AWS system.

2.2.1. Remote Transmission Unit

Remote Telemetry Unit (RTU) is based on GPRS technology; integrated battery pack recharged via solar panel and it store meteorological data for up to 6 months for a standard setup. RTU has more than twelve analog inputs sensors (Figure 3). These are SEN-R combined sensor for many meteorological elements, leaf wetness, soil temperature salinity, irrigation sensor, conductivity and moisture (Adcon, 2009).

2.2.2. A850Telemetry Gateway

The A850 Telemetry Gateway (Figure 3) is a low-power, battery-backed device that acts as an interface between an ADCON Telemetry net-work and one or more hosts running addVANTAGE Pro and similar data acquisition software.

Figure 3. AWS RTU and A850 Telemetry Gateway

The A850 Telemetry Gateway (Figure 3) is a low-power, battery-backed device that acts as an interface between an ADCON Telemetry net-work and one or more hosts running addVANTAGE Pro and similar data acquisition software. The capabilities of the A850 telemetry gateway allow managing up to 1000 RTUs depending on the version used. In addition, responsible for sending configurations to RTUs, polling for data from RTUs and storing data every 15 minutes (Adcon, 2007).

2.2.3. AddVANTAGE Pro

The addVANTAGE Pro server is based architecture which collects data from one or several ADCON Telemetry Gateways receivers and makes it available for viewing or for analysis. The server is that part of the software where all the actual processing takes place. The server is responsible for download data from the A850Telemetry Gateway, storing data into the database, starting and stopping extensions and servicing clients as they connected (Adcon, 2010).

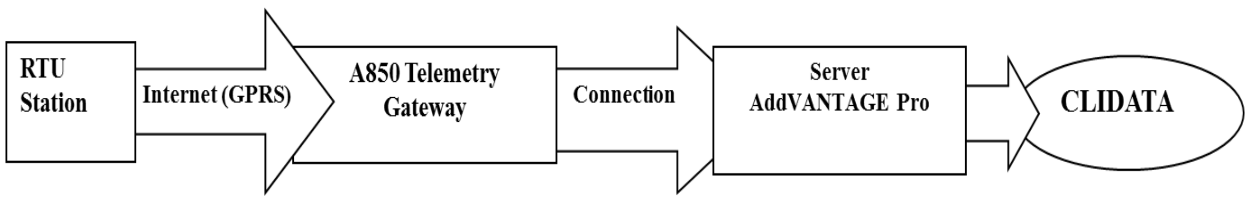


Figure 4. Flow chart for Communication between AWS and CLIDATA

Generally, addVANTAGE Pro server is Oracle based database software, has features such has user access via browser (Internet Explorer), multiple data sources (Gateways or server to server), visualization of collected data, and calculation of extensions by using statistics and disease models (Adcon, 2010). Figure 4 shows the simplicity communication system between the RTU, A850Telemetry Gateway, addVANTAGE Pro and CLIDATA (it is the main database server at NMA).

2.3. Distribution of AWS in NMA of Ethiopia

NMA is currently operating more than 300 AWS in the country, of which 180 stations are ADCON Austria made and were installed since August, 2010 (Figure 5). The most common rainfall measuring equipment in AWS is the tipping bucket rain gauge. Gauges are rapidly blocked by debris such as leaves, sand or bird droppings; therefore, care must be taken with AWS used for long unattended operations (Adcon, 2009). Moreover, the East African Rift Valley together with the surrounding plateaus and mountain chains form the main topographic features; because, topography plays significant role by creating diverse microclimates ranging from hot deserts over the low lands to very cold mountain ranges (Dinku et al., 2008). Therefore, the horn of Africa needs even distribution of station.

Surface air temperature is a measured with sensors mounted inside thermoplastic radiation shield and the most common types of thermometers used in an AWS are pure metal resistance thermometers or thermistors (CIMO, 2014). The surface air temperature and rainfall extracted automatically from every fifteen minute organized and managed data by means of addVANTAGE Pro from the database server.

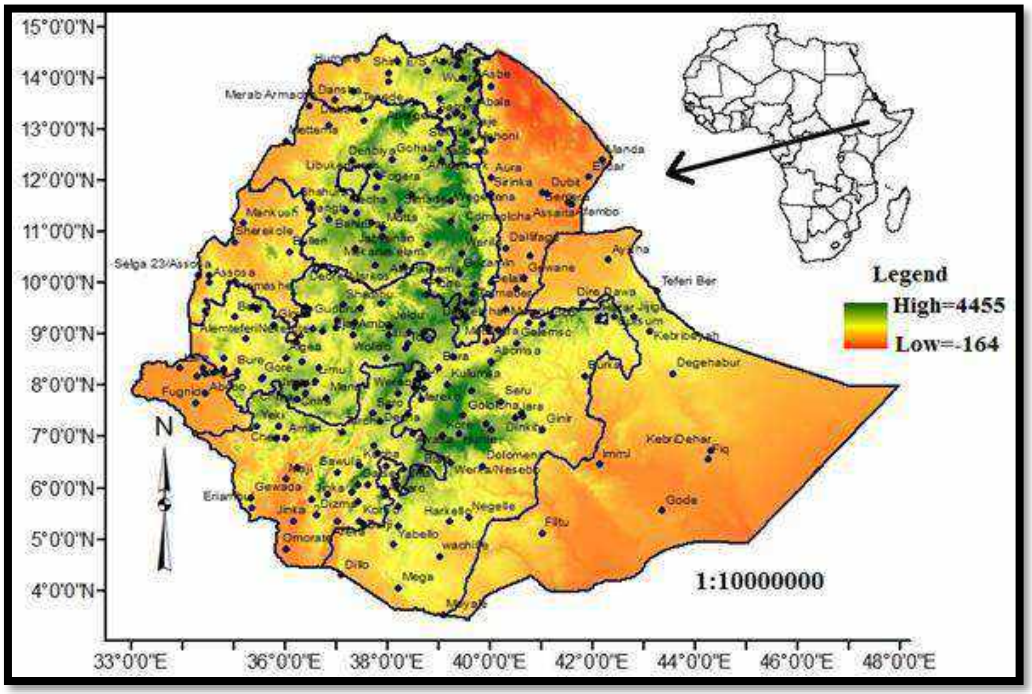


Figure 5. Distribution of 250 AWS at NMA of Ethiopia

2.4. Calibration Time for CWS and AWS

Calibration is the practice of checking an instrument against another of known accuracy. Also, the most common way to calibrate meteorological instruments is by comparison with standard instruments (Andrew, 2009). These are usually kept at the national center and checked from time to time against international standards. However, certain instruments and high-precision calibrations sometimes require rather sophisticated calibration equipment and have, therefore, to be sent to specialized laboratories (Darnhofer, 1985). Any physical measuring meteorological instruments have to be calibrated to meet comparability requirements as per WMO standard (Table 1). Initial calibrations are usually made by the supplier of the equipment, but many instruments need to be checked or recalibrated after transportation and installation (WMO, 1986; WMO, 2008). Recalibrations are a must after repairs or replacement of essential parts of the instruments. As the ageing process in most instruments affects zero level and eventually the sensitivity, is advisable to recalibrate at regular intervals to maintain the equipment's accuracy and comparability of data obtained (WMO, 2008).

Table 1. Time table for Weather station instruments Calibration

Conventional Weather Station				AWS
No	Instrument Name	Frequency	Reference	
1	Anemometer	1/2year	WMO_No.622(1986) page 339	Depending on the environment AWS sensor may need a recalibration every 5 years
2	Mercury barometers: Working Standard against primary Standard	1/2year	WMO_No.622(1986) page313 WMO_No.8(2006) 3.10.3.1	
	Mercury barometers: Reference Standard against National working Standard	1/2year	WMO_No.622(1986) page313 WMO_No.8(2006) 3.10.3.1	
	Mercury barometers: Station Barometer with Reference Standard	1/1 year	WMO_No.622(1986) page313 WMO_No.8(2006) 3.10.3.1	
3	➢ Thermometers -Glass ➢ Thermometers -metal resistance ➢ Thermometers- thermistor ➢ Humidity Hygrometer	➢ 1/5year ➢ 1/1year ➢ 1/6mont h ➢ 1/1year	WMO_No.622(1986) page325 WMO_No.8(2006) 2.2.5.2	
4	Thermo-hygrograph	1/1year	WMO_No.622(1986) page336	
5	Psychrometers	1/2year	WMO_No.622(1986) page337	
6	Rainfall recorder	1/2year	WMO_No.622(1986) page252	
7	Evaporation pan	1/2year	WMO_No.622(1986) page252	
8	Sunshine recorder	1/1year	WMO_No.622(1986) page252	
9	Actinograph	1/2year	WMO_No.622(1986) page347	

NMA have limitations of calibration facilities, especially for AWS, though it has sufficient number of mobile testing units. Thus, the current attempt is replacement of sensors with a new one, if found drifting or sensor life time ends.

3. Data and Methodology

3.1. Study area description

The study used 40 stations at parallel location (Figure 6) and is placed at horn of Africa over Ethiopia, has most complex topography on the continent and elevation ranges from below sea level 164 to above mean sea level 4455 meters (Dinku et al., 2013).

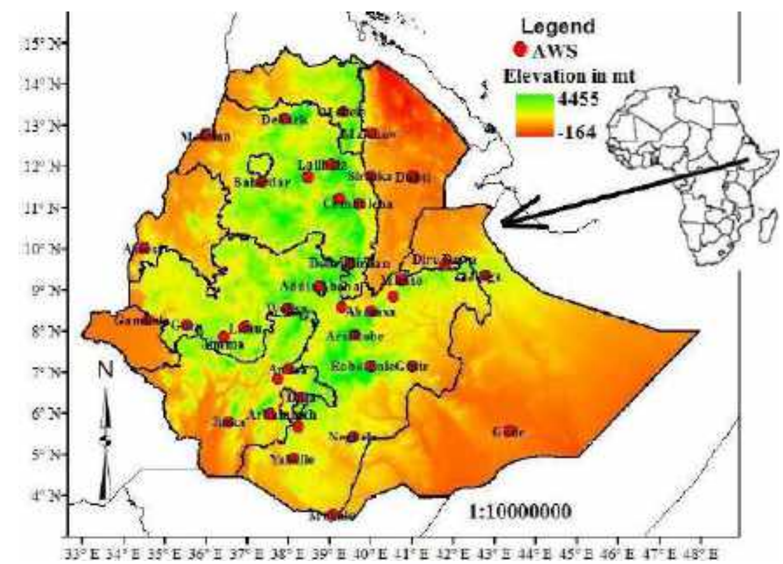


Figure 6. Distribution of 40 Selected AWS and CWS for this Study

*Table 2. List of Selected CWS and AWS Geographic location and Meteorological data period (*Reference: Ethiopia Road Authority and ArcGIS 10.3)*

No	Station Name	Elevation (meter)	Longitude	Latitude	Installation year AWS	AWS raingauge	Time of AWS
1	Abomsa	1630	40.00	8.47	2013	Stand	Feb/2016
2	Addis Ababa	2330	38.75	9.08	2011	Stand	Jul/2017
3	Ambamariam	2918	39.22	11.20	2014	Stand	Not
4	Arbaminch	1220	37.53	5.96	2011	Arm	Feb/2016
5	Arsi Robe	2434	39.62	7.88	2015	Stand	Not
6	Assosa	1600	34.50	10.00	2015	Stand	2015
7	Awasa	1694	38.00	7.06	2013	Stand	2016
8	Bahirdar	1800	37.36	12.00	2011	Arm	2016

9	Combolcha	1857	39.7	11.08	2011	Arm	Feb/2016
10	Debark	2843	37.90	13.14	2014	Stand	2019
11	DebreBirhan	2750	39.50	9.63	2015	Stand	Not
12	Dilla	1570	38.30	6.37	2014	Stand	2018
13	Dire Dewa	1260	41.80	9.60	2011	Arm	Feb/2016
14	Dubti	378	41.01	11.723	2011	Arm	Feb/2016
15	Gambela	500	34.58	8.25	2011	Arm	2015
16	Gelemso	1739	40.53	8.81	2011	Arm	Feb/2016
17	Ginir	1750	41.00	7.13	2013	Stand	Feb/2016
18	Gode	287	43.35	5.55	2013	Stand	Not
19	Gore	2033	35.53	8.13	2011	Arm	2015
20	Hageremariam	1861	38.23	5.65	2011	Arm	Feb/2016
21	Jijiga	1775	42.78	9.33	2011	Arm	Feb/2016
22	Jimma	2000	36.42	7.84	2011	Arm	Jul/2017
23	Jinka	1373	36.55	5.77	2011	Arm	2018
24	Lalibela	2487	39.04	12.04	2011	Arm	2016
25	Limu	1772	36.95	8.07	2014	Stand	2018
26	Maichew	2432	40.00	12.78	2013	Stand	2019
27	Mekele	2257	39.32	13.32	2011	Arm	2017
28	Metehara	790	36.00	12.77	2011	Arm	Sep/2016
29	Metema	790	35.99	12.73	2013	Stand	2019
30	Miesso	1332	40.75	9.23	2011	Stand	Feb/2016
31	Moyale	1110	39.07	3.52	2011	Arm	Feb/2016
32	Nazreth	1622	39.28	8.55	2011	Arm	Feb/2016
33	Neghele	1544	39.57	5.42	2011	Arm	Feb/2016
34	Nifasmewcha	2980	38.47	11.73	2014	Stand	2019
35	Robe-Bale	2480	40.00	7.13	2011		Feb/2016
36	Semera	590	41.00	11.76	2013	Stand	Feb/2016
37	Sirinka	1861	40.00	11.75	2013	Stand	2019
38	Wolaitasodo	1854	37.73	6.81	2015	Stand	Not
39	Woliso	2058	37.97	8.54	2015	Stand	Not
40	Yabello	1729	38.10	4.88	2011	Arm	Feb/2016

3.2. Data collection

Both CWS and AWS data from pairs of collocated 40 stations were obtained from the NMA national climatic database for the period of 2012 to 2017. The locations of the paired CWS and AWS stations are shown in Figure 6 and Table 2. 24 hrs accumulated CWS rain gauge data is compared with the data of AWS for the same period of time. Besides, MinT data were taken at 900 LST hours and MaxT observation taken at 1800 LST from CWS and compared with the data of the same accumulation time of AWS. Data quality checked using Climate Data Tools of IRI.

3.3. Inter-Comparison Methods

Microsoft Excel 2013 is an application and a powerful spreadsheet program that allows us to organize data, complete calculations, makes decisions and graph data (Wilks, 2006). The inter-comparison of CWS and AWS product at observed rainfall and surface air temperature amount are evaluated using daily data. Surface air temperature and rainfall extracted automatically from every fifteen minutes collected data from AWS database server and from CWS at 0900 and 1800 time of observation. Different statistical tools used for inter-comparison are shown in table 3, where: comparison statistics with n is number of observations, AWSi stand for AWS value for the ith observations and CWSi stand for manual observed value for the ith gauge measurement. Lower value of RMAE indicates good fit of the model and higher value of Bias, r and Eff indicate good fit of the model. Pearson correlation coefficient (r) analysis is used to distinguish the degree of measures of the relationship between the observation that taken from both stations (Wilks, 2006; Carolien et al., 2015). If data are well correlated and independent variable coefficient (a) should be close to one, and the intercept (b) should close to zero (Hilton, 2006). Besides, Relative RMAE estimates the average error in the unit as fractions (Dinku et al., 2013; Carolien et al., 2015) and Eff without unit shows the skill of AWS relative to CWS mean and varies from minus infinity to one. One corresponds to a perfect match between CWS and AWS data (Dinku et al., 2013). The Bias without unit indicates how well the mean of AWS and CWS correspond (Anita et al., 2010; Edebeatu, 2015). Some basic questions related to the first hypothesis are: How similar are the datasets generated by AWS and CWS? To answer these questions, an exploratory comparison analysis using line and scatter plot with statistical equations and linear regression has been applied (Table 3). Thus, scatter plot is used to compare the two sets of value and it shows the relationships between pairs of data when data presents. In addition, line charts are used to show trends over time (days) and observation from the station. Depending on the situation, temperature and rainfall differences between AWS and CWS described by the percentage differences (PD) defined as shown in the table 3 and the results are presented using CWS as a reference (Brandsma, 2014).

Table 3. Statistical method for Inter-comparison

Name	Equatio n	Perfect Score
Relative Mean Absolute Error	$RMAE = \frac{\sum_{i=1}^{n} \frac{\lvert AWSi - CWSi \rvert}{n}}{mean(CWSi)}$	0
Bias	$Bias = \frac{\sum_{i=1}^{n} AWS_i}{\sum_{i=1}^{n} CWS_i}$	1
Pearson Correlation Coefficient	$r = \frac{n\sum_{i=1}^{n} AWS_i\, CWS_i - \sum_{i=1}^{n} AWS_i \sum_{i=1}^{n} CWS_i}{\sqrt{((n\sum_{i=1}^{n} (AWS_i^2 - (\sum_{i=1}^{n} AWS_i)^2)(n\sum_{i=1}^{n} CWS_i^2 - (\sum_{i=1}^{n} CWS_i)^2))}}$	1
Nash-Sutcliffe Efficiency Coefficient	$Eff = 1 - \left[\frac{\sum_{i=1}^{n} (AWS_i - CWS_i)^2}{\sum_{i=1}^{n} (CWS_i - \overline{CWS_i})^2}\right]$	1
Percentage Differences	$PD = 100*((AWS-CWS)/CWS)$	Smaller amoun t

Thus, scatter plot is used to compare the two sets of value and it shows the relationships between pairs of data when data presents. In addition, line charts are used to show trends over time (days) and observation from the station. Depending on the situation, temperature and rainfall differences between AWS and CWS described by the percentage differences (PD) defined as shown in the table 3 and the results are presented using CWS as a reference (Brandsma, 2014).

4. Result and Discussion

The linear regression analysis gives a significant analysis at 95 % significance by computing p values, and it presented the scatter plot with the results of the four statistical methods and linear regression of 40 stations. Furthermore, the line charts indicated an observation error between both stations measurement versus date.

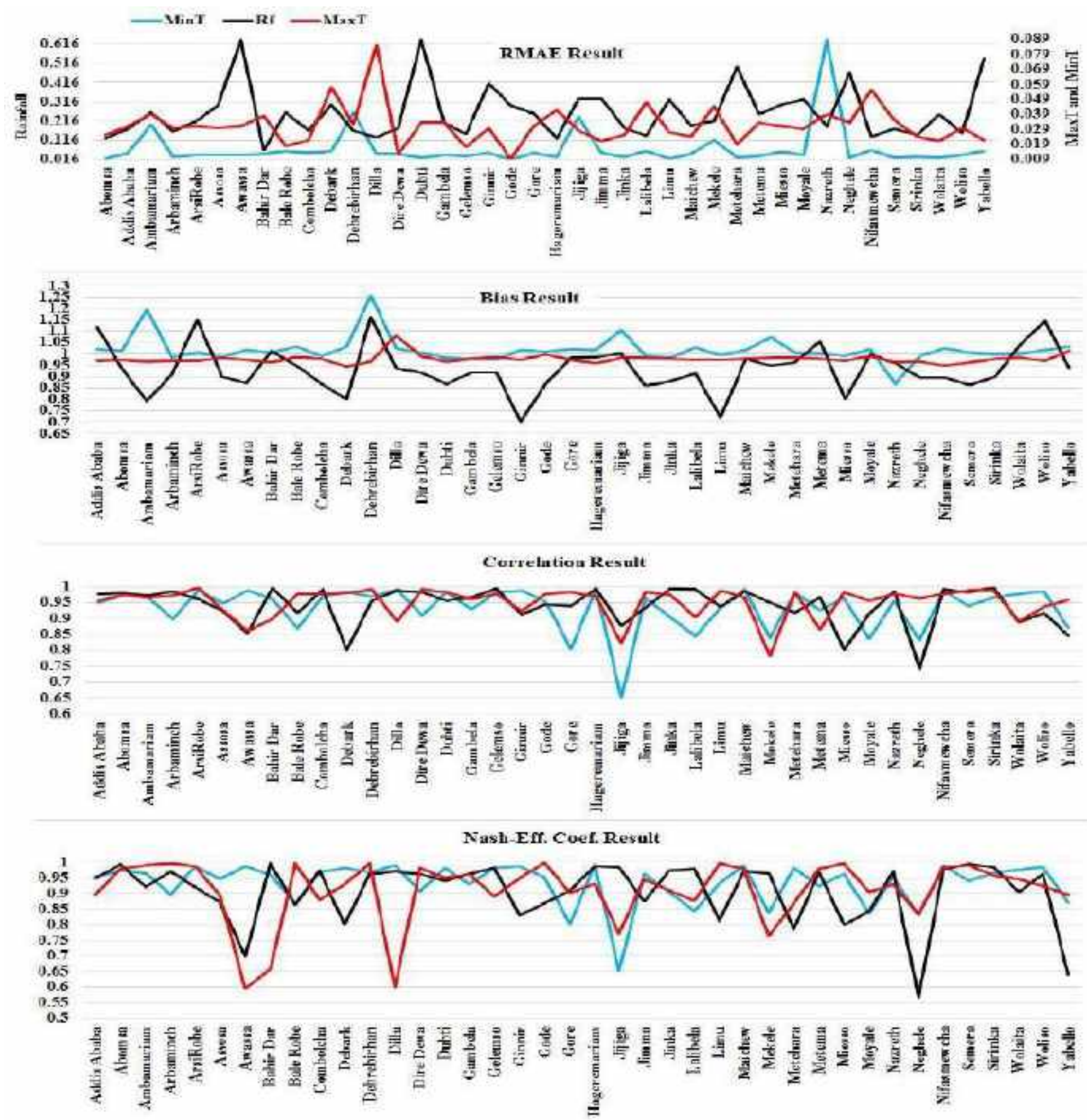


Figure 7. Line Chart for Result from the four Statistical Methods

Figure 7 show the result of the statistical methods during the study periods, for MaxT, MinT, and Rf. The correlation ranges from 0.78 to 0.99, 0.65 to 0.97 and 0.74 to 0.99 respectively. Most AWS data show higher correspondence (correlation coefficients) with the CWS data, but low correlation for Neghele and Debark rainfall and Jijiga stations MinT. Figure 7 shows for the coefficients determination range between 0.61 to 0.98, 0.42 to 0.98 and 0.55 to 0.99 for MaxT, MinT, and Rainfall, respectively for the dataset from most of the stations. However, lower values obtained for the Ginir (0.53) and Jijiga stations (0.42) for MinT, and Hawasa (0.55) for rainfall. The RMAE indicated better result for MaxT and MinT (ranging from 0.01 to 0.04 and 0.02 to 0.24, respectively), except for Nazreth station (0.64) for MinT. It is bad for Neghele (0.47), Hawasa (0.64), Dubti (0.64), Ginir (0.40), Metehara (0.50), and Yabello (0.54) station rainfall data. The correlation coefficient result shows Hawasa (0.75), Dilla (0.78) for MaxT; Hawasa (0.60), Negelle (0.70), and Yabello (0.60) for rainfall, also Jijiga (0.65) for MinT had relatively lower values. Bias had better value except for Ginir station (0.7).

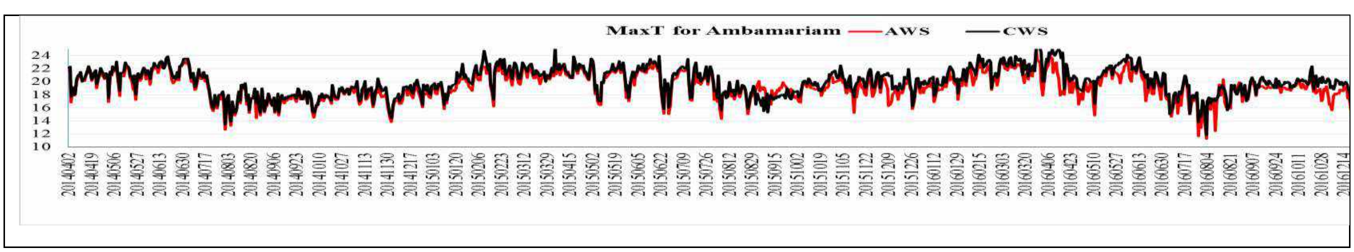
4.1. Sources of error

Additionally, the studies identified possible sources of error in the process of meteorological measurements and are discussed below in six parts.

4.1.1 Accuracy is affected due to meteorological observation, non-skilled staff, or Parallax Error.

The efficiency of the instrument shelter which should certify that the air in the housing is at the same temperature as the air immediately surrounding, in this case this error is small, but the difference between an effective and an unproductive shelter may be the major in exact conditions. The accuracy of a measuring instrument is the ability to give responses close to a true value.

Furthermore, another source of error common to all instruments is parallax reading errors and it occurs because the approach of the observer to read the thermometer usually disturbs the surroundings in some way. Therefore, the study identified these errors on maximum temperature observation at Ambamariam, Debark, Dilla, and Neghele station as shown in Figure 8.



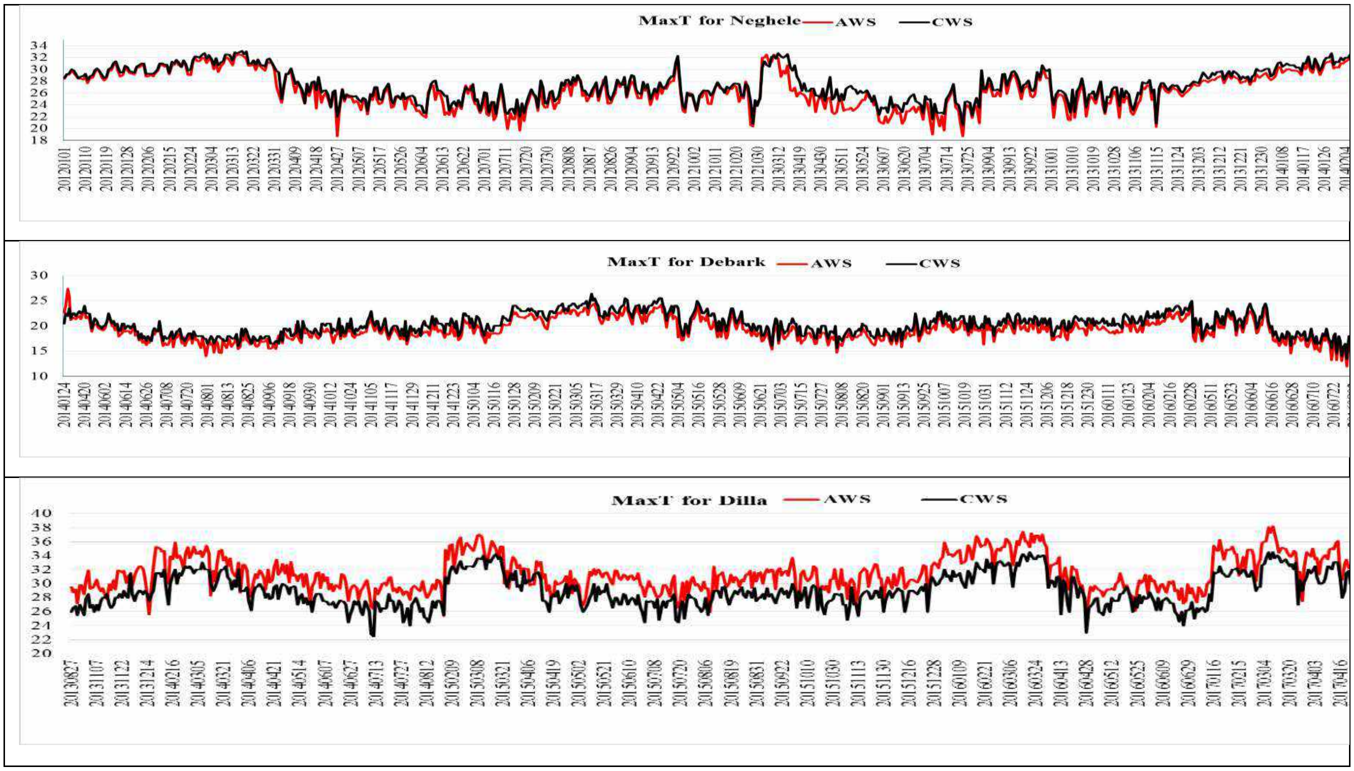
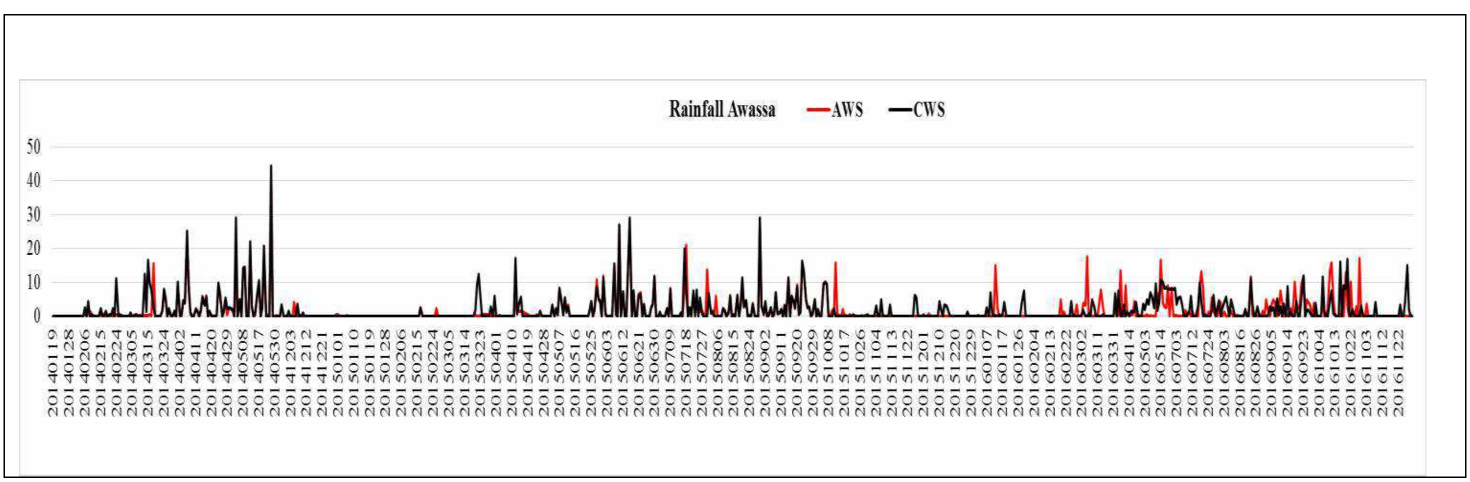


Figure 8. Station with Parallax reading Error

4.1.2. Uncleaning, and Touching Instrument before unplug the sensor of AWS

Observing sites and instruments should be maintained regularly so that the quality of observations does not deteriorate significantly between station inspections. Routine quality control checks carried out at the station or at a central point should be designed to detect equipment faults at the earliest possible stage. As WMO recommended the sensors and screen should be kept clean and should be repainted regularly.



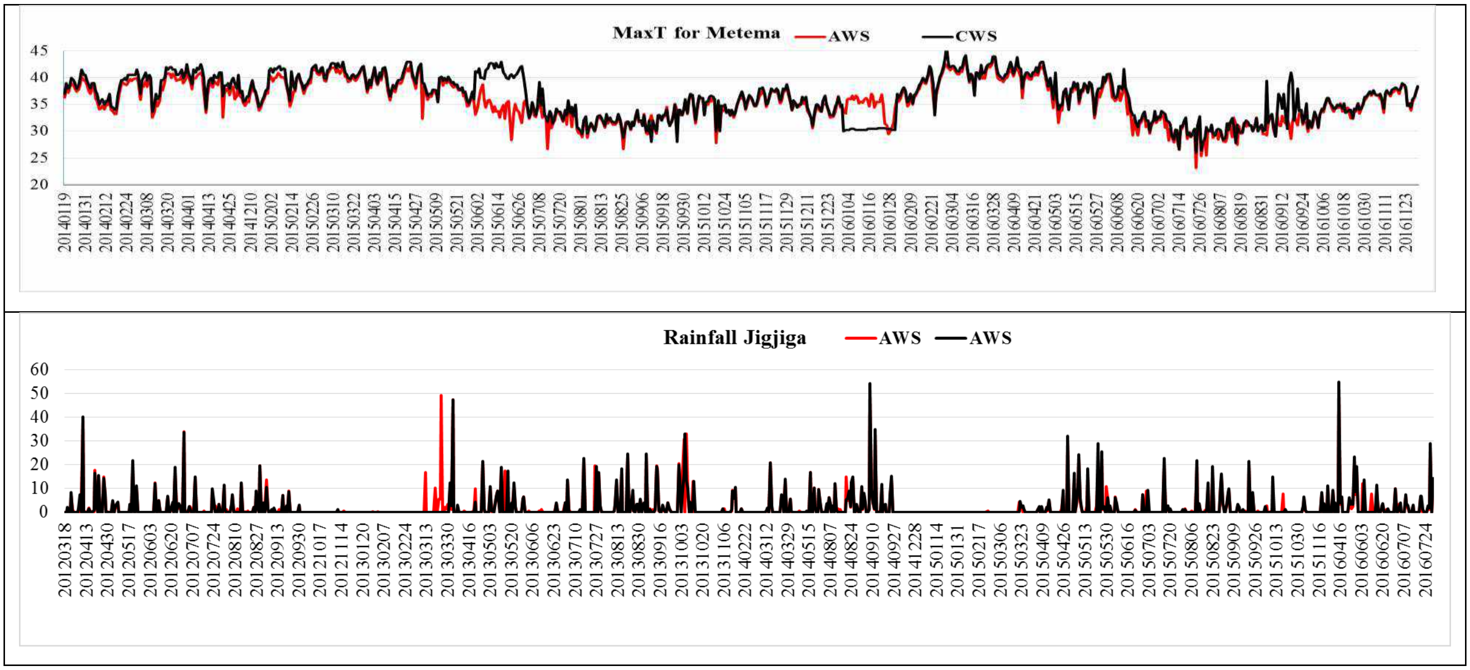


Figure 9. Error observation taken from the Station

The result of unclean tipping bucket would be blockage and no rain recorded or filling part of the bucket with dust and record rainfall higher that manual. Most kinds of dust will cause significant errors in observations and in most cases; this may be eliminated, or at least reduced, by cleaning and washing the instruments regularly. Routine maintenance should include cleaning the funnel and buckets of accumulated dirt and debris, as well as ensuring that the gauge is level. As required, the outer container of the gauge as well as the graduate, should be kept clean at all times both inside and outside by using a long handle brush. The gauge must be kept level and the funnel and buckets clean and free from obstruction. A good system to adopt is one of a monthly maintenance check in which the rain gauge is checked for detritus, including the buckets, and funnel cleaned of dirt. Let us look observation taken from Hawasa, Metema, Jigjig and station (Figure 9). Cleaning of AWS must be after unplugged sensors from RTU.

4.1.3. Disturbance of Wind for AWS rain gauge

The exploratory analysis also suggests that AWS sensors are more sensitive to instant fluctuation events than CWS, mainly for wind gusts. Although differences in the catch of rain gauges can often be explained by differences in wind error, this is probably only partly the reason here. Two factors should be considered. First, CWS rain gauge is mostly installed by its stand while AWS stations the rain gauge support by horizontal stand as an arm. This fluctuation can mainly affect the daily extreme values, increasing the difference between CWS and AWS measures (Figure 10).

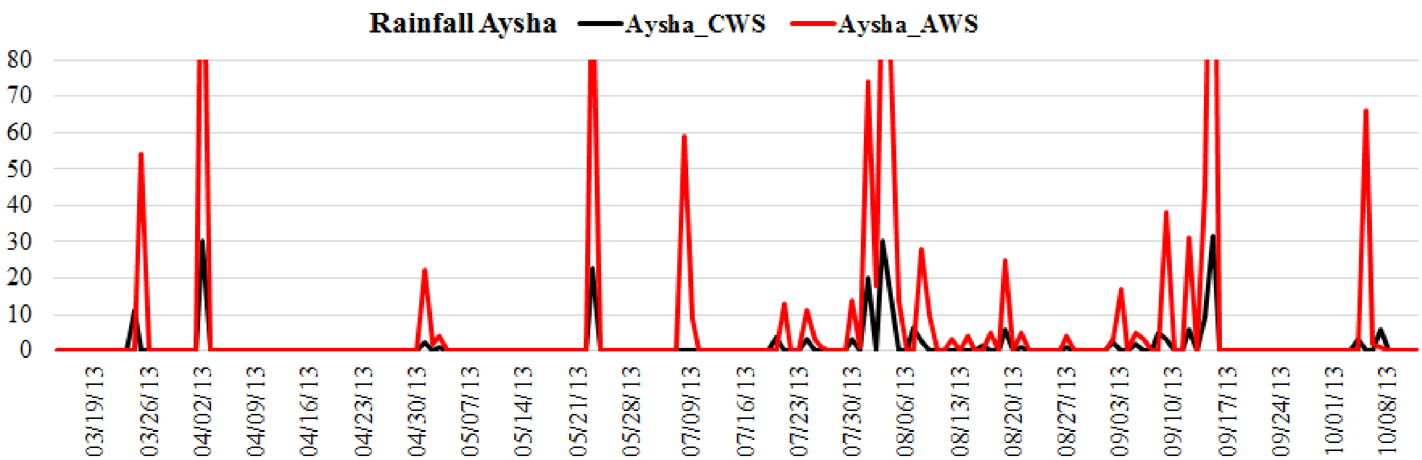


Figure 10. Rainfall data from Aysha AWS and CWS

The tipping bucket gauge is not satisfactory for indicating the onset of very light rain, or in prolonged periods of freezing weather. Totals will be lower than the true values due to wind effects around the gauge orifice, evaporation from the buckets between showers, and loss between tips of the buckets in heavy rain.

4.1.4. Untimely Observation

Artificial error includes bias caused by the observer's carelessness in the reading the scale and untimely observation. They can be considerably reduced if the observer takes care in reading measurements timely (Figure 11).

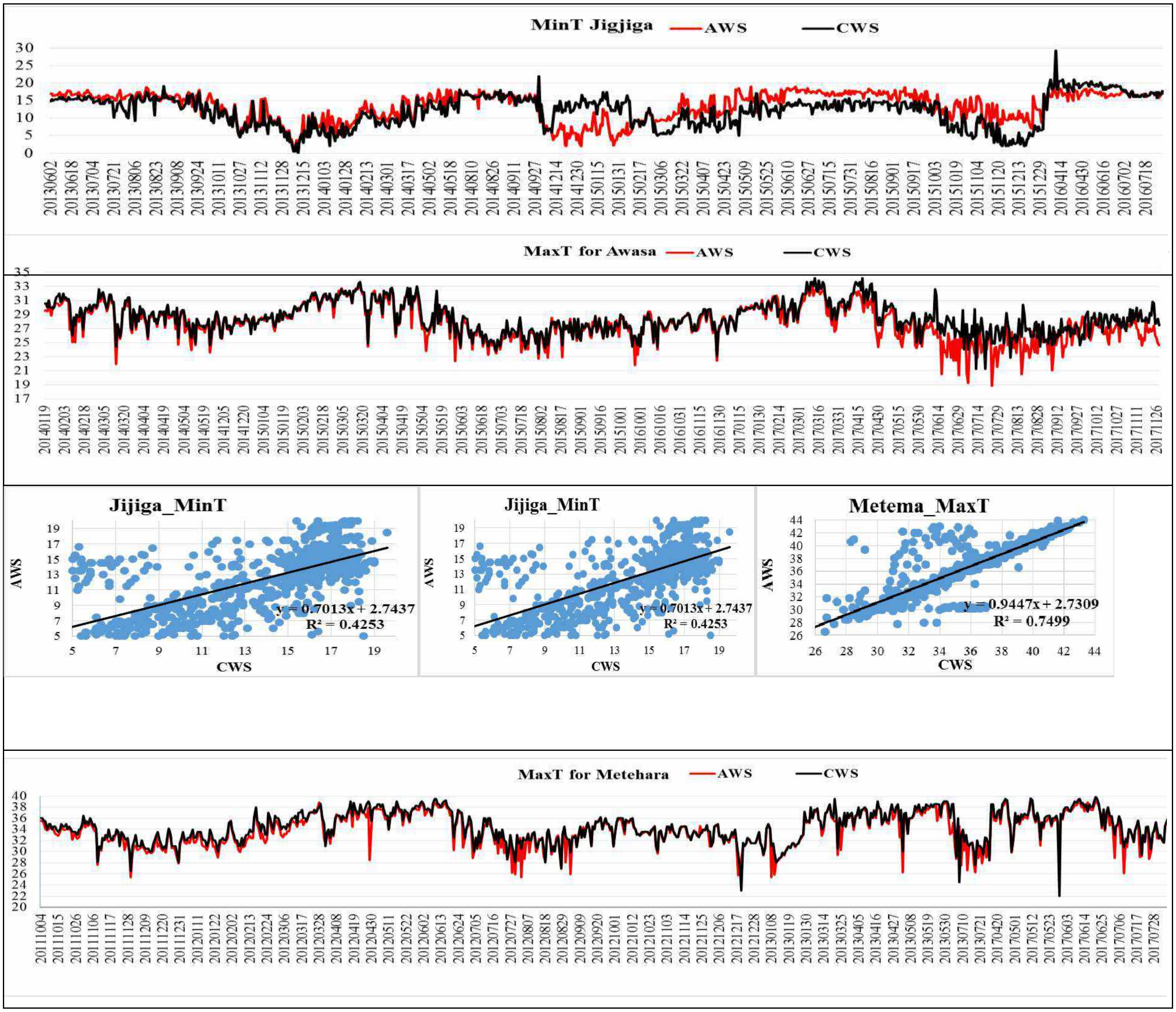


Figure 11. Rainfall data from Aysha AWS and CWS

4.1.5. Percentage Difference (PD)

The study selects the following nine stations that have reading error from the results. Thus, figure 12 shows the daily percentage difference (PD) between AWS and CWS of the daily MaxT, MinT and rainfall observation for Ambamariam, Hawasa, Debark, Dilla, Ginir, Jijiga, Metehara, Metema, and Neghele stations.

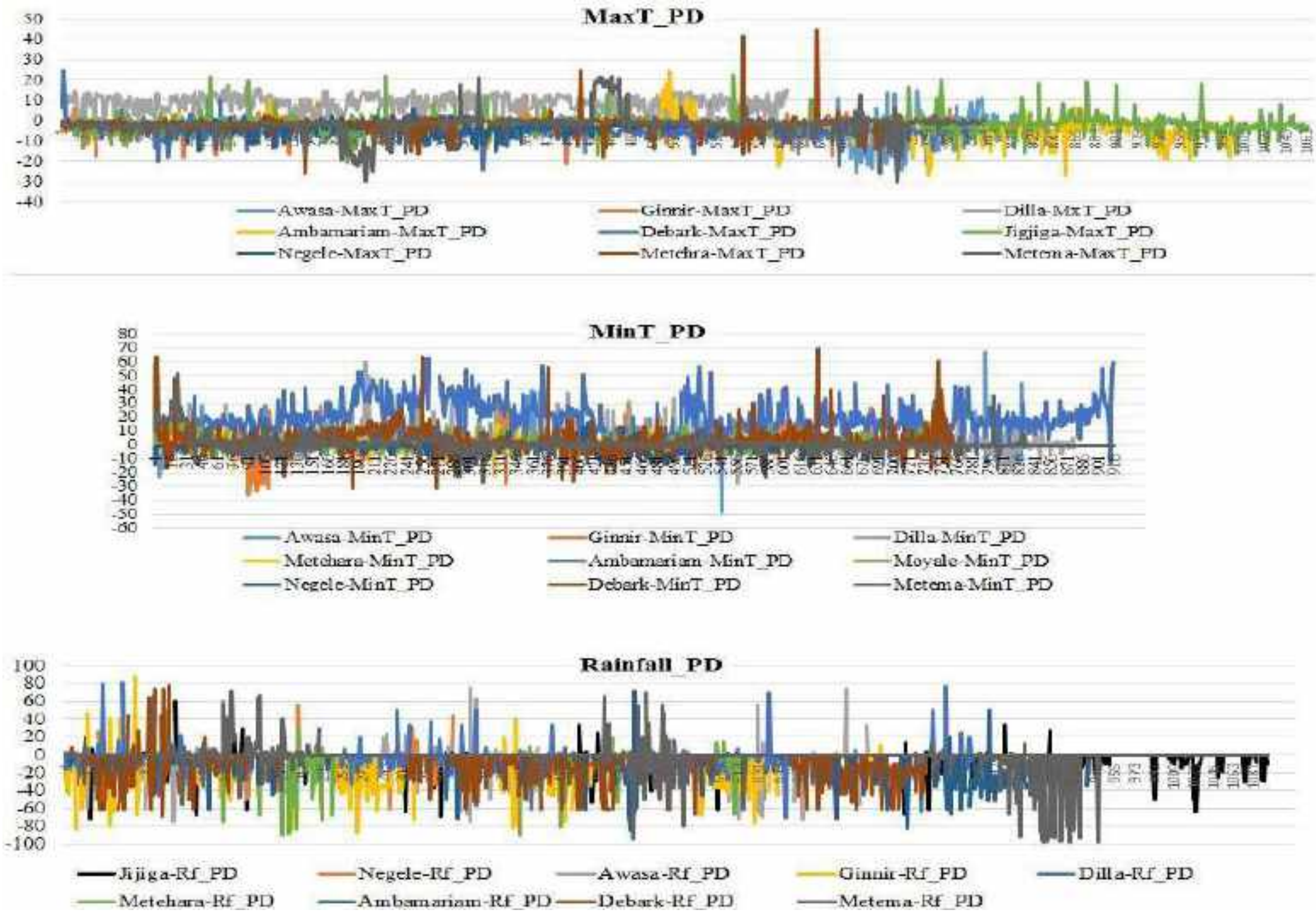


Figure 12. Percentage differences between the MaxT, MinT and Rainfall amounts of the AWS and the CWS in the 2012-2017 periods

There are large differences between the data sets. There is, however, for MaxT, MinT, and Rf correlation coefficients is range from 0.65-0.99 for these stations. Temprature measured by AWS, in most of the cases, is lower than the temperature readings from alcohol and mercury in glass thermometer. Although the maximum percentage difference in individual values reaches up to -20 to 30% in a few cases. High PD has been observed in the values of daily rainfall in these stations. The few exceptional cases may be outliers due to data quality. While the PD results shows very less in the rest stations relative to others.

4.1.6. Extreme Observation

These are contingent on sensors specification. For instance, specification of air temperature measurement ranges from -40 to +60 °C and accuracy is ± 0.1 °C. Furthermore, for rainfall has resolution or sensitivity 0.2mm.

Figure 13 shows extreme value from CWS and AWS.

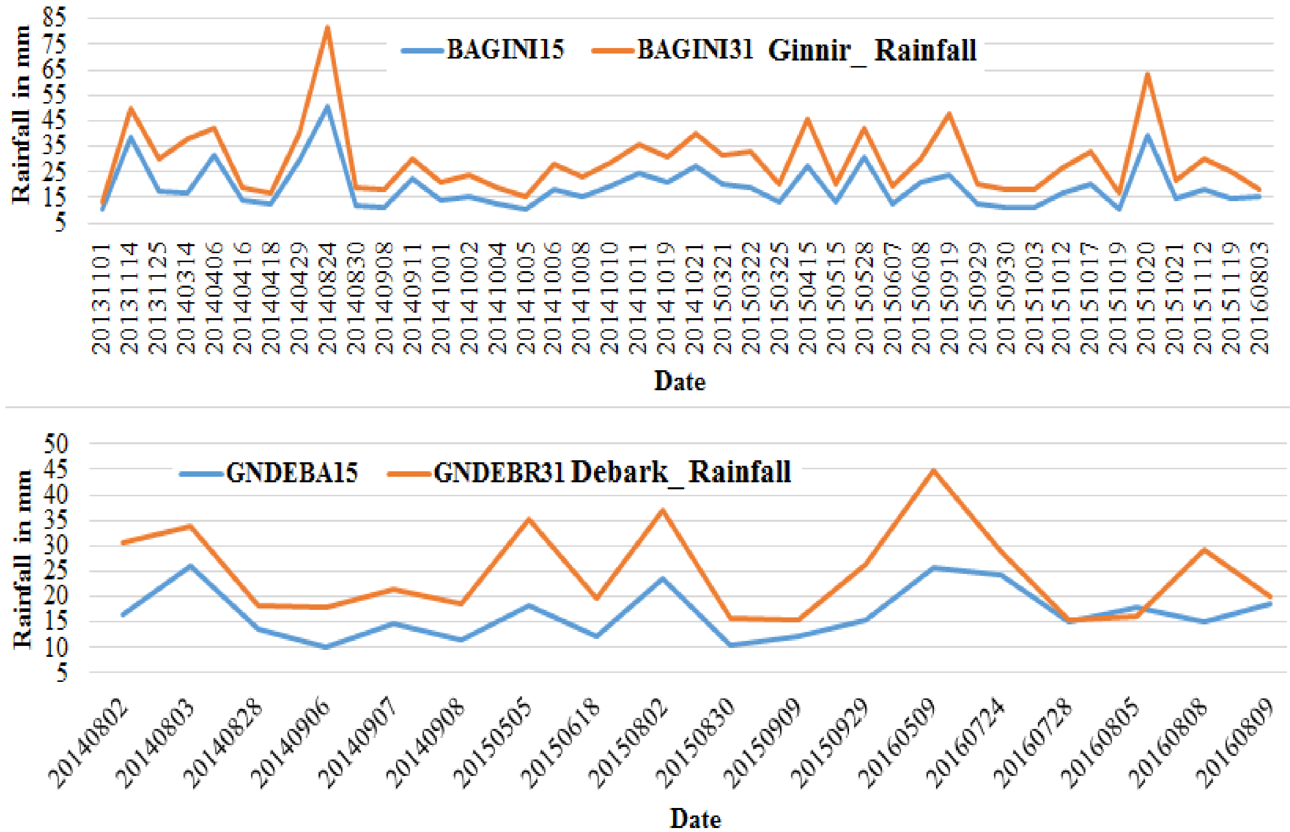


Figure 11. Extreme Value from CWS and AWS

5. Conclusion and Recommendation

5.1. Conclusion

Results showed that 40 stations have the correlation coefficients between two data sets of 32 of 40 the stations are strong and positive. The t-test shows that the difference between means of two data sets is not statistically significant at 95 % confidence. From Ginnir and Debark rainfall values obtained from AWS are lesser than CWS surface observation system. It can be argued that the generally lower rainfall recordings by the automatic rain gauge is due to the installation that results in systematic errors subject to wind field distortions along with the gauge opening. Since the automated gauge uses the tipping bucket mechanism and the rainfall in the country is mostly of the heavy type, there is also the possibility of the overflow of the water collected due to the delay of the tipping, hence a lower recording than CWS. This analysis has attempted to study the difference and similarity between AWS and CWS measured daily air temperature and daily rainfall total. Based on the data, daily MinT measured by AWS in thermoplastic radiation shield housing is found lower than the temperature readings from alcohol thermometer with result consistent in 13 stations. But, the daily MinT measured by AWS found higher than the temperature readings from alcohol thermometer housed in wooden Stevenson screen with result consistent in 27 stations. In addition, daily MaxT measured by AWS found higher than the temperature readings from mercury in glass thermometer with result consistent in ten stations. At large, the differences are systematic in all stations but the magnitude of the difference varies from AWS to CWS. Although the difference between them measured daily air temperature is systematic. It is in most of the cases might be associated with the difference in the sensitivity and in the design of weather shelter, but the difference is very random. The rainfall measuring equipment in AWS is the tipping bucket rain gauge and rapidly blocked by debris such as wind, leaves, and sand or bird droppings. So, the difference is suspected to be associated with instability in mechanical arms as a result of wind and the lack of proper fixing of a rain gauge. Additionally, the study found sources of error in the meteorological measurements are discussed in this and it is convenient to take the air temperature and the rainfall as an example to discuss how errors arise. Therefore, the found error identified in the following five parts on observation between the two devices. Accuracy is affected due to meteorological observation, non- skilled staff, unclean, and touching instrument before unplugging the sensor, disturbance of wind for AWS rain gauge, untimely observation, and percentage differences are the source of observation errors.

5.2 Recommendation

Electronics technologies applied at AWS are significantly different from those used at CWS. The software built into AWS (RTU) includes a routine to monitor the operation of the overall system and a quality control function to check the reliability of observed data. The difference is suspected to be associated with instability in mechanical arms as a result of wind and the lack of proper fixing of the rain gauge. The rain gauges stand support not only with the horizontal stand, but should also through the vertical stand. In addition, at time of installation AWS stand strain by angle iron rather than guy wire. This is to control disturbance from wind and cleaning of AWS must be after unplugged sensors from RTU. Considerations for adopting AWS the following advantages and disadvantages can be expected when automatic weather stations are accepted:

Continuous observation is possible and observational data at CWS can be obtained even when no staffs are present. Fully automated systems can also be installed at unreachable sites. In addition, it is possible to reduce observer numbers and operating costs;

- Since the meteorological data are taken as the electrical signals, observer errors in reading are removed. Standardized observation techniques enable the homogenization of observed data in regions where AWS is accepted;
- From AWS data could be collected 24/7 in near time depending on the quality of the GPRS network;
- For Data collection the sensors are sufficient accuracy, robust, operate in wide temperature range, low power consumption, little drift over time, simple installation and low maintenance;
- Due to AWS lifetime may need re-investment every five years, because the lifetime of AWS is short as compare to CWS. This is might be challenge in terms of budget; Note that the life time of temperature sensors ranges from 3 to 5 years. Thus, if not changed, data shift should be expected beyond the period.
- The main disadvantage of AWS is it dependent on GPRS network, need high frequency visit, and relatively expensive initial investment and parts replacement.

- The possibility of using direct AC electric power in the station where there is the main line will help to minimize thefts of solar panel;

- A good system to adopt is one of a monthly maintenance check in which the rain gauge is checked for detritus, including the buckets, and the funnel cleaned of dirt;

- Calibration is the practice of checking an instrument against another of known accuracy, or with a process of known properties. Calibration is as essential for the amateur as for the professional meteorologist but is one of the most commonly neglected tasks.

- Technical specification for automated weather station is must be revised every year.

- The study recommends further study with stations from other providers that have different processing approach for the sample data.

6. References

Adcon Telemetry GmbH. 2007. Telemetry Gateway A850: User Guide. Vienna, Austria.

Adcon Telemetry GmbH. 2009. A75x addWAVE GPRS Series 4: User Guide. Vienna, Austria.

Adcon Telemetry GmbH. 2010. AddVANTAGE Pro 6.0: Admin and User Guide. Vienna, Austria.

Agnihotri Geeta and Panda Jagabandhu. 2014. Comparison of rainfall from automatic and ordinary rain gauges in Karnatka. Mausam 65(4) 575-584.

Amudha B., Ranalkar M., Niyas N., Pratap R. and Vashistha R. 2008b Preliminary results of the performance of AWS in the perpetual frost climate of East Antarctica WMO Technical Conference on Instruments and Methods of Observations, Russian Federation.39

Andrew K. Overton. 2009. A Guide to the Sitting, Exposure and Calibration of Automatic Weather Stations for Synoptic and Climatological Observations

Anita Asadullah, Neil Mcintyre and Max Kigobe. 2010. Evaluation of five satellite products for estimation of rainfall over Uganda. Hydrological Sciences Journal, 53:6, 1137-1150.

C. Holder, R. Boyles, A. Syed, D. Niyogi, and S. Raman. 2006. Comparison of Collocated Automated and Manual Climate Observations in North Carolina. American Meteorological Society. Carolina State University.

Carberry Peter. 2008. Building adaptive capacity to cope with increasing vulnerability due to climatic change in Africa – A new approach. Physics and Chemistry of Earth 33: 780-787.

Carolien T., Domingos P., Hendrik B., Raymond van der W. Elena T. and Chris F. 2015. Evaluation of Satellite Rainfall Estimates for Drought and Flood Monitoring in Mozambique. Remote sensing. Belgium 8:1758-1776.

Central Statistical Agency (CSA).2016. National Strategy for the Development of Statistics (2015/16 – 2019/20 Addis Ababa, Ethiopia.

Commission for Instruments and Methods of Observation (CIMO).2014. Measurements at Automatic Weather Stations through Recommendation 2, CIMO-16.

David P., Elizabeth G. and Rob C. 2011. Reviews of Observational Data Available over Africa for Monitoring, Attribution and Forecast Evaluation. Hadley Centre Technical Note. 86.

Dinku T. P. Ceccato, E. Grover-Kopec, M. Lemma, S. J. Connor and C. F. Ropelewski. 2008. Validation of satellite rainfall products over East Africa's complex topography. International Journal of Remote Sensing, 28:7, 1503-1526.

Dinku T., Kinfe H., Ross M., Elena T. and Stephen C.2013. Combined use of satellite estimates and rain gauge observations to generate high-quality historical rainfall time series over Ethiopia. International Journal of Climatology. 34: 2489–2504.

Dinku, T., Ceccato, P., Grover-Kopec, E., Lemma, M., Connor, S. J. and Ropelewski, C. F. 2007. Validation of satellite rainfall products over East Africa's complex topography. International Journal of Remote Sensing. 28(7), 1503–1526.

Edebeatu, Chinedu Callistus. 2015. Comparison of four empirical evapotranspiration models against the penman montieth in a mangrove zone. International Journal of Applied Sciences and Engineering Research. 4:580-589

Enric Aguilar, Alba Gilabert, and Marc Prohom. 2013. Comparison of parallel temperature measurements from conventional and automatic weather stations at Fabra Observatory. Geophysical Research Abstracts. 15, 7287-2. Barcelona.

Giri R.K. March. 2015. Inter-Comparison of Meteorological Elements of Automatic Weather Stations and Conventional Observations over Bihar Region. International Journal of Physics and Mathematical Sciences. 5(1): 87-104.

Giri R.K., Devendra P. and Sen A.K. June. 2015. Rainfall Comparison of Automatic Weather Stations and Manual Observations over Bihar Region. International Journal of Physics and Mathematical Sciences. 5 (2). 1-22.

Harpal S. Mavi and Graeme J. Tupper. 2004. Agro-meteorology Principles and Applications of Climate Studies in Agriculture. Food Products Press. New York.

Hilton S, Giampaolo Q., Daniela B., Gustavo C., Paulo H., Ana M. H. 2006. Comparison between Daily Meteorological Data Collected by Automatic and Conventional Stations. Brazil.

Japan Meteorological Agency (JMA). 2013. Lecture Notes of the JMA/WMO Training Workshop on Calibration and Maintenance of Meteorological Instruments in RA II. Japan.

Jose R. L., Antonio C. A., Eduardo S. S., Claude H., Suzana L. M. and Carlos A. Oliveira L. 2013. Calibration of Hargreaves-Samani Equation for Estimating Reference Evapotranspiration in Sub-Humid Region of Brazil. Journal of Water Resource and Protection. 1-5

Kidd, C., and G. Huffman, 2011, Global precipitation measurement Meteorological Application 18, 334-353

Kidd, C., P. Bauer, J. Turk, G.J. Huffman, R. Royce, K.L. Hsu and D. Braithwaite. 2012. Inter comparison of high-resolution precipitation products over north-west Europe, 13(1), 67-83.

Manual of Surface Weather Observations (MANOBS) Working Group. 2015. Minister of Environment and Climate Change. Canada.

Mohapatra M., Kumar N. and Ranalkar M. 2011. Utility of Automatic Weather Station Data for Monitoring and Prediction of Cyclonic Disturbances during 2010 India meteorological department 189-203

National meteorological Agency. www.ethiomet.gov.et Accessed December 11, 2017.

Ogallo, L. 2010. The Mainstreaming of Climate Change and Variability Information into Planning and Policy Development Procedia Environmental Sciences 1: 405-410

Patt AG, Ogallo L, Hellmuth M. 2007. Learning from 10 Years of Climate Outlook Forums in Africa. Science 5:49–50.

T. Darnhofer. August 1985. Meteorological Elements and Their Observation: Working paper Nr. I4. International Council for Research in Agroforestry. Nairobi, Kenya

Theo Brandsma. 2014. Comparison of automatic and manual precipitation networks in the Netherlands. Royal Netherlands Meteorological institute

UNDP. 2011. Improving Access, Understanding and Application of Climate Data and Information. Discussion Paper Series. United Nations Development Programme. Vol. 2 New York

UNFCC. 2007. Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries. Available at unfccc.int/resource/docs/publications/impacts.pdf

Vashistha R., Amudha B. and Pratap R. 2005. Present status of surface meteorological observations in India. WMO Technical Conference on Instruments and Methods of Observations Bucharest Romania 1265

Wikipedia.org/wiki/Meteorological instrumentation Accessed December 10, 2017

Wilks. D. 2006. Statistical Methods in the Atmospheric Sciences USA: Academic Press is an Imprint of Elsevier. Vol. 91.

WMO. 1986. Compendium of Lecture Notes on Meteorological Instruments for Training Class III and IV Meteorological Personnel. WMO_No.622, Volume I

WMO. 1992a: International Meteorological Vocabulary. Second edition, WMO-No. 182, Geneva.

WMO. 2003a Guidelines on Climate Metadata and Homogenization WMO-TD-No 1186,WCDMP-No 53 Geneva.

WMO. 2008. Guide to Meteorological Instruments and Methods of Observation. WMO-No. 8.Geneva, Switzerland

WMO. 2012: Guide to the Global Observing System. WMO- No. 488, Geneva, Switzerland

NATIONAL METEOROLOGICAL AGENCY

METEOROLOGICAL RESEARCH AND STUDIES DIRECTORATE

Comparative Analysis of Observed Evaporation Data by Nma Made Class-A Pan with Imported Class-A Pan Evaporimeter

Yosef Tesfaye[1], Tofik Reddi[2]

[1]Meteorological Research and Study of Directorate NMA, mobile: +251949411906, Email: matyyos@gmail.com, Addis Ababa, Ethiopia

[2] Meteorological Research and Study Directorate of NMA, Mobile: +251930641963, Email: tofikk858@gmail.com, Addis Ababa, Ethiopia

ADDIS ABABA, ETHIOPIA
JUNE 2019

Abbreviations and Acronyms

Lat	Latitude
Long	Longitude
NMA	National Meteorological Agency
RMSC	Regional Meteorological Service Center
U.S.	United State
UTC	Universal Time of Coordinate
WMO	World Meteorological Organization

Abstract

The study formulates a comparative analysis based on data of Pan-evaporation collected from Class-A Pan and NmaMade pan at NMA, in 03:00, 06:00, 09:00, 12: 00 and 15:00 UTC time of observation. These instruments are located in town where the American and first made by Ethiopia National Meteorological Agency were installed. Measuring water evaporation from the ground surface is of crucial importance to a wide range of research areas and sciences including water resource management, agriculture, and meteorology. The main aim of this study was, therefore to analysis observed evaporation data by Nmamade pan with class-a pan at national meteorological agency, Ethiopia. The evaporation data at 03:00, 06:00, 09:00, 12: 00 and 15:00 UTC was obtained from Adama Regional Meteorological center service from October 2017 to September 2018. The correlation of observed evaporation data from ClassA Pan Evaporimeter showed satisfactory results in statistical indices applied. Statistical indices as Bias, Correlation Coefficient, and standard error are able to detect such errors, also noticeable by observing the bias graphs of the parameters. Therefore, the mean bias ranged from -2.32 to 8.69, with a standard error ranged from 1.60 to 1.71 and as the correlation coefficient results show higher correspondence with the ClassA Pan Evaporation data. Moreover, the new finding is after the result of data calibration it has no significant difference between evaporation measurements acceptable performances. Furthermore, according to the World Meteorological Organization instrument specification the study recommended proper welding and galvanizing the newly made Pan Evaporimeter and rust spots should be repaired when they occur, and repaired spots must be painted the same color as the pan.

Keywords: ClassA, comparative, Evaporimeter, Evaporation, Nma -made

1. Introduction

1.1 Background

Pan evaporation is a measurement that combines or integrates the effects of several climate elements, such as temperature, humidity, rain fall, drought dispersion, solar radiation, and wind. Evaporation is greatest on hot, windy, dry, sunny days; and is greatly reduced when clouds block the sun and when air is cool, calm, and humid (Richard et al., 1982). Measuring water evaporation from the ground surface is of crucial importance to a wide range of research areas and sciences including water resource management, agriculture, and meteorology. Out of numerous direct and indirect methods proposed for evaporation measurement, using evaporation pan is the most common method because of its low manufacture and maintenance costs (Stanhill, 2002). In fact, evaporation pans constitute one of the main instruments in weather stations for determining water requirements, estimating evaporation from lakes and dam reservoirs and many more water resource management studies.

The current available methods for measuring rates of evaporation are limited. Unfortunately, the three accurate direct methods of measurement available that is weighing lysimeter, Bowen ratio and eddy flux instrumentation, are unstable for monitoring evaporation as a routine direct measurement at meteorological enclosures because of high demand of complex computations (Yahaya et al., 2018). Nevertheless, WMO has recommended that the evaporation pan be adopted as the standard instruments for crop water use determination, the best known of the pans are the “class A” evaporation pan and the “sunken Colorado pan” (Stanhill and Cohen, 2001. The pan has proved its practical value and has been used successfully to estimate reference evapotranspiration by observing the evaporation loss from a water source and applying empirical coefficients to relate pan evaporation to reference evapotranspiration (Stanhill and Cohen, 2001). However, routine measurement of evaporation in Nigeria still suffers from poor coverage and non-uniform instrumentations (Parmele, 2014). Thus, pan evaporation is a measurement that combines or integrates the effects of several climate elements. So, the pan rests on a carefully leveled, wooden base and is often enclosed by a chain link fence to prevent animals drinking from it. The measurement day begins with the pan filled to exactly 5cm from the pan top. At the end of 24 hours, enough water is added, in measured increments, to again fill the pan to exactly5cm from its top. If precipitation occurs in the 24-hour period, it has taken into account in calculating the evaporation. Sometimes precipitation is greater than evaporation, and measured increments of water must be dipped from pan (Richard et al., 1982). It is observed that in humid climates ClassA pan evaporation measurements were reasonable estimates of evapotranspiration when soil water was not restricting plant growth (Parmele, 2014). Because of its nature, evaporation from water surfaces or water bodies is rarely measured directly, except over relatively small spatial and temporal scales (Jones, 2002). The evaporation rate can be measured by manual readings or with an analog output evaporation gauge. A large number of studies have compared evaporation pans and made a comparison between floating and ClassA pans and concluded that, for lakes smaller than an area of 10000 m2, floating pan evaporation was significantly lower than that of ClassA pan (Masoner et al., 2008). Pan evaporation measurements enable farmers and ranchers to understand how much water their crops will need (Smajstrla et al., 2000).

1.2 Statement of the problem

In NMA the most common type of pan evaporation is the U.S. ClassA Pan, which is made of galvanized iron and has a diameter of 1207mm, a depth of 250 mm, 8mm thick, and 50 to 75mm from rim. This instrument has weight of 65 kg copper or Monel metal and the stilling well diameter must be 100mm. Besides, at NMA work shop constructed the sample evaporation measurement pan instrument to reduce the purchasing costs. Pan Evaporimeter made with the same ClassA Pan standard specification and installed near some stations. Several studies for comparison of instruments have been done in the past by Geeta and Panda (2014). However, an attempt has been made to compare observation difference between ClassA and NmaMade measured data of evaporation using Bias, Pearson Correlation coefficient, and standard error was used to comparative and analysis relationship between two instruments.

1.3 General objective

To compare the accuracy and similarity of NMA-made pan evaporimeter with imported ClassA pan evaporimeter by taking observation over Nazreth station fulfil the WMO standard by statistical methods (WMO, 2010). Thus, to confirm if NMA-made pan would replace imported pan, with possible calibration and without comromizing data quality.

1.4 Specific objectives

To identify the standard error between both measurements by statistical methods and calibrates the new measured data with reference evaporation data.

1.5 Significance of research

The study has compared and verified the constructed pan according to ClassA satisfied WMO standard (WMO, 2006, WMO, 2010). So, the attention and significant of this study is to compare similarity of ClassA Pan with NmaMade Pan based on the measured data from pan evaporimeter. After this, the study accomplishes the similarity and functionality for evaporation data accurately at time of observation. As result, the research develops and encourages the sustainability of the NmaMade instrument products in NMA of Ethiopia.

2. Materials and Methods

2.1. Study area description

The study used two Class A pan evaporimeter at Nazreth meteorological station installed at the same geo-location and is placed at Adama town. Elevation of the station is 1622 meters above sea level. This study selected the Pan-evaporation data observed at the same conventional station Adama which are part of the network of the NMA, from Oct 2017 to Sep 2018. The information of the station is shows in Table1. As shown in table 2, the NmaMade constructed pan was made from stainless steel sheet, but not galvanized iron of 2mm thick metal sheet. According to technical specification Annex 1, the diameter of the constructed pan 120.7 cm, depth of 25.0 cm to compare ClassA standard (WMO, 2006). This study planned to evaluate the accuracy of sample pans using a comparison with ClassA pan as the reference evaporation measurement tool side by side at Adama station.

Table 1. Station Information

Station	**Reference Instrument**	**New Instrument**	**Long**	**Lat**	**Duration**
Adama	ClassA Pan	NMA Made	36.28	8.53	01/10/2017 to 30/09/2018

Evaporation pans were commonly constructed of galvanized steel. They are also available in stainless steel and Monel (plated) metals, but these materials are more expensive. The greater expense may be required if the water used is corrosive to the galvanized steel pan (Smajstrla et al., 2000). Moreover, the ClassA Evaporation Pan was normally installed on a wooden platform on the ground (Figure 1).

Table 2. Pan Evaporimeter Information (Hyquest, 2016)

Specification (Criteria)	**Imported ClassA Pan Evaporimeter**	**NMA Made Pan Evaporimeter**
Material	Stainless Steel 2mm thick	Metal sheet Steel 2mm thick
Construction	Welded	Welded
Stainless Steel	Galvanized	**not Galvanized**
Bird Guard	Optional with a hinged door	Optional with a hinged door
Diameter of pan(Size)	1207 mm	1207 mm
Packed Weight:	65 Kg	**Unknown**

Depth	250mm	250mm
Stilling well Diameter	100mm	100mm

Measuring principle of evaporation pan provides a measurement of combined the effect of temperature, humidity, wind speed and sunshine on the evapotranspiration (Eijkelkamp, 2009; Hyquest, 2016).

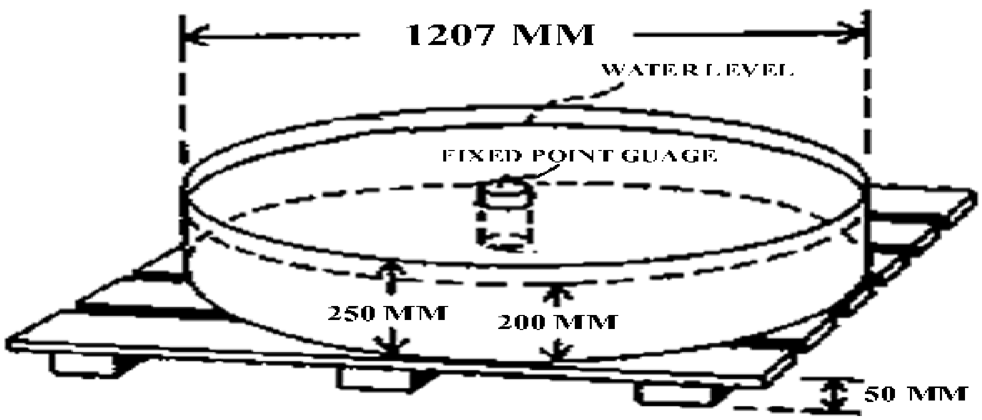


Figure 1. ClassA Evaporation Pan installed on a Wooden Platform

2.2. Data collection

The ground-based one year every three our data evaporation was collected from Class A and NMA Made pan evaporimeter in Adama RMSC. For the sites used in this study, both types of the instrument are collocated at the same geo-location. Evaporation data at 03:00, 06:00, 09:00, 12:00 and 15:00 UTC from October 2017 to September 2018.

2.3. Statistical Analysis Methods

For this study, statistical method has used and likewise, it uses data import in to ArcGIS 10.3 for all statistical analysis were run under it. One of the statistical methods to use for this study is Bias, it is a type of systematic error that is introduced into the testing and encourages one outcome over another. Moreover, it is any trend or deviation from the truth in data collection, which can cause the false conclusion (Gardenier and Resnik, 2002; Creswell, 2013). Accordingly, the difference between readings from two instruments, also known as gross bias: Bias = ClassA – NmaMade. Where, ClassA and NmaMade are measured values at station Class A pan and made by NMA, respectively. Furthermore, Pearson Correlation Coefficient(r), used to distinguish the degree of measures of the relationship between the observation that taken from both stations (Wilks, 2006; Carolien et al., 2015) also, standard error used to comparative and analysis relationship between two instruments. Besides, the study reflects the calibration to minimize the standard error of the measured pan evaporation data. Thus, the pan evaporation data was compared through Bias Graphs of the time series between the two instruments, and then calculated the Pearson Correlation Coefficient(r). Pearson Correlation Coefficient is a technique for investigating the relationship between two quantitative, continuous variables. It is a measure of the strength of the association between the two variables.

$$\mathbf{r} = \frac{n\sum_{i=1}^{n} a_i b_i - \sum_{i=1}^{n} a_i \sum_{i=1}^{n} b_i}{\sqrt{\left(\left(n\sum_{i=1}^{n}(a_i^2 - (\sum_{i=1}^{n} a_i)^2\right)\left(n\sum_{i=1}^{n} b_i^2 - (\sum_{i=1}^{n} b_i)^2\right)\right)}}$$

Where, comparison instruments with n is number of every hour's observations, "a_i" stand for NmaMade pan evaporimeter measured value for the i^{th} observations and "b_i" stand for ClassA pan evaporimeter measured value for the i^{th} gauge measurement. In addition, the Pearson's correlation coefficient values of for continuous (interval level) data ranges from -1 to +1. The standard error (SE) tells you how far the NmaMade Pan Evaporation (Sample) statistic deviates from the actual mean (ClassA Pan). The SE of the NmaMade Pan Evaporation mean depends on both the standard deviation and the sample size, by the simple relation SE = SD/√n (Faison, 2015).

2.4. Calibration

In measurement technology and metrology calibration is a comparison of two measurement devices against each other and the documentation of the comparison (Ligowski and Tabe, 2011). Such a standard could be another measurement device of known accuracy, a device generating the quantity to be measured a physical artifact, such as a meter ruler. The outcome of comparison can result in one of the following from no significant error being noted on the device under test, or a significant error being noted but no adjustment made, or an adjustment made to correct the error to an acceptable level (Imtiaz and Erfan, 2011). The reasons of calibration may be required for a new instrument, after an instrument has been repaired or modified, before and after a critical measurement, and whenever observations appear questionable or instrument indications do not match the output of replacement instruments (Altman and Carroll, 2005). The Calibration models procedure is designed to construct a statistical model describing the relationship between two variables, X and Y, where the intent of the model- building is to construct an equation that can be used to predict X given Y. In a typical application, X represents the true value of some important quantity, while Y is the measured value. Initially, a set of samples with known X values are used to calibrate the model. Later, when samples with unknown X values are measured, the fitted model is used to make an inverse prediction of X from the measured values Y.

3. Result and Discussion

3.1. Statistical comparative analysis of pan-evaporation

Nma-made pan evaporimeter was placed nearby a ClassA evaporation pan at the Nazareth station. The measurements of water loss have taken every three hours from the period of October 2017 to September 2018 to compare accuracy for NmaMade measurement. As the observational method of the two instruments is the same, so, an attempt has been made to analyze measurement difference between same located instrument data of evaporation. A Pan Evaporation observation is measured by WMO standard and intermediate synoptic hour from 0300 to 1500 UTC from ClassA and NMA Made pan evaporimeter (WMO, 2010).

Table 3. Statistical Analysis Annual Mean

Observation Time in UTC	Correlation	Standard Error	Bias Before Calibration	After Standard Error	Bias After Calibration
0300	0.99	1.67	2.66	1.52	1.33
0600	0.99	1.61	2.57	1.44	1.32
0900	0.99	1.71	2.51	1.50	1.24
1200	0.99	1.60	2.63	1.46	1.37
1500	0.99	1.60	2.56	1.47	1.26
On Average	**0.99**	**1.64**	**2.59**	**1.48**	**1.30**

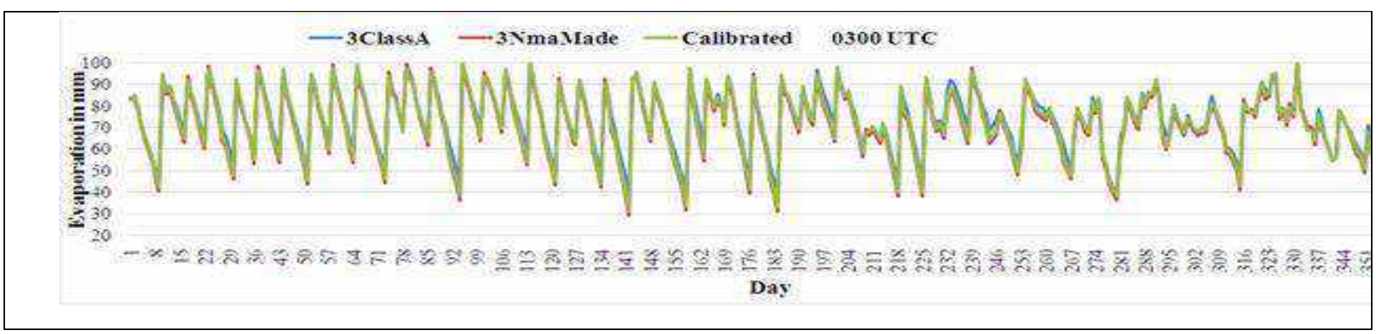
The time series of two measurements in one location should, ideally, coincide. The study of the difference between these values identified errors that oscillate around a mean that change throughout the month. The mean bias ranged from -2.32 to 8.69, with a standard error ranged from 1.60 to 1.71 and as Pearson Correlation Coefficient used to comparative and analysis relationship, NmaMade pan evaporation data show higher correspondence with the ClassA Pan Evaporation data, has 0.99. Due to this bias and standard error output the study needed calibrate the newly observed pan evaporation readings for acceptable performance before applying it for NmaMade observation, because of the tendency of over estimation the value. Therefore, NmaMade pan evaporation reading was calibrated against the ClassA pan evaporation data (Table 3). The study proposed the ClassA pan method as a standard reference to calibrate and evaluated the NmaMade data. In that case, the mean bias before calibration from had 2.59 with a standard error had 1.64 and mean bias after calibration from had 1.30 with a standard error 1.48. In addition, after calibration NmaMade pan evaporation data show higher correspondence with the ClassA Pan Evaporation.

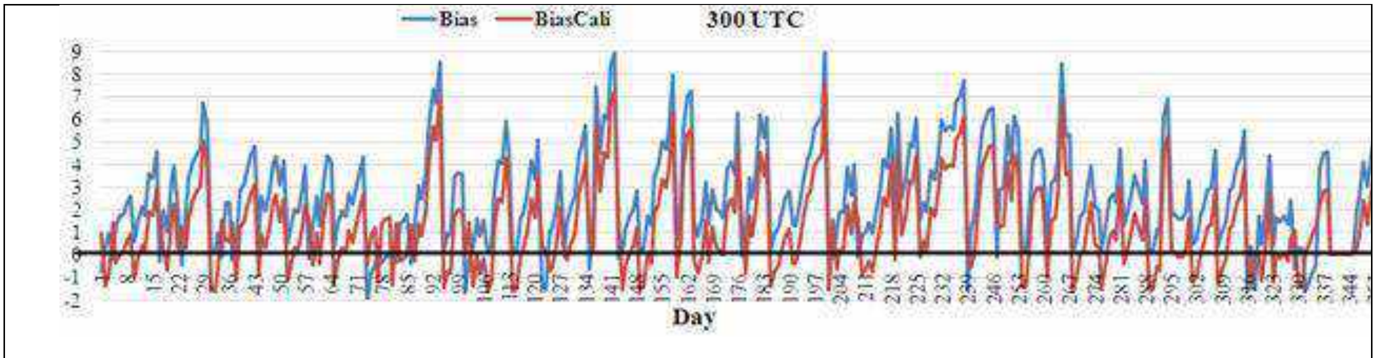
3.2. Seasonal analysis of pan-evaporation

The investigation of comparative analysis of pan-evaporation observed data by Class-A Pan and NmaMade Pan the study obtained good agreement between the statistical indices in the comparison of evaporation data from measurements. Statistical analysis of the evaporation data from the two pans showed that they were very well correlated and not significantly different. These achievements were in fact already expected, due to the small amplitude of variation, throughout the day of the observed parameters. To specific this comparative analysis the study focus on the three season of Ethiopia over the Nazareth station.

3.3. Data analysis at 0300 UTC time of observation

As indicated in Figure 2, the seasonal standard error from evaporation measurements was 1.26, 1.72, and 1.86 during Bega, Belg, and Kiremt respectively.





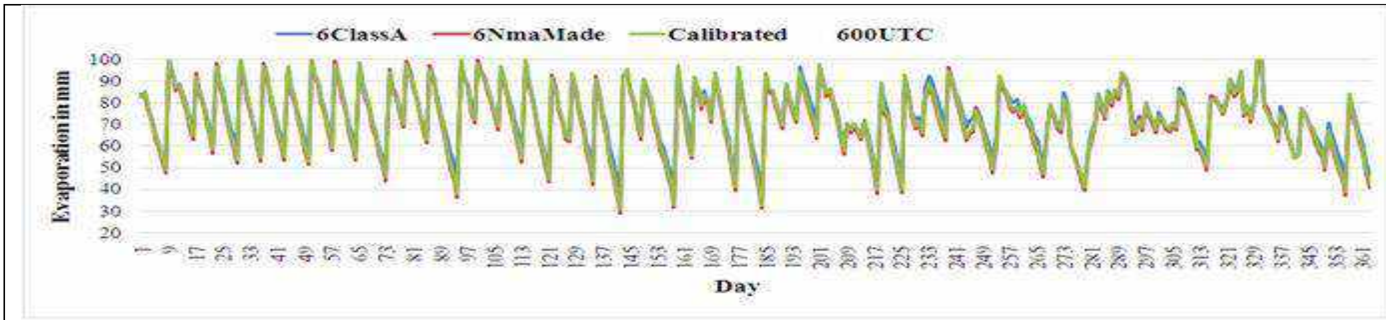
Season/0300	Standard Error	Bias Before Calibration	Bias After Calibration
Bega	1.26	2.14	0.98
Belg	1.72	3.27	1.78
Kiremt	1.86	2.60	1.25

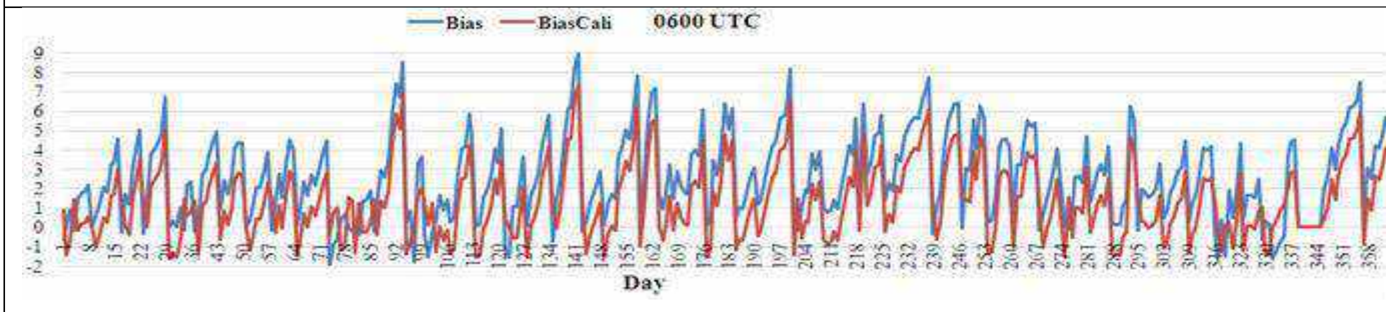
Figure 2. Statistical Analysis for 0300 UTC

Bias before calibration the seasonal variation on ClassA and NmaMade Pan ranged from 2.14 to 3.27 mm and averaged 2.67 mm observation taken at 0300 UTC. Observation reading highly varied during belg season relative to the other. Likewise, bias after calibration the seasonal variation on measurements ranged from 0.98 to 1.78 mm and averaged 1.34 mm observation taken at 0600 UTC (Figure 2).

3.3.1. Data analysis at 0600 UTC time of observation

The seasonal standard error from instruments was 1.22, 1.59, and 1.83 during Bega, Belg, and Kiremt respectively. Bias before calibration the seasonal difference on ClassA and NmaMade Pan ranged from 2.01 to 3.25 mm and averaged 2.58 mm observation taken at 0600 UTC. Observation reading highly varied during Kiremt season relative to the other. Likewise, bias after calibration the seasonal variation on measurements ranged from 0.95 to 1.74 mm and averaged 1.32 mm observation taken at 0600 UCT (Figure 3).



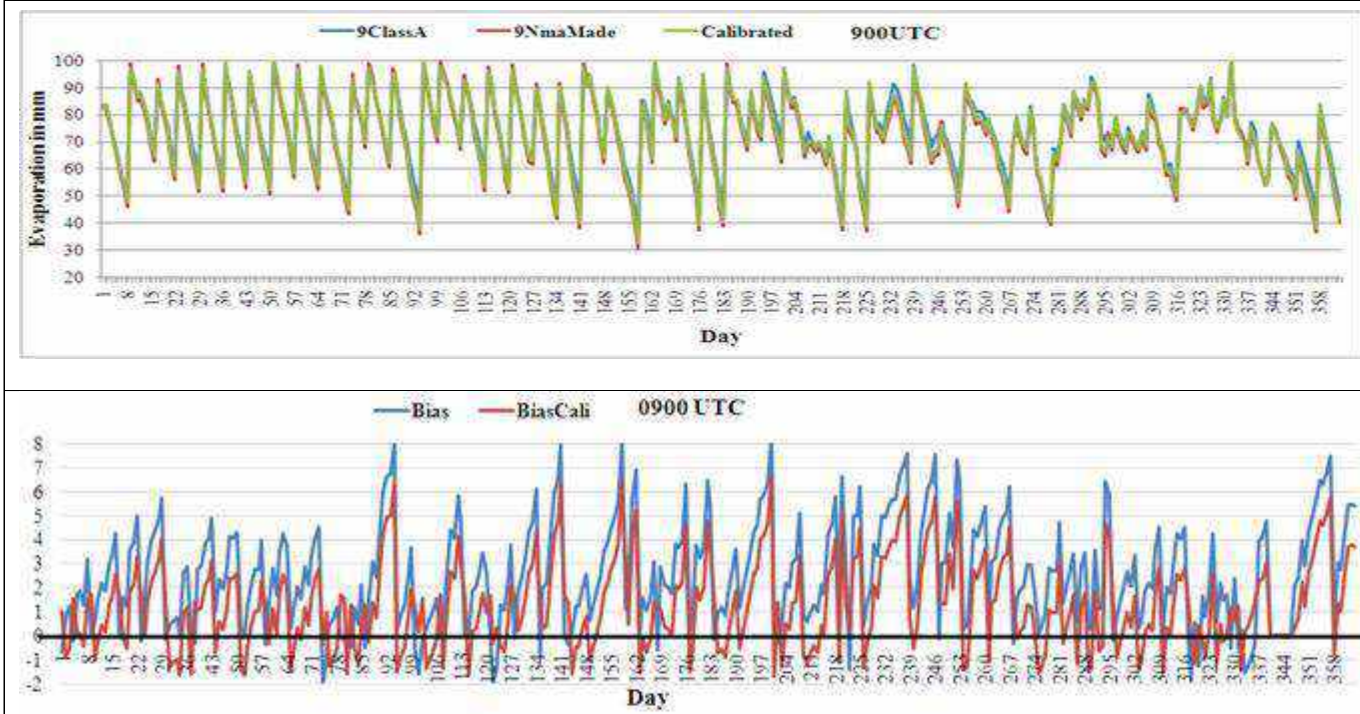


Season/0600	Standard Error	Bias Before Calibration	Bias After Calibration
Bega	1.22	2.01	0.95
Belg	1.59	3.25	1.74
Kiremt	1.83	2.47	1.28

Figure 3. Statistical Analysis for 0600 UTC

3.3.2. Data analysis at 0900 UTC time of observation

As shown in figure 4 below, the seasonal standard error from measurements was 1.14, 1.91, 1.92 during Bega, Belg, and Kiremt respectively. Bias before calibration the seasonal variation on ClassA and NmaMade Pan ranged from 1.99 to 2.98 mm and averaged 2.50 mm observation taken at 0900 UTC. Observation reading has small variation during Bega season comparative to the other. As well, bias after calibration the seasonal variation on measurements ranged from 0.89 to 1.52 mm and averaged 1.23 mm observation taken at 0900 UTC.

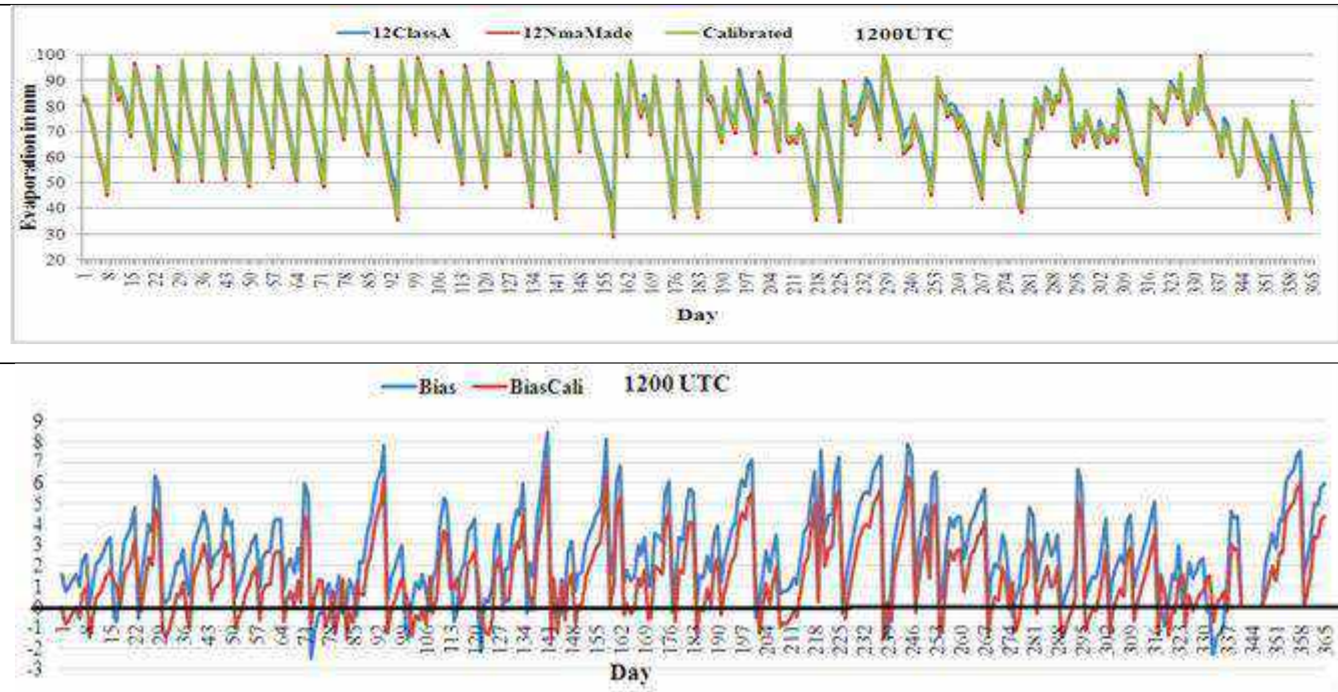


Season/0900	Standard Error	Bias Before Calibration	Bias After Calibration
Bega	1.14	1.99	0.89
Belg	1.91	2.98	1.53
Kiremt	1.92	2.54	1.28

Figure 4. Statistical Analysis for 0900 UTC

3.3.3. Data analysis at 1200 UCT time of observation

The seasonal standard error from ClassA Pan and NmaMade Pan was 1.17, 1.59, and 1.87 during Bega, Belg, and Kiremt respectively. Thus, Bias before calibration the seasonal variation on ClassA and NmaMade Pan ranged from 2.10 to 3.18 mm and averaged 2.62 mm observation taken at 1200 UTC. Observation reading highly varied during Kiremt season relative to the other. Likewise, bias after calibration the seasonal variation on measurements ranged from 0.94 to 1.79 mm and averaged 1.36 mm observation taken at 1200 UTC (Figure 5).

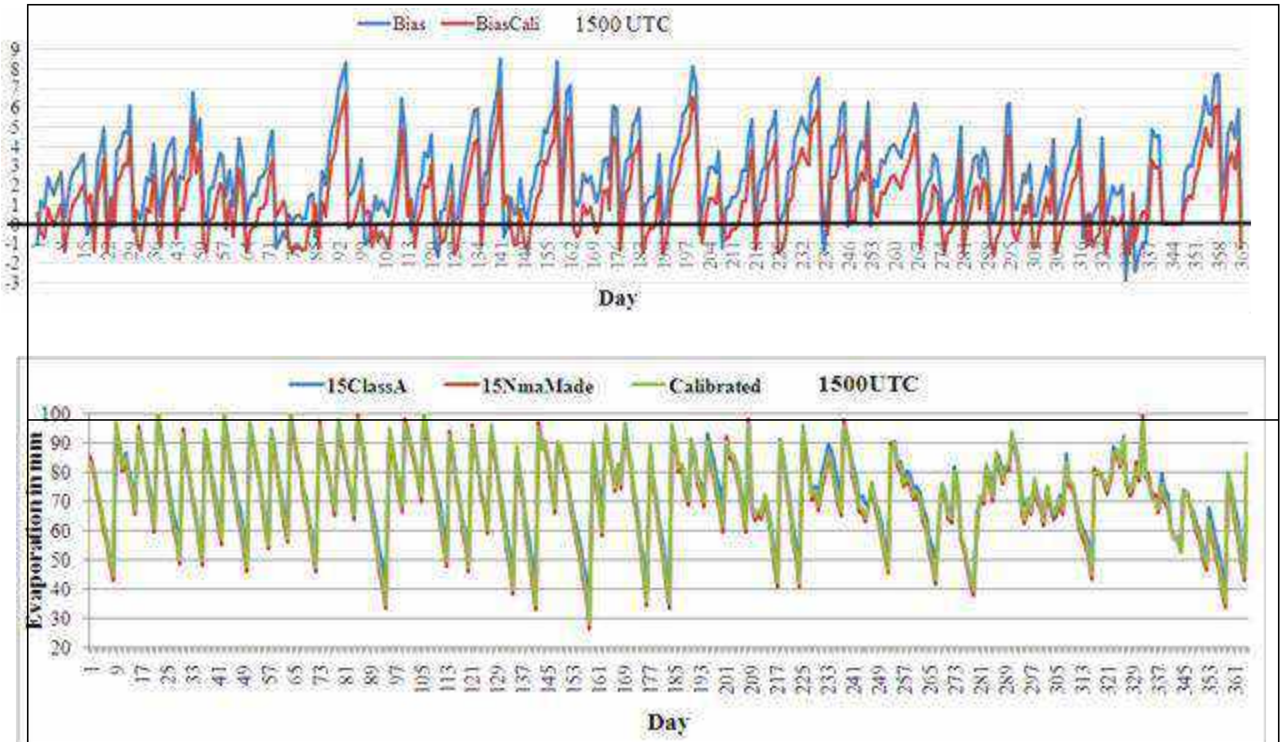


Season/1200	Standard Error	Bias Before Calibration	Bias After Calibration
Bega	1.17	2.10	0.94
Belg	1.59	3.18	1.79
Kiremt	1.87	2.59	1.35

Figure 5. Statistical Analysis for 1200 UTC

3.3.4. Data analysis at 1500 UCT time of observation

As point out in Figure 6, the seasonal standard error from measurements was 1.22, 1.55, and 1.86 during Bega, Belg, and Kiremt respectively. Bias before calibration the seasonal variation on ClassA and NmaMade Pan ranged from 2.15 to 3.07 mm and averaged 2.56 mm observation taken at 1500 UTC. Observation reading highly varied during Kiremt season relative to the other season. Likewise, bias after calibration the seasonal variation on measurements ranged from 0.94 to 1.63 mm and averaged 1.26 mm observation at 1500 UTC.



Season/1500	Standard Error	Bias Before Calibration	Bias After Calibration
Bega	1.22	2.15	0.94
Belg	1.55	3.07	1.63
Kiremt	1.86	2.47	1.22

Figure 6. Statistical Analysis for 1500 UTC

4. Conclusion and Recommendation

4.1. Conclusion

The comparative study of observed evaporation data from ClassA Pan Evaporimeter showed satisfactory results in statistical indices applied. However, changes in average level of bias occur frequently and are associated with standard errors that can vary from interruptions in the data series on the NmaMade until reading errors of the observed on ClassA Pan. Indices as Bias, Correlation Coefficient, and standard error are able to detect such errors, also noticeable by observing the bias graphs of the parameters. Therefore, the mean bias ranged from -2.32 to 8.69, with a standard error ranged from 1.60 to 1.71 and as Pearson Correlation Coefficient used to comparative and the analysis relationship the NmaMade pan evaporation data shows higher correspondence with the ClassA Pan Evaporation data. Moreover, the new findings are after data calibration it has no significant difference between evaporation measurements acceptable performances. In general, this study used the NmaMade Pan Evaporimeter which constructed with the same specification of WMO meteorological instruments standard guideline, except for galvanizing the stainless steel sheet.

4.2. Found problems

This study found some problems and identified in the following parts on Pan Evaporimeter and observation.

- False mistake includes bias caused by the observer's negligence in the reading the scale, untimely observation and improper resetting specially during rainy season;
- Not galvanizing the stainless steel sheet after constructed the pan in NMA work shop and
- Has calibration problem.

4.3. Recommendation

- Proper welding and galvanizing the Newly made Pan evaporimeter is unquestionable
- Rust spots should be repaired when they occur, and repaired spots must be painted the same color as the pan.
- Other color and Oil or grease will tend to heat up faster and increase rates and prevent evaporation. Also, Evaporation pans must be kept fenced to prevent animals and birds from drinking from them.
- Calibration is must the practice of checking an instrument against another of known accuracy, or with a process of known properties.
- This study has to be extended by taking sample data from diverse climate of the country

5. References

A. G. Smajstrla, F. S. Zazueta, G. A. Clark, and D. J. Pitts. 2000. Irrigation Scheduling with Evaporation Pans. University of Florida.

Agnihotri Geeta and Panda Jagabandhu. 2014. Comparison of rainfall from automatic and ordinary rain gauges in Karnatka. Mausam 65: 575-584.

Altman Douglas, and Martin Bland. 2005. Standard deviations and standard errors. National Center for Biotechnology Information, U.S. National Library of Medicine 8600 Rockville Pike, Bethesda MD, 20894 USA

Carolien T., Domingos P., Hendrik B., Raymond van der W. Elena T. and Chris F. 2015. Evaluation of Satellite Rainfall Estimates for Drought and Flood Monitoring in Mozambique. Remote sensing. Belgium 8:1758-1776.

Creswell J. 2013. Qualitative, quantitative, and mixed methods approach. Sage publications.

Eijkelkamp. 2009. Evaporation Pan operating instructions. Environmental Research. The Netherlands

Faison Douglas and Brickenkamp Carroll. 2015. Calibration Laboratories: Technical Guide for Mechanical Measurements. NIST Handbook 150-2G

Gardenier JS, and Resnik DB. 2002. The misuse of statistics: concepts, tools, and a research agenda. Account Research, 9:65.

Hyquest. 2016. Instruction Manual ClassA Evaporation Pan. Hyquest Solutions Pty Ltd. Australia

Jones C. 2002. Empirical method of estimating evapotranspiration using primarily. GIJJC Journal 16: 100-123.

Ligowski, M and Tabe, M .2011. Procedure for Calibrating Kelvin Probe Force Microscope, Mechatronics: Recent Technological and Scientific Advances, 227

Masoner, J., Standard, D and Christenson, S. 2008. Differences in Evaporation between a Floating Pan and Class A Pan on Land1, Journal of the American Water Resources Association, 44: 552-561.

Parmele Y, McGuinness O. 2014. Comparison of measured and estimated daily potential evapotranspiration on humid region. Atmospheric Research 40: 77-84.

Richard K., Edwin S. Thompson, and Eugene L. Peck. 1982. Evaporation Atlas for the Contiguous 48 United States, National Weather Service, Washington, D.C.

Stanhill G, Cohen S. 2001. Global dimming: a review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences. Agricultural and Forest Meteorology 107: 255-278.

Stanhill, G. 2002.Is the ClassA evaporation pan still the most practical and accurate meteorological method for determining irrigation water requirements? Agricultural and Forest Meteorology, 112: 3, 233-236.

Wilks. D. 2006. Statistical Methods in the Atmospheric Sciences. USA: Academic Press is an Imprint of Elsevier. Vol. 91.

WMO. 2006. Guide to Meteorological Instruments and Methods of Observation: Annex 1 Technical Specification, World Meteorological Organization. Geneva, Switzerland

WMO. 2010. Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8), World Meteorological Organization. Geneva, Switzerland.

Yahaya O, Smart B, Omoakhalen AI, Ehibor OG. 2018. Development and Calibration of Automated ClassA Evaporimeter. Hydrological Current Research 9: 304

Part Two: Research Outputs to Improve Forecast,Early Warning and Applied Meteorological Services

Assessing the Impact of Future Climate Change on Wheat Production over Bale Zone of Ethiopia

Principal Investigator:-Abate Getachew Feleke[1]

Co-Investigators:-Bahiru Maregn Areda[2]

Fitsum Bekele[3]

[1,2,3] Meteorological Research and Studies Directorate, Addis Ababa, Ethiopia

National Meteorology Agency (NMA)

Submitted to Meteorological Research and Studies Directorate

JUNE 2018
ADDIS ABABA, ETHIOPIA

Acronyms and Abbervaition

BOFED	Bureau of Finance and Economic Development
BZADO	Bale Zone Agricultural Development Office
CORDEX	Coordinated Regional Downscaling EXperiment
CSA	Central Statistics Agency
DF	Degrees of Freedom
ENACTS	Enhanced National Climate Services
GLAM	Global Large Area Model
IPCC WG II	Intergovernmental Panel on Climate Change Working Group II
NMA	National Meteorological Agency
RCP	Repersentative Concentration Pathway
RMSE	Root Mean Square Error
SARC	Sinana Agricultural Research Center
SMHI	Sewdish Meteorological and Hydrological Institute
SRS	Simple Random Sampling

Abstract

Studying the impact, projected climate change on agriculture is crucial for farmer, policy makers and decision makers. in order to reduce the expected impacts taking an appropriate action beforehand. This paper investigates the potential impact of climate change on wheat yield over Bale zone of Ethiopia and addresses three key issues. Frist, CORDEX data has been used to indicate the expected change of temperature and rainfall over the study area under RCP4.5 and RCP8.5 scenarios. Taking 1981-2010 as baseline and 2021-2050 as future. The analysed results of the percentage change of rainfall indicate that there would be a change of rainfall in ranges of -11.28%to 15.86% and -14.00% to 8.00%under RCP4.5 and RCP 8.5 respectively. Whereas, the mean annual temperature would change between 0.57^{0}C to 1.33^{0}C Under RCP 4.5 and 0.76^{0}C to 1.55^{0}C under RCP8.5. Second, the simulated wheat yield over the study area shows that there would be a reduction of wheat yield by 11% under RCP4.5 and 14% under RCP8.5 climate scenarios. Finally, the questioner survey, which has been conducted over two kebeles located over the study area, has been analysed and the possible adaptation options, which enables the farmers, policy makers and decision makers to reduce the negative impacts of climate change on future wheat yield of the study area.

Key words: climate change, climate scenarios, CORDEX, RCPs, wheat yield, questioner survey,

1. Introduction

1.1 Background

The world's climate is governed by a great many factors including the amount of incoming solar radiation and atmospheric conditions. Variability, in both time and space is an inherent feature of climate, as atmosphere is always in state of turmoil and instability leading to variation in weather and climatic condition. Climate change thus, is defined as variations and shifts in weather condition over space and time of different scale and magnitude resulted in change in climate type (Ahrens, 2009).

In many developing countries, agriculture is the cornerstone of their economy, the basis of economic growth and the main source of livelihood. But agriculture in the developing world is often cited as being one of the sectors most vulnerable to climate change. There have been numerous studies on the impact of climate change on crop yields in tropical regions, mostly using climate models projections to drive process-based or statistical crop models. Climate change is generally expected to have detrimental impacts on low latitude crop yields, even under a moderate 1–2 °C local warming Intergovernmental Panel on Climate Change (IPCC WG II Summary for Policymakers, 2007). Over Africa in particular, crop yield changes are expected to be generally negative.

Ethiopia is highly vulnerable to the negative impacts of climate change. Changes in seasonality, frequency and intensity of precipitations, as well as the increase in average temperatures, are some of the most severe consequences occurring in the country as a result of climate change. Rural communities of the country, where 83% of the total population live, rely on rain-fed agriculture as sources of living and income are highly vulnerable to negative impacts of climate change.

Wheat plays an important role in the diet of many Ethiopian living in urban and rural areas. It is used for making of bread and other local food. Wheat is also an industrial crop used for the manufacture of pasta products (Macaroni, spaghetti and Noodles).

This paper assessed the potential impact of projected climate change on the production of wheat over Bale Zone of Ethiopia.

1.2 Problem Statement

Climate change affect agriculture in most parts of Africa specially the semi-arid areas of sub-Saharan African countries. It is expected that climate change will further increase the frequency and severity of extreme weather events in Africa as well as elsewhere (IPCC, 2012). Over the last two decades many studies on the impact of climate change on crops have been undertaken at the global and regional scales. Such studies have been used by local governments, policy makers and decision makers as an input for local planning. However, it is clear that global and regional scale studies may not exactly show the reality prevailing in smaller spatial scales hence reliable future projections for local planning will not be guaranteed unless climate change impact studies in the scale required undertaken.

In Ethiopia there are few studies on climate change impact on crops. Therefore, more studies should be undertaken at zonal level that can be helpful for formulating and planning of adaptation options.

1.3 Objective of the study

1.3.1 General objective

The main objective of the study was to assess the potential impact of projected climate change on the production of wheat in the Bale zone of Ethiopia.

1.3.2 Specific objectives

The specific objectives the study were:

- To produce maps showing the projected temperature and rainfall over the study zone,
- To simulate and compare wheat yield under baseline and future climatic conditions, and
- To assess the autonomous climate change adaptation practices by the community over the zone

2. Materials and Methods

2.1 Description of the Study Area

Bale zone is one of the 18 administrative zones in Oromia national regional state which is located in south-eastern Ethiopia. It has borderlines with Arsi, Guji, West and East Hararge zones as well as Somali and Southern Nations and Nationalities and Peoples' Regional States. It has 18 districts out of which nine are located in highland agro-ecology whereas the remaining nine are located in mid and lowland respectively. The zone is found in Southeast of Oromia Regional State that extends from 5° 22'S – 8° 08'N latitude and 38° 41'W – 40° 44'E longitudes. Bale zone has four agro-ecological zones namely extreme highlands 0.04%, highland 14.93%, midland 21.5%, and lowland 63.53%. The altitude ranges from below 1000 in the lowlands to 4377m above sea level in the highlands.

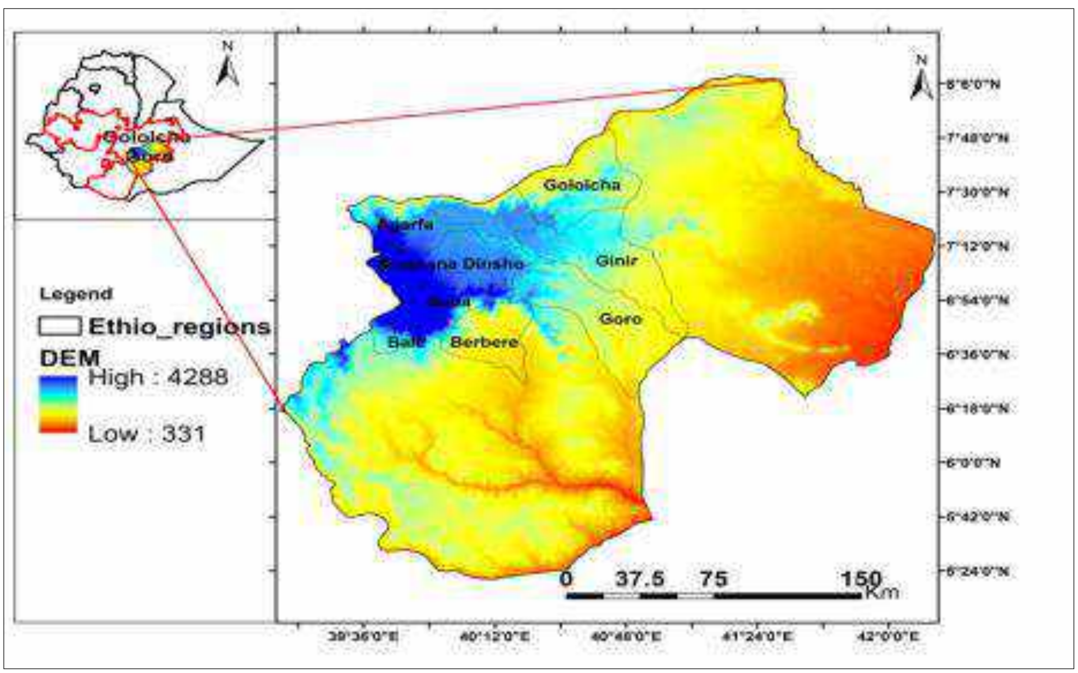


Figure1: Map of the study area (Bale Zone)

Total area of Bale zone is about 63,555 km^2 which is 16.2% of Oromia region. About 10.6% of the land is arable land used for crop production, 24.6% grazing land, 41.8% forest, and others 25% (BZADO, 2012). Most of the districts in Bale highlands are known for their bimodal rainfall patterns and are therefore highly suitable for agriculture.

2.1.1 Climate of the study Area

The figure 2 and figure 3 below show monthly rainfall and monthly mean temperature climatology of Bale Zone respectively, during the time period 1981-2015 (www.ethiopmet.gov.et/maproom).

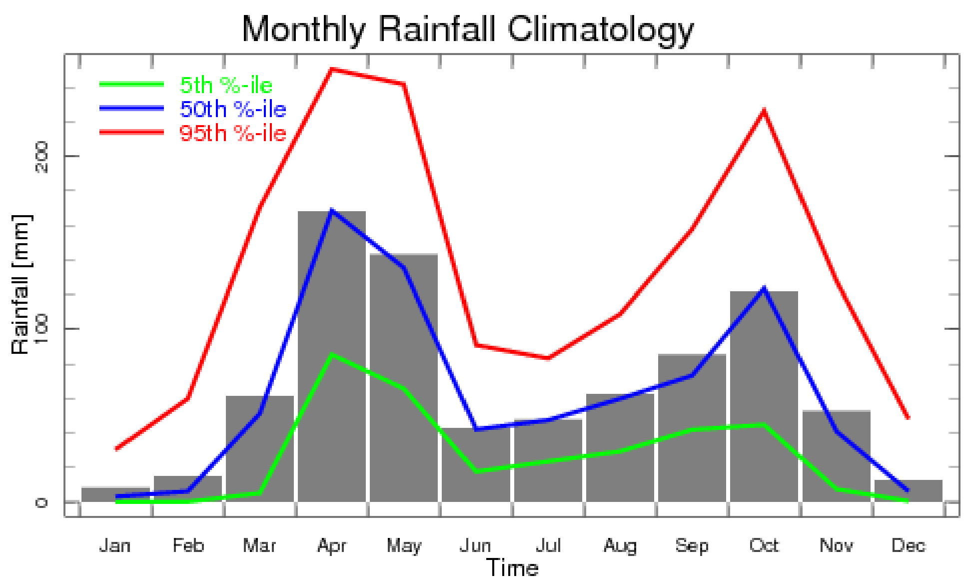


Figure 2: monthly rainfall climatology of Bale zone

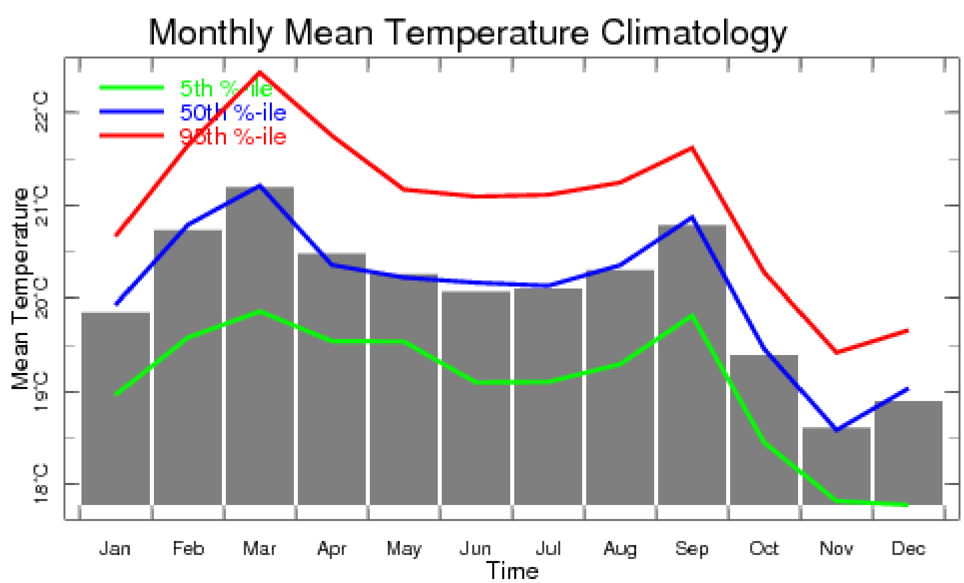


Figure 3: Monthly mean temperature climatology of Bale Zone

2.2 Data used and method of analysis

2.2.1 Data

2.2.1.1 Observed meteorological data

To analyze climate change and variability of the study area, all historical daily temperature and rainfall meteorological data (1981-2016) were collected from National Meteorological Agency (NMA).

GCM	RCM	Spatial Resolution
CNRM-CERFACS-CNRM-CM5	CLMcom	$0.44^0X0.44^0$
	RCA4	
ICHEC-EC-Earth	CLMcom	$0.44^0X0.44^0$
	RCA4	
MOHC-HadGEM2-ES	CLMcom	$0.44^0X0.44^0$
	RCA4	
MPI-M-MPI-ESM-LR	CLMcom	$0.44^0X0.44^0$
	RCA4	
CNRM-CERFACS-CNRM-CM5	CLMcom	$0.44^0X0.44^0$
	RCA4	
ICHEC-EC-Earth	CLMcom	$0.44^0X0.44^0$
	RCA4	
MPI-M-MPI-ESM-LR	CLMcom	$0.44^0X0.44^0$
	RCA4	

Table 2: Scenario-model used in the study

2.2.1.2 Model data

Coordinated Regional Climate Downscaling EXperiment (CORDEX) Ethiopian domain data from Swedish Meteorological and Hydrological Institute (SMHI) was used extensively to predict future climate change.in this study 1981-2010 is used as baseline and 2021-2050 is used as future. Detail of the CORDEX data used is provided in the table below.

2.2.1.3 Wheat yield data

The yield/production rates for wheat in the Zone collected in the agricultural statistics, aggregated at the level of Administrative Zone (that is, Bale Zone), from CSA for the 1990- 2016. The data on this crop yields (in quintals per hectare) were used for this study.

2.2.1.4 Soil Data

Soil hydrological properties were derived from FAO/UNESCO (1974) soil map of the world.

2.2.1 Method of climate data analysis

2.2.1.1 Analysis of current climate, and future climate change of the study area

The Climate Data Operators (**CDO**) software was used to analyze the current and/ as well as the projected temperature and rainfall over the study area..

2.2.1.2 Methods of survey data analysis

A questioner survey , on the perception of farmers on climate change and the autonmous adaptation methods they used to tackle the impacts of the exsiting climate change ,was developed and collected from different communities living on the Zone. The collected data was analyzed using the methods described below.

Sampling methods

Simple random sampling technique with proportionate representation was used to determine sample size for understanding of farmers` perception about climate change. The sample households were selected using simple random sampling (SRS) with probability proportional to size technique. There are 636 and 923 householders living in the selected *Kebeles* (Tulta and Welti Berisa), respectively.

A simple modelwas used to determine the required sample size at 95% confidence level, 5% degree of variability and 10% level of precision. (Yamane,1967citedin:Mesfin,2006) The formula used to calculate the sample size is as follows.

$$n = \frac{N}{1 + N(e)^2}$$

$$n_{Ginir\ (Tulta)} = \frac{636}{1+636\times(0.1)^2} \quad \text{and} \quad n_{Sinana\ (WeltiBeris\ a)} = \frac{923}{1+923\times(0.1)^2}$$

$n_{Ginir(Tulta)} = 86$ and $n_{Sinana(Welti\ Berisa)} = 90 \leq 92$

Where '**n**' is the least required sample size, '**N**' is the total households, and '**e**' is the level of precision (expectation error).

The information will also be obtained from a community member (**key informant**) interview that will be in a position to know the community (such as elders with their farming experiences) to fill the gaps.

2.2.1.3 Analysis of the perception of farmers about climate change

To assess farmers` perception on climate change, descriptive statistics based on summary counts of the structured questionnaire were used to provide insights into farmer's perception on climate change. Descriptive statistical tools such as, mean, percentages, frequencies and standard deviations were used to assess farmers' perception on the rainfall and temperatures trends and variabilityanddescribing the impact of climate change on crop production and farmers respondents about climate change. Chi-square (χ^2) and t-tests were employed to analyze and compare group means.

The chi-square test is always testing what scientists call the **null hypothesis,** which states that there is no significant difference between the expected and observed result. The formula for calculating chi-square (χ^2) is:

$$\chi^2 = \sum \frac{(O-E)^2}{E} = \sum \frac{d^2}{E}.$$

That is, chi-square is the sum of the squared difference between observed (O) and the expected (E) data (or the deviation, *d*), divided by the expected data in all possible categories.

A chi-square table is used to determine a critical value (Table 2). Critical values are important in both hypothesis tests and confidence intervals. For hypothesis tests, a critical value tells us the boundary of how extreme a test statistic we need to reject the null hypothesis. For confidence intervals, a critical value is one of the ingredients that goes into the calculation of a margin of error.

To determine a critical value, three things were used:

1. The number of degrees of freedom (DF or $\nu=(r-1)(c-1)$, where *r* rows and *c* columns)

2. The number and type of tails (one-sided tests or upper-tail)
3. The level of significance (95%).

Table 2: Upper-tail critical values of chi-square distribution with v degrees of freedom

	Probability less than the critical value				
v	0.90	0.95	0.975	0.99	0.999
1	2.706	3.841	5.024	6.635	10.828
2	4.605	5.991	7.378	9.210	13.816
3	6.251	7.815	9.348	11.345	16.266
4	7.779	9.488	11.143	13.277	18.467
5	9.236	11.070	12.833	15.086	20.515
6	10.645	12.592	14.449	16.812	22.458
7	12.017	14.067	16.013	18.475	24.322
8	13.362	15.507	17.535	20.090	26.125
9	14.684	16.919	19.023	21.666	27.877
10	15.987	18.307	20.483	23.209	29.588

2.2.1.4 Wheat yield simulation

One of the analytical tools provided to be used to study crop impacts will be Global Large Area Model for annual crops (GLAM).

GLAM is a process-based crop model that operates at larger spatial scales than traditional crop models and use with regional and global climate model output and remotely sensed data (Challinor et al., 2004). GLAM seeks to combine the benefits of empirical modeling (validity over large areas, low input data requirement) with the benefits of process based modelling (capturing the impacts of sub seasonal variability and retaining validity under unprecedented conditions, such as are likely under future climates). GLAM is designed for use with daily time series of weather data.

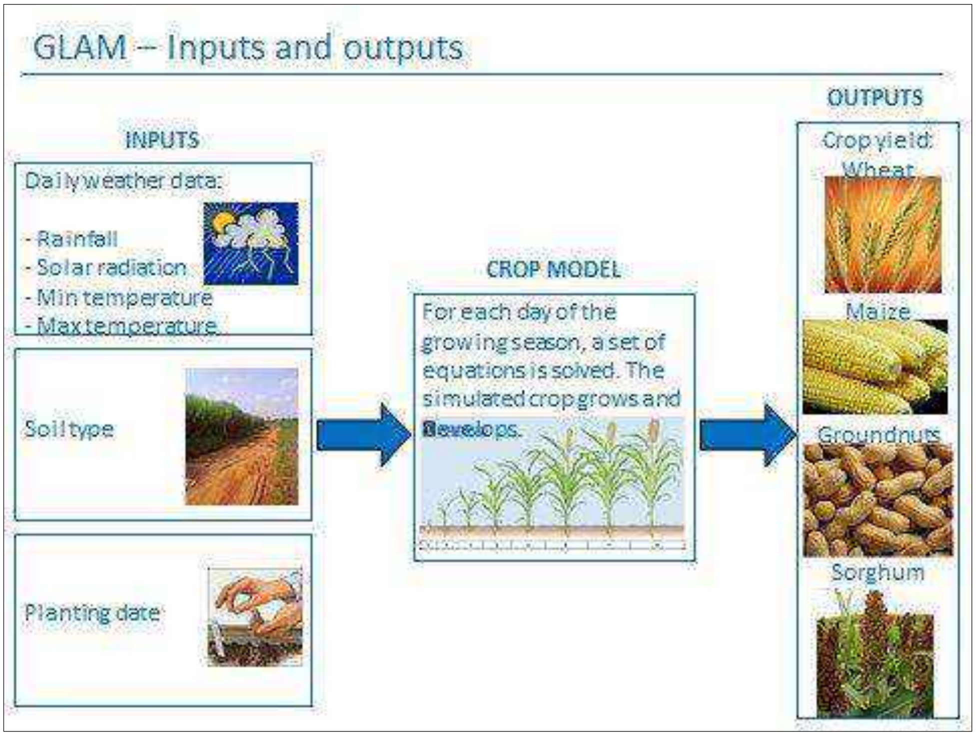


Figure 4: GLAM Model Description

The model, as it was used here, uses daily values of solar radiation, minimum and maximum temperature, and rainfall. Radiation was used to determine evapotranspirative demand and rainfall was used as the input to the upper most soil layer. Maximum and Minimum temperatures were averaged to produce daily mean temperature, and they were also used to calculate the vapor pressure deficit if those data are not available. GLAM has an intelligent sowing window. Sowing occurs on the first day on which the upper most layers are moist enough or at the end of the window (crisis-sowing) if this does not occur. The soil water model was initialized at the start of the sowing window with zero available soil moisture.

The impacts on yield due to factors other than weather (pests, diseases, management factors, etc., which acts to reduce yields by an amount referred to as the yield gap) only two are modelled explicitly: planting date and soil type. The key soil attribute is the water storage capacity. This is simulated using a lower limit, drained upper limit and saturated limit. Other soil influences are not simulated. All remaining influences on yield are modelled using a single yield gap parameter (YGP), which acts to decrease the leaf area available for transpiration. This allows the model to focus on the impact of weather and climate on the spatial and temporal variability of the crop yield. The YGP may also be

YGP is equal to one to simulate potential yield gaps (i.e. yield potential, which is limited only by water, radiation, humidity and temperature). However, it is observed yields with which model output is compared, and this necessitates the calibration of the YGP.

Crop development is determined by accumulating daily mean values of temperature above a base temperature (thermal time) with development stages occurring at specific thermal times. The leaf area index (LAI) is modelled using a maximum growth rate modified by an indicator of water stress. LAI and solar radiation are used to calculate the energy-limited, and will depend on the available water as given by the soil/roots sub model. The ratio of the actual to energy limited evapotranspiration is the indicator of water stress. Use of a transpiration efficiency (which is a function of ambient vapor pressure deficit) then allows the calculation of biomass, which through a harvest index allows the calculation of Yield. GLAM has a soil water balance with 25 layers which simulates evaporation, transpiration and drainage. Separate simulation of biomass accumulation, by use of transpiration efficiency allows specific leaf area (SLA, the mass of leaf per unit area of leaf) to be used as an internal consistency check. Leaf area and leaf mass can be derived independently of each other and can be used to calculate values of SLA which can be compared to typical observed values. Quantitative method to simulate and predict the impacts of high temperature episodes have been included in this model.

2.2.1.5 Model calibration

As it is mentioned in the above part of this paper, GLAM requires daily weather inputs for maximum and minimum temperature, precipitation and solar radiation. The yield gap parameter (YGP) takes values between zero and unity, in steps of 0.05, and it is calibrated using observed yields. Hence, calibration is a form of mean bias-correction, which may incorporate the impact of biases additional to the yield gap, such as input data bias and crop model error. GLAM accounts for many processes that are important under climate change. The model contains parameterizations of the impact of changes in atmospheric CO2 on transpiration efficiency (TE) and SLA, as well as the impacts of mean temperature on crop duration. Sub seasonal processes are also parameterized, so that changes in temperature, radiation, atmospheric humidity and water availability will affect evapotranspiration and crop growth and development. Daily values of VPD, for example, will affect transpiration efficiency.

3. RESULT and DISCUSSIONS

3.1 Validation of GLAM -Wheat

To investigate the performance of CORDEX for climate impact studies over bale zone, the observed yield data were compared with the simulated wheat yield data. The result showed that the RMSE between the observed and simulated wheat yield value for the baseline period is 1981-2010 therefore, it can be concluded that the GLAM wheat model forced by CORDEX was able to capture the observed yield of Bale.

3.2 Projected climate change

3.2.1 The percentage change of annual rainfall

The percentage change of annual rainfall is used to indicate the projected rainfall over the zone under the RCP 4.5 and RCP 8.5 scenarios.

$$\text{Percentage change of rainfall} = \frac{\text{Observed}}{Obeserved + \Pr edicted} \times 100\%$$

The projected rainfall over Bale zone under RCP4.5 showed-11.28 %to 15.86%, while the RCP8.5 scenario predicted-14.00% to8.00%.

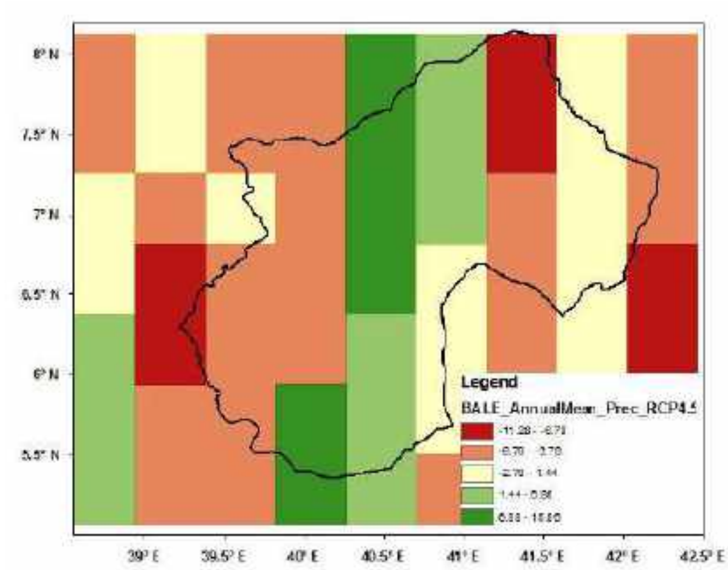


Figure 5: Changes in the average rainfall (%) under RCP4.5 scenario

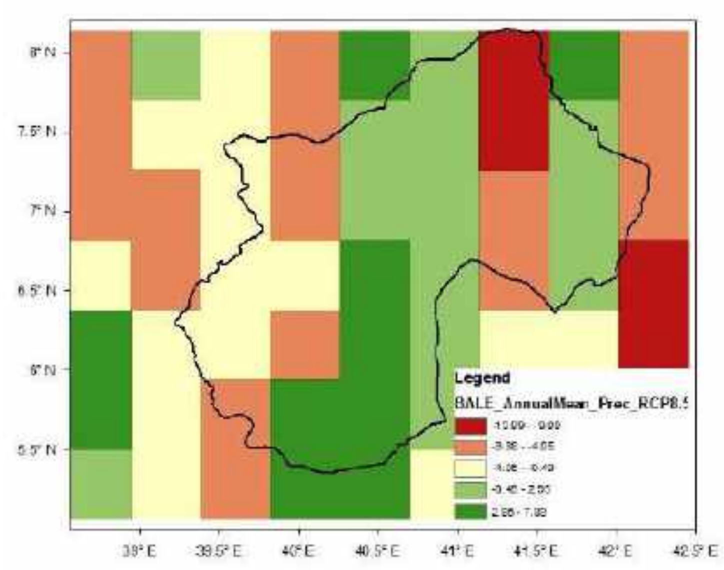


Figure 6: Changes in the average rainfall (%) under RCP8.5 scenario

3.2.2 The projected changes in average temperatures

The projected changes in average temperatures from CORDEX at a 0.44 ⁰ x 0.44 ⁰scales for Bale zone indicate that, it will increase by about 0.57to 1.33 for RCP4.5 scenarios. Similarly, the temperature will increase by about 0.76 to 1.55 for RCP8.5 scenario compared to the baseline (1981-2010). Generally, there will be a warming trend over the zone.

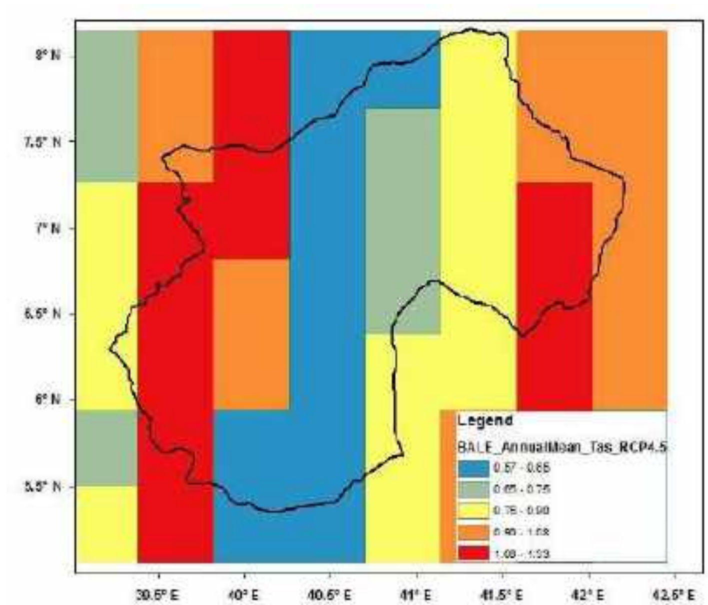


Figure 7: Changes in the average temperature (⁰C) under RCP4.5 scenario

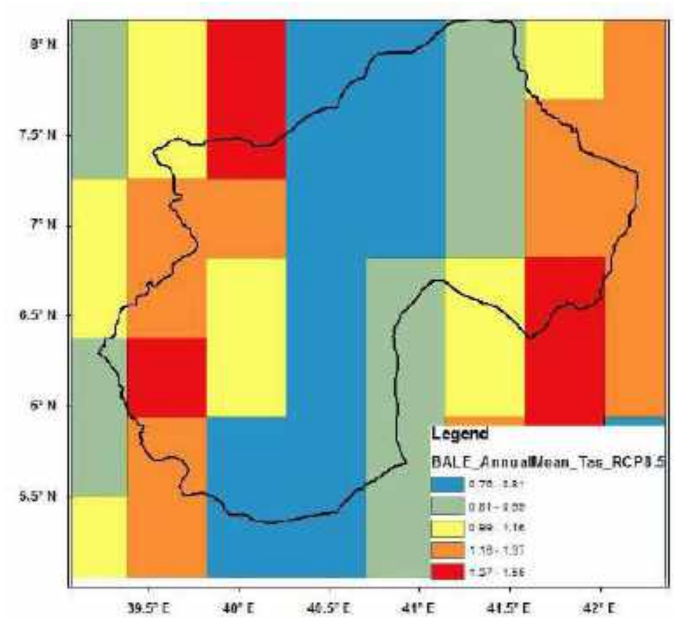


Figure 8: Changes in the average temperature (°C) under RCP8.5 scenario

3.3 Wheat yield simulation

3.3.1 Model validation

In order to validate the performance of CORDEX and GLAM –wheat, daily rainfall maximum and minimum temperature from ensemble RCMs of the CORDEX were used and daily solar radiation from ERA-intrem retrieved and re-gridded to 0.44^0 x 0.44^0. The baseline used in the validation is 1981-2010.

Since the production of wheat over Bale zone dominantly rain-fed, GLAM –wheat is simulated under rain-fed condition in this study. YGP was calibrated based on the observed yield data.

The Root Mean Square Error (RMSE) is used to select the optimum value of YGP. RMSE are often used to assess how well the model simulation fits the observation by quantitatively measuring the distance between observed and simulated values (Wallach et al., 2014)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_{obs,i} - y_{model,i})^2}{n}}$$

3.3.1.1 GLAM –Wheat Yield Simulation

The simulated wheat yield using general large area model for annual crops over the study area shows that on aggregate there would be a reduction of wheat yield by 11% under RCP4.5 and 14% under RCP8.5 climate scenarios.

3.3.2 Farmers' perceptions about climate change

A total of 178 respondents were interviewed in the two *Kebeles*. 48.3% of the respondents were from Tulta *Kebele*in Ginir district and 51.7% were from Welti Berisa*Kebele* in Sinana district (Figure 9). Information on the socio-economic characteristics of respondents showed that 100% were males in Tulta *Kebele* of Ginir district, while 91.3% and 8.7% were males and females in Welti Berisa *Kebele* of Sinana district, respectively. This implies that males were more involved in rural agriculture than their female counterpart in the selected sub-districts of both districts. Figure 1 revealed that the respondents of male farmers were more than female farmers in both *Kebeles* of the study area. Also in Tulta *Kebele*, majority (45.4%) of the respondents were between the age range of 21-30 years, 43% were between the age ranges of 31-40 years, and 5.8% were between the age range of 41-50 years and above 50 years of age, while in Welti Berisa majority (44.5%) of the respondents were between the age range of 41-50 years, 32.6%

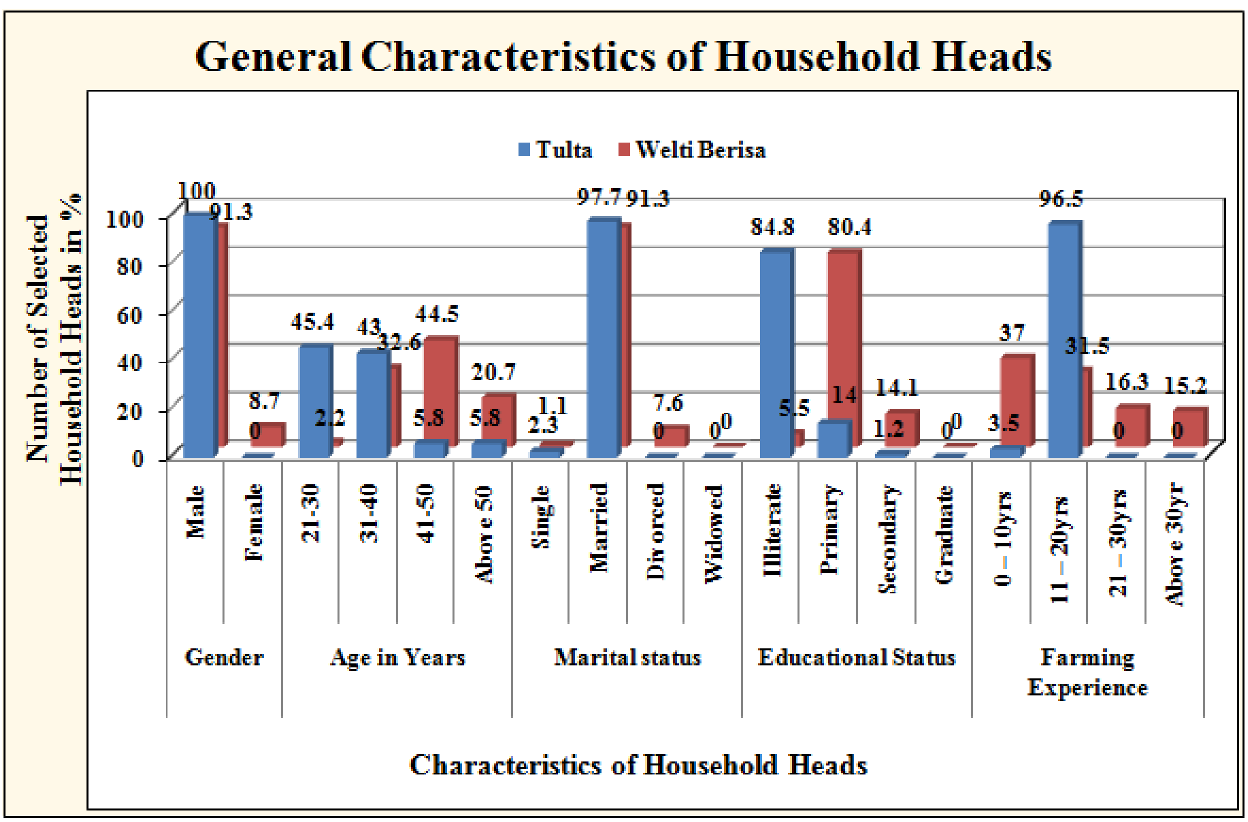


Figure 9: General characteristic of household heads in the sample selected Kebeles.

were between the age ranges of 31-40 years, 20.7% were above 50 years of age, and 2.2% were between the age range of 21-30 years, respectively (Figure 9). This implies that all the farmers sampled for the study were mature and they are expected to have adequate knowledge about the respective effects of climatic change. Furthermore, 97.7% and 91.3% in Tulta and Welti Berisa *Kebeles*, respectively, were married indicating their chances of getting family labor for use on the farm especially among the children, only 2.3% and 1.1% in Tulta and Welti Berisa *Kebeles*, respectively, were single and 7.6% in Welti Berisa were divorced (Figure 9).

In addition, the education of respondents indicated that majority (84.8%) were Illiterate, 14% were Primary School, and 1.2% were Secondary school, and 0% were Graduate in Tulta *Kebele*, while majority (80.4%) were Primary School, 14.1% were Secondary school, 5.5% were Illiterate, and 0% were Graduate in Welti Berisa *Kebele*,. This signified low level of education in both *Kebeles*. The length of farming or number of farming years is an important characteristic that enable farmers to appreciate and give good account of the impacts of climate variations in their environment. The study revealed that 96.5% and 31.5% of the farmers were 11- 20 years of farming experience, 3.5% and 37% indicated 01-10 years of farming experience in Tulta and Weliti Berisa *Kebeles*, respectively, while 16.3% and 15.2% revealed that 21-30 years and above 30 years of farming experience in Welti Berisa *Kebele*, respectively (Figure 9).

Table 3: General characteristics of household heads in both Kebeles of Tulta and Welti Brisa Kebelesin Ginir and Sinanadistricts respectively (n=178).

General Characteristics of Household Heads		Surveyed *Kebeles* (sub-district) in Ginir District		Surveyed *Kebeles* (sub-district) in Sinana District	
		Tulta *Kebeles*(n=86)		Welti Brisa *Kebeles*(n=92)	
		Frequency	Percentage	Frequency	Percentage
Gender	Male	86	100	84	91.3
	Female	0	0	8	8.7
	Total	**86**	**100**	**92**	**100**
Age in years	21-30	39	45.4	2	2.2
	31-40	37	43.0	30	32.6
	41-50	5	5.8	41	44.5
	Above 50	5	5.8	19	20.7
	Total	**86**	**100**	**92**	**100**
Marital status	Single	2	2.3	1	1.1
	Married	84	97.7	84	91.3
	Divorced	0	0 0	7	7.6
	Widowed	0	0.0	0	0
	Total	**86**	**100**	**92**	**100**
Educational Status	Illiterate	73	84.8	5	5.5
	Primary	12	14.0	74	80.4
	Secondary	1	1.2	13	14.1
	Graduate	0	0	0	0
	Total	**86**	**100**	**92**	**100**
Farming Experience	0 – 10yrs	3	3.5	34	37.0
	11 – 20yrs	83	96.5	29	31.5
	21 – 30yrs	0	0	15	16.3
	Above 30yr	0	0	14	15.2
	Total	**86**	**100**	**92**	**100**

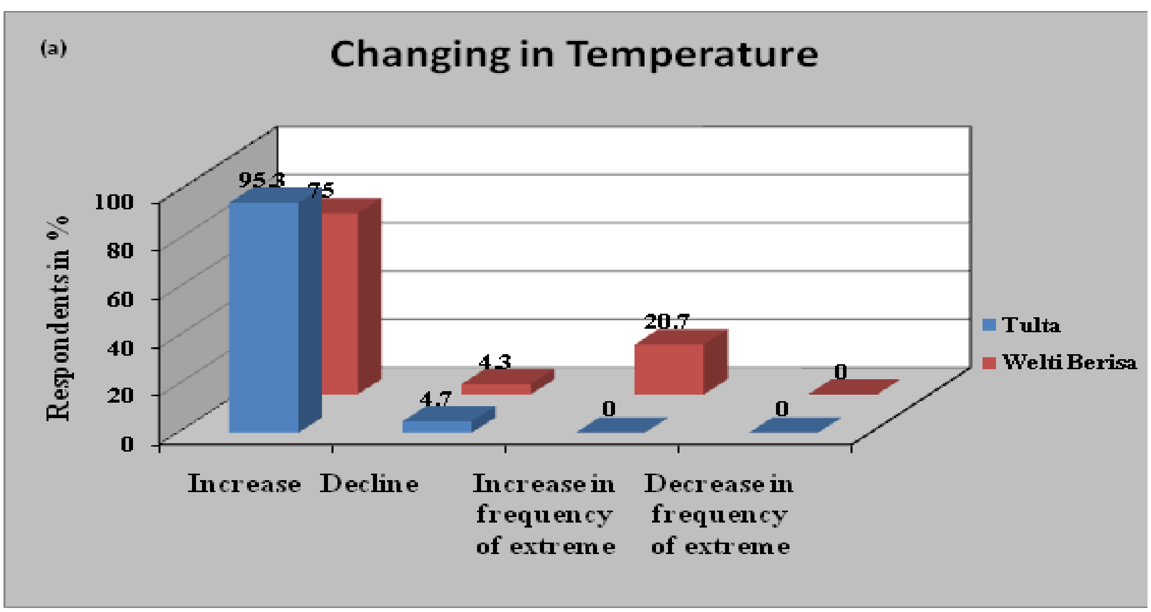
3.3.3 Farmer's perception on climate change in surveyed area

The results oftemperature condition, rainfall condition and change in the timing (duration) of the rain analysis are presented in Table4a-d. This is attributed to the fact that famers perceived climate change in different ways in different socio-economic characteristics of respondents.

1. Farmers' perceptions about climate change

The result revealed that the farmers interviewed in both *Kebeles* perceived about changing in temperature and rainfall. Majority of the farmers (95.3% and 75%) interviewed believed that number of hot days over the last 20 years has increased in Tulta and Welti Berisa *Kebeles* respectively. Only 4.7% and 4.3% noticed a decline in number of hot days over the last 20 years in Tulta and Welti Berisa *Kebeles* respectively, while the percentage of respondents (20.7%) were perceived that increase in frequency of extreme the last 20 years in Welti Berisa *Kebele* (Figure 10(a)).

The 55.4% of respondents have perceived that more rainfall amount with short period of time over the last 20 years in Welti Berisa *Kebele*. On the other hand, 100% and 26.1% farmers` interviewed have been believed that the less rainfall amount with short period of time in the rainfall performance during the last 20 years concerning amount and duration in each rain events in Tulta and Welti Berisa *Kebeles* respectively, while the percentage of respondents (18.5%) in Welti Berisa *Kebele* were believed that less rainfall amount with long period of time contrary to this opinion (Figure 10(b)).



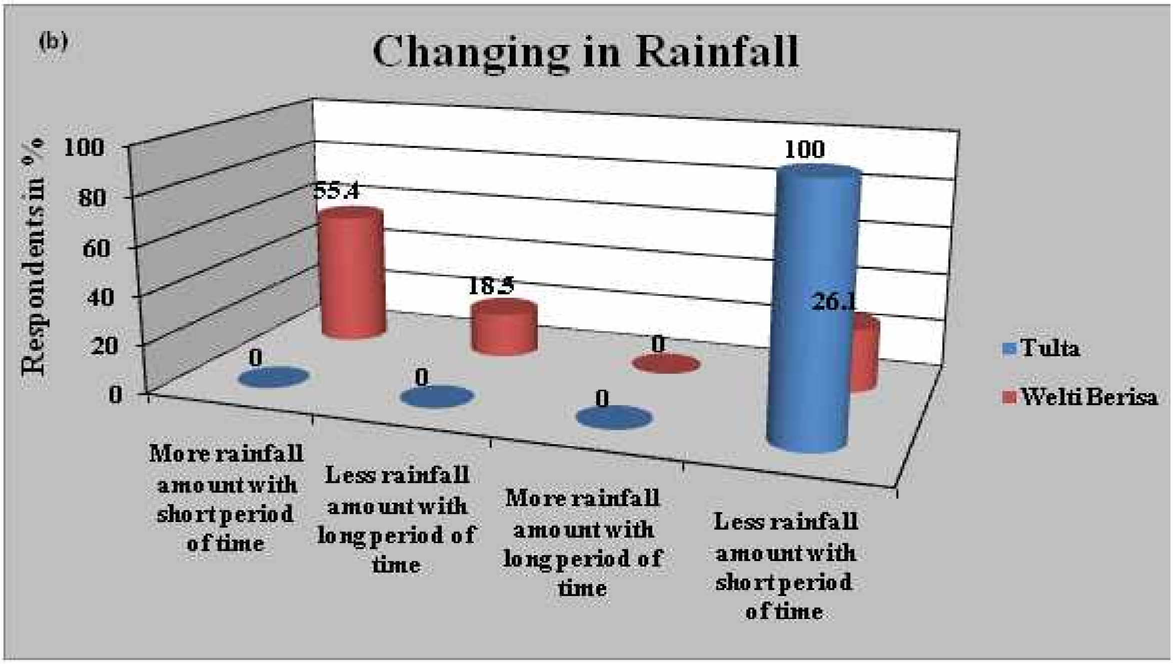


Figure 10: Changing in (a) temperature and (b) rainfall

2. Farmers' perception towards the occurrence of drought

Farmers in the study area perceived that the frequency of drought events. It has been indicated that 95.3% of the farmers had observed every year in Tulta *Kebele* and 44.6% once every 5 years in Welti Berisa *Kebeles*. Moreover, 4.7% and 55.4% had observed once every two years in Tulta and Welti Berisa *Kebeles*, respectively (Figure 11).

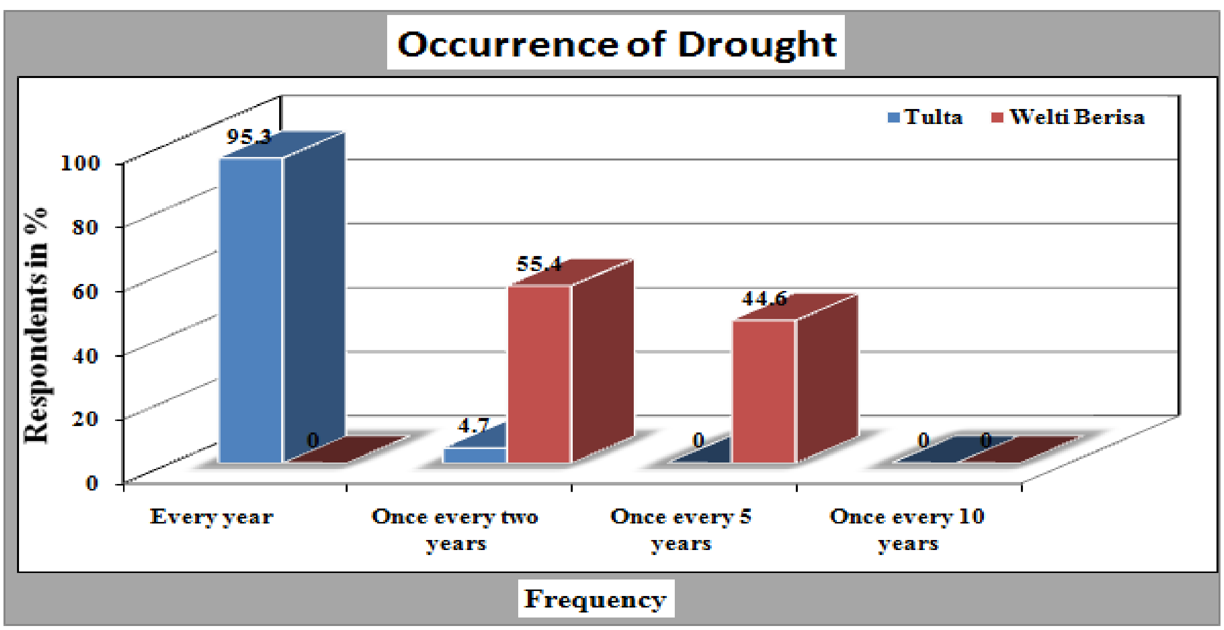


Figure 11: Occurrence of drought

3. Farmers' perception about the impact of climate change on crop production

The figure 12 showed that the farmers` perception about the impact of climate change on crop production. Out of all the farmers interviewed, 96.5% and 84.8% farmers of respondents observed the crop failure as the main impact of climate changes on the local community in Tulta and Welti Berisa *Kebeles*, respectively, while 96.5% and 52.2% perceived that decrease crop production associate with climate change in Tulta and Welti Berisa, respectively.

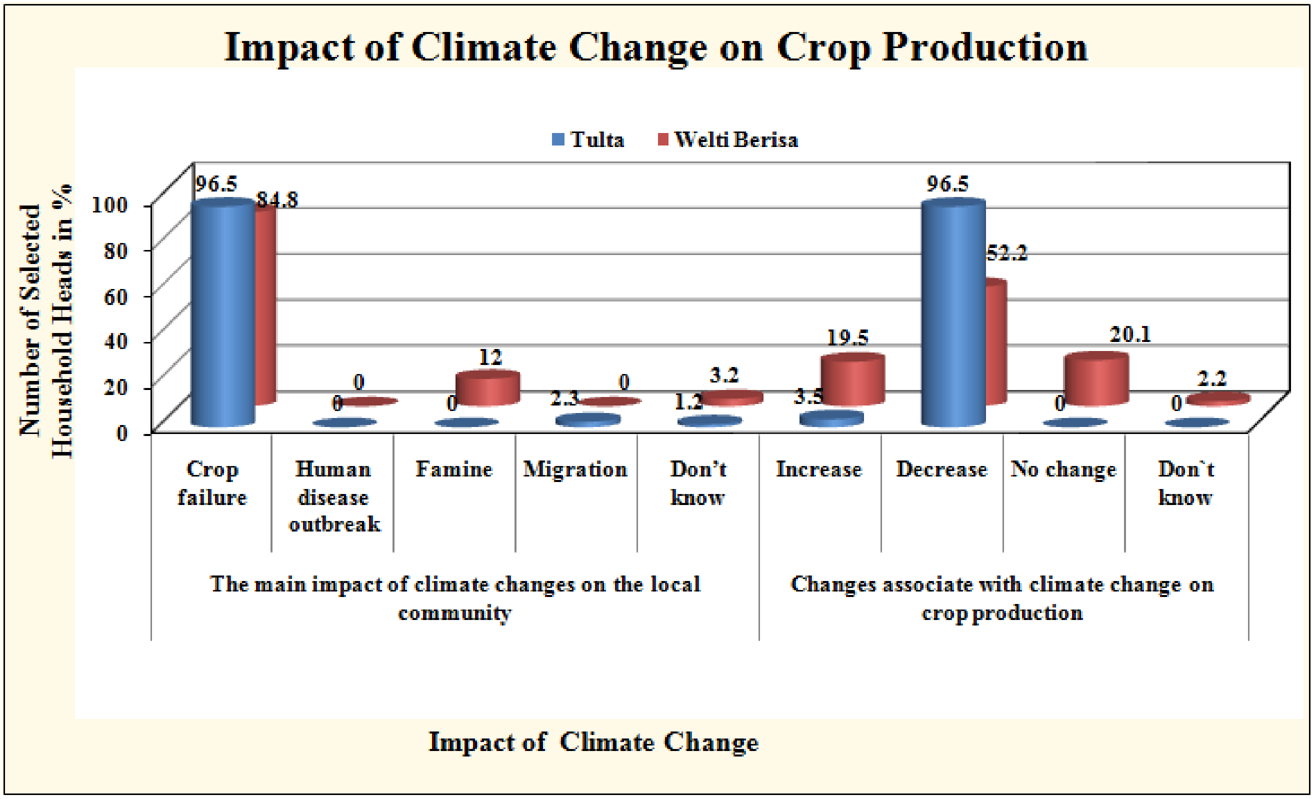


Figure 12: Impact of climate change on crop production.

Table 4a: The impact of climate change on crop production by farmers` perception in both Kebeles of their districts (n=178).

Households` Perception		Number and Percentage of Respondents			
		Surveyed *Kebeles* in Ginir District		Surveyed *Kebeles* in Sinana District	
		Tulta *Kebeles*(n=86)		Welti Brisa *Kebeles*(n=92)	
		Frequency	Percentage	Frequency	Percentage
Frequency of drought	Every year	82	95.3	0	0
	Once every two years	4	4.7	51	55.4
	Once every 5 years	0	0.0	41	44.6
	Once every 10 years	0	0.0	0	0
Farmer's own perception on the fertility level	Very fertile	4	4.7	10	10.9
	Fertile	0	0.0	51	55.4
	Infertile	0	0.0	5	5.4
	Don`t know	82	95.3	26	28.3
The frequency of extension service	Daily	23	26.7	0	0
	Weekly	24	27.9	49	53.3
	Monthly	34	39.5	43	46.7
	Every three month	5	5.8	0	0
	Six month	0	0.0	0	0
Observed significant changes in weather over the last 20 years	Unpredictable rain	6	7.0	39	42.4
	Prolonged drought	1	1.2	3	3.2
	Very hot seasons	79	91.9	0	0
	Very wet seasons	0	0.0	0	0
	No change	0	0.0	10	10.9
	Don't know	0	0.0	7	7.6
	Frequently spell	0	0.0	10	10.9
	Erratic onset	0	0.0	23	25
	Erratic Cessation	0	0.0	0	0
The main impact of climate changes on the local community	Crop failure	83	96.5	78	84.8
	Human disease outbreak	0	0.0	0	0

	Famine	0	0.0	11	12
	Migration	2	2.3	0	0
	Don't know	1	1.2	3	3.2

Table 4b: The impact of climate change on crop production by farmers` perception in both Kebeles of their districts (n=178).

Households` Perception		Number and Percentage of Respondents			
		Surveyed *Kebeles* in Ginir District		Surveyed *Kebeles* in Sinana District	
		Tulta *Kebeles*(n=86)		Welti Brisa *Kebeles*(n=92)	
		Frequency	Percentage	Frequency	Percentage
Changes associate with climate change on crop production	Increase	3	3.5	18	19.5
	Decrease	83	96.5	48	52.2
	No change	0	0.0	24	20.1
	Don`t know	0	0.0	2	2.2
Number of hot days over the last 20 years	Increase	82	95.3	69	75.0
	Decline	4	4.7	4	4.3
	Increase in frequency of extreme	0	0.0	19	20.7
	Decrease in frequency of extreme	0	0.0	0	0
Number of rainy days over the last 20 years	Increase	4	4.7	26	28.2
	Decline	82	95.3	40	43.5
	No change	0	0.0	25	27.2
	Don`t know	0	0.0	1	1.1
Rainfall performance during the last 20 years concerning amount and duration in each rain events	More rainfall amount with short period of time	0	0.0	51	55.4
	Less rainfall amount with long period of time	0	0.0	17	18.5
	More rainfall amount with long period of time	0	0.0	0	0

	Less rainfall amount with short period of time	86	100.0	24	26.1
Parameters frequently damages crops	Moisture stress drought	85	98.8	8	8.7
	Moisture excess or water logging	1	1.2	0	0
	Frost damage	0	0.0	84	91.3
	Strong wind damage	0	0.0	0	0

Table 4c: The impact of climate change on crop production by farmers` perception in both Kebeles of their districts (n=178).

Households` Perception		Number and Percentage of Respondents			
		Surveyed *Kebeles* in Ginir District		Surveyed *Kebeles* in Sinana District	
		Tulta *Kebeles*(n=86)		Welti Brisa *Kebeles*(n=92)	
		Frequency	Percentage	Frequency	Percentage
Impact of climate change on pest and disease	Increase in frequency of pest and diseases outbreaks	86	100	51	55.4
	Decrease in frequency of pest and diseases outbreak	0	0	5	5.5
	Emergence new pest and diseases	0	0	36	39.1
	Disappearance of already existing pest and diseases	0	0	0	0
Wintering of wheat rust occurrence in intensive	Good rain in Belg and Kiremt	1	1.2	1	1.1
	Less rain in Belg and good rain Kiremt	85	98.8	10	10.9
	Both seasons are poor	0	0	72	78.2
	Belg is good and Kiremt is poor	0	0	9	9.8
Season frequently	Belg	0	0	58	63.0
	Kiremt	0	0	18	19.6
	Both	86	100	16	17.4

Benefit get from the two seasons concerning wheat	From Belg	0	0	12	13.0
	From Kiremt	86	100	75	81.5
	From the two seasons	0	0	5	5.5
Get climate information that disseminate from national meteorology agency	Radio	43	50	45	48.9
	Television	2	2	45	48.9
	Development Agent (DA)	41	48	0	0
	No means	0	0	2	2.2
Institutions/organizations community has worked with to address the effects of climate change on livelihood	NGOs	0	0	0	0
	Government	0	0	75	81.5
	Both	86	100	17	18.5

Table 4d: The impact of climate change on crop production by farmers` perception in both Kebeles of their districts (n=178).

Households` Perception		Number and Percentage of Respondents			
		Surveyed *Kebeles* in Ginir District		Surveyed *Kebeles* in Sinana District	
		Tulta *Kebeles*(n=86)		Welti Brisa *Kebeles*(n=92)	
		Frequency	Percentage	Frequency	Percentage
Convenient time for get weather information	Morning 6 to 7AM	40	46.5	11	12
	Morning 7 to 8AM	0	0	0	0
	Morning 8 to 9AM	5	5.8	1	1.1
	Afternoon 4 to 5PM	1	1.2	0	0
	Afternoon 5 to 6PM	0	0	0	0
	Evening 6 to 7PM	1	1.2	17	18.5
	Evening 7 to 8PM	39	45.3	63	68.5
Convenient time for get seasonal climate outlook that help plan cropping	Early	3	3.5	33	35.9
	On time	0	0	57	62
	Late	83	96.5	2	2.2
Adjustments made in	Change crop Variety	43	50	48	52.2

farming practices to long-term shifts in temperature and rainfall	Building water harvesting schemes	6	7	0	0
	Implementing soil conservation schemes	1	1.2	3	3.3
	Diversification of crop types and varieties	5	5.8	3	3.3
	Changing planting dates	3	3.5	21	22.8
	Changing size of land under cultivation	3	3.5	16	17.3
	Apply supplementary irrigation	14	16.2	1	1.1
	Diversify from farming to non-farming activity	6	7		
	Apply water conservation agronomic practices	5	5.8	0	0
Main constraints to adaptation measures	Lack of capital	51	59.3	40	43.5
	Lack of information	0	0	0	0
	Shortage of labor	3	3.5	44	47.8
	Lack of access to water	29	33.7	0	0
	Poor health	3	3.5	8	8.7

3.3.4 Awareness of farmers about scientific findings of climate change

The farmers` perceptions about climate change in terms of awareness were classified as aware, not aware and can`t tell. Awareness of the perception of farmers related to scientific findings of climate change respondents were presented with respect to household demographics and socio-economic characteristics in Figure 13.

A chi-square test was used to determine the association between respondents' (household` heads) characteristics and perception about climate change. Characteristics of the respondents include gender, age, marital status, education level and experiences in farming activities as shown in Table 5. The chi-square (χ^2) test results showed an existence of significant differences ($P< 0.05$) among respondents' gender, age, marital status, education level and number of years in farming activity, and perceptions about climate change.

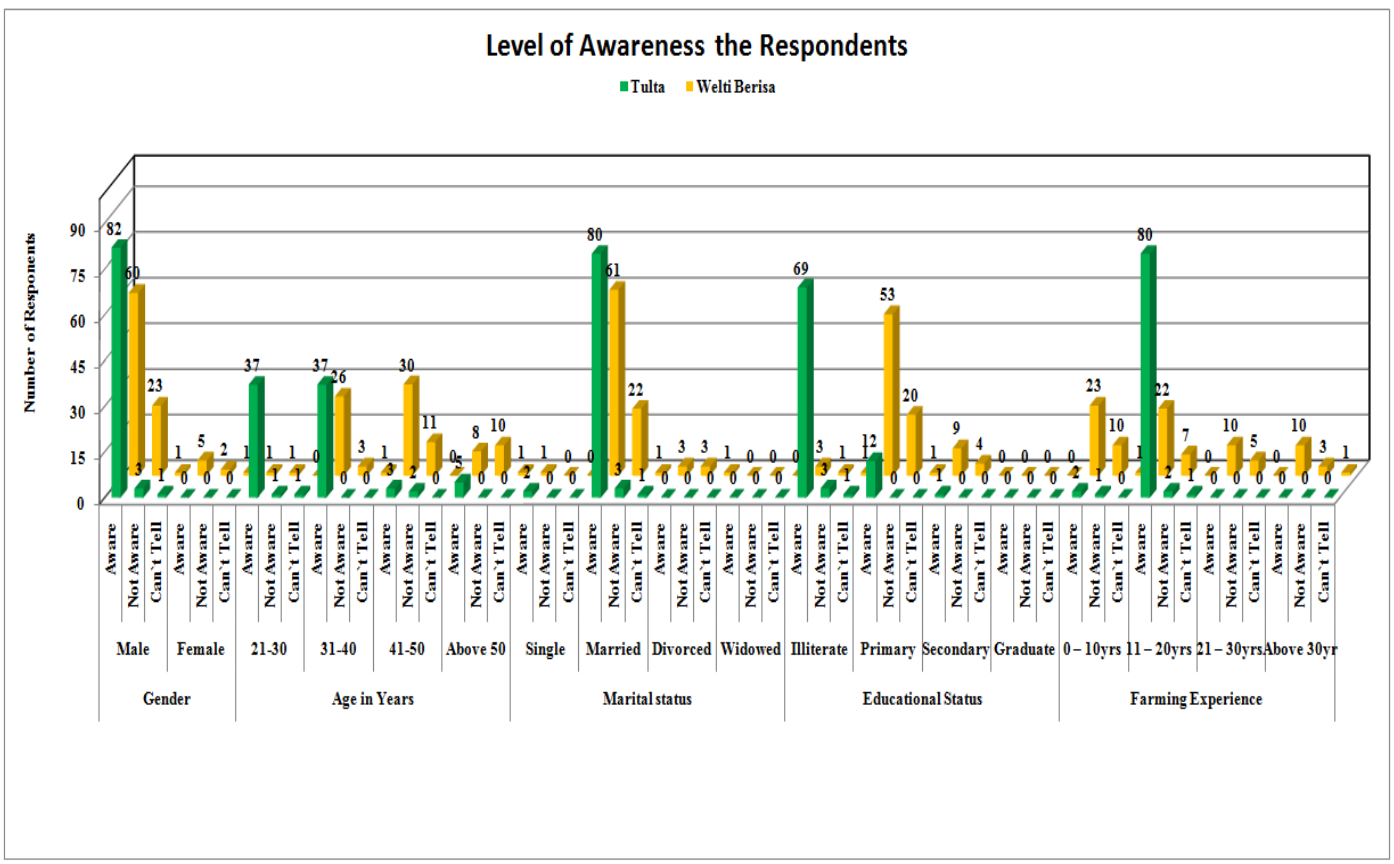


Figure 13: Level of Awareness in different Characteristics of the Respondents

Effects of socio-economic variables on level of awareness on climate change

This section analyses the effects of socio-economic characteristic (gender, age, marital status, educational level and faming experience) on their level of awareness using chi-square statistical test in both *Kebeles*. The research hypothesis tested is stated as follows:

H_o: There is no association between the level of awareness of climate change and socio economic variable (gender, age, marital status, educational level and farming experience)

H_1: There is association between the level of awareness of climate change and socio-economic variables (gender, age, marital status, educational level and farming experience)

Table 5: Awareness of households` perceptions toward climate change in each Kebeles

Socio-economic characteristics		Surveyed *Kebeles* (sub-district) in Ginir District			Surveyed *Kebeles* (sub-district) in Sinana District		
		Tulta *Kebeles* (n=86)			Welti Brisa *Kebeles* (n=92)		
		Aware	Not Aware	Can't Tell	Aware	Not Aware	Can't Tell
Gender	Male	82	3	1	60	23	1
	Female	0	0	0	5	2	1
	Total	**82**	**3**	**1**	**65**	**25**	**2**
Age	21-30 years	37	1	1	1	1	0
	31-40 years	37	0	0	26	3	1
	41-50 years	3	2	0	30	11	0
	Above 50 yrs	5	0	0	8	10	1
	Total	**82**	**3**	**1**	**65**	**25**	**2**
Marital status	Single	2	0	0	1	0	0
	Married	80	3	1	61	22	1
	Divorced	0	0	0	3	3	1
	Widowed	0	0	0	0	0	0
	Total	**82**	**3**	**1**	**65**	**25**	**2**
Educational Status	Illiterate	69	3	1	3	1	1
	Primary	12	0	0	53	20	1
	Secondary	1	0	0	9	4	0
	Graduate	0	0	0	0	0	0
	Total	**82**	**3**	**1**	**65**	**25**	**2**
Farming Experience	0 – 10yrs	2	1	0	23	10	1
	11 – 20yrs	80	2	1	22	7	0
	21 – 30yrs	0	0	0	10	5	0
	Above 30yrs	0	0	0	10	3	1
	Total	**82**	**3**	**1**	**65**	**25**	**2**

i. Gender and Level of Awareness of Climate change

As shown in Table 6a, the gender distribution of the respondent in Tulta *Kebele* reveals male to be 86 (100 %) and female to be 0 (0%) while in Welti Berisa male to be 84 (91.3 %) and female to be 8 (8.7%). However, both genders have significance level of awareness about climate change. The chi-square result for the test of the research hypothesis is as shown in the Table 6a. Since in Tulta andWelti Berisa *Kebeles* calculated values are 0.3 and 4.4 respectively, it is less than the critical value (5.99) at significance level 0.05. Hence, we accept Ho. Therefore, we conclude that there is no an association between level of awareness of climate change and gender.

ii. Age and Level of Awareness of Climate change

Age alone can influence human being to be more aware of his living environment Thus, older people especially, acquire more experience within their environment as indicated in Table 6b. Furthermore, the entire age categories were acquainted with their living environment but at various degrees. Then, Chi-Square was used to ascertain age and level of awareness of climate change. These shown that the calculated values (22.6 and 13.6 in Tulta and Welti Berisa *Kebeles* respectively) are greater than the critical value (12.59) at significant level of 0.05. Hence, we reject H_o and accept H_1. Therefore, we conclude that there is an association between age and level awareness of climate change.

Table 6a: Gender and Level of Awareness of Climate Change

Gender	Aware	Not Aware	Can't Tell	Total	Chi Square Value	DF	Critical Value
Surveyed *Kebeles* (sub-district) in Ginir District							
Tulta *Kebeles*(n=86)							
Male	82 (82.0)	3 (3.0)	1(1.0)	86	0.3	2	5.99
Female	0(0.0)	0 (0.0)	0 (0.0)	0			
Total	**82**	**3**	**1**	**86**			
Surveyed *Kebeles* (sub-district) in Sinana District							
Weltibrisa *Kebeles*(n=92)							
Male	60 (59.3)	23(22.8)	1 (1.8)	84	4.4	2	5.99
Female	5 (5.7)	2 (2.2)	1 (0.2)	8			
Total	**65**	**25**	**2**	**92**			

Note: Expected counts are printed in bracket

Table 6b: Age and Level of Awareness of Climate Change

Age	Aware	Not Aware	Can't Tell	Total	Chi Square Value	DF	Critical value
Surveyed *Kebeles* (sub-district) in Ginir District							
Tulta *Kebeles*(n=86)							
21-30 yrs	37(37.2)	1(1.4)	1(0.5)	39	22.6	6	12.59
31-40 yrs	37(35.3)	0(1.3)	0(0.4)	37			
41-50 yrs	3(4.8)	2(0.2)	0(0.1)	5			
> 50 yrs	5(4.8)	0(0.2)	0(0.1)	5			
Total	**82**	**3**	**1**	**86**			
Surveyed *Kebeles* (sub-district) in Sinana District							
Weltibrisa *Kebeles*(n=92)							
21-30 yrs	1(1.4)	1(0.5)	0(0.0)	2	13.6	6	12.59
31-40 yrs	26(21.2)	3(8.2)	1(0.7)	30			
41-50 yrs	30(29.0)	11(11.1)	0(0.9)	41			
> 50 yrs	8(13.4)	10(5.2)	1(0.4)	19			
Total	**65**	**25**	**2**	**92**			

Note: Expected counts are printed in bracket

iii. Marital Status and Level of Awareness of Climate change

The marital statuses of the respondents of the households in both *Kebeles* were insignificant in the level of awareness of climate change. The chi-square revealed that the calculated values (0.1 and 7.0 in Tulta and Welti Berisa *Kebeles* respectively) for marital statuses of the respondents are less than the critical value (12.59) at significance level of 0.05 (Table 6c). Thus, we accept Ho. Therefore, we conclude that there is no an association between level of awareness of climate variability and marital statuses.

iv. Educational Qualification and Level of Awareness of climate change

As indicated in Table 6d those with illiterate, primary school, secondary school and graduate levels of education were aware that their immediate environment is variations. Then, chi-square analysis was used to ascertain whether there is an association between educational qualification and level of awareness of climate change. In Table 6d, the chi-square results indicated that the calculated values (0.8 and 8.1 in Tulta and Welti Berisa *Kebeles* respectively) are less than the critical value (12.59) at significance level of 0.05. Hence, we accept H_o and reject H_1. Therefore, we conclude that there is no an association between level of awareness of climate change and educational qualification.

Table 6c: Marital Status and Level of Awareness of Climate Change

Marital status	Aware	Not Aware	Can't Tell	Total	Chi Square Value	DF	Critical value
Surveyed *Kebeles* (sub-district) in Ginir District							
Tulta *Kebeles*(n=87)							
Single	2(1.9)	0(0.1)	0(0.0)	2	0.1	6	12.59
Married	80(80.1)	3(2.9)	1(1.0)	84			
Divorced	0(0.0)	0(0.0)	0(0.0)	0			
Widowed	0(0.0)	0(0.0)	0(0.0)	0			
Total	82	3	1	86			
Surveyed *Kebeles* (sub-district) in Sinana District							
Weltibrisa *Kebeles*(n=92)							
Single	1(0.7)	0(0.3)	0(0.0)	1	7.0	6	12.59
Married	61(59.3)	22(22.8)	1(1.8)	84			
Divorced	3(4.9)	3(1.9)	1(0.2)	7			
Widowed	0(0.1)	0(0.0)	0(0.0)	0			
Total	**65**	**25**	**2**	**92**			

Note: Expected counts are printed in bracket

Table 6d: Educational Qualification and Level of Awareness of Climate Change

Educational Level	Aware	Not Aware	Can't Tell	Total	Chi Square Value	DF	Critical value
Surveyed *Kebeles* (sub-district) in Ginir District							
Tulta *Kebeles*(n=87)							
Illiterate	69(69.6)	3(2.5)	1(0.8)	73	0.8	6	12.59
Primary	12(11.4)	0(0.4)	0(0.1)	12			
Secondary	1(1.0)	0(0.0)	0(0.1)	1			
Graduate	0(0.0)	0(0.1)	0(0.0)	0			
Total	**82**	**3**	**1**	**86**			
Surveyed *Kebeles* (sub-district) in Sinana District							
Weltibrisa *Kebeles*(n=92)							
Illiterate	3(3.5)	1(1.4)	1(0.1)	5	8.1	6	12.59
Primary	53(52.3)	20(20.1)	1(1.6)	74			
Secondary	9(9.2)	4(3.5)	0(0.3)	13			
Graduate	0(0.0)	0(0.0)	0(0.0)	0			
Total	**65**	**25**	**2**	**92**			

v. Farming Experience and Level of Awareness of climate change

The experience acquires especially through farming determine how farmers respond to changes in farming techniques. As indicated in Table 6e, all the respondents have reasonable years of farming experience to ascertain their environments. The chi-square test was used to determine farming experience and level of awareness of climate change. The result in Table 6e indicated that the calculated values 8.3 and 3.4 in Tulta and Welti Berisa *Kebeles* respectively are less than the critical value (12.59) at a significant level of 0.05. Hence, we accept H_o and reject H_1. Therefore, we conclude that there is no an association between farming experience and level of awareness of climate change.

Farmer's perception about climate change and its effects on their crop production

Farmers' awareness of climate change and its effects on their crop production Table 7 displayed the chi square distribution of the respondents in both *Kebeles* of the study area. The calculated value (19.4) was greater than critical value (12.59); this means that the null hypothesis was rejected in favor of the alternate hypothesis which stated that opinion concerning climate change and its impact on crop production does not depend on the agro-ecology zone in which the farmer cultivates crop yields. By implication, respondents in both agroecology zones (in area of Tulta and Welti Berisa *Kebeles*) in the study area of Bale zone were much aware of climate change and its impact on their farming activities ranging from the time of planting their crops to time of harvesting and drying their crop yields. Thus changing in climatic factors was restricted to the study area.

Table 6e: Farming Experience and Level of Awareness of Climate Change

Farming Experience	Aware	Not Aware	Can't Tell	Total	Chi Square Value	DF	Critical value
Surveyed *Kebeles* (sub-district) in Ginir District							
Tulta *Kebeles*(n=87)							
0 – 10yrs	2(2.9)	1(0.1)	0(0.0)	3	8.3	6	12.59
11 – 20yrs	80(79.1)	2(2.9)	1(1.0)	83			
21 – 30yrs	0(0.0)	0(0.0)	0(0.0)	0			
> 30yrs	0(0.0)	0(0.0)	0(0.0)	0			
Total	**82**	**3**	**1**	**86**			
Surveyed *Kebeles* (sub-district) in Sinana District							
Welti Brisa *Kebeles*(n=92)							
0 – 10yrs	23(24.0)	10(9.2)	1(0.7)	34	3.4	6	12.59
11 – 20yrs	22(20.5)	7(7.9)	0(0.6)	29			
21 – 30yrs	10(10.6)	5(4.1)	0(0.3)	15			
> 30yrs	10(9.9)	3(3.8)	1(0.3)	14			
Total	**65**	**25**	**2**	**92**			

Note: Expected counts are printed in bracket

Table 7: Households` Awareness of Climate Change in both Kebeles with Chi-Square Distribution

Selected *Kebeles* (Sub-District)	Aware	Not Aware	Can't Tell	Row Total
Tulta *Kebeles* (in Ginir District)	82 (71.0)	3(13.5)	1 (1.4)	86
Weltibrisa *Kebeles* (in Sinana District)	65(76.0)	25(14.5)	2(1.6)	92
Column Total	**147**	**28**	**3**	**178**
Chi Sq = 19.4 DF = 2 P value =0.05				

Note: Expected counts are printed in bracket

4. Conclusion and Recommendation

4.1. Conclusion

The first part of this study assessed the impact of future climate change on the production of wheat using the Global Large Area Model (GLAM)for annual crops for the first time over Bale zone. While the second part of this study analyzed the questioner survey conducted over two *Kebeles* located over the study area and proposed the possible adaptation options that can help to reduce the negative impacts of climate change on agriculture over the zone.

Based on the findings of this research the following conclusions can be drawn.

I. The mean annual rainfall of the zone expected to change in ranges of -11.28 %to 15.86 % under RCP4.5 and -14.00%-8.00% under RCP 8.5 climate scenarios
II. The projected change of annual average temperature generally shows a warming trend that is 0.57-1.33^{0}C and 0.76-1.55^{0}C under RCP4.5 and RCP8.5 climate scenarios.
III. The projected simulate wheat yield over the study area would be decreased by 11% under RCP4.5 and 14% under RCP8.5

The study also assessed farmers' perceptions about climate change and the extent to which these perceptions have influenced their current practices with respect to adapting with changes in rainfall and temperature. Most of the interviewed farmers of the selected *Kebeles* in the study area perceived that they have observed the changing rainfall and temperature, such as number of hot days and less rainfall amount with short period of time over the last 20 years has increased, the frequency of drought events has been increased, the crop failure as the main impact of climate changes on the local community and decrease crop production associate with climate change. They also stated that these changes have been affecting their farming activities.

Based on the findings, the results show that perceptions are nearly unified for the whole sample households including the gender and social groups. Therefore, this study concludes that there are no multiple perceptions and varying insights among rural households with regards to the subject under consideration. This has emanated from an existence of widespread covariate risks in the area as a direct result of climate change.

4.2. Recommendations

Based on the findings of farmers` perception about climate change study, the following recommendations are provided to improve their perception and to enable farmers to better combat future impact of climate change on their agriculture activities:

I. Farmers should not attribute the low yield they witnessed from the output of their farms produce only to rainfall and temperature changing instead they must be encouraged to look into other factors such as low soil fertility, untimely planting, improper selection of cropping systems, diseases and pest infestation among others.

II. Farmers with access to extension services are likely to perceive changes in the climate because extension services provide information about climate change. An extension agent could be contact farmers individually and in the group.

III. Since rainfall distributions in the study area have no definite pattern and trend, irrigation investment needs should be reconsidered to allow farmers increased water control to counteract adverse impacts from climate change.

IV. There is a need to undertake an awareness of campaign regarding future unavoidable impacts of climate change so that policy makers can design appropriate policies that can enable farmers easily adapt to the changing climate.

5. Reference

1. Brklacich, M., Stewart, R.B. 1995. Impacts of climate change on wheat yield in the Canadian Prairies. In: Rosenzweig, C., Ritchie, J.T., Jones, J.W. (Eds.), Climate Change and Agriculture: Analysis of Potential International Impacts, No. 59. ASA Special Publication, Madison, pp. 147–161.

2. Centeral Statistical Agency of Ethiopia (CSA). http://www.csa.gov.et.

3. Challinor etal .2004. Design and optimization of a large-area process-based model for annual crops. Agricultural and Forest Meteorology, 124, (1-2) 99-120.

4. Deressa. 2007. "Measuring the economic impact of climate change on Ethiopian agriculture: Ricardian approach," Policy Research Working Paper Series 4342, The World Bank.
5. Http://www.see.leeds.ac.uk/see-research/icas/climate_change/glam/glam.html

6. IPCC.2007. Summary for policymakers. Climate change: the physical science basis, Working Group I contribution to IPCC fourth assessment report: climate change 2007. Geneva.

7. Kurukulasuriya P etal. 2006. Will African Agriculture Survive Climate Change?

8. LI Sanai et al. 2010. Simulating the impact of global warming on wheat in china using a large area crop model. Acta Meteorological Sinica, 24(1), 123-135.

9. Mearns, L.O. 1995. Research issues in determining the effects of changing climate variability on crop yields. In: Rosenzweig, C., Ritchie, J.T., Jones, J.W. (Eds.), Climate Change and Agriculture: Analysis of Potential International Impacts, No. 59. ASA Special Publication, Madison, pp. 123–146.

10. National Adaptation Program of Action of Ethiopia (NAPA). 2007. Addis Ababa, Ethiopia.

11. Seino, H. 1995. Implication of climate change for crop production in Japan. In: Rosenzweig, C., Ritchie, J.T., Jones, J.W. (Eds.), ClimateChange and Agriculture: Analysis of Potential International Impacts, No. 59. ASA Special Publication, Madison, pp. 293– 306.

12. The World Bank. 2010. Economics of Adaptation to Climate Change (EACC). synthesis report for Ethiopia.

13. Yesuf et al. 2008. Impact of Climate Change and Adaptation to Climate Change on Food Production in Low-Income Countries: Household Survey Data Evidence from the Nile Basin of Ethiopia. IFPRI Discussion Paper 00828. Washington, DC: International Food Policy Research Institute.

14. Zenebe Ge bre egzia et al.2011.Climate Change and the Ethiopian Economy.Discussion Paper Series. EfD DP 11-09

ETHIOPIAN SOMALI AND NEIGBORING REGIONS
METEOROLOGICAL SERVICE CENTER

Season Classification and Integrated Impact of ENSO and IOD on Seasonal Rainfall over Southeast Ethiopian Low Lands

Zerihun Hailemariam and Abel Sisay

June 2019

Abstract

Analyzing homogeneity in terms of space and time for weather and climate parameters like rainfall is fundamental procedure leading to effective seasonal climate forecast system for a country located in highly diversified climate systems like Ethiopia. Lots of literatures boldly remarked that ENSO and IOD oceanic indexes are key climate drivers over tropical areas including east Africa and Ethiopia, but limited or no work were performed on the directions to which those indexes drives the climate of specific area like south eastern Ethiopian low lands on specific seasons. As south eastern Ethiopian low lands is located in one of the tree rainfall regimes of Ethiopia identified as Bimodal type 2, an effort were mad to define regime specific season classification from the decadal based inter annual rainfall pattern. And the following result were obtained "Seasons are well defined and marked if the calendar year is categorized into four Heterogeneous periods.

- MAM(Mar-May) with 52% contribution to annual total rainfall/rainy season/
- JJA(Jun-Aug) with 6% contribution to annual total rainfall/dry season/
- SON(Sep-Nov) with 38% contribution to annual total rainfall/rainy season/
- OND(Oct-Dec) with 4% contribution to annual total rainfall/dry season/

Based on this regime oriented season classification further effort were also exerted for analyzing the integrated impact of ENSO and IOD oceanic indexes on seasonal rainfall of the region in focus. Relatively significant correlation coefficient was obtained with SON (Sep-NOV) season that is 0.8 with IOD and 0.5 with ENSO indexes. Following this correlation IOD based analogue and statistical methods are recommended to be considered as an input for this season rainfall forecast systems.

Unlike ENSO index, IOD index is computed from SST anomalies of two extremes at the same time from the same tropical Indian Ocean and this makes the temporal changes to be in slow motion. By analyzing SON season IOD index distribution from 1981 to 2017, a threshold value of 0.19 was set for subjective analysis with the seasonal rainfall. The subjective analysis made based on this threshold value (0.19) indicates that 95% of SON (Sep-Nov) season rainfall were Normal to below Normal when IOD index is less than or equal to the threshold value (IOD <= 0.19) whereas 94% of seasonal rainfall were Normal to above Normal when IOD index is greater than the threshold value (IOD > 0.19). This indicates that if IOD index in SON season is forecasted to be greater than the threshold value of 0.19, Normal to above normal seasonal rainfall is expected with very high probability and the opposite is

expected if the IOD index value is forecasted to be less than or equal to the threshold value of 0.19. Furthermore, the forecasted value of IOD index is available at least a head of six months from the International forecast centers with reasonable accuracy. This might be an opportunity to provide a probabilistic forecast of SON (Sep-Nov) season rainfall performance, six months before the onset of the season.

Acronyms

CCA- Canonical Correlation Analysis

CHIRPS -Climate Hazards Group Infra-Red Precipitation with Station data

DJF- December to February

ENACTS -Enhancing National Climate Services

ENSO- Elion & Southern Oscillation

IOD- Indian Ocean Dipole

IRI-International Research Institute

JJA – June to August

MAM- March to May

MSC- Meteorological Service Center

NMA- National Meteorological Agency

NOAA-National Oceanic and Atmospheric Administration

SE- Southeastern

SON –September to November

SST- Sea Surface Temperature

WMO- World Meteorological Organization

1. General Introductory Background

1.1 Introduction

Season may be defined differently from different discipline points of view. From meteorological point of view, season is a period when an air mass characterized by homogeneous weather elements such as temperature, rainfall, relative humidity, wind etc., dominates a region or part of a country. The selection of dominant weather parameters that determine seasonal classification depends on its level of social and economic impacts, for tropical area as most economical and social activities are rainfall dependent, season is related to rainfall and identified as wet and dry but for subtropical area the issue of season is highly sensitive in term of temperature. In the case of Ethiopia, however, the seasons are unique and are classified based on inter annual rainfall patterns. Inter annual rainfall pattern analysis performed over Ethiopia indicates the existence of three rainfall regimes (Tesfaye Haile and L. yarotskaya, 1987) that are: -

- Uni-modal (Single-maxima) dominated by single maxima rainfall pattern, represent western and north western Ethiopia.
- Bi-modal type-1, dominated by quasi-double maxima rainfall pattern, with small peak in April and maximum peak in august, represent central and north eastern Ethiopia.
- Bi-modal type-2, dominated by double maxima rainfall pattern with peaks during April and October, represent southern and south eastern Ethiopia.

Ethiopian National Meteorology Agency (NMA) uses three season definition as Bega (October-January), Belg (February-May) and Kiremt (June-September) for developing seasonal forecast system. But there is no clear evidence on using this three season definition except Tesfay Haile and L. Yarotskaya, 1987 in there published paper indicated that this three-season definition is representative only for Bi-modal type-1 rainfall regime. Hence, this research is expected to focus on south eastern Ethiopian low lands which were categorized as Bi-modal type-2. Much effort is exerted to define regime oriented season classification which in turn be used as an input for analyzing the integrated impact of ENSO and IOD on seasonal rainfall. Based on this analysis, further effort is also exerted to define regime and season specific seasonal forecast model for rainfall.

1.2 Study Area

The study area in terms of Administrative boundary is located in Ethiopian Somali Regional state, this region is dominated by pastoralist community and highly affected by climate change, either flooding or drought is expected once in 3-5 years. This region is characterized by two distinct wet periods separated by two distinct dry periods. The peak rainfall months are April and October. The region covers most of the Lowlands of the South eastern Ethiopia low lands (in between 35°E to 48°E and 3°N to 9°N grid). According to Koppen's climatic classification, this area is categorized as BWH which is hot arid climate, with the mean annual temperature between 27-32 ºC and the mean annual rainfall is less than 450mm and usually characterized by strong wind, high temperature, low relative humidity and little cloud amount. Evaporation is 10-20 times more in excess of annual rainfall in same places.

1.3. Relevance of the Research

NMA, currently utilize three season definition such as Bega (Oct-Jan), Belg (Feb-May) and Kiremt (Jun-Sep) at National level. But this "three-season" definition is appropriate only for Bi-modal type-1 rainfall regime (Tesfay Haile and L. Yarotskaya, 1987). Hence there is logical demand to define season for the remaining rainfall regimes.

Fundamental rule leading to relatively better seasonal forecasting skill is to identify local climate drivers and analyze it with long term seasonal rainfall data averaged over homogenous space and time. ENSO and IOD are already identified key climate drivers for Ethiopia and East African climate. But long term rainfall data over south eastern Ethiopian low land were not yet organized in terms of space and time in such a way to be analyzed with ENSO and IOD for developing local level seasonal forecast model. Furthermore the National level seasonal forecast is too general to represent such highly diversified climate systems. Hence there is a need to analyze key climate drivers with rainfall data averaged over homogenous space and time that is with properly identified rainfall regime and season.

1.4. Objectives of the Study

This research has the following objectives

- By analyzing inter annual rainfall patterns from long term historical rainfall data, to define locally representative season classification for one of the Ethiopian rainfall regimes that is Bimodal type-

2 which is dominated by double maxima rainfall pattern and geographically covers Southeastern Ethiopian Low lands.

- By analyzing historical data of seasonal rainfall with ENSO and IOD indexes, to define seasonal forecast model for seasons that may have significant Correlation over Ethiopian Low Lands

1.5 Expected output from the research

The following outputs are expected from this research:

- In addition to the operational, National level season classification, Regime oriented season classification is expected to be defined in such a way to represent local areas rainfall regimes of south eastern Ethiopian low lands.
- The impact of Oceanic indexes (ENSO and IOD) on seasonal rainfall performance over south eastern Ethiopia is expected to be clearly identified.
- Hence locally suitable and season specific seasonal forecast model is expected to be available for rainfall over south eastern Ethiopia.

2. Review of Related Literature

2.1 Climate systems in Ethiopia

The first traditional Agro climate categorization, categorized the country in to three Agro climate zones as Kola, Weynadega and Dega. This classification system enables farmers to recognize broad vegetation types adapted to the environmental conditions and select crops and livestock best suited to the climate regimes and still highly implemented at the community level. This classification system was scientifically supported by considering the relationship between elevation and temperature (Dove, 1890). Further improvement considered annual rainfall and extend these tree Agro climate zones in to five as Wurch, Dega, Weina Dega, Kolla and Bereha (Table 1).

Table: 1 Climate classification of Ethiopia based on altitude and annual rainfall

No	Altitude(mtr)	Annual Rainfall(mm)	Climate Classification	Remark (Vegetation/Crop)
1	above 3000	above 2200	Wurch (Cold highlands)	Barley is dominant crop
2	2500-3000	1200 to 2200	Dega (Cool, humid, highlands)	Barley and wheat are >>
3	1500 to 2500	800-1200	Weina Dega (Temperate, cool sub-humid, highlands)	all types of crops especially teff
4	800 to 1500	200-800	Kolla (Warm, semi-arid))	Sorghum and corn are >>
5	> 800	>200	Bereha (Hot and hyper-arid):	desert type vegetation

From Global point of views, world was classified into five climate categories, which are designated by capital letter A, B, C, D and E, based on monthly mean rainfall and temperature data, these five climatic groups can be further divided in to sub principal climatic types (Koeppen climate classification system). By using this climate classification system, the country was categorized in to ten heterogeneous categories after Lemma Gonfa, 1996, such as (Fig 1 left).

1. Bwh (Hot arid climate)
2. Bsh (Hot semi-arid climate)

6. Cwb (Warm temperate rainy climate)
7. Cfb (Warm temperate rainy climate)

3. Bsk (Cool semi-arid climate)

4. Aw (Tropical rainy climate)

5. Am (Tropical rain forest climate)

8. Aws (Tropical climate)

9. Cws (Warm Temperate climate

10. H (Highland climate)

Thornthwaite's climate classification system is defined as moisture index rainfall effectiveness and is a function of the availability of water and water need as potential evapotranspiration (P.E). Based on this climate classification system Ethiopia has five moisture zones: humid, moist sub-humid, dry sub humid, semi-arid and arid climates (Lemma Gonfa, 1996) (Fig 1 right).

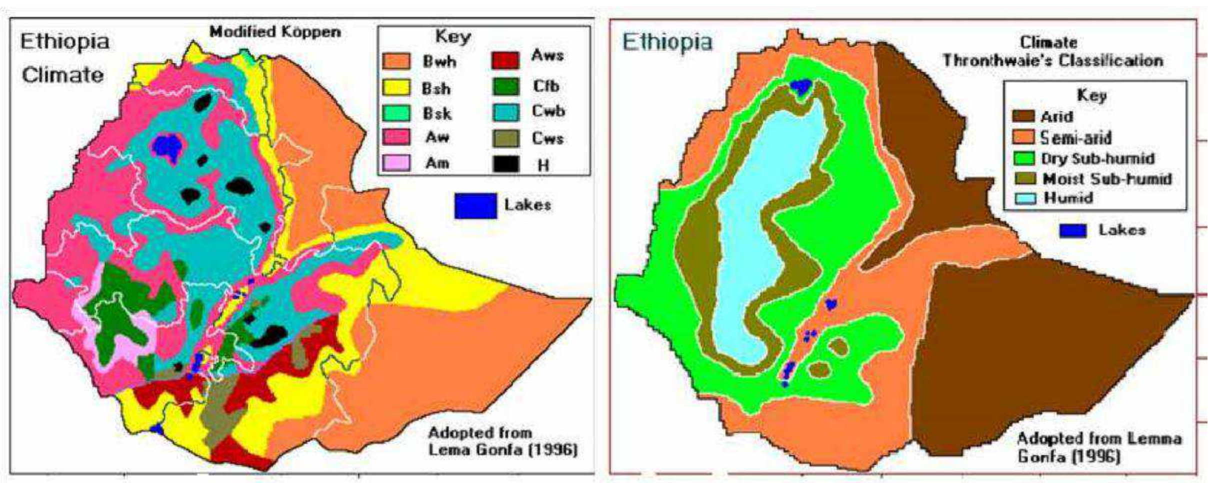


Fig 1: Climate classification in Ethiopia based on Koeppen (left), based on Thornthwaite's (right)

Climate classification system that considers spatial and temporal distribution of rainfall was performed After Tesfaye Haile, 1987. This classification system is a function of inter annual rainfall pattern and categorized the country in to three rainfall regimes as Uni-modal (Single-maxima), Bimodal type-1 and Bi-modal type-2(Fig 2).

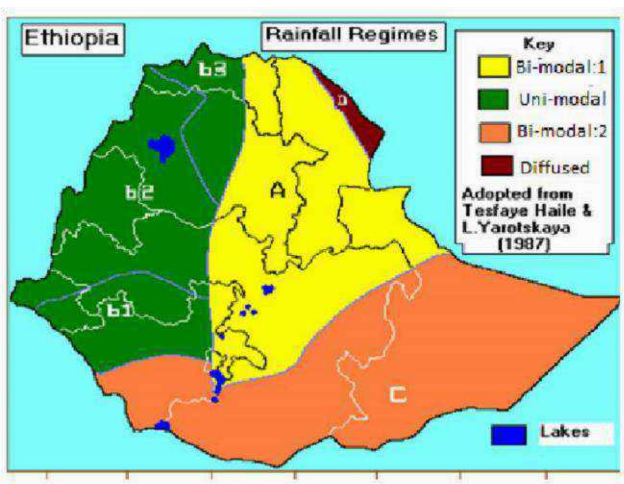
Following these three rainfall regimes, three kinds of season classification were expected to divide the calendar year in to two over western Ethiopia as dry and rainy seasons, in to three over central and northeastern Ethiopia as Belg, Kiremt and Bega and in to four over southeastern Ethiopia as two rainy and two dry seasons. But it is the three season definition what NMA has been using to represent the Nation since the year at which seasonal forecast were started.

There is traditional evidence indicating that this kind of season classification system along with Agro climatic zoning (as dega, weynadega and kola) has been practiced hundred years before by central

Ethiopian farmers. In this regard, the contribution of NMA can be considered as supporting the traditional season classification system with scientific evidence.

NMA's meteorological research report titled on "Climate and Agro climatic resources of Ethiopia" Were published by year1986. This research report was the first attempt to assemble together the climate and Agro climatic recourses of the country. In this report mean seasonal rainfall, mean annual rainfall, nnnual rainfall variability, rainfall regimes and season classification were analyzed.

The other work, as NMA, were "Agro Climatic Zones of Ethiopia "that was performed by considering the concept of water balance, length of growing period and its associated onset date, dependable length of growing period, and expected minimum growing period at a given probability level. Based on this classification system, the country was divided into 53 distinct zones but by combining zones that have homogeneous growing periods with temperature and moisture regimes, these 53 distinct zones were regrouped into 14 agro climatic zones (NMA, 1996) (Fig 3). Even if scientific standards were applied in this work, agro climatic and Education sectors are not using this product.



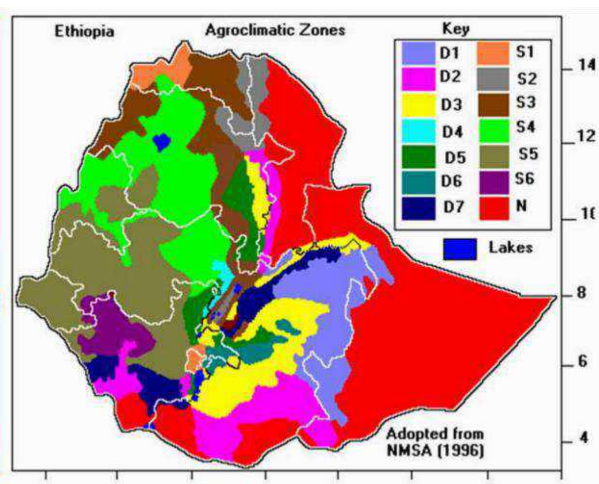


Fig 2: Rainfall Regimes of Ethiopia, Tesfaye, 1987. Fig 3: Agro Climatic Zones of Ethiopia, NMA, 1996

2.2. Seasonal forecast in Ethiopia

Seasonal climate prediction in Ethiopia began in 1987 for three seasons, Bega, Belg and Kiremt. Input parameters were from Local, regional and global centers. The parameters set for predictions were Rainfall in terms of amount, distribution, intensity, onset and cessation and temperatures in terms of mean, maximum, minimum and extremes. Trend analysis, analogue method, statistical assessments, probabilistic methods (terciles) and using model products are currently major operational forecasting methods. Monitoring ENSO and IOD oceanic indexes are also major activities for updating the provided seasonal forecast in monthly as well as in ten days' bases. In addition to the National level seasonal forecast, regime specific seasonal forecast is expected from regional service centers.

The variability in the rainy season onset and cessation could pose socio-economic and developmental challenges as they threaten food security and induce poverty. This is so because erratic and significant delays in rainfall affect the country's overall food production.

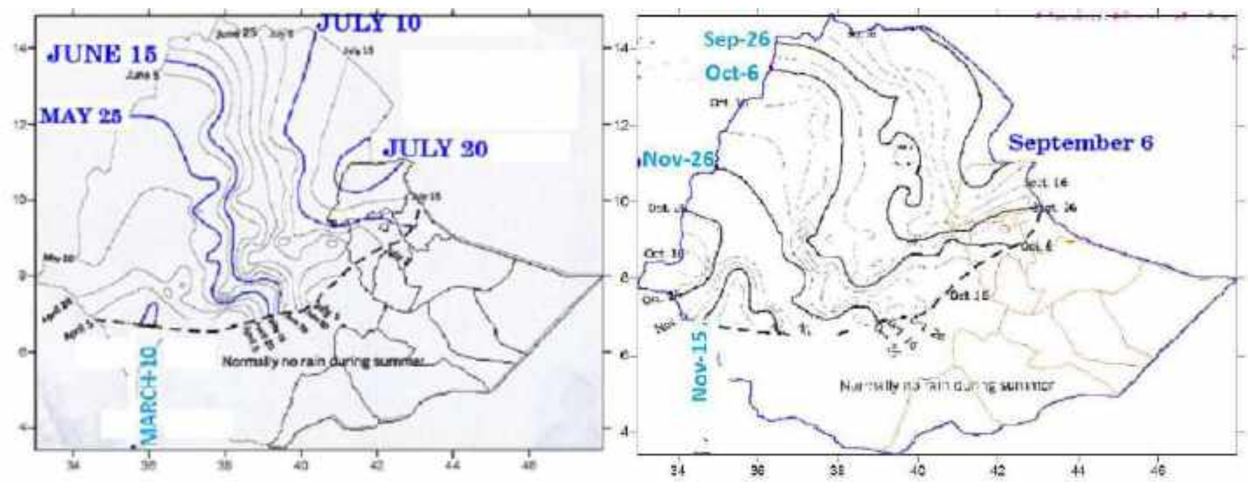


Fig 4: Mean onset date (left) and cessation date (right) of kiremt season After T. Segele and P. J. Lamb 2005

Forecasting of onset and cessation of rainy season is meaning full only if the local areas climatical normal onset and cessation date of rainy season is known. In this regard the mean onset and cessation date of Kiremt season (After T. Segele and P. J. Lamb, 2005) (Fig 4) can be used as an input for providing down scaled Kiremt season rainfall forecast. But this work also did not consider the existence of heterogeneous rainfall regimes.

Another input that was considered to improve the rainy season forecast is Dr Diriba's work tilted on" Validation of operational seasonal rainfall forecast in Ethiopia, 2013". By this study the performance of the seasonal forecast system for two rainy seasons were validated based on eight homogeneous rainfall regions over the periods 1999–2011. Based on this work we can evaluate the performance of the seasonal forecast what we have been issued at local levels in such a way to identify gaps on improving the skills of the seasonal forecasts system which is already indicated in terms of forecasting methods, rainfall regime and season.

Even if eight heterogeneous season classifications are expected behind those eight homogeneous rainfall regimes, the validation were performed based on the operational three season definition. Hence the performance validation is expected to be more realistic over the regimes that are in harmony with the three season definition than the other rainfall regimes.

Predicting seasonal rainfall by using Canonical Correlation Analysis (CCA) Method (Kassa, 2015) is currently one of the operational seasonal forecast systems with better skill than others. After this work regional meteorological service centers are able to provide region specific seasonal forecast by using CPT. The serious challenge that we have been facing on lack of continuous and reliable data for climate analysis as well as for forecasting was solved by Enhancing National Climate Services (ENACT, NMA). But ENACT utilized very limited stations especially over eastern Ethiopia hence requires using additional station data for operational activities over those areas.

3. Data and Methodology

A problem that we have been facing on performing rainfall related research were lack of continuous and reliable historical climate data, this problem currently solved by Enhancing National Climate Services (ENACTS) and Climate Hazards Group Infra-Red Precipitation with Station data (CHIRPS). Relatively ENACTS has better resolution that is 0.04 degree but starts from 1983.

Hence we have used Ethiopian Improved Decadal CHIRPS precipitation data with resolution 0.05 degree as it has started from 1981. Historical ENSO Index data were taken from National Oceanic and Atmospheric Administration (NOAA) and Historical monthly data for IOD index were taken from Japan Agency for Marine-Earth Science and Technology (JAMSTEC) via http://www.jamstec.go.jp/frcgc/research/d1/iod/e/iod/about_iod.html.

Decadal based inter annual rainfall analysis were used to categorized homogenous periods leading to season classification and standard statistical techniques were also used to analyze the quantitative relationships between oceanic indexes (ENSO, IOD) and seasonal rainfall averaged over the region in focus. For subjective analysis of seasonal rainfall, NMA standards were used to define Above Normal, Normal and Below Normal cases.

4. Results and Discussions

4.1. Rainfall regimes in Ethiopia and season classification over SE Ethiopian low lands

4.1.1. Rainfall regimes in Ethiopia and inter annual rainfall pattern over SE Ethiopia

After Tesfay Haile and L. Yarotskaya, 1987, Geographical area of Ethiopia is categorized in to three distinct rainfall Regimes (Fig: 5) that are Uni-modal (Single-maxima): The wet period extends from February/March to October/November. However, the duration of the wet period decreases from south to north. This region covers the western half of the country enclosed between latitudes 6°N to 15°N and longitudes 33°E to 38°E). Bi-modal type-1: In this regime, a small peak occurs in April and a major one in August. This type of climate is found between latitudes 6°N to 15°N and longitudes 38°E to 44°E. It is for this rainfall regime that the “three-season” definition is appropriate. These are Bega (October to January of the next year), Belg (March to May), and Kiremt (June to September). Bi-modal type-2 - This region is characterized by two distinct wet periods separated by two distinct dry periods. The peak rainfall months are April and October. The region covers most of the Lowlands of the South and Southeast (in between 35°E to 48°E and 3°N to 9°N grid). The study area of this research is located in this rainfall regime and has an annual rainfall total 150-500mm (Fig: 5).

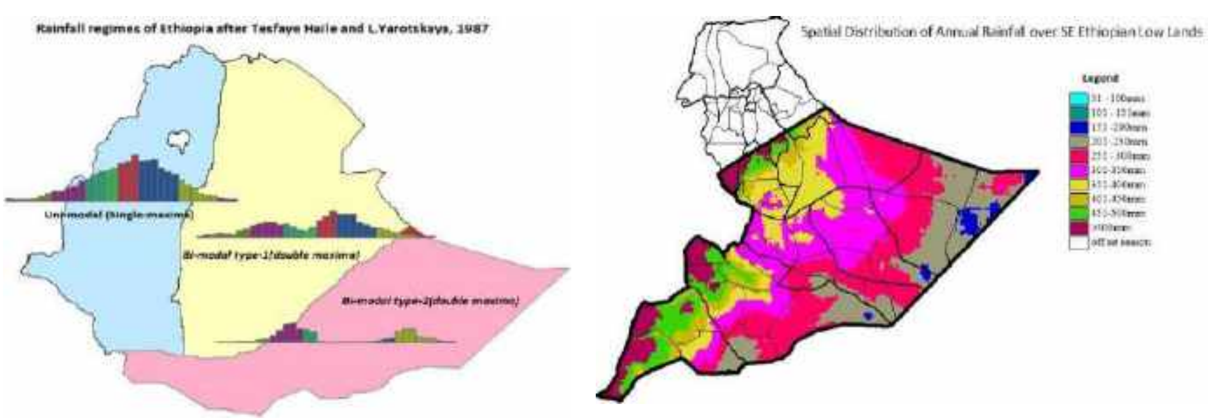


Fig5: Rainfall Regimes of Ethiopia (left) and Annual rainfall over SE Ethiopian Low Lands (right)

As Ethiopia is located in highly diversified topography and climate systems, seasons are unique and are classified based on inter annual rainfall patterns. When we analyze decadal based inter annual rainfall patterns, averaged over SE Ethiopian low lands in terms of the operational “three season” and the recommended “four season” definition, in the “three season” definition the first rainy season which is known as Belg is expected to start on the first deked of February but this month has no significant rainfall(Fig 6).The second rainy season known as Bega is also expected to start on October first decade but the season already started one month ahead at September first decade. As indicated in the same Fig:6, "four season" definition (MAM(Mar-May) rainy season, JJA(Jun-Aug) dry season, SON(Sep-Nov) rainy season and OND(Oct-Dec) dry season) is best to represent onset and cessation of rainy seasons.

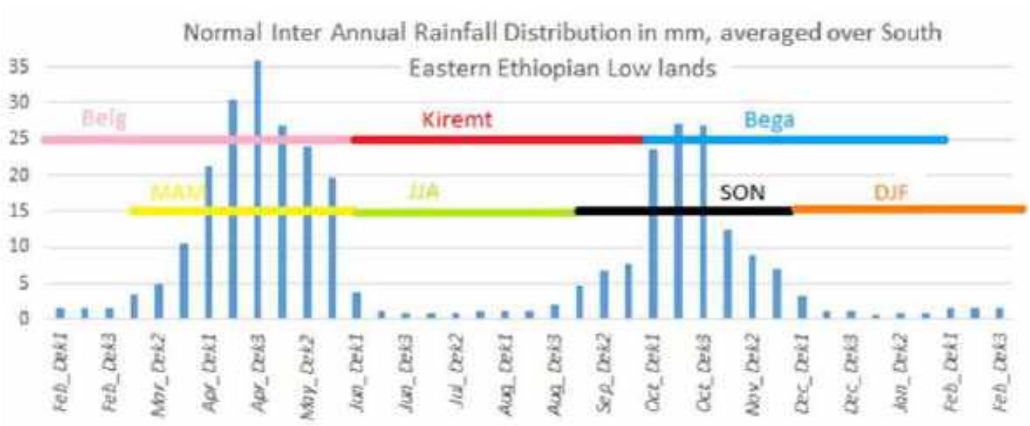


Fig 6: Normal Inter Annual Rainfall Distribution in mm, averaged over South East

4.1.2 Percentage contribution of seasonal rainfall to the annual total and spatial distribution

Eight months of the year in "three season "definition are categorized as rainy season (Belg + Bega) but the percentage contribution to annual total rainfall is 89% (55 +34) (Fig 7). Whereas only six months of the year in "four season" definition are categorized as rainy season (MAM + SON) and the percentage contribution to annual total is 89% (52 +38) (Fig 8). Furthermore, kiremte season is the only dry season in "three season "definition but has 11% contribution to annual total rainfall) (Fig 7). This indicate that homogenous periods that are dry and wet are well organized if the calendar year is categorized in to four seasons that are MAM (Mar-May), JJA(Jun-Aug), SON(Sep-Nov) and DJF(Dec-Feb).

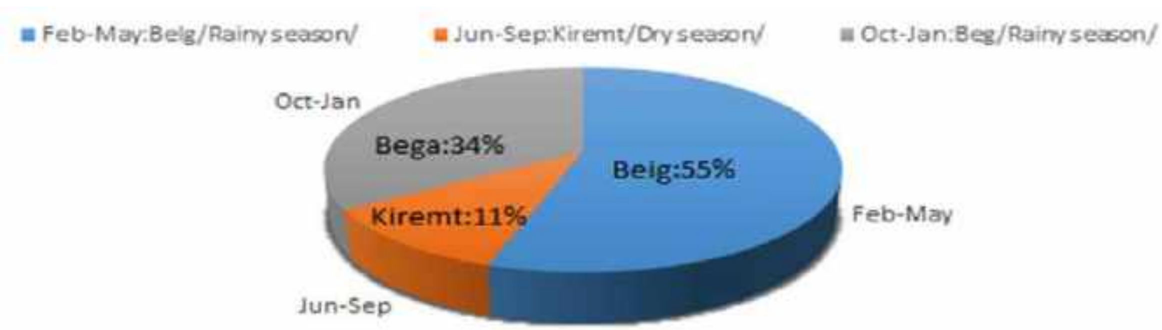


Fig 7: Percentage Contribution of Seasonal Rainfall to annual total for Bega, Kiremt and Belg Seasons

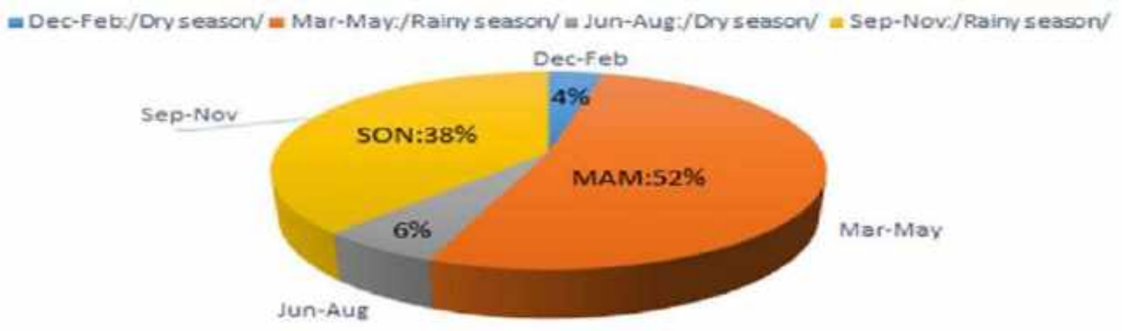


Fig 8: Percentage Contribution of Seasonal Rainfall to annual total for SON, DJF, MAM and JJA Seasons

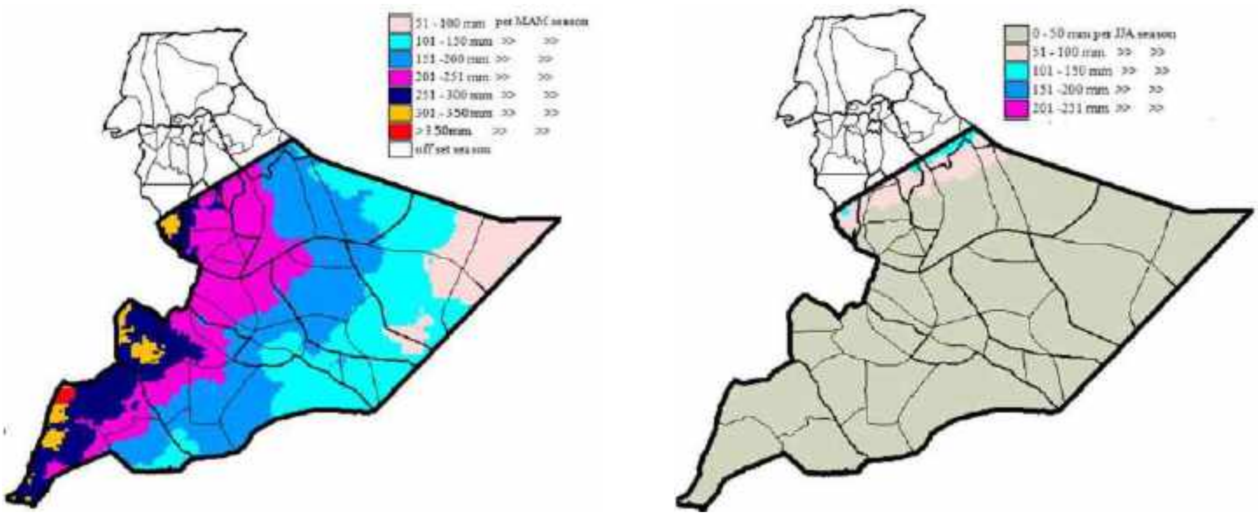


Fig 9: Seasonal Rainfall Distribution for MAM (Mar-May) Season (Left) for JJA (Jun-Aug) Season (right)

4.1.3. Spatial distribution of seasonal rainfall as MAM, JJA, SON and OND

In this four season definition dry and rainy seasons are alternating one after the other, unlike the rest of Ethiopia there is significant dry period between two rainy seasons. The first rainy season named as *MAM (Mar-May)* accounts for 52% (Fig 8) of the annual rainfall. As nomadic inhabitants dominate the region, failure of this season, seriously affect pasture production which leads to catastrophic drought. As it is indicated in Fig 6 few areas in western age have 275mm of rain per this season and decreased to 75mm towards the eastern side. The second rainy season which will be prevailed after dray season is named as SON (Sep-Nov) and accounts for 38% of the annual total (Fig 8). As indicated in Fig 8 western age of the region have 275mm of rain per this season and decreased to 75mm towards the eastern side. The second rainy season which will be prevailed after dray season is named as SON (Sep-Nov) and accounts for 38% of the annual rainfall. As indicated in Fig 10 western age of the region have 175mm of rain per this season and decreased to 75mm towards the southern side. Dry seasons are named as *JJA (Jun-Aug) and DJF (Dec-Feb). As indicated in* Fig 9(left) and Fig 10(left) the dryness is uniformly distributed across the region. Hence seasons are well defined and marked if the year is categorized into four heterogeneous

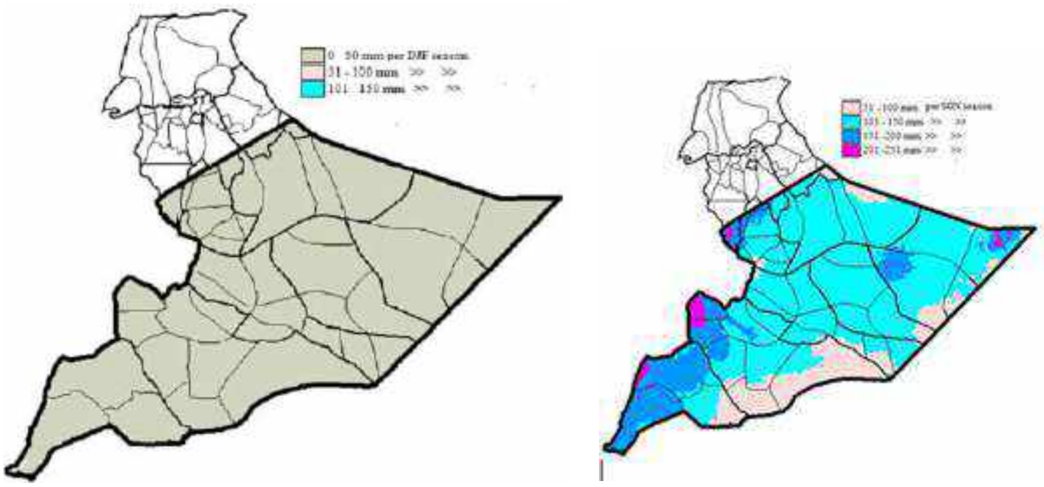


Fig 10: Seasonal Rainfall Distribution for SON (Sep-Nov) Season (Left) for DJF (Dec-Feb) Season (right)

4.1.4. National level rainfall regime analysis

These tree homogenous rainfall regimes that are defined as Uni-modal, Bi-modal type-1 and Bi-modal type-2, came to existence because of the regional and global climate drivers behind the regimes. The season classification that is operational at National level is best representative, only for central and northeastern Ethiopia which is about 37% of the Nation. In other words, about 63% of the Nation is not significantly represented by the current ongoing National level season classification. The delivered seasonal forecast is expected to attain its maximum quality over an area which is relatively highly represented by the season classification system. Hence improving the quality of seasonal forecast is also the issue of homogeneity in terms of rainfall regimes and season.

From the National point of views spatially and temporally oriented nine heterogeneous seasons are recommended to be practically implemented, two seasons over western Ethiopia, three seasons over central and north eastern Ethiopia and four seasons over southern and south eastern Ethiopia.

Over western and north western Ethiopia, only two seasons are defined as rainy and dry seasons

- For example, Jun and September are reference months to analyze onset and cessation of kiremt rainy season respectively at National level. In the meantime, western Ethiopia gets significant amount of rainfall during these months this indicates that the three season classification system has no any business with this area.

- Hence Meteorological Service Centers located over western Ethiopia that are Gambela, Bebishangule, western Amhara and South western Oromia Meteorological Services Center are strongly recommended to reorganize long term historical meteorological data's averaged over their respective spatial coverage as rainy and dry seasons in such a way to be analyzed with the globally identified climate drivers ENSO, IOD and others

Over central and north eastern Ethiopia, three seasons are defined as Bega, Belg and Kiremt seasons

- This area is highly represented by the current National level three season classification system that is Bega, Belg and Kiremt
- Hence Meteorological service centers located over central and NE Ethiopia that are central Oromia, eastern Amhara, Afar and Somali and Neibouring Regions Meteorological Service Cenetrs are recommended to proceed with the current National level season classification

Over southern and south eastern Ethiopia, four seasons are defined as two rainy and two dry seasons

- According to the National level season classification, for example October is the standard reference month to analyze onset of Bega season which is defend as rainy season over SE Ethiopian low lands but the rainy season starts one month ahead by September this indicates that the three season classification system has no any business with this area
- Hence Meteorological Service Centers located over Southeastern Ethiopian low lands that are South western Oromia, Southern Nation Nationalities and Peoples Region and Somali and Neibouring Regions MSC are strongly recommended to reorganize the long term historical meteorological data's averaged over their respective spatial coverage as MAM, JJA, SON and OND seasons in such a way to be analyzed with the globally identified climate drivers ENSO, IOD and others.

4.2 integrated impact of Oceanic indexes (ENSO, IOD) on Seasonal Rainfall over target area

4.2.1 Quantitative Relationship between Oceanic Indexes and seasonal Rainfall

Even if Oceanic Indexes such as ENSO and IOD are known climate drivers over East Africa, in order to improve regional level seasonal, forecast we have to analyze such indexes with logically categorized homogenous regions and seasons.

Fig 11: Correlation Coefficients between seasonally averaged ENSO index and Seasonal Rainfall

When we analyze the quantitative relationship between seasonal rainfall, averaged over SE Ethiopian low lands with ENSO index for years 1981-2017, relatively significant correlation coefficient that is 0.5 where obtained between SON (Sep-Nov) season rainfall and ENSO index of the same season (Fig 11). This may indicate that by using the forecasted value of SON (Sep-Nov) season ENSO index, we can forecast the seasonal rainfall even before two seasons with 50% accuracy. When we did the same analysis with IOD index, much better correlation coefficient that is 0.8 where obtained (Fig 12). This also indicate that by using the forecasted value of SON (Sep-Nov) season IOD index, we can forecast the seasonal rainfall even before two seasons with 80 % accuracy over the target area

.

Fig 12: Correlation Coefficients between seasonally averaged IOD index and Seasonal Rainfall

4.2.2. Quantitative Relationship between Enso and IOD Oceanic Indexes and with SON season

4.2.2.1. Quantitative Relationship between Enso and IOD Oceanic Indexes

The El Niño/Southern Oscillation (ENSO) is well-known as a dominant mode of interannual climate variability that develops from air–sea interactions in the tropical Pacific arises from a complex interaction of a variety of climate systems and mainly characterized by Niño 3.4 see surface temperature(SST) anomalies (McPhaden et al., 2006). During an El Niño, air–sea interactions promote the growth of positive sea surface temperature (SST) and sea level anomalies in the central and eastern Pacific and corresponding negative anomalies in the western Pacific. Whereas Indian Ocean dipole (IOD) is an intrinsic coupled mode of variability in the tropical Indian Ocean. An IOD index is defined as the difference between sea surface temperature (SST) anomalies averaged over the representative locations of western and eastern Indian Ocean.

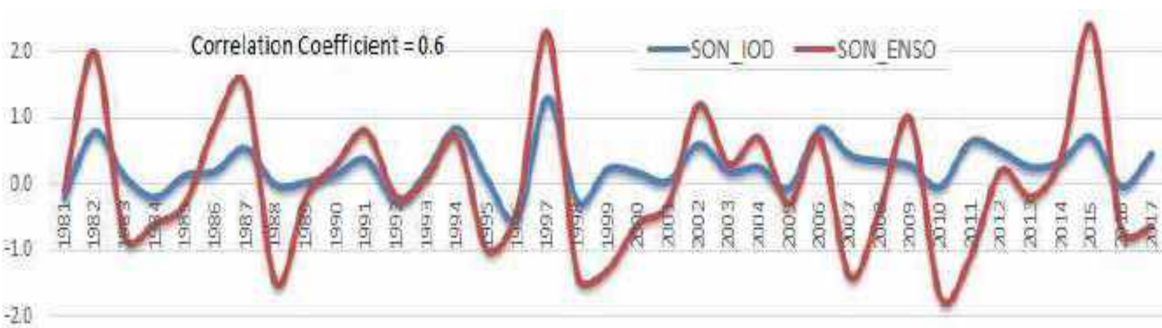


Fig 13: SON Season averaged ENSO index verses IOD index l, 1981-2017l

These two oceanic indexes are independent climate modes, which frequently co-occur, driving significant inter annual changes within the Indian Ocean. Even if the correlation coefficients between SON season averaged ENSO and IOD indexes is 0.6(Fig 13), opposite extremes were observed in years 1999, 2000, 2008 and 2011. This may indicate the degree of dependency/ independency. When we analyze 37 years' data (1981-2017), averaged for SON season, IOD is highly compressed between -0.5 and +1.3 but ENSO is relaxed between -1.7 and +2.4, furthermore, the time serious patter of IOD looks minor scale of ENSO time serious Fig 13. In years recorded as El Niño dominancy during SON season, both indexes attain there peak in the same fashion with different scale (Fig 13). But for *La Niña years the relation is complex and not well defined*. This may indicate that the probability of predicting IOD from predicted ENSO is more realistic for El Niño years than for *La Niña years. Even if* both indexes are known climate drivers in large scale system for example for tropical Africa, regional and local level applications require detailed analysis in terms of homogenous space and time. Homogeneity in terms space came to existence, only when we focused on one of the properly categorized rainfall regimes as this research focused on one of the three Ethiopian rainfall regimes named Bi-modal type-2(Fig 5). Homogeneity in terms time is a function of specific rainfall regime and defined by categorizing the calendar year in to homogenous seasons, this research defined four *seasons as MAM (Mar-May)*, JJA (*Jun-Aug), SON (Sep-Nov) and DJF (Dec-Feb) over the specified* rainfall regime (Fig 6-10).

4.2.2.2. Quantitative Relationship between SON season rainfall and ENSO Index

ENSO index is one of the known climate drivers over tropical area like Ethiopia. But the impact is highly variable in terms of location and season. For example, the most recent strong El Niño that was prevailed as ENSO index value of 1.8, during Ethiopian Kiremt season by year 2015, were responsible for the catastrophic loss of food production over kiremt benefiting areas.

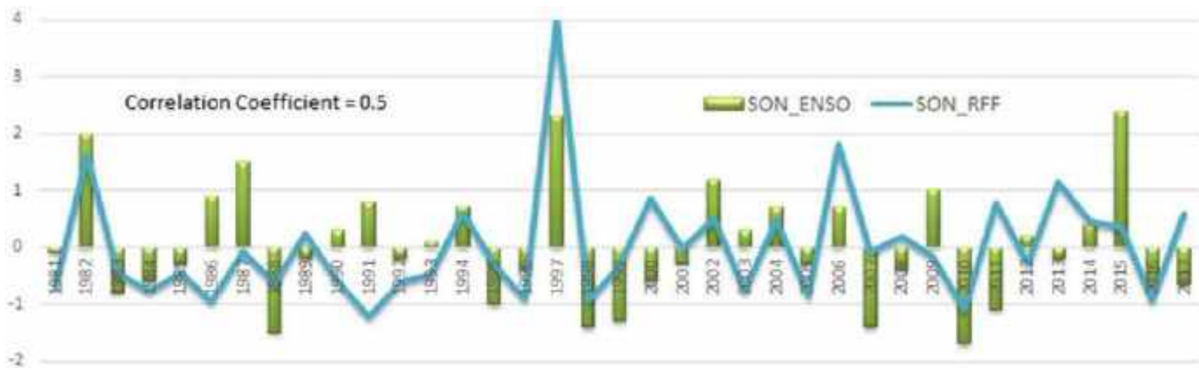


Fig 14: SON Season averaged ENSO index verses Standardized Seasonal Rainfall, 1981-2017

Seasonal rainfall was analyzed with the respective ENSO index (1981-2017). The correlation obtained was 0.5 and the pattern is a bit complex to draw an arithmetic driven conclusion (Fig 14). ENSO has three phases the warmest phase called El Niño when ENSO index is greater than or equal to 0.5, Neutral phase when ENOS index is between -0.5 and +0.5 and cold phase called La Niña when ENSO index is less than or equal to - 0.5. National Meteorology Agency also uses three standards to describe seasonal rainfall that are above Normal (percent of Normal > 125%), Normal (75% < = % of Normal < =125%) and below Normal (percent of Normal < 75%). The subjective analysis made based on those two standards indicates that 75% of SON(Sep-Nov) season rainfall were Normal to below Normal when the season is under La Niña influence whereas 82% seasonal rainfall were Normal to above Normal when the season is under El Niño influence (Table 2). This indicates that if SON season is forecasted to be under the influence of El Niño conditions, Normal to above normal seasonal rainfall is expected with high probability and the opposite is expected under La Niña influence over south eastern Ethiopian low lands.

Table 2: ENSO index verses Rainfall for SON Season, over SE Ethiopian Low Lands, 1981-2017

Observed SON Season ENSO index		Observed SON Season rainfall per NMA standard		
Category	No of years	Category	No of years	In %
La Nina(ENSO < - 0.5) Below Normal	12	Percent of Normal < 75%/ Below Normal/	5	42
		75% <= % of Normal <=125%/Normal/	4	33
		Percent of Normal > 125%/Above Normal /	3	25
Neutral (+0.4 >ENSO > -0.4) Normal	14	Percent of Normal < 75%/ Below Normal/	7	50
		75% <= % of Normal <=125%/Normal/	6	43
		Percent of Normal > 125%/Above Normal /	1	7
El Nino (ENSO > 0.5) Abov Normal	11	Percent of Normal < 75%/ Below Normal/	2	18
		75% <= % of Normal <=125%/Normal/	4	36
		Percent of Normal > 125%/Above Normal /	5	46
Total	37		37	

4.2.2.3. Quantitative relationship between SON season rainfall and IOD index

An Indian Ocean dipole (IOD) index is defined as the difference between sea surface temperature (SST) anomalies averaged over the western Indian Ocean (WIO, 50°–70°E, 10°S– 10°N) and eastern Indian Ocean (EIO, 90°– 110°E, 10°S–Eq). This gradient is also named as Dipole Mode Index (DMI). When the DMI is positive then, the phenomenon is refereed as the positive IOD and when it is negative, it is refereed as negative IOD. This index attains its peak in about October, and decay by the end of the calendar year. Like ENSO index, the impact on seasonal rainfall is highly variable in terms of location and season.

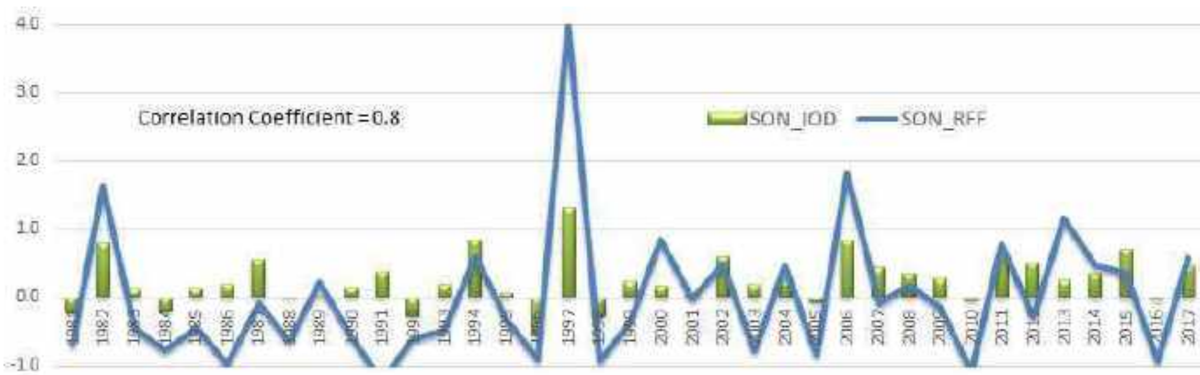


Fig 15: SON Season averaged IOD index verses Standardized Seasonal Rainfall, 1981-2017

SON (Sep-Nov) season rainfall of SE Ethiopian low lands, were analyzed with the respective IOD indexes (1981-2017) and significant linear relation with 0.8 correlation where observed (Fig 15). Unlike

ENSO index, IOD index is computed from SST anomalies of two extremes at the same time in the same tropical Indian Ocean and this makes the changes to be in slow motion. By analyzing SON season IOD index distribution from 1981 to 2017, a threshold value of 0.19 was set for subjective analysis with the seasonal rainfall. The subjective analysis made based on this threshold value (0.19) indicates that 95% of SON (Sep-Nov) season rainfall were Normal to below Normal when IOD index is less than or equal to the threshold value (IOD <= 0.19) whereas 94% of seasonal rainfall were Normal to above Normal when IOD index is greater than the threshold value (IOD > 0.19) (Table 3). This indicates that if IOD index in SON season is forecasted to be greater than the threshold value of 0.19, Normal to above normal seasonal rainfall is expected with very high probability and the opposite is expected if the threshold value is less than or equal to 0.19.

Table 3: IOD index verses Rainfall for SON Season, over SE Ethiopian Low Lands, 1981-2017

Observed SON Season IOD index, Centered at 0.19		Observed SON Season rainfall per NMA standard		
Category	No of years	Category	No of years	In %
IOD Index at and Below 0.19 (IOD <= 0.19)	19	Percent of Normal < 75%/ Below Normal/	13	69
		75% <= % of Normal < =125%/Normal/	5	26
		Percent of Normal > 125%/Above Normal /	1	5
IOD Index Above 0.19 (IOD > 0.19)	18	Percent of Normal < 75%/ Below Normal/	1	6
		75% <= % of Normal < =125%/Normal/	9	50
		Percent of Normal > 125%/Above Normal /	8	44
Total	37		37	

4.2.3 SON Season Percent of Normal Rainfall when IOD index tends to its extreme.

Even if ENSO and IOD indexes are both seasonal climate drivers over eastern Africa and Ethiopia, it is IOD index that significantly drives the SON (Sep-Nov) season rainfall over south eastern Ethiopian low lands. IOD index during SON (Sep-Nov) season attains its maximum value of 1.3 by year 1997 and minimum value of -0.5 by year 1996 (Fig 15, this index varies from –0.5 to +1.3 in years 1998

)

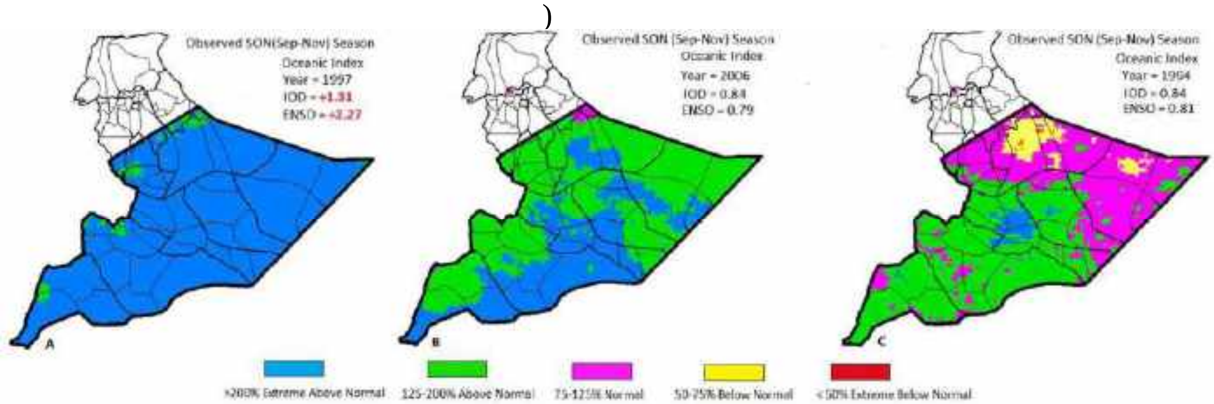
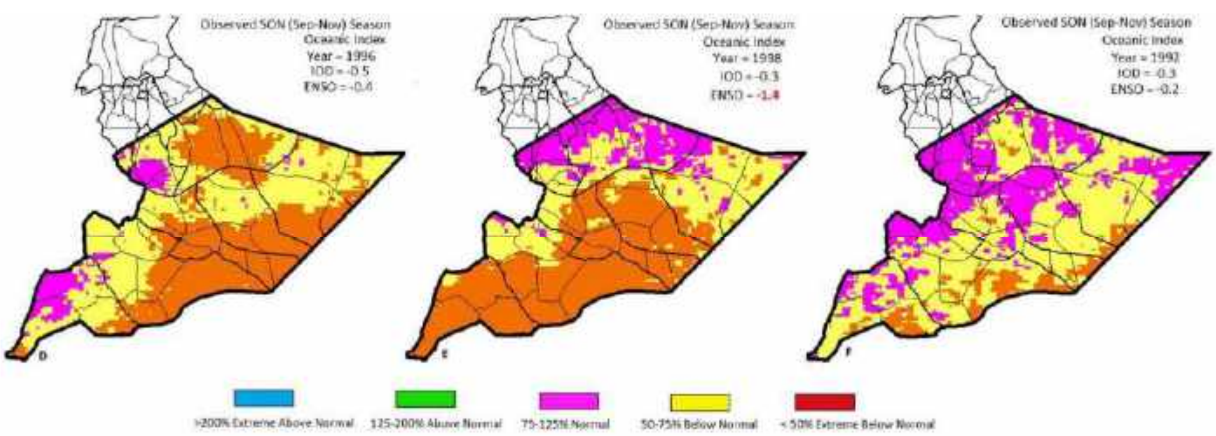


Fig 16: Percentage of Average Rainfall for SON (Sep-Nov) Season, A (1997),B(2006),C(1994), SE Ethiopian

Year 1997 is also known as El Niño year with the seasonal ENSO index of +1.3 and strong rainfall deficit were recorded in kiremt season over central and north eastern Ethiopia, but ever recorded extreme above normal rainfall, greater than 200%, were observed during SON season uniformly over south eastern Ethiopia low lands (Fig 16, A). By years 2006 and 1994, the recorded IOD index were +0.8 and the seasonal rainfall observed over the region in focus were from extreme above normal to above normal on year 2006 and from normal to above normal on year 1994(Fig 16, B, C).



-

Fig 17: Percentage of Average Rinfall for SON Season, A (1996), B(1998),C(1992),SE Ethiopia

Year 1996 is the year in which the minimum IOD index of -0.5 were recorded during SON season in this year below normal too extreme below normal rainfall were also recorded over the region in focus (Fig 17, A). By years 1998 and 1992, the recorded IOD index were -0.3 and the seasonal rainfall observed over the region in focus were from extreme below normal to normal on year 1998 and from normal to below normal for 1992(Fig 17 B, C). Almost in all the years, the SON season rainfall of the region in focus tends to the above normal extreme when IOD index is tending to its positive extremes.

4.3. IOD Based Alternative Seasonal Forecast System for SON Season over the target area

In addition to the significant correlations, observed between IOD index and SON season rainfall that is 0.8, over the region in focus (Fig 15), the forecasted value of IOD index is available at least a head of six months from the International forecast centers, with reasonable accuracy. This might be an opportunity to provide a probabilistic forecast about the performance SON season rainfall, six months before the onset of the season.

4.3.1. IOD Based Analogue method to forecast SON Season Rainfall for year 2015

IOD based selected best analogue years to forecast SON season rainfall performance for year 2015 over the region in focus were 1994 and 1987.In both years IOD index were observed being tending towards the positive extreme and greater than the threshold value 0.19 throughout the season (Fig 18). According to the subjective analysis (table 3), from an average point of views, we expect normal to above normal rainfall. For detailed spatial and temporal distributions of intra seasonal performance, we have to trace back to the selected IOD based analogue years' rainfall performance.

Fig 18: Analogues for SON season, 2015 based on IOD anomaly, SE Ethiopia

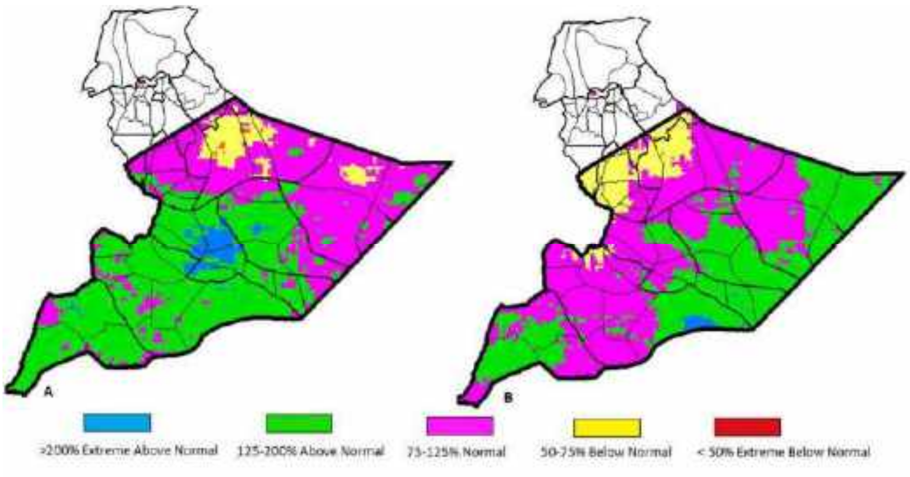


Fig 19: SON season Percent of Normal Rainfall Distribution A (IOD based forecast), B(observed) ,2015

From the spatial distribution of IOD based SON season rainfall forecast of year 2015, normal to above normal performance over most areas in Nogob, Shebele, Afder and Liban zones: normal performance over Warder and Korahe zones and below normal performance over few areas in Jerer zone were expected (Fig 19, A). What is observed in (Fig 19, B) is almost what is forecasted in (Fig 19, A).

4.3.2. IOD Based Analogue method to forecast SON Season Rainfall for 2016 year

IOD based selected best analogue years to forecast SON season rainfall performance for year 2016 over the region in focus were 1981 and 1998. Unlike year 2015, both IOD index were observed being tending towards the negative extreme and less than the threshold value 1.9 throughout the season (Fig 20). According to the subjective analysis (table 3), we expect normal to below normal rainfall performance from an average point of views. For detailed spatial and temporal distributions of intra seasonal performance, we have to trace back to the selected IOD based analogue years' rainfall performance.

Fig 20: Analogue years for SON season, 2016 based on IOD anomaly, SE Ethiopia

The spatial distribution of IOD based SON season rainfall forecast of year 2016 indicate that, except few areas of the western side, below normal too extreme below normal performance was expected to dominate the region (Fig 21, A). What is observed in (Fig 21, B) is almost what is forecasted in (Fig 21. A).

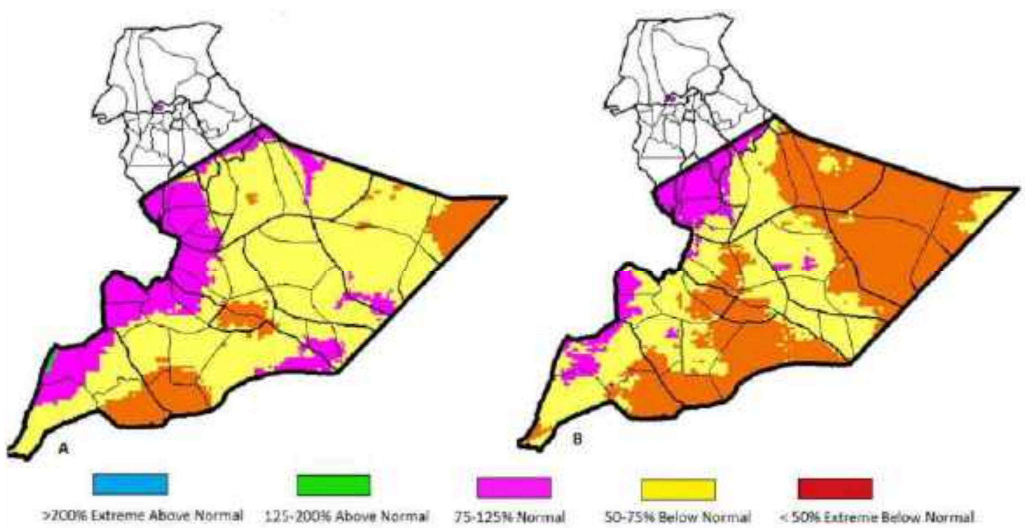


Fig 21: SON season Percent of Normal Rainfall Distribution A (IOD based forecast), B (observed), 2016

4.3.3. IOD Based *analogue method to forecast SON* Season Rainfall for year 2017

IOD based selected best analogue years to forecast SON season rainfall performance for year 2017 over the region in focus were only 1994 and the IOD index were observed being tending towards the positive extreme and greater than the threshold value 1.9 throughout the season (Fig 22). According to the subjective analysis (table 3), we expect normal to above normal rainfall performance from an average point of views. For detailed spatial and temporal distributions of intra seasonal performance, we have to trace back to the selected IOD based analogue years' rainfall performance.

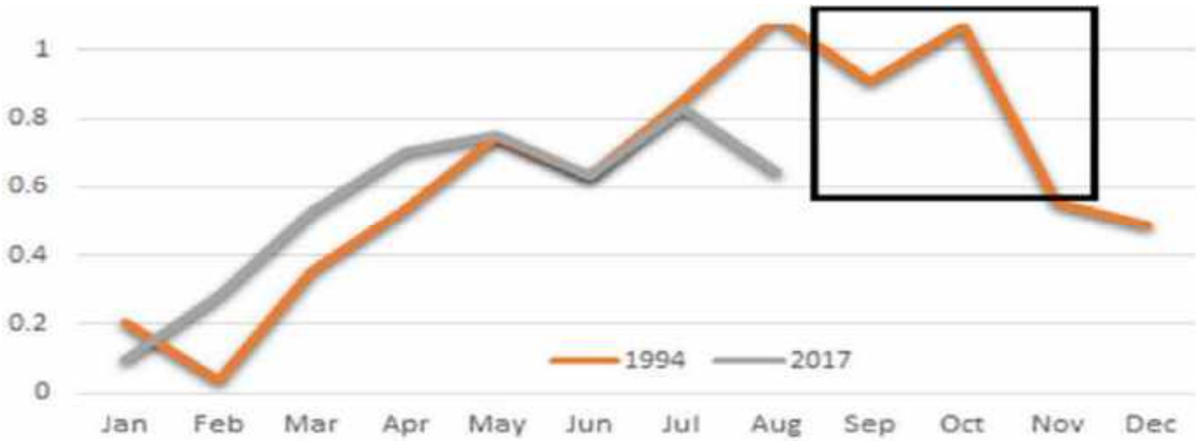


Fig 22: Analogue years for SON season, 2017 based on IOD anomaly, SE Ethiopia

From the spatial distribution of IOD based SON season rainfall forecast of year 2017 except few areas of Jerer zon, normal to above normal performance is expected to dominate the region (Fig 22, A). What is observed in (Fig 22, B) is almost what is forecasted in (Fig 22, A)

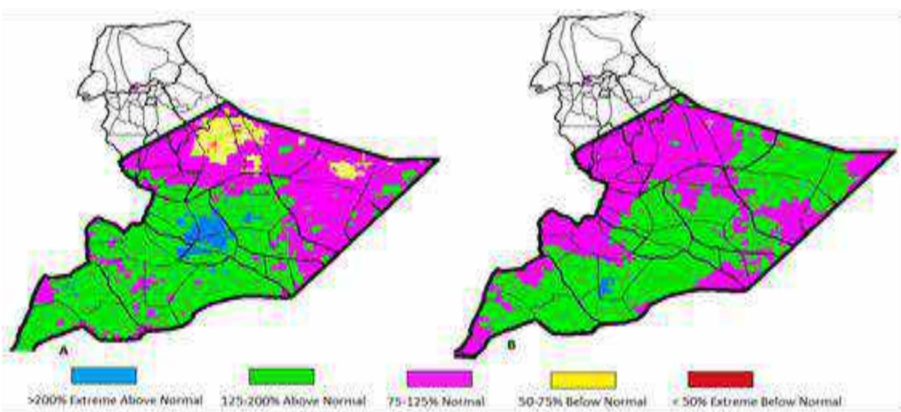


Fig 23: SON season Percent of Normal Rainfall Distribution A (IOD based forecast), B (observed), 2017

5. Conclusion and Recommendations

As SE Ethiopian low lands is located in one of the tree rainfall regimes of Ethiopia named as Bimodal type 2, an effort were mad to define regime specific season classification from the decadal based inter annual rainfall pattern. The discussion (page4-6) indicates that Seasons are well defined & marked if the calendar year is categorized into four Heterogeneous periods as.

- MAM(Mar-May) with 52% contribution to annual total rainfall/rainy season/
- JJA(Jun-Aug) with 6% contribution to annual total rainfall/dry season/
- SON(Sep-Nov) with 38% contribution to annual total rainfall/rainy season/
- OND(Oct-Dec) with 4% contribution to annual total rainfall/dry season/

By this four season definition onset and cessation of rainy seasons are clearly identified furthermore length of dry spells are well organized (Fig 4-7). From the National point of views spatially and temporally oriented nine heterogeneous seasons are recommended to be practically implemented, two seasons over western Ethiopia, three seasons over central and north eastern Ethiopia and four seasons over southern and south eastern Ethiopia.

The quantitative relationships that ENSO and IOD indexes have with seasonal rainfall, averaged over SE Ethiopian low lands were analyzed from 1981-2017(page6-8). Relatively significant correlation coefficient was obtained for SON (Sep-Nov) season that is 0.8 with IOD and 0.5 with ENSO. Hence further analysis was made over this specific season and the following major conclusions are drawn (page6-8).

- If SON season is forecasted to be under the influence of El Niño conditions, Normal to above normal seasonal rainfall is expected with high probability and the opposite is expected under La Niña influence over south eastern Ethiopian low lands
- If IOD index for SON season is forecasted to be greater than the threshold value of 0.19, Normal to above normal seasonal rainfall is expected with **very high** probability and the opposite is expected if the threshold value is less than or equal to 0.19.
- If ENSO and ION indexes are both forecasted to towards their positive extremes for SON (Sep-Nov) season, above normal to very above normal seasonal rainfall is expected with **very high**

level confidence and the opposite is expected if both indexes are forecasted towards their negative extremes.

- Relatively IOD has significant correlation (0.8) with seasonal rainfall, averaged over SE Ethiopian low lands, then ENSO (0.5) for SON (Sep-Nov) season, hence **IOD based analogue method** and **model products** are **highly recommended** to be an input for seasonal forecast. The following major recommendations are forwarded by this research report
- The suggested four season definition (MAM, JJA, SON and DJF) and IOD based seasonal forecast system for south eastern Ethiopian low lands is recommended to be **legally operational** along with the current ongoing National level standard.
- Building the capacity of Regional Meteorological Service Centers up to the extent of providing seasonal forecast based on **regime oriented season classification** is also recommended.
- As Indigenous knowledge is the foundation for the current operational season classification as well as Agro climatic zoning, supporting the traditional forecast systems with scientific evidence is recommended.

6. Reference

- Bekele, F., 1992: The Effect of Southwest Indian Ocean Cyclones on Belg and Kiremt. NMSA
- C. A. Williams1 and N. P. Hanan2, ENSO and IOD teleconnections for African ecosystems: evidence of destructive interference between climate oscillations,2010
- Climate Classifications: Köppen
- Diriba Korecha1, Validation of operational seasonal rainfall forecast in Ethiopia,2013
- Ethiopian Meteorological Agency (1986) Climatic & Agro climatic resources of Ethiopia
- FAO Agro meteorology series working paper No. 9. "Rainfall variability and drought in Sub Saharan Africa since 1960"
- Hui Wang, Interaction between the Indian Ocean Dipole and ENSO Associated with Ocean Subsurface Variability, NOAA/NCEP Climate Prediction Center,1997
- Hui Wang1, Arun Kumar1, and Raghu Murtugudde2, Interaction Between the Indian Ocean Dipole and ENSO Associated with Ocean Subsurface Variability ,2016
- Kassa Fekadu, Ethiopian Seasonal Rainfall Variability and Prediction Using Canonical Correlation Analysis (CCA),2015
- Kruzhkova, T.S., 1981: On certain features of the atmospheric circulation in periods of drought.
- Laban J. Ogallo, Teleconnection between Seasonal Rainfall over East Africa and Global SST,1988
- Llei fan and Qinyulu Liu, Indian Ocean Dipole Modes Associated with Different Types of ENSO Development,2016
- LOERY, Compendium of lecture notes in climatology
- Negash Wagesho, N.K. Goel & M.K. Jain, Temporal and spatial variability of annual and seasonal rainfall over Ethiopia, 2013
- NMSA (Long-Range Forecast Group), 1990: Seasonal Weather Outlook of Kiremt
- T. Gissila, Seasonal forecasting of the Ethiopian summer rains,2009
- WCRP, 1992: A Study of Climate Variability and Predictability. Geneva, Switzerland, WMO.
- WMO, 1985: The Global Climate System: A Critical Review of the Climate System during 1982-84.

- WMO, 1987: The Global Climate System: 1984-86. Geneva, Switzerland: WMO
- WMO, 1992: International Meteorological Vocabulary No. 182. Geneva, Switzerland, WMO.
- World meteorological organization (1983) Guide to climatological practices.

NATIONAL METEOROLOGY AGENCY

EASTERN AND CENTRAL OROMIA METEOROLOGY SERVICE CENTRE

Intra Seasonal Rainfall Variability of Eastern and Central Oromia

Authors: Abdisa Hirko[1]

Zerihun Bikila Muleta[1]

Collaborators: Getachew Kebede[2]

Merga Bayu[2]

Yenenesh H/Mariam[1]

Kebede Lemma[1]

[1] Meteorological Forecast and Early Warning, ECOMSC, Adama, Ethiopia.

[2] Meteorological Data, Station Administration and Climatology, ECOMSC, Adama, Ethiopia.

NOVEMBER 2018

ADAMA, ETHIOPIA

Abstract

Natural climate variability must be identified and quantified to minimize its negative consequences and maximize its positive ones. While, mainly Eastern and Centeral oromia (ECO) benefited rainfall twice per a year, the two rainy seasons 'Belg' and 'Kiremt' focused on the study. The research was conducted in ten zones of ECO and daily rainfall data obtained from 101 rain gauge station and 116 dekadal gridded from 1987-2016. Relevant statistical methods are used to diagnosis the variation of rainfall in the long year and by categorizing into three decades (1987-1996, 1997-2006 and 2007-2016). Spatially and temporally, wetness and dryness significantly changed one decade after the other decade in Belg season. Northern, central rift valley and the adjoining places of ECO are the places mostly affected by Belg season rainfall variability. The rest places of ECO have less rainfall variation. There is a significant change in each decade, of the Kiremt season spatially and temporally within the climatological year over ECO. Except few pocket areas, which have high variability, most areas of ECO have less Kiremt rainfall variation. The result of CV based on gauge and grid data result shown that Belg season has higher variability than Kiremt season. Belg season is twofold higher variable to that of Kiremt season on most places of ECO. Generally, rainfall variation was investigated temporally and spatially during intra-seasonal over ECO.

Keywords: rainfall, seasonal variability, SPI, Belg and Kiremt, Oromia

1. Introduction

The earth's climate varies significantly at broad frequencies, covering intra-monthly, intra- seasonal, inter-annual and longer time scales. Severe climate events may trigger crisis of water, food, and energy supply, environmental problems, socio-economic losses, and even conflicts (wars) between different countries and nations (Hsiang et al. 2011). Natural climate variability must be identified, quantified, and understood if ways are to be found to minimize its negative consequences and maximize its positive ones. The most important climatic factor that directly affects natural resources and life is rainfall. Identifying rainfall variability areas using updated and revised climate knowledge increases quality of weather service provided. Variability of rainfall is believed to be variations of tropical oceanic and atmosphere interaction, especially El Niño-Southern Oscillation (ENSO) (Haile, 1988). ENSO was confirmed as having a dominant role in Eastern Africa during both the July–September rainy season in Ethiopia, and the October– December rains in East Equatorial areas (Camberlin_et_al-2001). The role of the El Niño Southern Oscillation (ENSO) on the Ethiopian seasonal rainfall is well documented and associated hazards often coincide with the occurrence of major ENSO events [NMSA, 1996; Camberlin, 1997; Bekele, 1997; Tsegay, 1998; Gissila et al., 2004; Segele and Lamb, 2005; Korecha and Barnston, 2007 and Diro et al 2011. This work didn't include the impact of ENSO as well as any other factors of climate variability, except trying variation of temporally and spatially. The western portion of Eastern and Central Oromia (ECO) characterized by mono-modal rainfall type, whereas the eastern portion characterized by bi-modal rainfall type. Annually the distribution of rainfall begins early February and ended late October and attains peak ones in August over the mono-modal regimes, but the annual distribution over bi-modal regimes attains peak amount twice. While, mainly ECO benefited rainfall twice per a year, the two rainy seasons 'Belg' and 'Kiremt' focused on the study.

The enthusiasm for this study was investigation whether severe climate events (droughts and floods) over Eastern and Central Oromia (ECO) are a manifestation of medium-scale persistent rainfall anomalies, or are due to a change in the nature of the intra-seasonal variability. Mainly this study deals with: if there a distinct difference in intra-seasonal variability between the most dominant perturbation of the wettest/flood/ years and the drought years. Herewith climate professionals can minimize forecast uncertainty and decision and policy makers enabled to have relevant climate resource of their concern. Additionally, this study was to use recently updated average and range of rainfall resources to make important societal decision which serve as a baseline to compare current weather and climate data. It also addresses questions such as; firstly, is there more significant intra-seasonal rainfall variability over Eastern and Central Oromia (ECO) through long years? Secondly, are the spatial and temporal rainfall variations dominant in ‘Belg’ or ‘Kiremt’ seasonal means?

1.1 Objective of the study

The aims of this study were:

- To diagnosis ‘Belg’ and ‘Kiremt’ seasonal rainfall (climate) variability for an accurate climate outlook which will be deliver for the communities of the study area.
- To investigate sub-regional climatic characteristics spatially and temporally; and
- To identify areas frequently affected by intra-seasonal climate variability.

2. Data and Methods

2.1. Study Area

The research was conducted in ten zones of Eastern and Central Oromia region; namely West Shoa, North Shoa, Arsi, West Arsi, Southwest Shoa, West Harerghe, Horoguduru Wellega, East Wellega, East Hareghe and East Shoa. Eastern and Central Oromia located within 6.30°–10.4°N, 36.5°– 43°E, and the altitudinal range of the study zone is between 500 to 4216 meter above sea level. Such zones are characterized by three climatological rainy seasons: June–September (Kiremt), October–January (Bega), and February–May (Belg); (Shanko and Camberlin 1998; Sileshi and Demarée 1995; Tsegaye 1998, 2001; Gissila et al.2004).

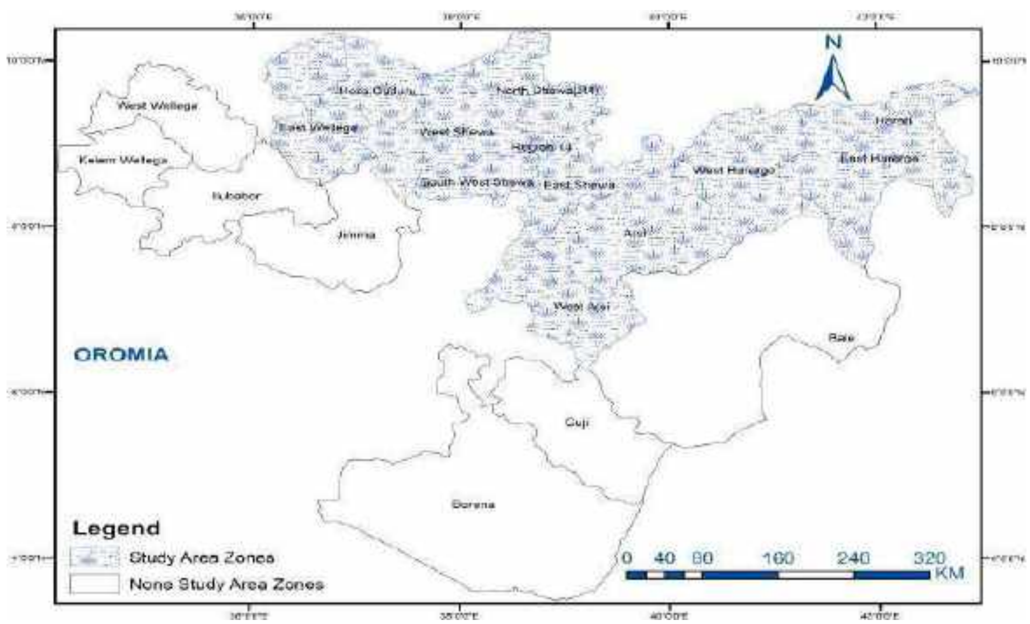


Figure 1: Study Area

2.2. Data

Daily rainfall data obtained from 101 rain gauge stations and 116 dekadal satellite ground station gidded-Blended rainfall data from district utilized (Figure 6). These data used for diagnostics of rainfall variability. Recorded rainfall data were obtained from National Meteorology Agency and Regional Meteorological Service Centers; also Grid-Blended data taken from the product of NMA-ENACTS of the year 1987 to 2016.

2.3. Methods

The paper is organized as follows. First, it describes the gauged rainfall and satellite-gauged merged gridded data of the years 1987 to 2016 are information used for the analysis. Next, the rainfall data analysis done to attest the intra-seasonal variability using three statistical methods, variation coefficient (CV), standard precipitation index (SPI) and probability of occurrences. Next, the result was discussed separately as Belg and Kiremt. Finally, the paper investigates the degree of rainfall variation and its threshold of wetness/surplus/ and dryness/deficit/ over ECO. These studies identify rainfall intra-seasonal variability using the relevant statistical methods.

$$CV = \frac{\sigma}{\mu} * 100\%$$

Where; **CV** coefficient of variation, ***σ*** standard deviation and **u** mean

Tools such as, SPSS version 16; Instat v3.37; XLSTAT; Microsoft Excel; ArcGIS version 10.1 were used. Pearson correlation method was used to calculate for each seasons of each year using station rainfall data to district mean point grid data. Ideally homogeneity check was done on selected station to neighboring stations. Using SPSS software, the normality test (Kolmogorov- Smirnov Normality Test) of both gauge and grid data for each station was done; and while an obtained value of most station was more than 0.05, distribution of seasonal rainfall data is normal. Spatial distribution of SPI values was done using inverse distance weighting interpolation (IDW) method by categorizing into three decades (1987-1996, 1997-2006 and 2007-2016).

$$SPI = \frac{X - Xm}{\sigma}$$

Where X = Precipitation for the station
Xm = Mean precipitation
σ = Standardized deviation

$$P_{SPI} = \frac{(SPI_N x\ 100)}{30}$$

Where P_{SPI} is probability of occurrence in percent SPI_N is frequency of wet/dry/ normal etc. occurrences

Table 1: SPI Classification

SPI Values	Drought/Wetness Condition
2.00 and above	Extremely Wet
1.50 to 1.99	Very Wet
1.00 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.50 to -1.99	Severely Dry
-2.00 and less	Extremely Dry

3. Results and Discussion

3.1. Kiremt season

3.1.1. Decadal mean SPI

Most parts of ECO showed that moderately dry condition, except third decade which was more variable than the two consecutive decades. Most parts of Arsi and West Hararge and pocket areas of Horo, North Shoa and West Shoa dominated by extreme wet condition, meanwhile, severe dry happened over East Hararge, southern part of West Shoa (Figure 2, A-E).

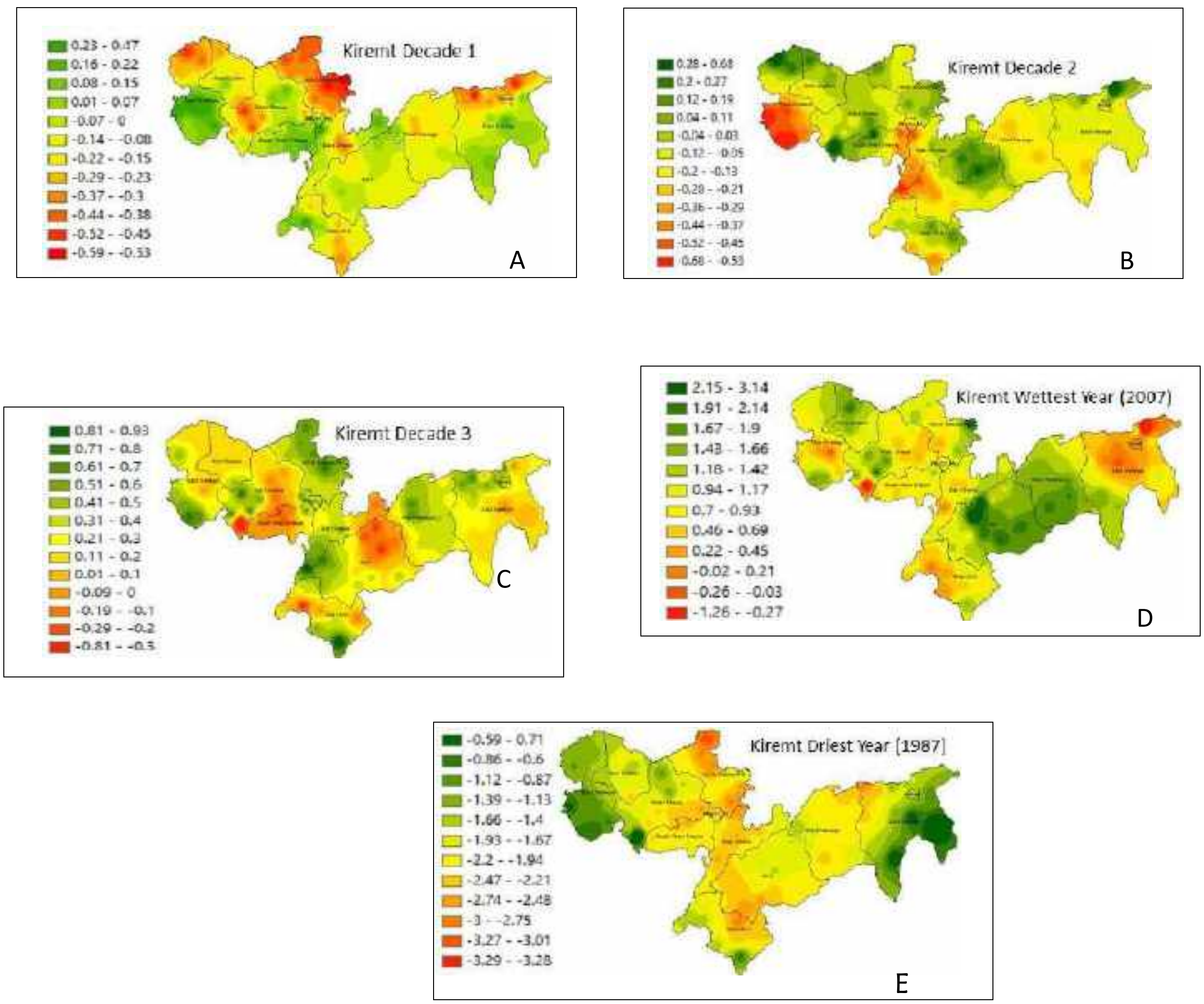


Figure 2: Mean Decadal Standard Precipitation Index for Kiremt Season

3.2. Belg season

3.2.1. Decadal mean SPI

Spatially, the rainfall varied decade by decade. i.e in decade one East Shoa Fentale district showed to moderately dry, but most western parts of East Wellega districts showed to moderately wet. During the wettest year, most parts of North Shoa, East Shoa, West Arsi, some parts of Arsi and East Hararghe appeared extreme wet, nevertheless, few southern parts of West Shoa showed moderately dry. During the driest year southern parts of East Wellega, some Arsi and few parts of West Shoa shown near normal, whereas the rest most parts of ECO performed moderate to extremely dry (Figure 3, A-E).

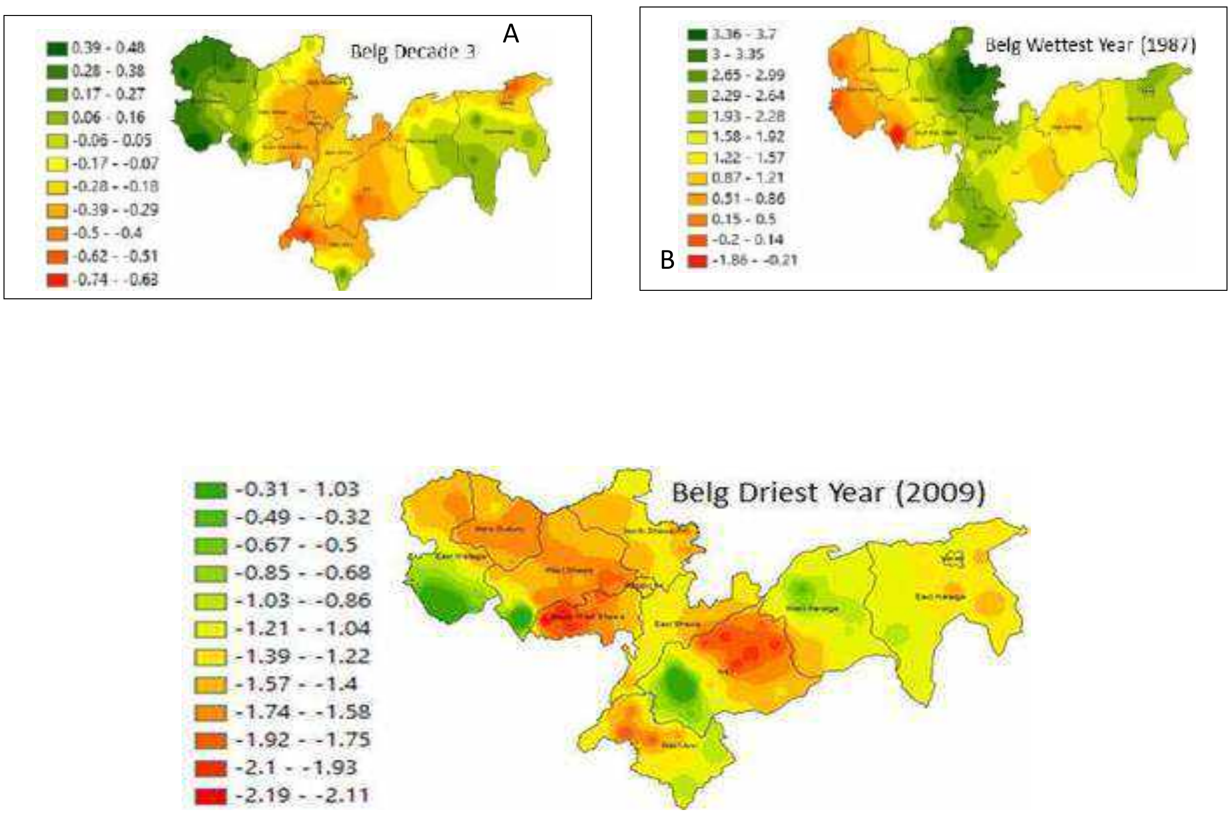


Figure 3: Mean Decadal Standard Precipitation Index for Belg Season

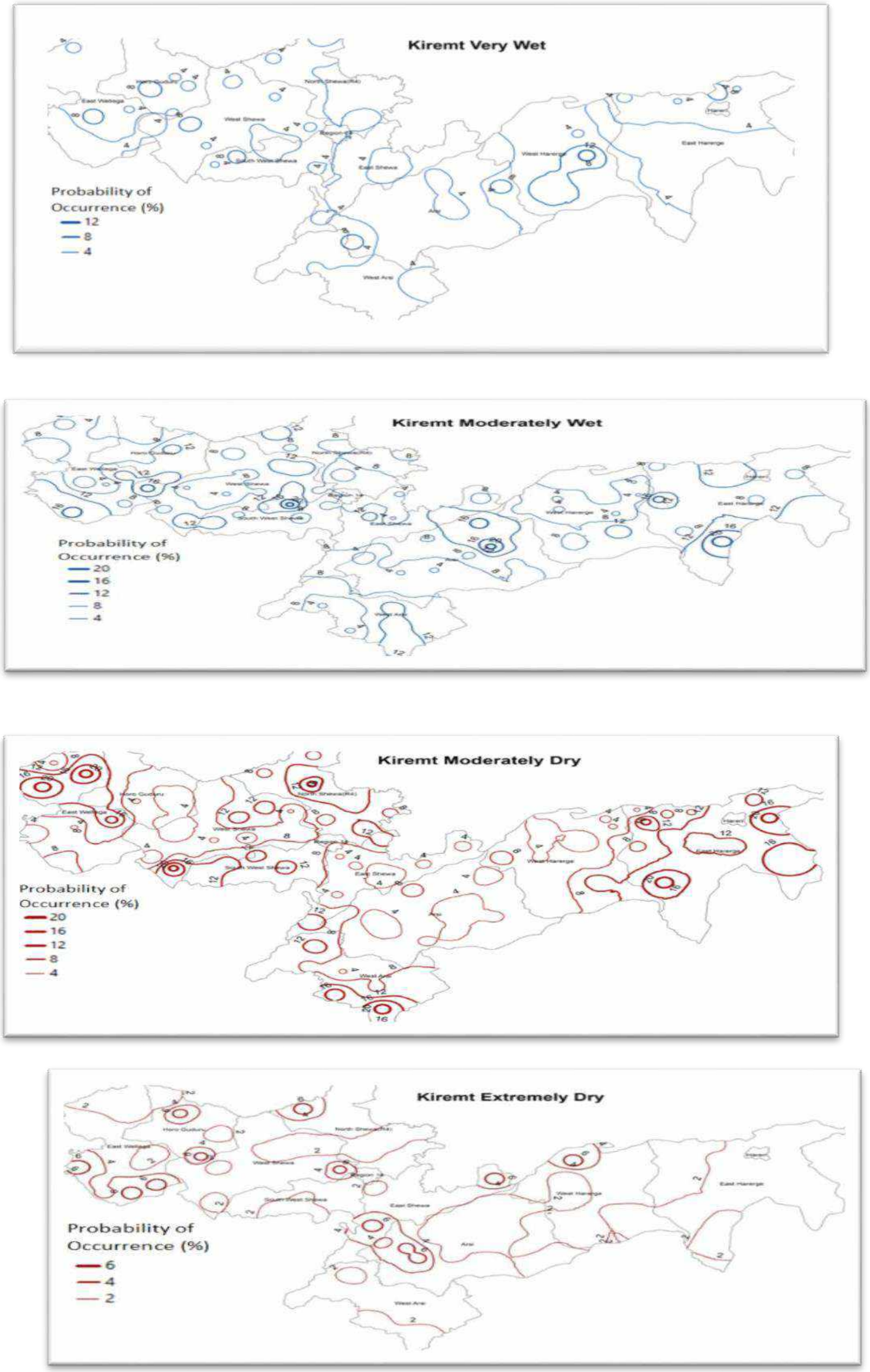
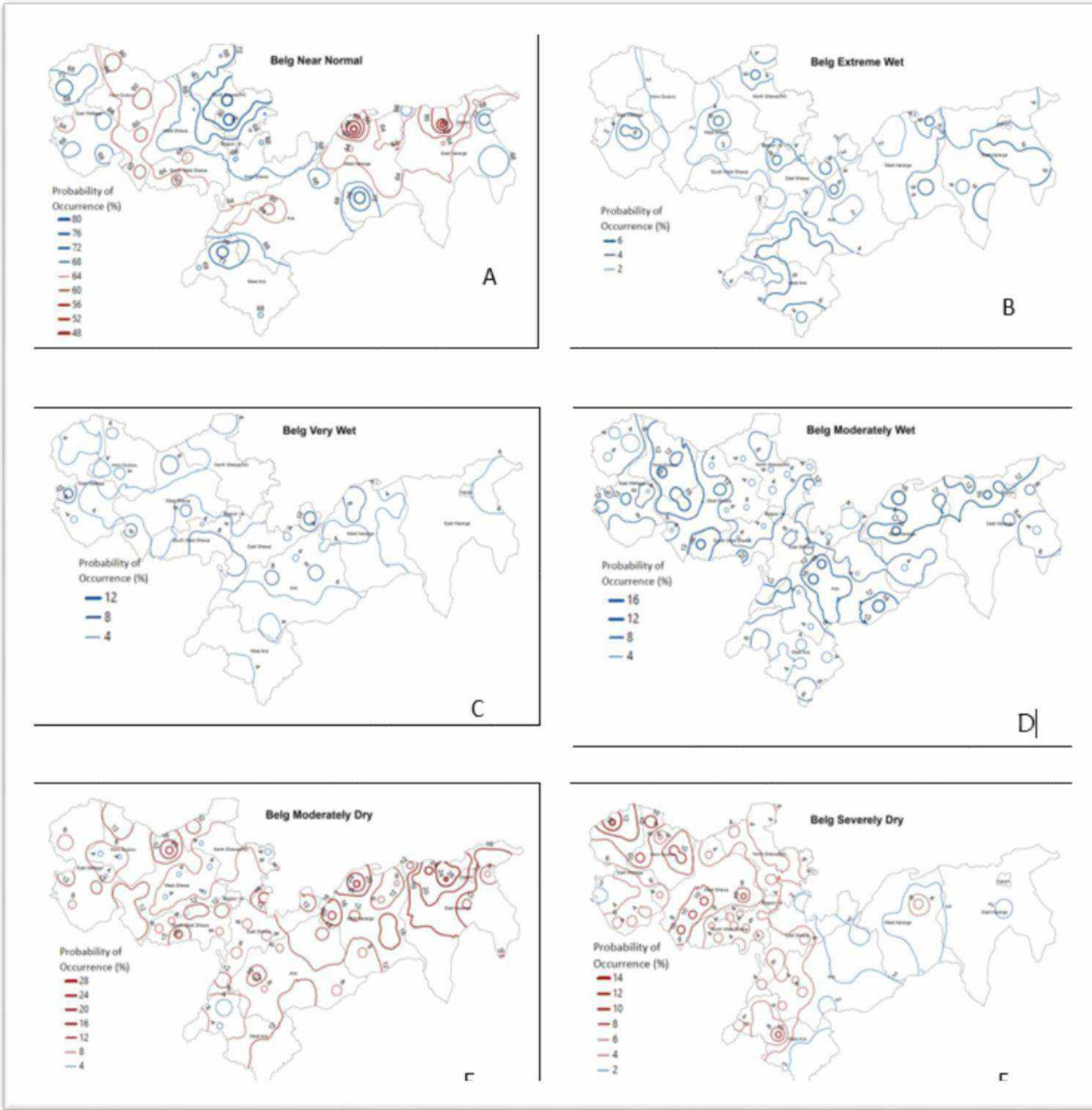


Figure 4: Probability of Occurrence for Kiremt Season (A-D)


Belg Near Normal
Probability of Occurrence (%)
80
76
72
68
64
60
56
52
48
A
Belg Extreme Wet
Probability of Occurrence (%)
6
4
2
B
Belg Very Wet
Probability of Occurrence (%)
12
8
4
C
Belg Moderately Wet
Probability of Occurrence (%)
16
12
8
4
D
Belg Moderately Dry
Probability of Occurrence (%)
28
24
20
16
12
8
4
Belg Severely Dry
Probability of Occurrence (%)
14
12
10
8
6
4
2

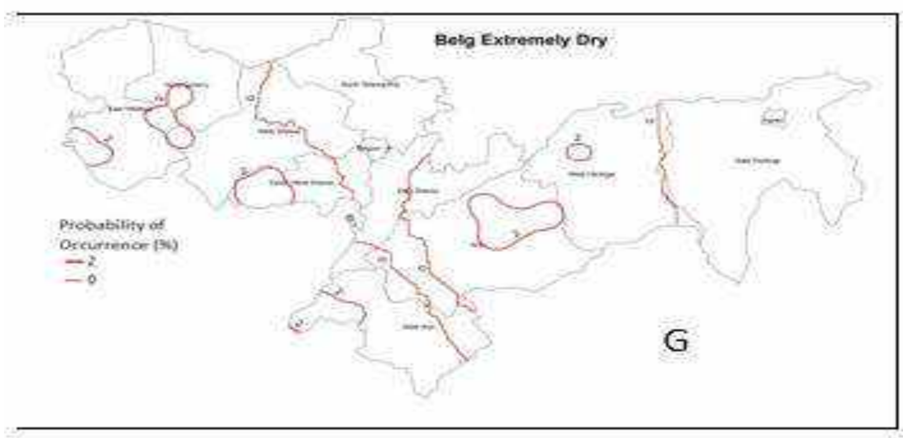


Figure 6: Seasonal Coefficient of Variation

3.1.3. Seasonal variation

During Belg season scrutiny of the long-term rainfall data of 116 meteorological stations in ECO indicated a coefficient of variation ranging from 17-56%. Two of the 116 stations data examined, which had CV of less than 20% indicating low variability, while, 96 of them observed 30-56% extreme variability of rainfall over ECO (Table 3). From this table, there is a decline or upraise in the total amount of rainfall as variability increases. Spatially, through the long year high rainfall variation dominated over North Shoa, central rift valley as well as the adjoining portion of East Hararge, West Shoa, Southwest Shoa and Arsi. The rest parts of Arsi, East Hararge, West Hararge, East Wellega, Horo Guduru Wellega, Southwest Shoa, West Shoa and most parts of West Arsi experienced medium rainfall variation (Figure 6, B). On the other hand, western parts of ECO performed negatively skewed rainfall distribution, whereas positively skewed distribution over most parts of central and eastern parts.

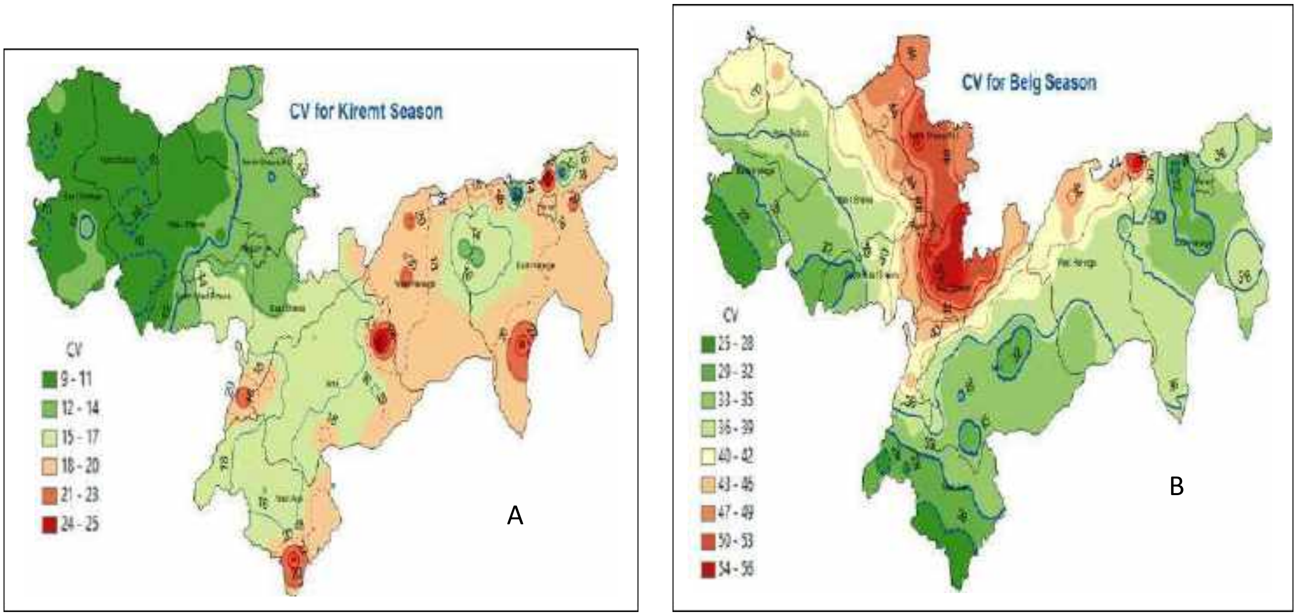


Figure 6: Seasonal Coefficient of Variation

Table 2: Sample Statistical Analysis of Grid and Station Data for Kiremt Season

Stations	Minimum	Maximum	Range	Mean	Std. Deviation	CV
Nekemte_StnDiga_Grid	1025	1610.3	585.3	1495.6	149.45	10.00%
	926.5	1342.4	415.9	1191	104.07	8.70%
Shambu_StnJimma_Horo_Grid	842.5	1453.3	610.8	1095.2	126.48	11.50%
	847.9	1300	452.1	1101.6	106.08	9.60%
Adama_StnAdama_Grid	341.5	1076.8	735.3	609.6	145.17	23.80%
	413.6	768.9	355.3	604.17	85.36	14.10%
Chiro_StnChiro_Grid	164	860.7	696.7	469.58	149.74	31.90%
	337.7	715.6	377.9	533.61	89.056	16.70%
Fiche_StnGerar_Jarso_Grid	452.7	1199	746.3	888.83	150.15	16.90%
	553.8	1048.5	494.7	853.8	104.45	12.20%
Haro_Maya_StnHaro_Maya_Grid	328	566	238	436.65	74.424	17.00%
	294.8	578.3	283.5	432.38	78.934	18.30%
Shashamane_StnShashamane_Grid	268.5	587.4	318.9	424.64	72.479	17.10%
	256.6	608.3	351.7	455.49	69.964	15.40%
Woliso_StnWalisona_Goro_Grid	690.8	1197.9	507.1	864.13	113.78	13.20%
	670.3	1138.5	468.2	899.46	114.71	12.80%

Shukute_StnJeldu_Grid	636	1341.8	705.8	1062.8	172.72	16.30%
	817.7	1275.4	457.7	1023.6	110.26	10.80%
Assela_StnTiyo_Grid	354.9	764.5	409.6	498.07	92.357	18.50%
	303.8	662.1	358.3	491.87	77.351	15.70%

Table 3: Sample Statistical Analysis of Grid and Station Data for Belg Season

Stations	Minimum	Maximum	Range	Mean	Std. Deviation	CV
Nekemte_Stn	60.6	595.8	535.2	373.79	148.41	39.70%
Diga_Grid	159.5	479.8	320.3	335.88	82.313	24.50%
Shambu_Stn	59	535	476	298.41	106.11	35.60%
Jimma_Horo_Grid	91.6	482.5	390.9	302.7	98.239	32.50%
Adama_Stn	47.4	427.7	380.3	199.06	96.404	48.40%
Adama_Grid	45.8	370.2	324.4	175.29	84.741	48.30%
Chiro_Stn Chiro_Grid	73	652.6	579.6	307.68	162.35	52.80%
	146.1	578.6	432.5	313.68	112.8	36.00%
Fiche_Stn	37.7	553.1	515.4	209.19	95.14	45.50%
Gerar_Jarso_Grid	27.7	489.1	461.4	188.64	83.445	44.20%
Haromaya_Stn	117.3	2005.9	1888.6	344.9	345.62	34.20%
Haromaya_Grid	183.4	492.1	308.7	289.6	87.557	30.20%
Shashamane_Stn	143	465.9	322.9	311.63	80.898	26.00%
Shashamane_Grid	157.1	495.2	338.1	331.26	85.258	25.70%
Woliso_Stn	118.4	453.9	335.5	256.89	80.11	31.20%
Waliso_Grid	101.6	410.9	309.3	267.38	82.924	31.00%
Shukute_Stn	125.9	495.1	369.2	274.73	110.97	40.40%
Jeldu_Grid	114.4	499.5	385.1	281.66	99.487	35.30%
Assela_Stn Tiyo_Grid	377.8	798.1	420.3	582.56	98.465	16.90%
	119.7	451.9	332.2	262.94	78.931	30.00%

4. Conclusion

The study emphasized on intra-seasonal variability of rainfall within the ECO considering the two rainy seasons, Belg and Kiremt. It is enthused by two basic questions:

- Is there more significant intra-seasonal rainfall variability over ECO through the long years?
- Are the spatial and temporal rainfall variations dominant in 'Belg' or 'Kiremt' intra-seasonal means?

Intra-seasonal rainfall variability is characterized by a set of simple statistics based on historical daily rainfall observations (1987–2016) of the study area. On the basis of the three scrutinizing statistical methods of variation, SPI, CV and probability of occurrence, the final result concluded as the following for the two seasons. Spratial wetness and dryness variation changed significantly from decade to decade during Belg season. Driest and wetest year do not have uniform spatial rainfall distribution over CEO. Frequently occurrences of highly extreme rainfall are occasional, but probability of near normal dominated. Northern, central rift valley and the adjoining places of ECO are the places mostly affected by Belg season rainfall variability. The rest places of ECO have less rainfall variation. There is a significant change in each decade, of the Kiremt season spatially and temporally within the climatological year over ECO. In the same way to that of Belg season, whenever the extreme wetness or dryness existed there will be sever or very dry or wet will be happen. The probability of frequently happening highly extreme climate events over ECO is very low, but normal condition is prevailing. Except few pocket areas, which have high variability, most areas of ECO have less Kiremt rainfall variation. The result of CV based on gauge and grid data result shown that Belg season has higher variability than Kiremt season. Belg season is twofold higher variable to that of Kiremt season on most places of ECO. Generally, rainfall variation was investigated temporally and spatially intra- seasonal over ECO.

5. Reference

Assessment of drought in Ethiopia, NMSA No.2 January 1996 application of the Standardized Precipitation.

Applied Climatology, Dallas, Texas, 15–20 January 1995. Boston American Meteorological Society, 233–236.

Edwards, D. C. and T. B. McKee, 1997: Characteristics of 20th century drought in the United States at multiple time scales. Climatology Report 97-2, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado.

Guttmann, N.B., 1998: Comparing the Palmer drought index and the Standardized Precipitation Index.

Index in arid locations and dry seasons. International Journal of Climatology,27(1):65–79.

Journal of the American Water Resources Association, 34(1):113–121. McKee, T.B., N.J. Doesken and J. Kleist, 1993: The relationship of drought frequency and duration to time scale. In: Proceedings of the Eighth Conference on Applied Climatology, Anaheim, California,17–22 January 1993. Boston, American Meteorological Society, 179–184. ———, 1995: Drought monitoring with multiple timescales. In: Proceedings of the Ninth Conference

Solomon M. Hsiang, Marshall Burke, Edward Migue፡ Quantifying the Influence of Climate on Human Conflict.

Vicente-Serrano, S.M., S. Beguería and J.I. López-Moreno, 2010: A multi-scalar drought index sensitive to global warming: the Standardized Precipitation Evapotranspiration Index – SPEI. Journal of Climate, 23(7):1696–1718, doi: 10.1175/2009JCLI2909.1.

Wilhite, D.A. and M.H. Glantz, 1985: Understanding the drought phenomenon: the role of defnitions. Water International, 10:111–120.

World Meteorological Organization, 2012: Standardized Precipitation Index User Guide (M. Svoboda, M. Hayes and D. Wood). (WMO-No. 1090), Geneva. Standardized Precipitation Index User Guide 3 1.

NATIONAL METEOROLOGICAL AGENCY

Impact of El Nino Southern Oscillation (ENSO) On Malaria Transmission, a Case Study in East Showa Zone, Oromia Region, Ethiopia

Prepared by: -

1. Tizazu Geremew (Principal investigator)
2. Kadir Kemal (member)
3. Asalifew Nuguse (member)
4. Gezahagn Merga (Member)
5. Getachew Kebede (member)

Abstract

The East Showa zone is severely affected by vector and water borne diseases due to their climate, humidity conditions, topography, and population dynamics. So far, very little research has been undertaken in these areas that inclusively employ the use of climate and weather information on health using International Research Institute (IRI) methodologies and ENSO conditions. The main aim of this study was to investigate the impact of ENSO on malaria transmission. Rainfall, Temperature, Relative humidity and Oceanic Nino Index (ONI) at Nino 3.4 region from 1987- 2018 and Malaria case data from 2004-2018 were used. The three criteria of IRI (monthly mean air temperature between 18°C-32°C, monthly mean relative humidity $\geq$ 60% and monthly total rainfall >80mm), simple correlation and spatial analyses methods were used to associate the ENSO events in the Pacific Ocean and local climate with confirmed malaria case in the study area. The research findings show that seasonality of climate greatly influences the seasonality malaria transmission. The rainfalls in June to August were creating favorable climate suitability conditions for malaria spreading in the next three months (September to November) and high percent occurrence of climate conditions suitable for malaria transmission were recorded from September to November. The high numbers of malaria cases were recorded following the main rainy season of the study area. High numbers of malaria case were recorded from September to November and peak in October. During El Nino year's high numbers of malaria case were recorded followed by Neutral years. In contrast, low numbers of malaria case were recorded during La Nina years. El Nino years associated with increasing number of malaria case, in contrast, La Nina years associated with decreasing number of malaria case. The climate variability (rainfall, temperature, relative humidity and Oceanic Nino Index at Nino 3.4 region) was weakly to moderately correlate with malaria cases during all seasons at lags of zero and one season over the study area. Therefore, climate information would be useful in early warning of malaria transmission for early preparedness and planning to control malaria outbreaks.

Kew words; Climate suitability, Correlation, ENSO events, Malaria case

1. Introduction

Malaria is the major public health problem and one of the deadliest killer diseases in Ethiopia (WHO, 2016) and directly linked to temperature relative humidity and rainfall. About 68 percent of the Ethiopia people are living in malaria prone areas (Ayele, 2017). Most of these areas have been experiencing seasonal malaria epidemics. Malaria continues to be the most significant mosquito-borne disease globally but it holds a particularly heavy burden across many countries in Africa where in 2015, 88% of global cases and 90% of global deaths due to malaria were recorded (WHO, 2016). Climate variability is a major factor and which can influence the life cycle of malaria (Bradley DJ Wiley: Chichester, 1993). However, malaria is sensitive to climate conditions and the occurrence is strongly influenced by climate variability (Ermert V, 2010). As many author mentioned that malaria is the most sensitive to climatic parameters (Lindsay SW, Birley MH 1996, Mabaso MLH, Vounatsou P, Madzi S, De Silva J, Smith T, 2006). Global climate models used to analyze scenarios of climate change and malaria transmission (Marten P. 1997) predict a worldwide increase in the disease associated with increases in temperature, humidity, and rainfall (Attenborough RD, Burkot TR, and Gardner DS. 1997., Bouma MJ, Dye C, and Van der Kaay HJ. 1996).

Rainfall is largely responsible for creating the conditions that allow sufficient surface water for mosquito breeding sites and is therefore recognized as one of the major factors influencing malaria transmission. Temperature also plays a role in malaria transmission through its influence on the development rate of mosquito larvae and the survival rate of adult mosquitoes. In the temperature critical regions, small changes in temperatures can generate large effects for the parasite (. Bradley DJ Wiley: Chichester, 1993, Lindsay SW, Birley MH, 1996) and vector (Pascual M, Ahumada JA, Chaves LF, Rodo X, Bouma MJ, 2006.). Moreover, at warmer temperatures, adult female mosquitoes feed more frequently and digest blood more rapidly and the plasmodium parasite matures more rapidly with in the female mosquitoes. Further, a relative humidity of at least 60% is often regarded as a requirement for malaria transmission. Malaria in Ethiopia is highly sensitive to climate, with epidemics historically occurring in unusually warm and wet years. As a result of higher temperatures was anticipated in the first health assessment of the impacts of global warming, malaria's shift to higher altitudes in malaria-endemic tropical regions (WHO: Geneva, 1990.).

This shift has recently been put on solid empirical footing for highlands in both Ethiopia and Colombia

(Siraj AS, Santos-Vega M, Bouma MJ, Yadeta D, Ruiz Carrascal D, Pascual M., 2014). Climate variability is widely considered to be a major driver of inter-annual variability of malaria incidence in Africa (Afrane et al., 2005). Several studies have suggested that climate can affect infectious disease patterns are clearly sensitive to temperature, rainfall, moisture and other ambient environmental conditions (Appawu et al., 2004; Ameneshewa et al., 1995). The IPCC Special Report on Regional Impacts of Climate Change (IPCC, 2001) acknowledges that climate has an impact on vector-borne diseases. Climate change affects potential geographical distribution and transmission of vector-borne infectious diseases such as malaria.

The climate of Ethiopia, one of the most complexes in Africa, is in part driven by global processes associated with the El Niño-Southern Oscillation (ENSO). In Ethiopia, the influence of climate variables on malaria transmission and the subsequent role of ENSO in the rise of malaria incidence are becoming more recognized. Large-scale climate phenomena could influence local malaria incidence via atmospheric teleconnection. The El Nino Southern Oscillation (ENSO) phenomenon refers to the cyclic warming and cooling of the equatorial Pacific Ocean coupled with changes in the atmospheric pressure across the Pacific. This is the most important climatic cycle contributing to worldwide inter-annual variability in climate and the likelihood of climatic anomalies. The two extremes of ENSO are El Nino (a warm event) and La Nina (a cold event), which create rainfall and temperature fluctuations. Their impact varies across the regions of the globe and can result in drought in some areas and flooding in others (Boumaet al., 1997a; Kovats, 2000; Kovats et al., 2003; Nicholls, 1993). However, which has impact on vector borne disease like malaria mostly over tropical regions.

On a global scale, there is nevertheless a striking associated between regions with ENSO-based rainfall anomalies and those where periodic malaria epidemics have been historically reported (Bouma MJ, Sondorp HE, Van der Kaay HJ; 1994), even though rainfall needs not be the determining epidemic driver. The effects of ENSO on malaria are most pronounced in epidemic- prone areas where climate conditions are generally not suitable for year-round vector reproduction. The effect of ENSO on malaria is mediated by its impact on rainfall, relative humidity and temperature patterns. In dry areas, intense rainfall can create water puddles; in wet areas, droughtcan result in reservoirs of stagnant water, both conducive to generation of new mosquito breeding sites. According to (M. J. Bouma, A. S. Siraj, X. Rodo and M. Pascual, 2016), study result indicates El Nino events associated with above normal winter temperatures in Ethiopia highlands, which increased malaria risk of 71%. Since 1994, many countries have found the association between ENSO and malaria outbreaks (Bouma MJ, van der Kaay HJ;1996, Bouma MJ, Dye C,1997) but in Ethiopia there is no revisit on the subject considering the IRI criteria's. As many studies result shown, ENSO has been found to have strong link with Ethiopian seasonal rainfall (Haile, 1988; Beltrando and Camberlin, 1993; Nicholls, 1993; Seleshi and Demar´ee, 1995; Nicholson and Kim, 1997; Kassahun, 1999). Haile (1988, 1992) based on which early forecast of malaria can also be possible in Ethiopia. The study will capture East Showa zone. The area is severely affected by vector and water borne diseases due to their climate, humidity conditions, and topography and population dynamics. So far very little research has been undertaken in these areas that inclusively employ the use of climate and weather information on health using IRI methodologies and ENSO conditions. However, the area has vast geographical area; it is known that all areas don't have the same impact of ENSO on malaria transmission. Therefore, the current study was undertaken to assess the link between ENSO events, climate variability and malaria transmissions at woreda level in the East Showa zone. The generated knowledge would be useful in early warning of malaria transmission for early preparedness and planning to control malaria outbreaks.

2. Data and Methodology

2.1. Study area

East Showa Zone is located in the central part of Oromia Region, it has an area of 8,370.90 sq. km and a population of 1,356,342, of whom 696,350 are men and 659,992 women according to the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA). The zone located in 38.4°E to 40.1°E longitude & 7.6°N to 9.2°N latitude. In East Showa Zone climate variations range from semi-arid to humid. The landscape in East Showa Zone is diverse with farmlands, forests, mountains, and grasslands. The climate of the East Showa Zone is influenced by the factors such as of altitude and latitude as well as topographic features such as water bodies, highlands and valleys.

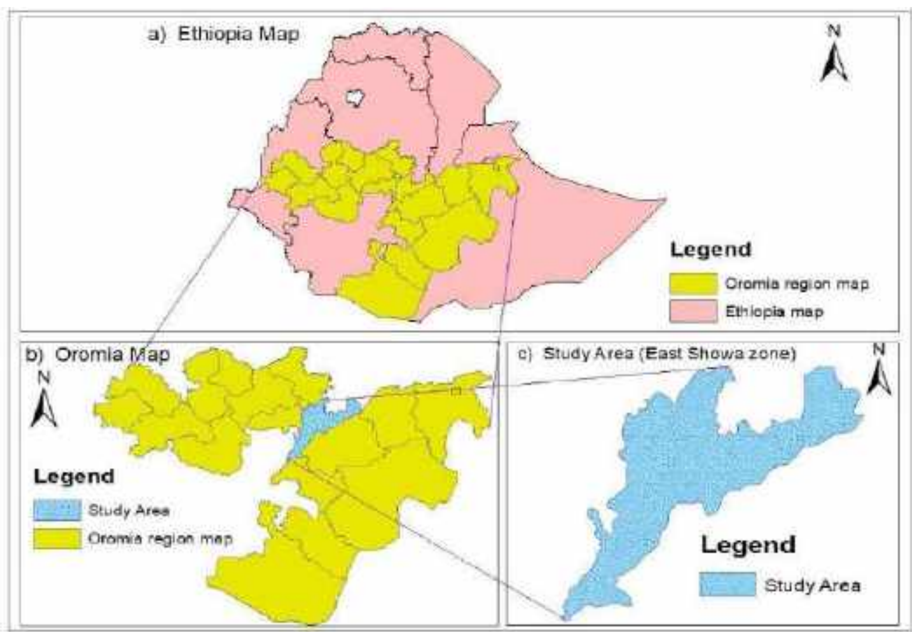


Figure 1. Location of study area

2.2. Data and Methods

2.2.1. Data

Under this study the various data were used to assess the impact ENSO events on the malaria transmission in East Showa zone. The datasets which were used in this study are Climatic and malaria cases data. Temperature, Relative humidity and rainfall data were obtained from National Meteorological Agency (NMA). The local climatic data was collected from seven meteorological station found in East Showa Zone. In Ethiopia, malaria is one of the most common public health problems. According to Oromia Health Bureau reports, the East Showa Zone is the most prone area than the other zones. Monthly malaria case data were obtained from woreda, zone and Oromia Health Bureau for the period from January 1, 2004 to December 31, 2018. Monthly Oceanic Nino Index (ONI) values at Nino 3.4 regions (170°W to 120°W longitude and 5°N to 5°S latitude) for the same period were downloaded from the Climate Prediction Centre in National Oceanic and Atmospheric administration (NOAA), Website. (http://www.cpc.ncep.noaa.gov/products). In addition, the study used Extended Reconstructed Sea Surface Temperature V3B (ERSST) produced by National Centre for Environment Prediction-National Centre for Atmosphere Research (NCEP-NCAR) reanalysis data, from 1987 to 2018 period (Kalnay et al.1996) which are gridded to a horizontal resolution of 2.5°x2.5°.

2.2.2 Methods

As the malaria cases across the different places of East Showa Zone vary greatly, standardized malaria case index that can bring them in single measurable scale compatible to ONI index was calculated to ease the analysis. To examine the impact of ENSO on malaria transmission over the study area, a composite analysis and different statistical methods were applied by using standardized data. The standardized anomaly malaria case index was calculated by: -

$$M=(X-\mu)/\sigma$$

Where, M is implying the standardized malaria cases,

X is an annual malaria cases,

μ is long-term mean malaria cases of the area (1987-2018) and **σ** is Standard deviation.

Similarly, the standardized anomalies of rainfall, temperature and relative humidity was calculated by:

$$Z= X-\mu)/\sigma$$

Where, **Z** is the standardized anomalies, **X** is an annual average, **μ** is long-term mean of the area for the period of (1987-2018) and **σ** is standard deviation. El Nino and La Nina conditions are determined using NOAA operational definitions based on the Oceanic Nino Index (ONI). ONI used in the determination of the value equation sea surface temperature (SST) anomalies in the Niño 3.4 region (120W-170W, 5 N-5 S) as follows:

Surface Temperature in Nino 3.4 region and SSTm is mean of Sea Surface Temperature from lon time series in Nino 3.4 region. When SST anomalies are positive, greater than or equal to +0.5^{O}c, then the phenomena that occurs is El Nino and conversely if SST anomalies are negative, less than or equal to -0.5^{O}c, then the phenomena that occurs is La Nina.

In this study the correlation analysis was used to investigate the relationship between monthly climatic variables (temperatures, relative humidity, and rainfall and ONI index) with malaria cases was examined using SPSS to analyses the relation between malaria cases and climatic factors. Simple correlation (rxy) between variables x and y (Yule, 1907) is expressed as: -

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{\left[n\Sigma x^2 - (\Sigma x)^2\right]\left[n\Sigma y^2 - (\Sigma y)^2\right]}}$$

The calculated correlation coefficients tested for statically significance using the t- test summarized defined by; -

$$t = \frac{r_{xy}\sqrt{n-2}}{\sqrt{1-r_{xy}^2}}$$

The calculated values of t were then compared with those of the theoretical t-distribution with N- 2 degrees of freedom. In this study, the IRI criteria were used to define areas with distinct malaria intensity and climate seasonality suitability patterns, to guide future interventions and development of an epidemic early warning system. International Research Institute (IRI) launched three criteria to identify the suitability of malaria transmission. According to (IRI) there are three criteria that related to malaria spreading. These are when monthly average temperature between 18°C – 32°C, monthly average humidity > 60% and monthly total rainfall >80mm. In this study Arc GIS, Grads and Surfer 8 software were employed to analyses the spatial distribution of climatic factors to identify the suitability areas for malaria transmission.

3. Result and Discussion

3.1 Climatic suitability for malaria transmission associated with ENSO events

The results of this study shows that monthly and seasonality of climate influences the variation in malaria transmission in East Showa Zone. The zone has nine woredas in which the climatic suitability for malaria transmission based on the rainfall, temperature and humidity, which are the most significant parameters for the malaria transmission. The analyses and the figures show the proportional occurrence of the climatic conditions for each month. As observed from the figures and tables that the seasonality of climate greatly influences the seasonality of malaria transmission in the study area. Specifically, rainfall plays an important role in the distribution and maintenance of breeding sites for the mosquito vector (anopheles species). Moreover, temperature also plays an important role in the variability of malaria transmission by regulating the development rate of mosquito larvae and influencing the survival rate of adult mosquitoes. Relative Humidity impacts the survival rate of the mosquito as well. Mosquitoes survive better under conditions of high humidity and they also become more active when humidity rises. Mosquitoes generally develop faster and feed earlier in their life cycle and at higher frequency in warmer and humid condition. Suitability is defined as the coincidence of Rainfall accumulation greater than 80 mm, mean temperature between 18°C and 32°C, and relative humidity greater than 60%. Temperature, Rainfall and relative humidity are factors of mosquito development time as well as an indicator of Plasmodium parasite development within the mosquito vectors (Grover-Kopec et al., 2006).

The malaria spread occurred when monthly values of rainfall, relative humidity and temperature concurrently full fill the criteria of IRI. Table 1 and figure 3 shows the number of months during the year that are suitable for malaria transmission, based on climatological averages. Figure 3 shows the monthly pattern and intensity of malaria transmission in different woredas within East Showa zone. Three woredas in East Showa Zone (Dugda Bora, Adami Tulu Jido Kombolcha and Lume) were more suitable for malaria transmission (table 1 and figure 3). As figure 2 shows three lakes are found in East Showa zone, (Lake ziway which found in Adami Tulu Jido Kombolcha woreda, Lake Koka which found in Lume, Dugda Bora and Adama woredas and lake Basaka which is found in Fantale Woreda for this reason, these lakes may propagate the breeding of mosquitoes

and increase the occurrence of malaria during dry season except lake Basaka, it is not suitable for malaria transmission due to its salinity. Besides, the irrigation systems undertaken in the area could create favorable conditions for malaria spreading. Climatologically, as figure 3 and table 1 shows 8 months (between March and October) were suitable for malaria transmission in Dogda Bora woreda and 6 months (between May and October) were suitable for malaria transmission in Adami Tulu Jido Kombolcha woreda. Five months (between June and October) were suitable for malaria transmission in Lume woreda. Climatologically, the major climate suitability for malaria transmission in East Showa zone occurs from March to September, which indicates the Belg and Kiremt seasons are more suitable for malaria transmission.

Table1. Climatology number of months suitable for malaria transmission in East Showa zone

Woreda Name	Number of months suitable for malaria transmission	Months suitable for malaria transmission
Fantale	3 months	July, August, September
Boset	3 months	July, August, September
Adama	5 moths	May, Jun, July, August, September
Ada'a	4 months	Jun, July, August, September
Dugda Bora	8 months	March, April, May, Jun, July, August, Sept, October
Adami Tulu Jido Kombolcha	6 months	May, Jun, July, August, September, October
Lume	5 months	Jun, July, August, September, October

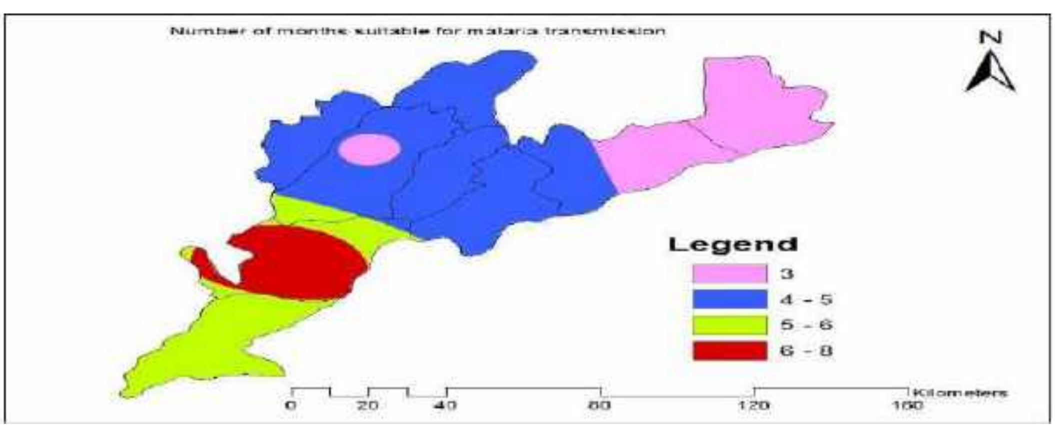


Figure 2: Number of months suitable for malaria transmission in East Showa zone

As indicated in Figure 4 the study area has a bi-modal rainfall type the long rainy season (June–

September) and short rains (March-May), locally referred as Kiremt and Belg rainy season respectively. The rest of the months (October to February) are dry period. A study area receives substantial amounts of rainfall in Kiremt season (June to September). As figure (4) shows climatologically the monthly total rainfall of the study area is receiving more than 80mm in the kiremt season (June to September) which is suitable for the malaria transmission and receives less than 80mm during Belg and Bega seasons (from October to May). In the study area, as figure 5 and 6 shows monthly mean air temperature is suitable for malaria transmission through the year and monthly mean relative humidity is also suitable except for the months of January and February, in which the values of relative humidity is less than 60%, that is not suitable for malaria transmission. Over the study area according to IRI criteria, the mean monthly relative humidity, temperature and rainfall total were concurrently fullfilled during the month of June to September, which is suitable for malaria transmission (figure 3, 4 and 5).

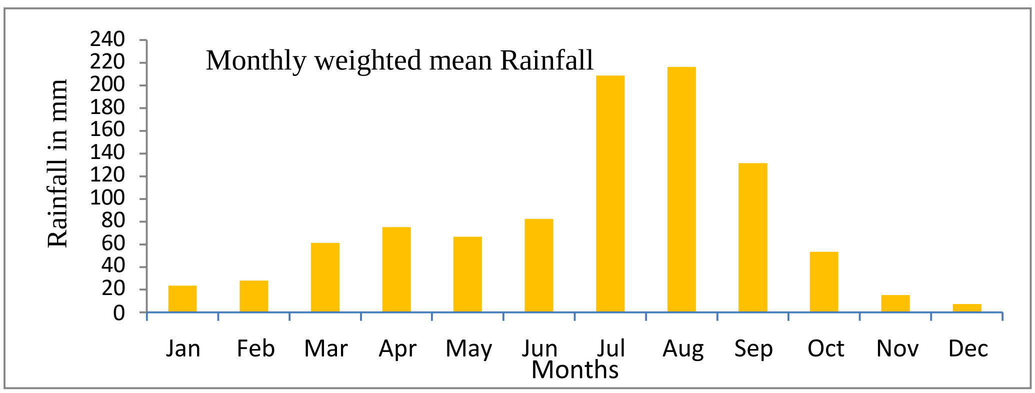


Figure 3: Monthly mean totals Rainfall of East Showa zone

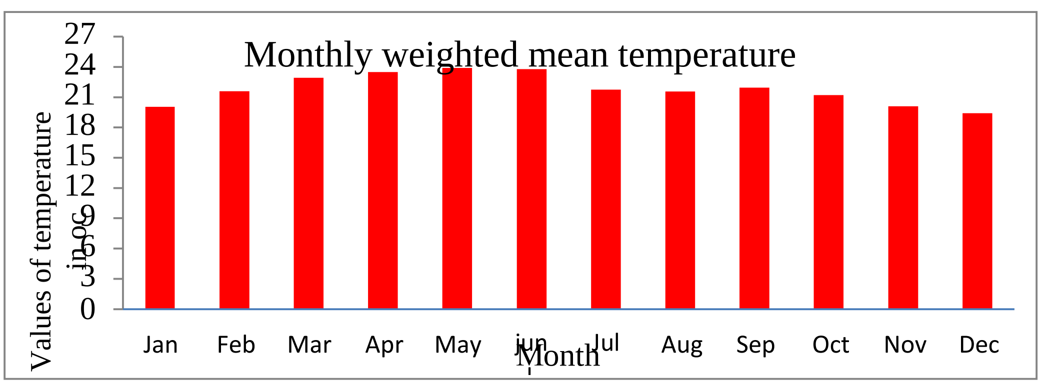


Figure 4: Monthly Temperature of East Showa Zone

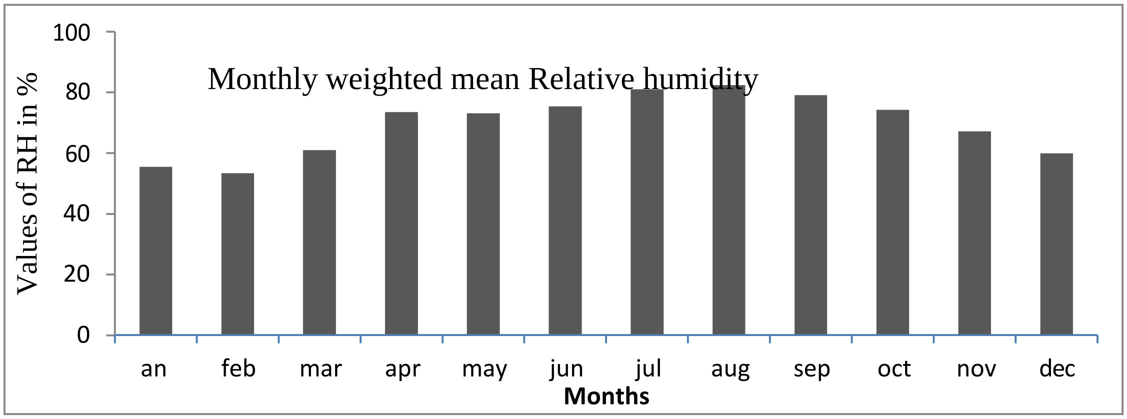


Figure 5: Monthly Mean Relative Humidity of East Showa Zone

Among the factors that affect malaria transmission, seasonal variation has direct role. As figure 8 indicates in the study area, high numbers of malaria case were recorded from September to November, peak in October with values of 740. The high numbers of malaria cases were recorded following the main rainy season of the study area and also the mean monthly temperature and relative humidity were satisfied for malaria transmission during this season (figure 3, 4 and 5 respectively). The heavy rain falls in July and August were creating favorable climate suitability conditions for malaria spreading in the subsquent three months (September to November). This period is considered as the peak malaria transmission period in the study area after heavy rain in July and August. As figure 6 shows that over the study area high percent occurrence of climate conditions suitable for malaria transmission were recorded from September to November, peak in October which causes a high number of malaria case were recorded in the study area during this period, along with the number of malaria cases peak in October (figure 7).

Figure 8 shows that low number malaria case were recorded from February to April over the study area, in this period the suitability conditions for malaria transmission were not satisfied concurrently, especially the monthly total mean rainfall is less than 80mm (figure 4) which is not favorable for malaria spreading. In general mosquitoes start breeding as soon as the rain stops, i.e. water collections that support vector breeding appear mainly after the rains; therefore, malaria transmission is highest following the rainy season. As figure 7 shows the maximum number of malaria case were recorded from September to November meaning. The vegetation coverageincreases in this period following the rainy season, which in turn increases the relative humidity of the environment which may cause favorable conditions for malaria spreading.

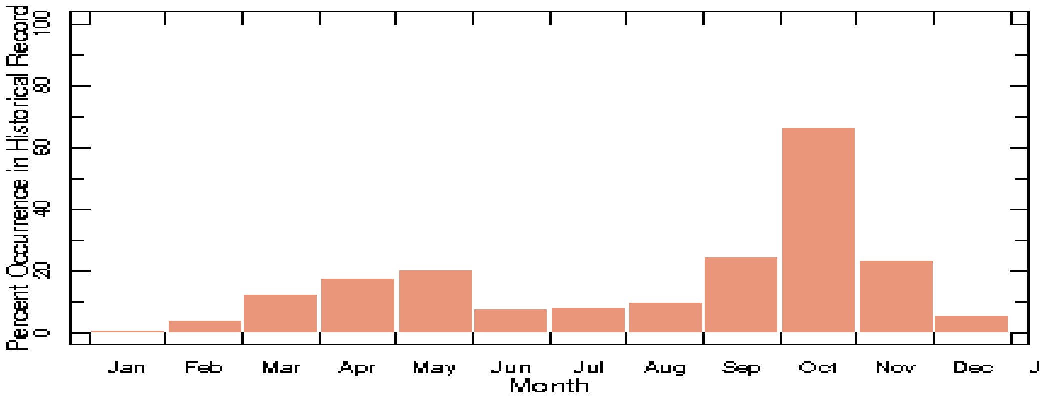


Figure 6: Monthly Climate Conditions Suitable for Malaria Transmission in East Showa zone

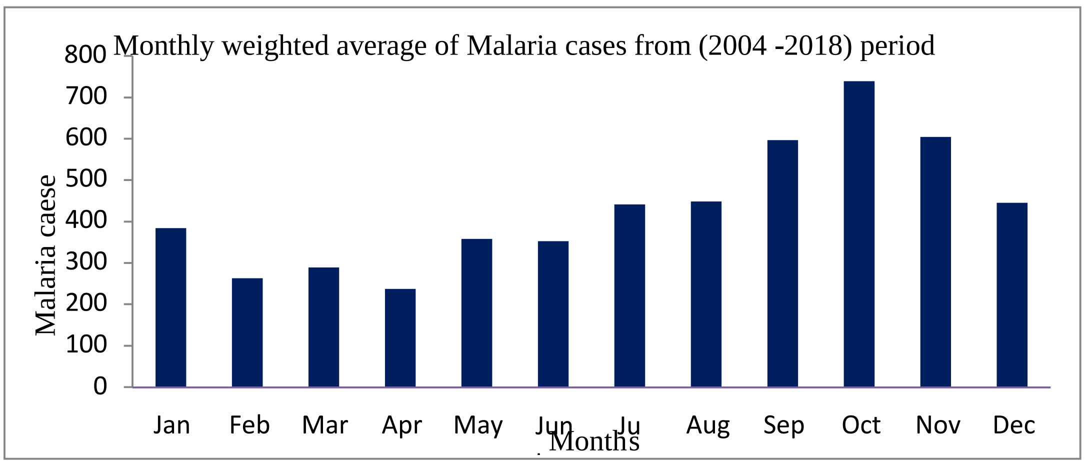


Figure 7: Monthly weighted average of malaria cases in East Showa Zone from 2004 – 2018

The figure 8 and 9 indicates the monthly, seasonal and annual weighted average number of malaria cases from January 2004 to December 2018 during ENSO events in East Showa Zone. The bar graph of figure 8 and 9 shows the number of malaria cases during El Nino, La Nina and Neutral years. Figure 8shows during El Nino year's high number of malaria case were recorded from August to January, peak in October with values about 921. The rain falls in July, August and September were creating favorable climate conditions for malaria spreading in the next two months (August to November) during El Nino years. This period is considered as the peak malariatransmission period in the study area after heavy rain in July, August and September. El Nino Years have been associated with increasing number of malaria cases from August to January and associated with decreasing number of malaria cases February, to May when we compared with the two other events over the study area. During La Nina years high number of malaria case were recorded in months of June and July, peak in July with values about 525. As figure 15 shows the rain falls in June to September were create favorable climate conditions for malaria spreading in the next three months (September to November) during La Nina years (figure 8). This period is considered as the peak malaria transmission period in the study area after heavy rain from June to September. La Nina years have been associated with increasing number of malaria cases during the months of June and July as compared the other two events and associated with decreasing number of malaria case during the months of over the study area except in the month of June and July. During neutral years high numbers of malaria case were recorded from February to May, peak in May as compared to the other two events. As figure 17 shows the rain falls in June to September were create favorable climate suitability conditions for malaria spreading in the next four months (September to December) during Neutral years (figure 8). Neutral Years have been associated with increasing number of malaria cases during the months of February to May as compared to the other events over the study area.

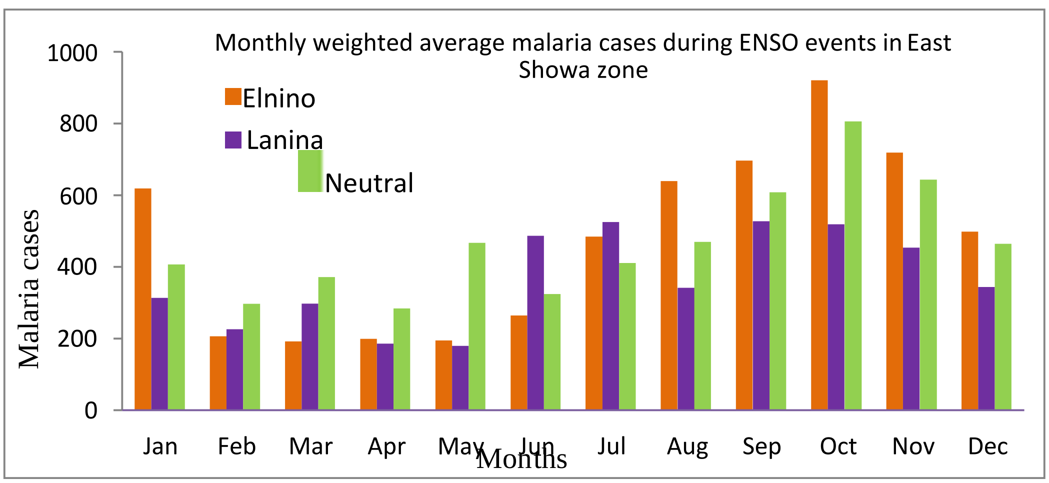


Figure 9. Monthly weighted average of malaria cases during ENSO events for the period 2004 – 2018

Figure 10 shows during El Nino year's high number of malaria case were recorded during both Bega and Kiremt season. The low numbers of malaria case were recorded during Belg season. During Neutral year's high number of malaria case were recorded during Belg season. El Nino Years have been associated with increasing the number of malaria case during Bega and Kiremt season and associated with decreasing number of malaria case during Belg season. In contrast Neutral years associated with increasing the number of malaria cases during Belg season. As figure 10 indicates, annually high numbers of malaria case were recorded with values of 5638 during El Nino years followed by Neutral years. In contrast, low numbers of malaria case were recorded during La Nina years with values of 4393. In general, annually El Nino years associated with increasing number of malaria case, in contrast La Nina years associated with decreasing number of malaria case.

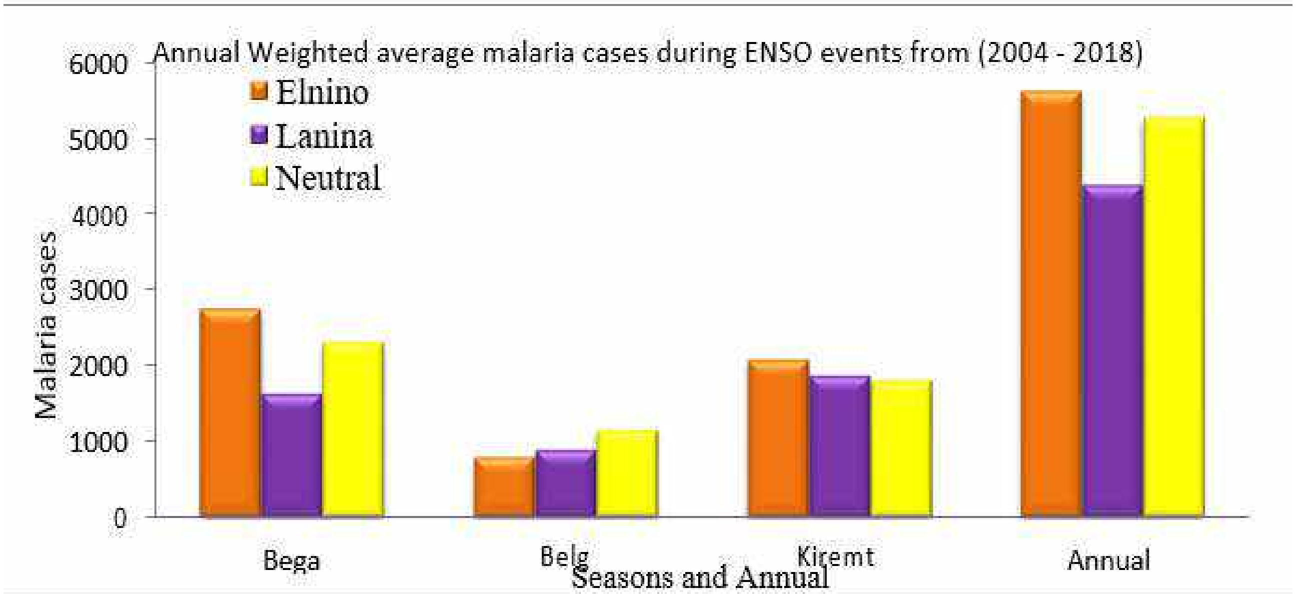
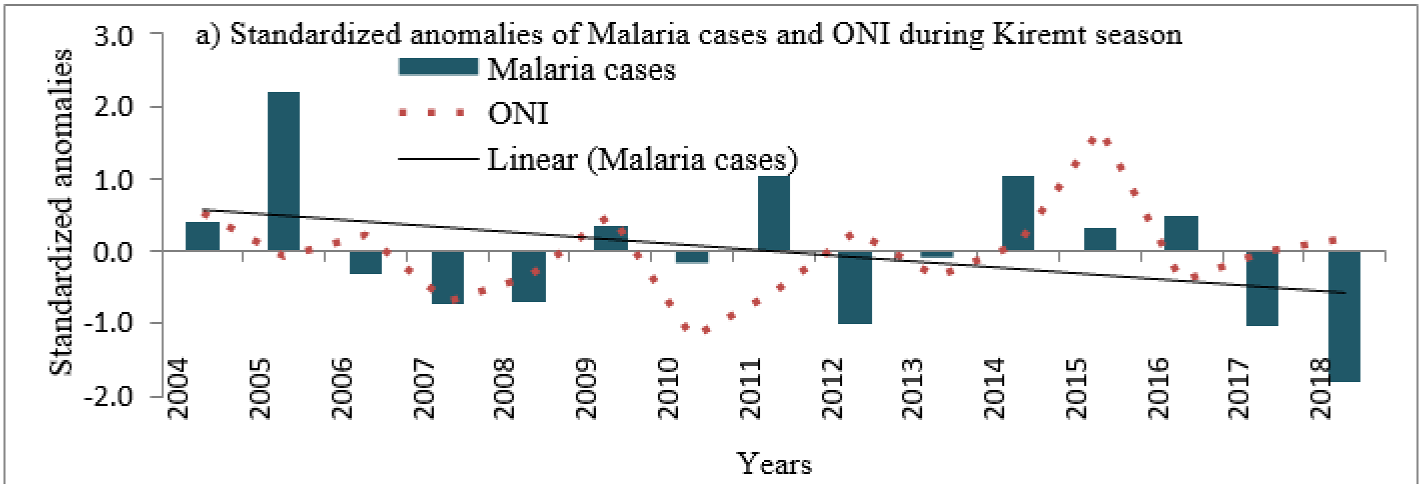
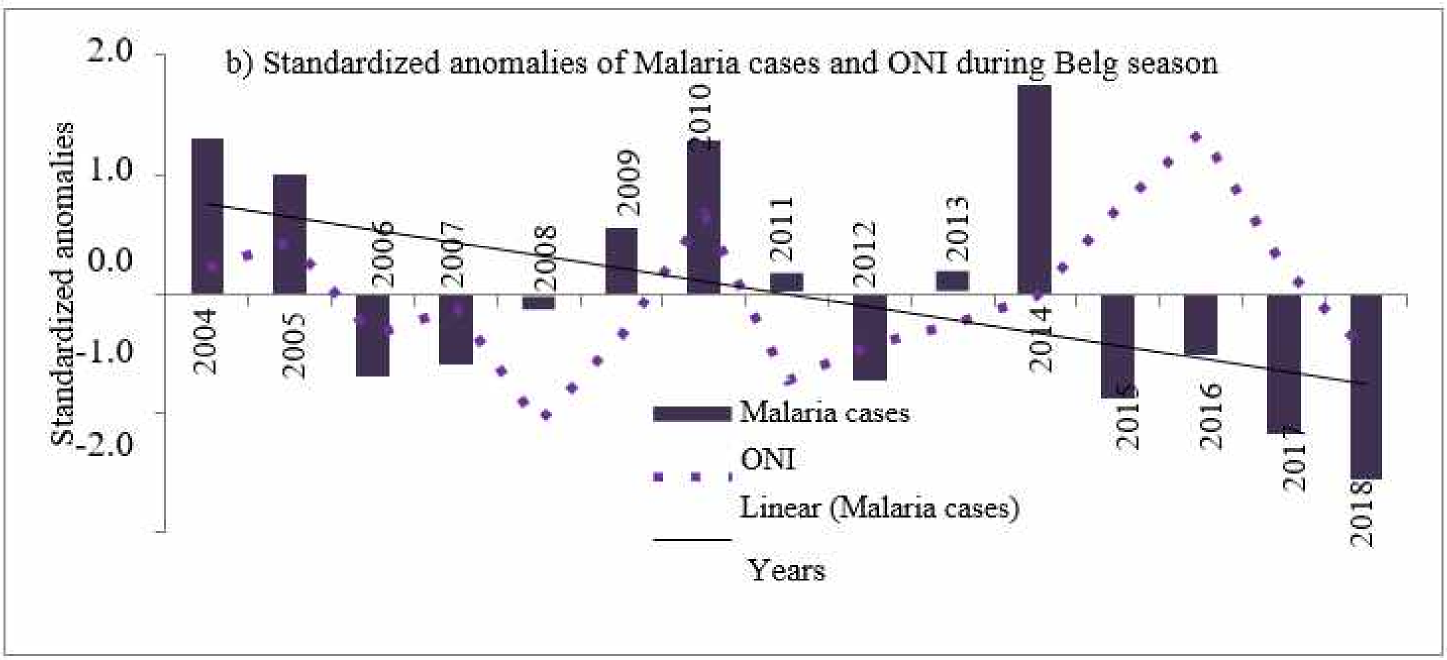


Figure 10 Annual averages of malaria cases during ENSO events for the period 2004 – 2018

Figure 11(a, b and c) shows that seasonal standardized anomalies of malaria case and Oceanic Nino Index (ONI). The Oceanic Nino Index (ONI) is one of the primary indices used to monitor the El Nino-Southern Oscillation (ENSO). The ONI is calculated by averaging sea surface temperature anomalies in an area of the east-central equatorial Pacific Ocean, which is called the Nino-3.4 region (5S to 5N; 170W to 120W). Over the study area during Kiremt Season above normal incidence rates of malaria case synchronized with El Nino years (positive values of ONI i.e. $\geq$ 0.5) and below normal incidence with La Nina years (negative values of ONI i.e. $\leq$ 0.5), in contrast incidence rates of malaria case associated with La Nina years, in contrast above normal incidence in 2011. As figure 11(c) shows during Bega season, above normal incidence rates of malaria case associated with El Nino years, in contrast below normal incidence in 2015 and below normal incidence rates of malaria case associated with La Nina years, in contrast above normal incidence in 2008. As figure 11(a, b and c) shows during Kiremt, Belg and Bega season neutral years (ONI values ranges between -0.5 to 0.5) associated with both above and below normal incidence rates of malaria case. Figure 11 shows during all seasons over the study area the trends of number of malaria case are decreasing.


a) Standardized anomalies of Malaria cases and ONI during Kiremt season
Malaria cases
ONI
Linear (Malaria cases)
Standardized anomalies
3.0
2.0
1.0
0.0
-1.0
-2.0
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Years


b) Standardized anomalies of Malaria cases and ONI during Belg season
Standardized anomalies
2.0
1.0
0.0
-1.0
-2.0
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Malaria cases
ONI
Linear (Malaria cases)
Years

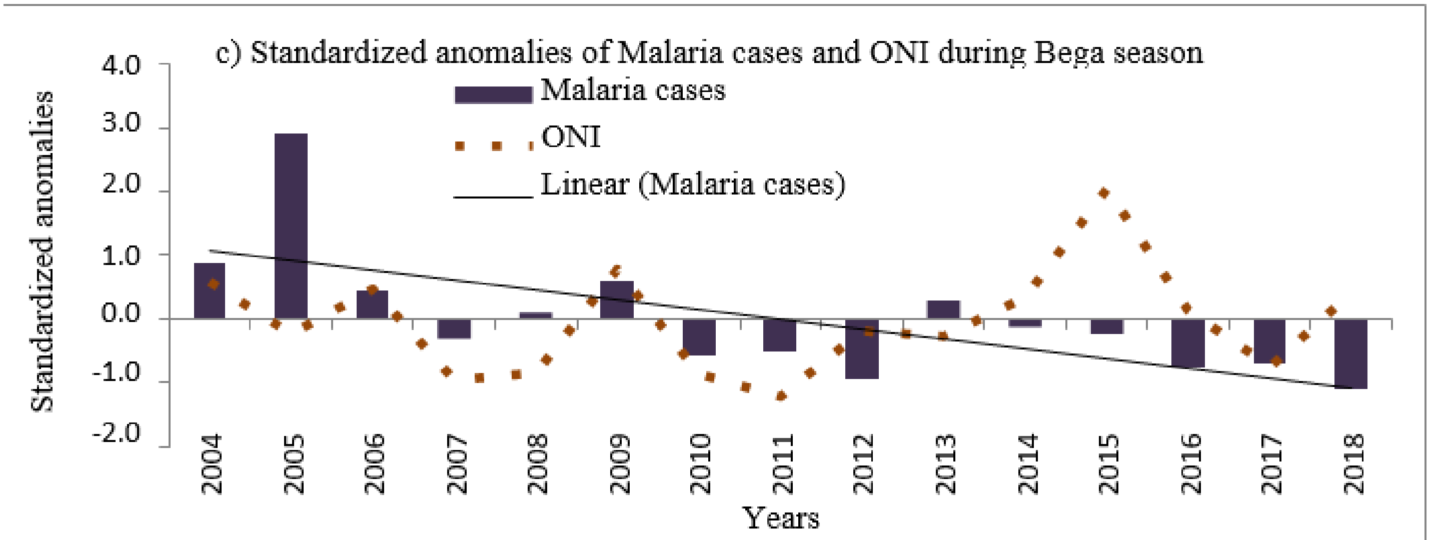


Figure 11 (a, b and c) Seasonal Standardized anomalies of Malaria cases and Oceanic Nino Index (ONI) in East Showa Zone for the period 2004 and 2018

3.1. Climate suitability for malaria transmission during El Nino years

El Nino may expand the distribution of malaria to the highlands through epidemics through the gradual expansion of the parasites territory in response to warming and perhaps as temperatures gradually increase above normal along the altitudinal gradient. While El Nino events will influence the climate variables that influence malaria transmission (i.e. Temperature, rainfall and relative humidity). Table 2 and figure 12 shows the number of months during the year that are suitable for malaria transmission during El Nino years. As figure 13 shows during El Nino years the monthly total rainfall of the study area is receives more than 80mm in the months of (April, May, July, August and September) which is suitable for the malaria transmission and receives less than 80mm in the months (January, February, March, June, October, November and December).

In the study area, as figure (13) shows monthly mean air temperature is suitable for malaria transmission through the year and monthly mean relative humidity is also suitable except for the month of January in which the values of relative humidity is less than 60%, that is not suitable for malaria transmission. During El Nino years Over the study area according to IRI criteria, the mean monthly of relative humidity, temperature and rainfall were concurrently occurred during the month of (April, May, July, August and September), which is suitable for malaria transmission (figure 13) and the rest months are not fulfills the criteria of IRI for malaria spreading.

Figure 12 shows the monthly pattern and intensifies of malaria transmission in different woredas during El Nino years within East Showa zone. As table 2 and figure 12 indicates during El Nino years 3 up to 7 months were suitable for malaria transmission in the study area. From East Showa zone Adama, Dugda Bora, Lume, and ada'a woredas were more suitable for malaria transmission for 7 months (between March and September), 6 months (between April and September) and 5months (between April and August) respectively. As table 2 and figure 12 shows that from East Showa zone, Fantale, Boset and Adami Tullu Jido kombolcha woredas were not much suitable for malaria transmission as other woredas found in the zone. As figure 2 shows that Dugda Bora and Adama woredas were surrounded by lakes of Ziway and Koka respectively, which in turn create favorable climate condition for malaria transmission in these woredas during El Nino years (figure 12). As figure 10 shows El Nino Years have been associated with increasing the number of malaria case during Bega and Kiremt season and associated with decreasing number of malaria case during Belg season. As figure 10 indicates, annually high numbers of malaria case were recorded during El Nino years. In general, annually El Nino years associated with increasing number of malaria case.

Figure 14 shows that during El Nino years the combination of the three climate conditions (rainfall, temperature and relative humidity) were satisfied for malaria spreading over the whole parts of East Showa zone during the months of July and August, and most places of Adami Tulu Jido kombolcha, Dugda Bora, Adama, Lume and Gimbichu woredas during the months of April, May, June and September. During the month of January to March and October to December the combination of climate conditions (rainfall, temperature and relative humidity) were not satisfied for the malaria spreading over the whole parts of East Showa zone (figure 14). Generally, as figure 14 indicates the climate condition were satisfied over the most places of the study area in the months of April to September. Therefore, there was the favorable combination of climate conditions (rainfall, temperature and relative humidity) for the existence of malaria spread over most places of Dugda Bora, Adami Tulu Jido kombolcha, Lume, Ada'a, Adama woredas and some places of Gimbichu, Bosat and Fantale woredas.

Table2: Number of months suitable for malaria transmission during El Nino years in East Showa zone

Woreda Name	Number of months suitable for malaria transmission	Months suitable for malaria transmission
Adama	7 months	March, April, May, Jun, July, August, September
Ada'a	5 months	April, May, Jun, July, August
Adami Tulu Jido Kombolcha	4 months	May, Jun, July, August
Boset	3 months	April, July, August
Dugda Bora	7 months	March, April, May, Jun, July, August, September
Fantale	3 months	April, July, August
Lume	6 months	April, May, Jun, July, August, September

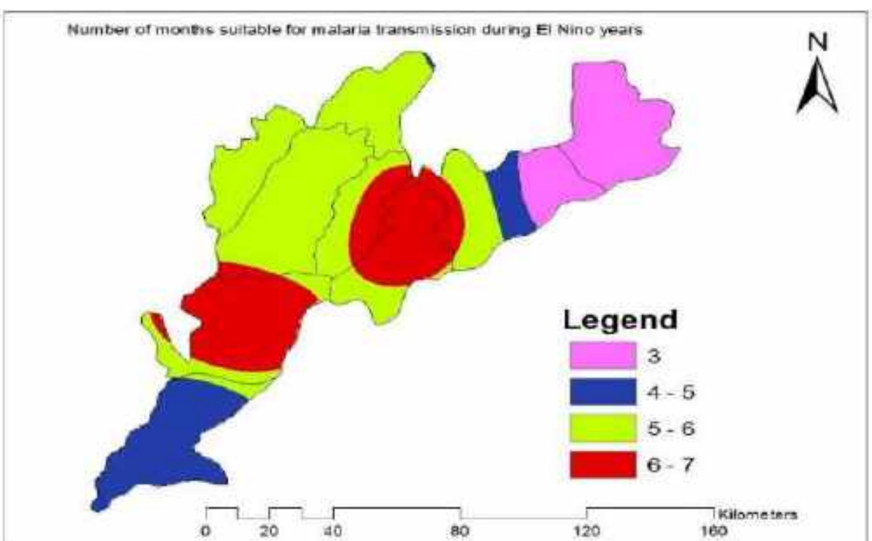


Figure 11: Number of months suitable for malaria transmission during El Nino years in East Showa zone

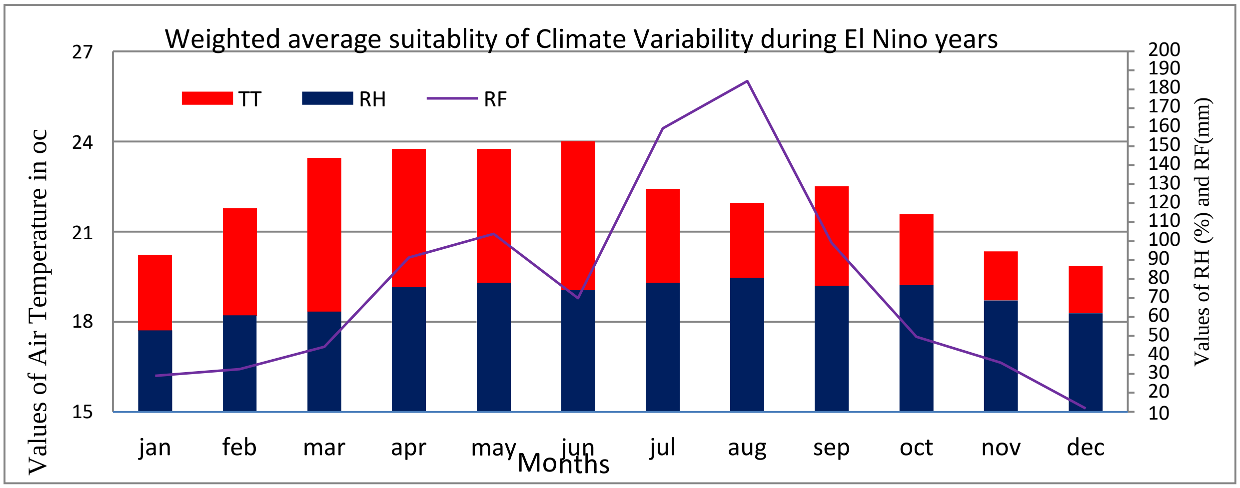


Figure 12: monthly suitability of Climate Variability during El Nino years in East showa zone.

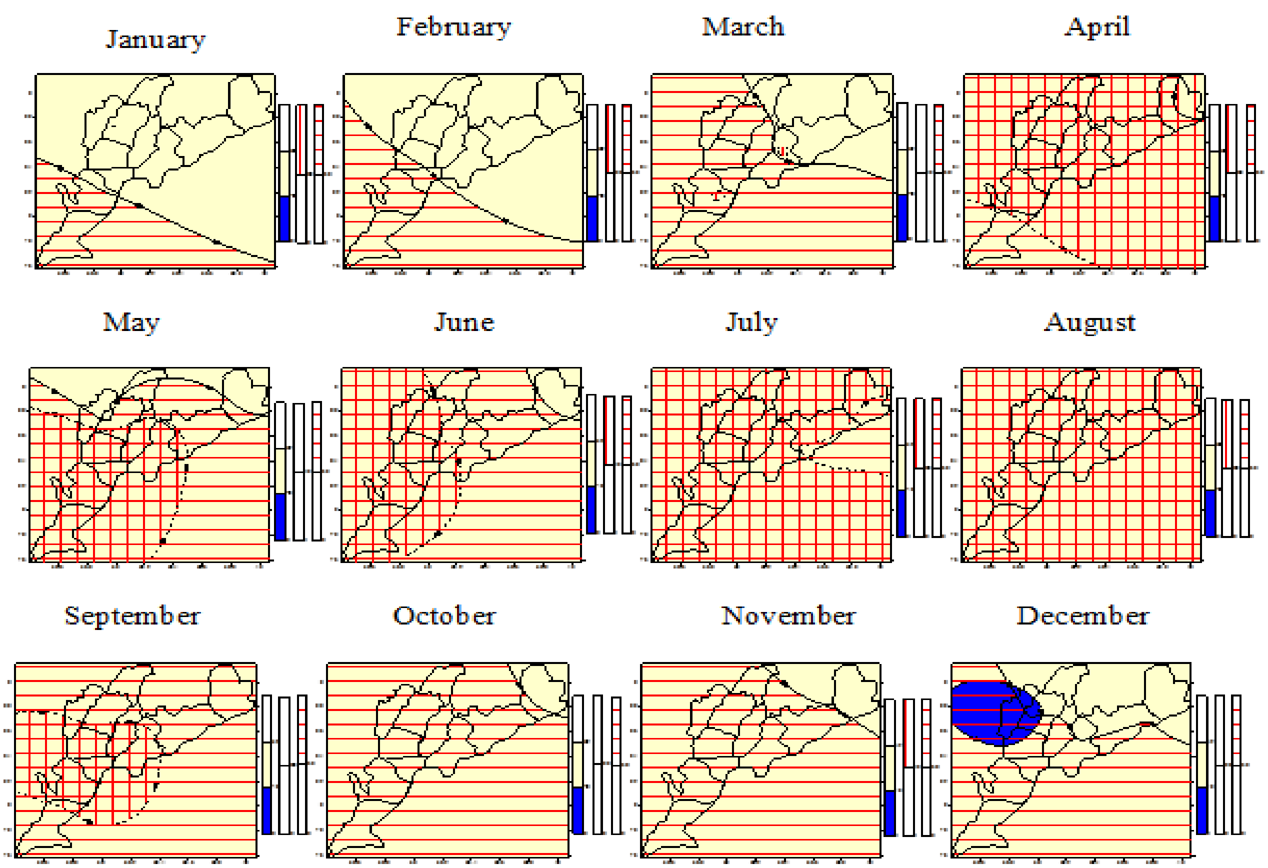


Figure 13: Combination of TT, RH and RF for each month during El Nino years

3.2. Climate suitability for malaria transmission during La Nina years

La Nina may expand the distribution of malaria to the mid land and lowlands through epidemics through the gradual expansion of the parasites territory in response to increase amount of rainfall above normal over these areas. While La Nina events will influence the climate variables that influence malaria transmission (i.e. Temperature, rainfall and relative humidity). Table 3 and figure 14 shows the number of months during the year that are suitable for malaria transmission during La Nina years. As figure 15 shows the monthly total rainfall of the study area is receiving more than 80mm from (June to September) which is suitable for the malaria transmission and receives less than 80mm in the months (January to May and October to December). In the study area, as figure (15) shows monthly mean air temperature is suitable for malaria transmission through the year and monthly mean relative humidity is also suitable except for the month of (January, February, March and December) in which the values of relative humidity is less than 60%, that is not suitable for malaria transmission. Over the study area during La Nina years according to IRI criteria, the mean monthly of relative humidity, temperature and rainfall were concurrently occurred during the month of (June to September) which is suitable for malaria transmission (figure 15) and the rest months are not fulfills the criteria of IRI for malaria spreading. Figure 14 clarifies the monthly pattern and intensifies of malaria transmission in different woredas during La Nina years within East Showa zone. As table 3 and figure 15 indicates 2 up to 7 months were suitable for malaria transmission in the study area. As table 3 and figure 14 shows that during La Nina years, from East Showa zone Dugda Bora woreda were more suitable for malaria transmission for 7 months (between March and September) and Fanatle woreda were not much suitable for malaria transmission than the other woredas found in the zone.

As figure 2 shows that Dugda Bora and Adama woredas were surrounded by lakes of Ziway and Koka respectively, which in turn create favorable climate condition for malaria transmission in these woredas during La Nina years (figure 14). As figure 10 shows La Nina Years have been associated with increasing the number of malaria case Kiremt season as compared with neutral years and associated with decreasing number of malaria case during Bega and Belg season. As figure 11 indicates annually Low numbers of malaria case were recorded during La Nina years. Ingeneral, annually La Nina years associated with decreasing number of malaria case over the study area.

Figure 16 shows that during La Nina years the combination of the three climate conditions (rainfall, temperature and relative humidity) were satisfied for malaria spreading over the whole parts of East Showa zone during the months of July and August, and except over Bosat and Fantale woreda during month of June and September the climate conditions were satisfied. During the month of January to May and October to December the combination of climate conditions (rainfall, temperature and relative humidity) were not satisfied for the malaria spreading over the whole parts of East Showa zone (figure 16). Generally, as figure 16 indicates the climate condition were satisfied over the most places of the study area in the months of June to September. Therefore, there was the favorable combination of climate conditions (rainfall, temperature and relative humidity) for the existence of malaria spread over most places of Dugda Bora, Adami Tulu Jido kombolcha, Lume, Ada'a, Adama woredas and Gimbichu during Kiremt season.

Table3. Number of months suitable for malaria transmission during La Nina years in East Showa Zone

Woreda Name	Number of months suitable for malaria transmission	Months suitable for malaria transmission
Adama	4months	Jun, July, August, September
Ada'a	4 months	Jun, July, August, September
Adami Tulu Jido Kombolcha	4 months	Jun, July, August, September
Boset	3 months	July, August, September
Dugda Bora	7 months	March, April, May, Jun, July, August, September
Fantale	2months	July, August
Lume	4 months	Jun, July, August, September

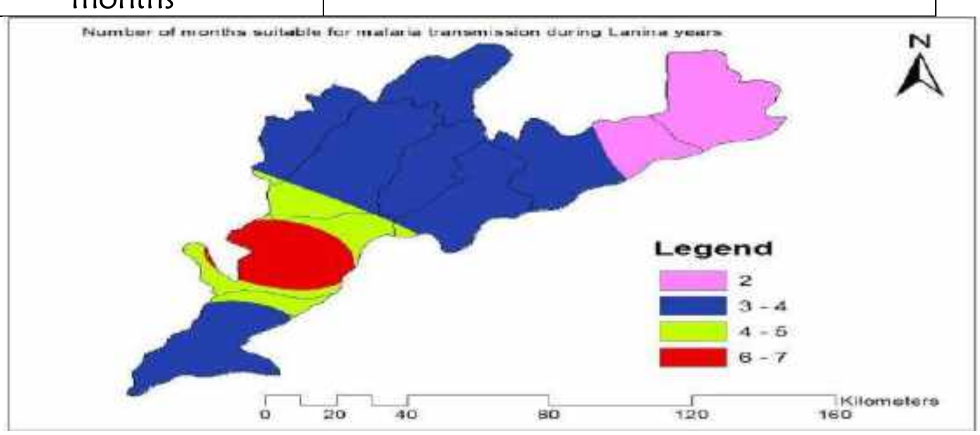


Figure 15: Number of months suitable for malaria transmission during La Nina years in East Showa

zone

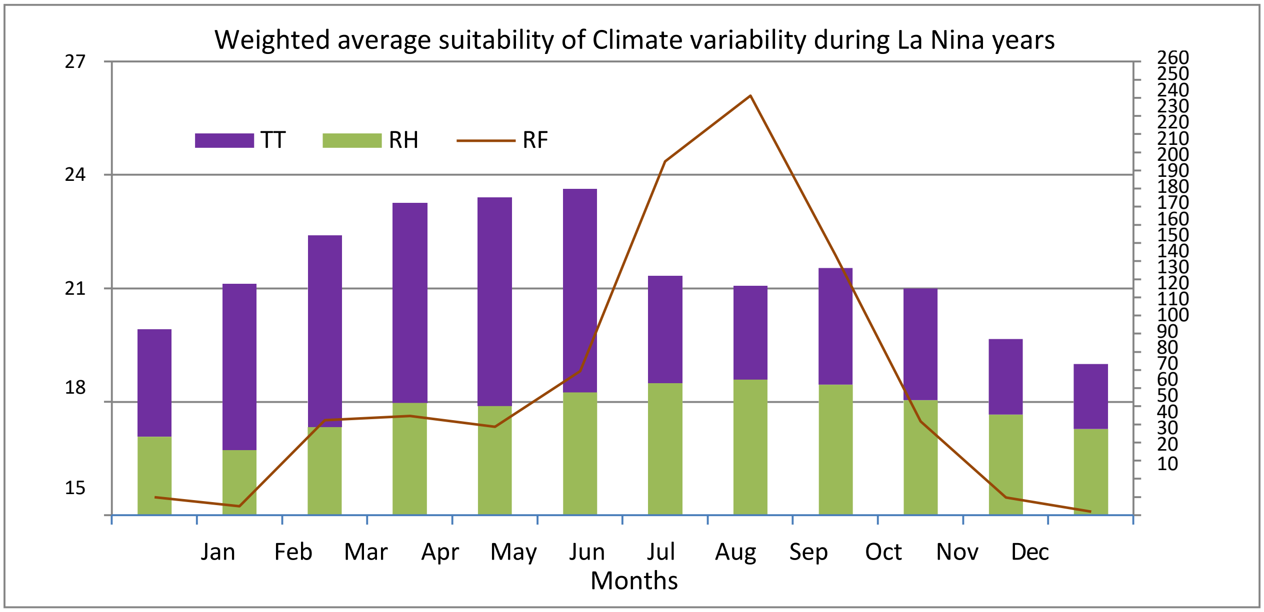


Figure 16: Monthly suitability of Climate Variability during La Nina years in East Showa zone.

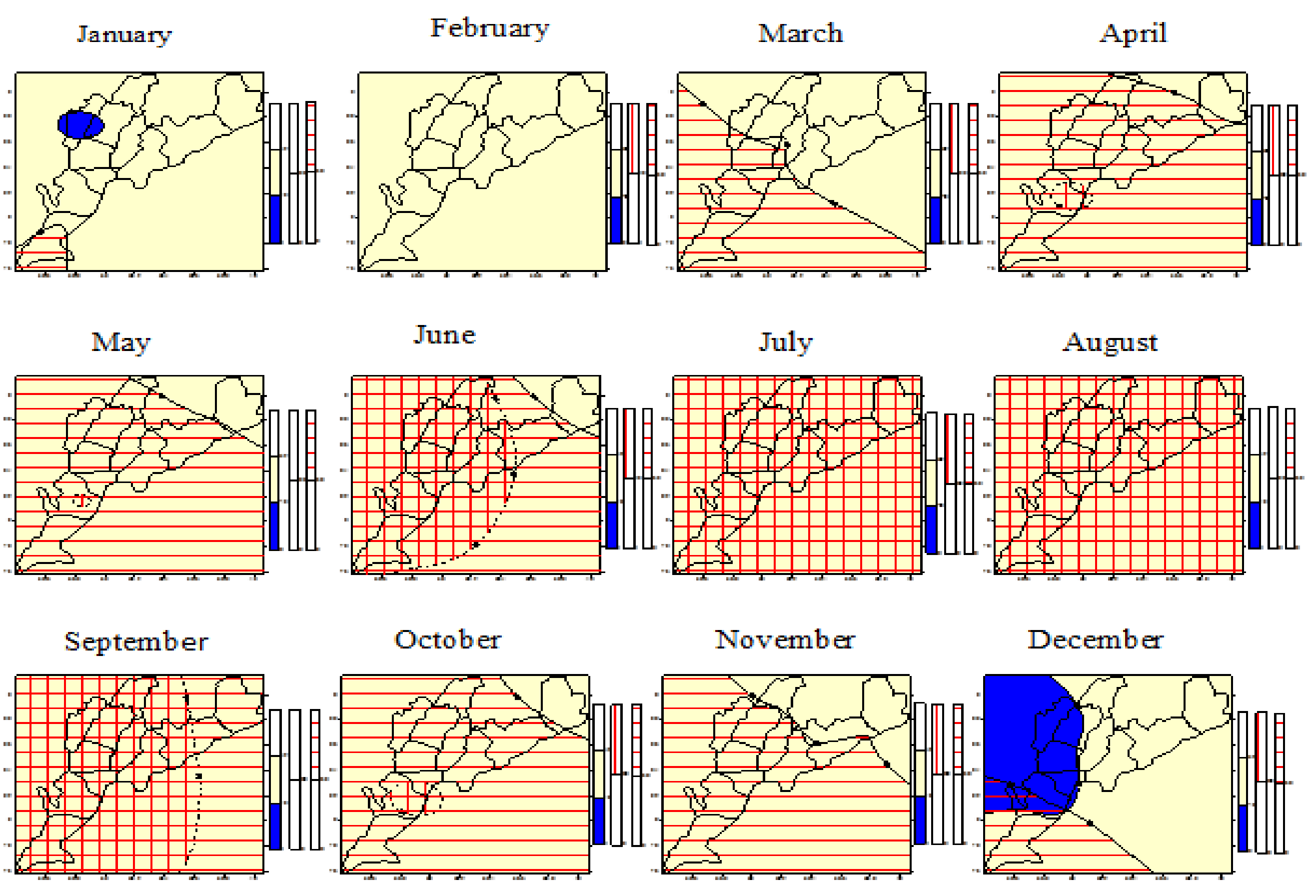


Figure 17: Combination of TT, RH and RF for each month during La Nina years

3.3. Climate suitability for malaria transmission during neutral years

As Table 4 and figure 18 shows the number of months during the year that are suitable for malaria transmission during Neutral years. As figure 19 shows the monthly total rainfall of the study area is receiving more than 80mm from (June to September) which is suitable for the malaria transmission and receives less than 80mm in the months (January to May and October to December). In the study area, as figure (19) shows monthly mean air temperature is suitable for malaria transmission through the year and monthly mean relative humidity is also suitable except for the month of (January and February) in which the values of relative humidity is less than 60%, that is not suitable for malaria transmission. Over the study area during Neutral years according to IRI criteria, the mean monthly of relative humidity, temperature and rainfall were concurrently

occurred during the month of (June to September) which is suitable for malaria transmission (figure 19) and the rest months are not fulfilling the criteria of IRI for malaria spreading. Figure 18 clarifies the monthly pattern and intensifies of malaria transmission in different woredas during Neutral years within East Showa zone. As table 4 and figure 18 indicates 2 up to 8months were suitable for malaria transmission in the study area. As table 4 and figure 16 shows that during Neutral years from East Showa zone Adama and Adami Tulu Jido Kombolcha woredas were more suitable for malaria transmission for 6months (between April and September) and Dugda Bora woreda were more suitable for malaria transmission for 8months (between March and October). Fanatle woreda were not much suitable for malaria transmission than the other woredas found in the zone, only suitable for 2months (July and August). As figure 2 shows that, Dugda Bora, Adama and Adami Tulu Jido Kombolcha woredas were surrounded by lakes of Ziway and Koka, which in turn create favorable climate condition for malaria transmission in these woredas during Neutral years (figure 18). As figure 10 shows Neutral Years have been associated with increasing the number of malaria case during Belg season and associated with decreasing number of malaria case during Kiremt season. As figure 10 indicates, annually high numbers of malaria case were recorded during Neutral years following El Nino years. Figure 20 shows that during Neutral years the combination of the three climate conditions (rainfall, temperature and relative humidity) were satisfied for malaria spreading over the whole parts of East Showa zone during the months of July and August, and except over Bosat and Fantale woreda during month of June and September the climate conditions were satisfied. During the month of May and June the climate condition were satisfied over Adami Tulu Jido Kombolcha, Dugda bora and Adama woredas and during the month of March were satisfied only over Dugda Bora woreda.

During the month of January to February and October to December the combination of climate conditions (rainfall, temperature and relative humidity) were not satisfied for the malaria spreading over the whole parts of East Showa zone (figure 20). Generally, as figure 20 indicates the climate condition were satisfied over the most places of the study area in the months of June to September. Therefore, there was the favorable combination of climate conditions for the existence of malaria spread over most places of Dugda Bora, Adami Tulu Jido kombolcha, Lume, Ada'a, Adama woredas and Gimbichu during Kiremt and Belg season.

Table4. Number of months suitable for malaria transmission during Neutral years in East Showa Zone

Woreda Name	Number of months suitable for malaria transmission	Months suitable for malaria transmission
Adama	6months	April, May, Jun, July, August, September
Ada'a	3 months	July, August, September
Adami Tulu Jido Kombolcha	6 months	April, May, Jun, July, August, September
Boset	3 months	July, August, September
Dugda Bora	8 months	March, April, May, Jun, July, August, September. October
Fantale	2 months	July, August
Lume	4 months	Jun, July, August, September

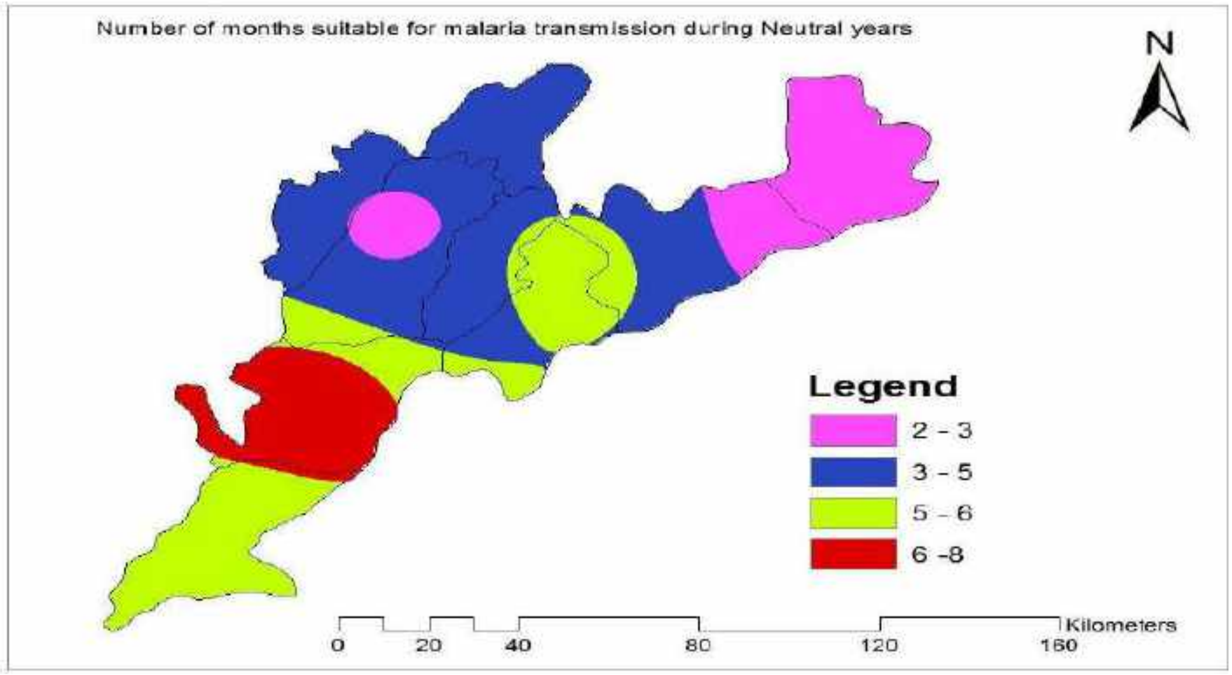


Figure 18 Number of months suitable for malaria transmission during Neutral years in East Showa zone

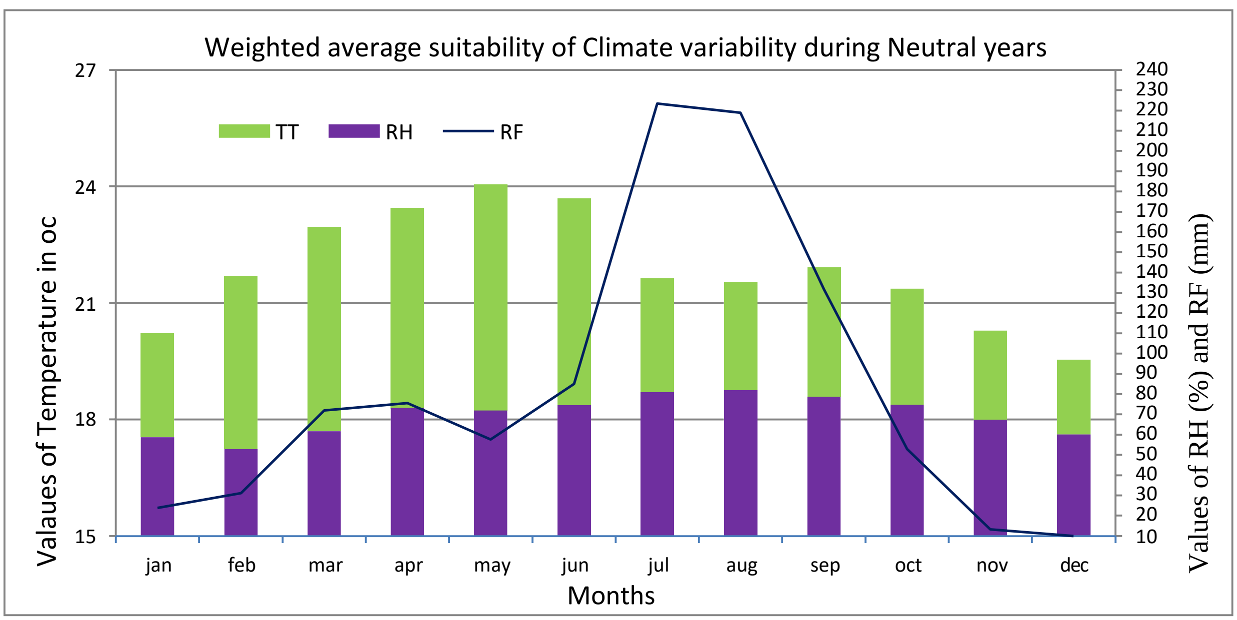


Figure 19 Monthly suitability of Climate Variability during Neutral years in East showa zone.

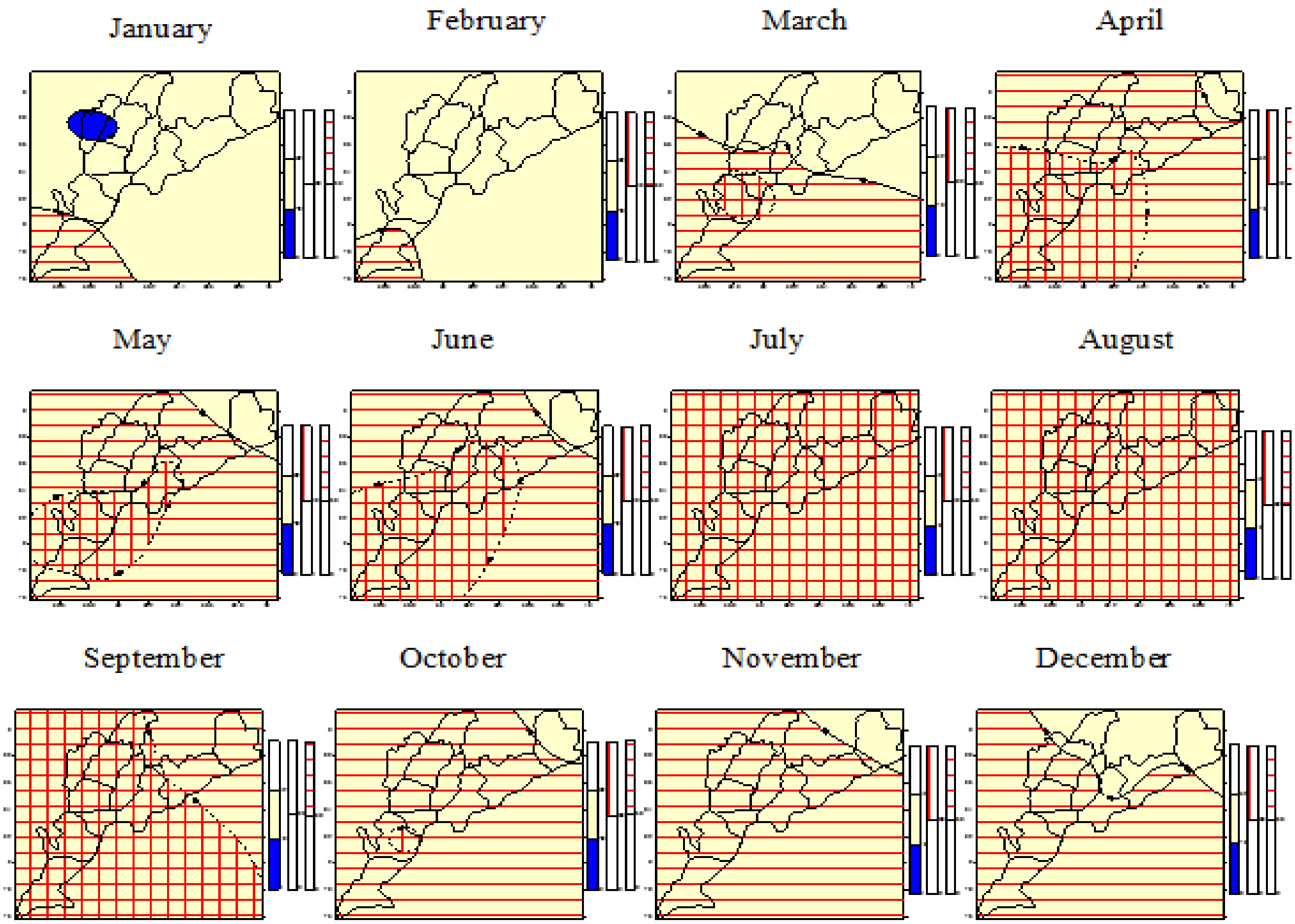


Figure 20. Combination of TT, RH and RF for each month during Neutral years

3.3. Correlation analysis

3.3.1. Correlation between climate variability and ONI with Malaria cases.

The generated map (figure 21 -25), shows spatial correlation at zero and one seasonal lag between climate variability (ONI at Nino 3.4 region, rainfall, temperature and relative humidity) and Malaria cases in East Showa zone. As figure 21(a, b, c and d) shows during Kiremt season (zero seasonal lag), the spatial correlation between ONI and Malaria case indicates positive correlation over Ada'a, Lume, Fantale, Adama and Bosat district, while negative correlation over Adami Tulu Jido Kombolcha and Dugda Bora district. The spatial correlation between rainfall and malaria case indicates positive correlation over Adami Tulu Jido Kombolcha, Dugda Bora, Ada'a, Lume and some parts of Bosat and Fantale districts, while negative correlation over some places of Adama and Bosat district. The spatial correlation between Temperature and Malaria case indicates positive correlations over Adama, Fantale and Bosat districts, while negative correlations over Ada'a, Lume, Adami Tulu Jido Kombolcha and Dugda Bora districs. The spatial correlation between Relative Humidity and Malaria case indicates positive correlations over Adami Tulu Jido Kombolcha and Dugda Bora districs, while negative correlations over Ada'a, Lume, Adama, Bosat and Fantale districs.

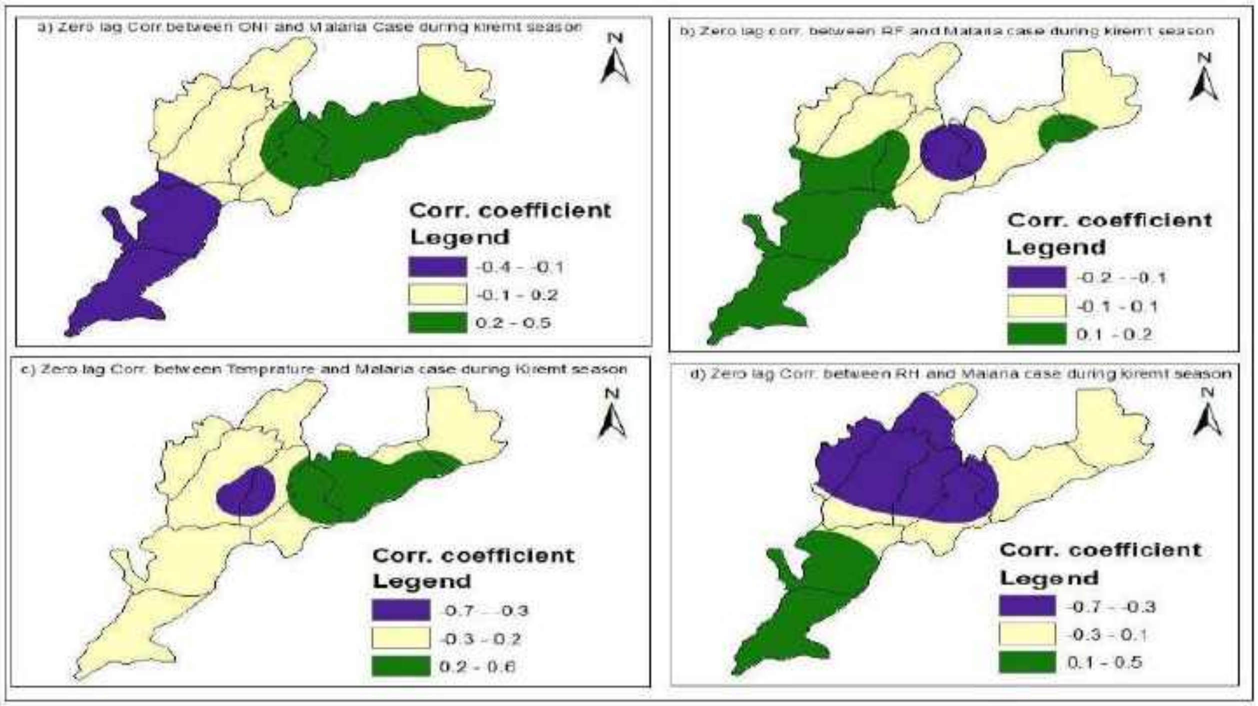


Figure 21. Zero lag season correlation of ONI, Rainfall, Temperature and Relative humidity with malaria cases during Kiremt season.

As figure 22(a, b, c and) shows that at one lag season the spatial correlation between climate variability (ONI, Rainfall, Temperature and Relative Humidity) durin Kiremt season and Malaria case during Bega season. The spatial correlation between ONI and Malaria case indicates positive correlations over Ada'a, Lume, Fantale, Bosat and Adama districts, while negative correlations over Adami Tulu Jido Kombolcha and Dugda Bora districts. The spatial correlation between Rainfall and Malaria case indicates positive correlations over Adami Tulu Jido Kombolcha, Dugda Bora, Ada'a, Lume and Fantale districts, while negative correlations over Adama and Bosat district. The spatial correlation between Temperature and Malaria case indicates positive correlations over Bosat, Fantale and some parts of Ada'a and Adama districts, while negative correlations over Adami Tulu Jido Kombolcha, Dugda Bora, Lume and some parts of Adama and Ada'a district. The spatial correlation between Relative Humidity and Malaria case indicates positive correlations over Adami Tulu Jido Kombolcha, Bosat and Fantale districts, while negative correlations over Dugda Bora, Lume, Adama and Ada’a district.

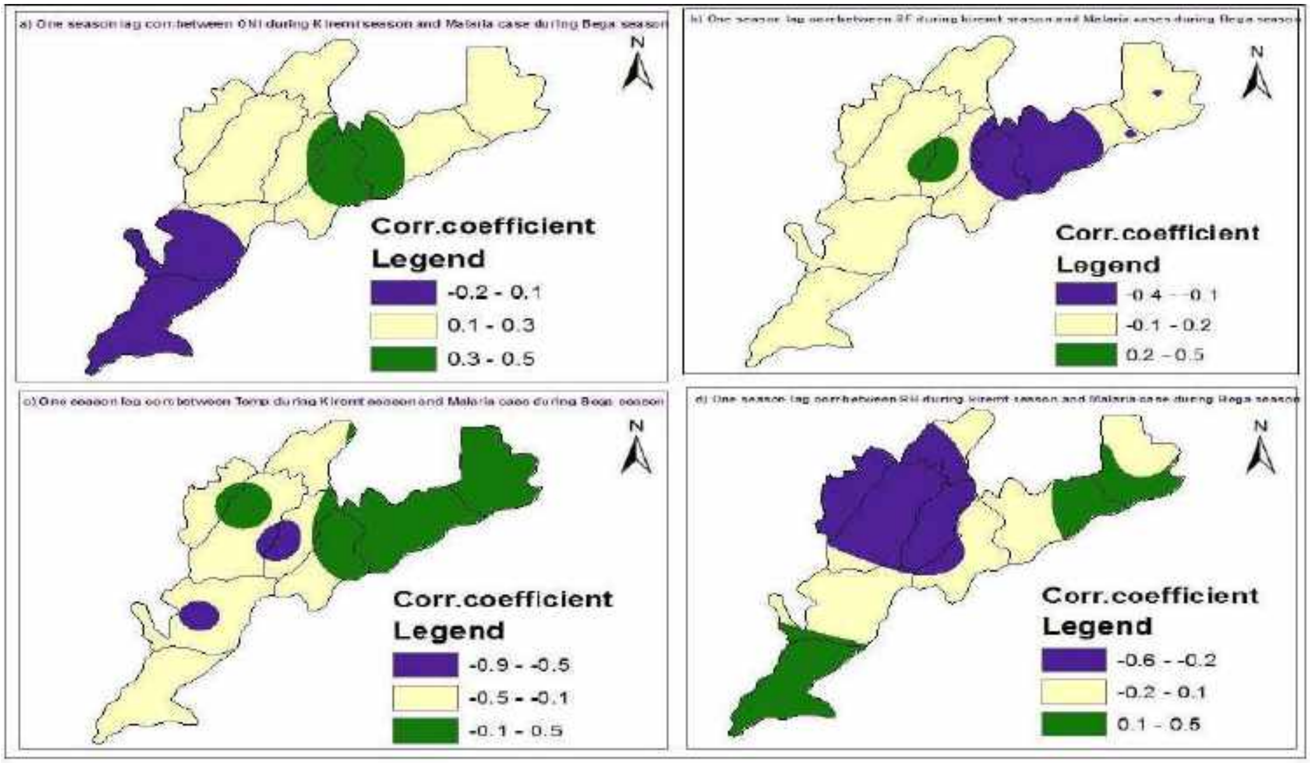


Figure 22. One season lag correlation of ONI, Rainfall, Temperature and Relative humidity during Kiremt season with malaria cases during Bega season.

Figure 23 (a, b, c and d) shows that during Belg season (zero seasonal lag) the spatial correlation between ONI and Malaria case indicates positive correlations over Adama, Bosat and Fantale districts, while negative correlations over Adami Tulu Jido Kombolcha and some parts of Ada’a and Lume districts. The spatial correlation between Rainfall and Malaria case indicates negative correlation over whole parts of East Showa zone except over Fantale district which indicates positive correlation. The spatial correlation between Temperature and Malaria case indicates positive correlations over Lume, Adama, Bosat and Fantale districts, while negative correlations over Adami Tulu Jido Kombolcha, Dugda Bora and Ada’a districts. The spatial correlation between Temperature and Malaria case indicates positive correlations over Lume, Adama, Bosat and Fantale districts, while negative correlations over Adami Tulu Jido Kombolcha, Dugda Bora and Ada’a districts. The spatial correlation between Relative Humidity and Malaria case indicates positive correlations over Adami Tulu Jido

Kombolcha, Bosat and Fantale districts, while negative correlations over Dugda Bora, Adama, Ada'a and Lume districts.

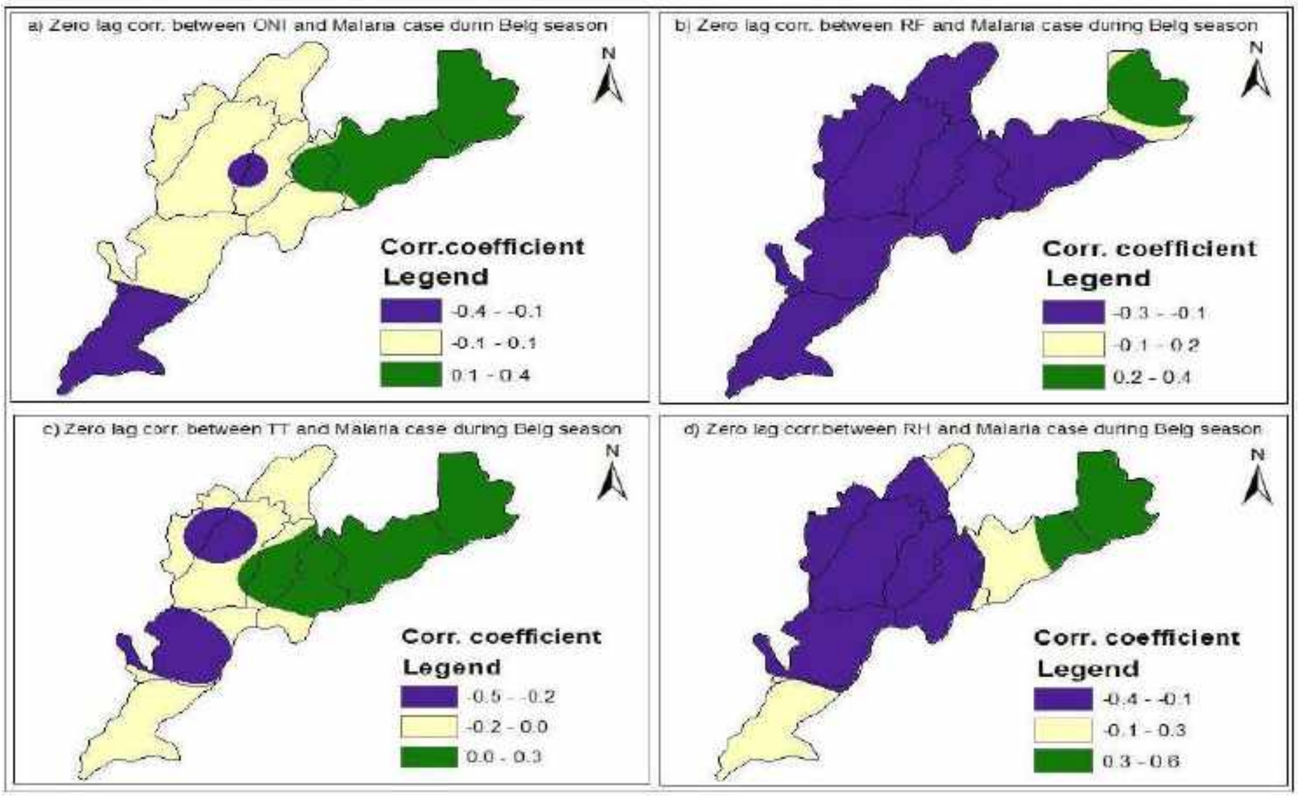


Figure 23. Zero season lag correlation of ONI, Rainfall, Temperature and Relative humidity with malaria cases during Belg season.

As figure 24 (a, b, c and) shows that at one lag season the spatial correlation between climate variability (ONI, Rainfall, Temperature and Relative Humidity) durin Belg season and Malaria case during Kiremt season. The spatial correlation between ONI and Malaria case indicates positive correlations over Adama, Lume, Fantale, Bosat, Adama and most parts of Ada'a districts, while negative correlations over Adami Tulu Jido Kombolcha, Dugda Bora and few parts of Ada'a districts. The spatial correlation between Rainfall and Malaria case indicates positive correlations over Adami Tulu Jido Kombolcha, Adama, Bosat, Ada'a, Fantale and most parts of Dugda Bora districts, while negative correlations over Ada'a and some parts of Dugda Bora district. The spatial correlation between Temperature and Malaria case indicates positive correlations over Bosat, and some parts of Fantale and Adama districts, while negative correlations over Adami Tulu Jido Kombolcha, Dugda Bora, Ada'a, Lume and some parts of Adama and Fantale districts. The spatial correlation between Relative Humidity and Malaria case indicates positive correlations over Adami Tulu Jido Kombolcha, Dugda, Adama, Bosat, Fantale and Lume districts, while negative correlations over Ada'a district.

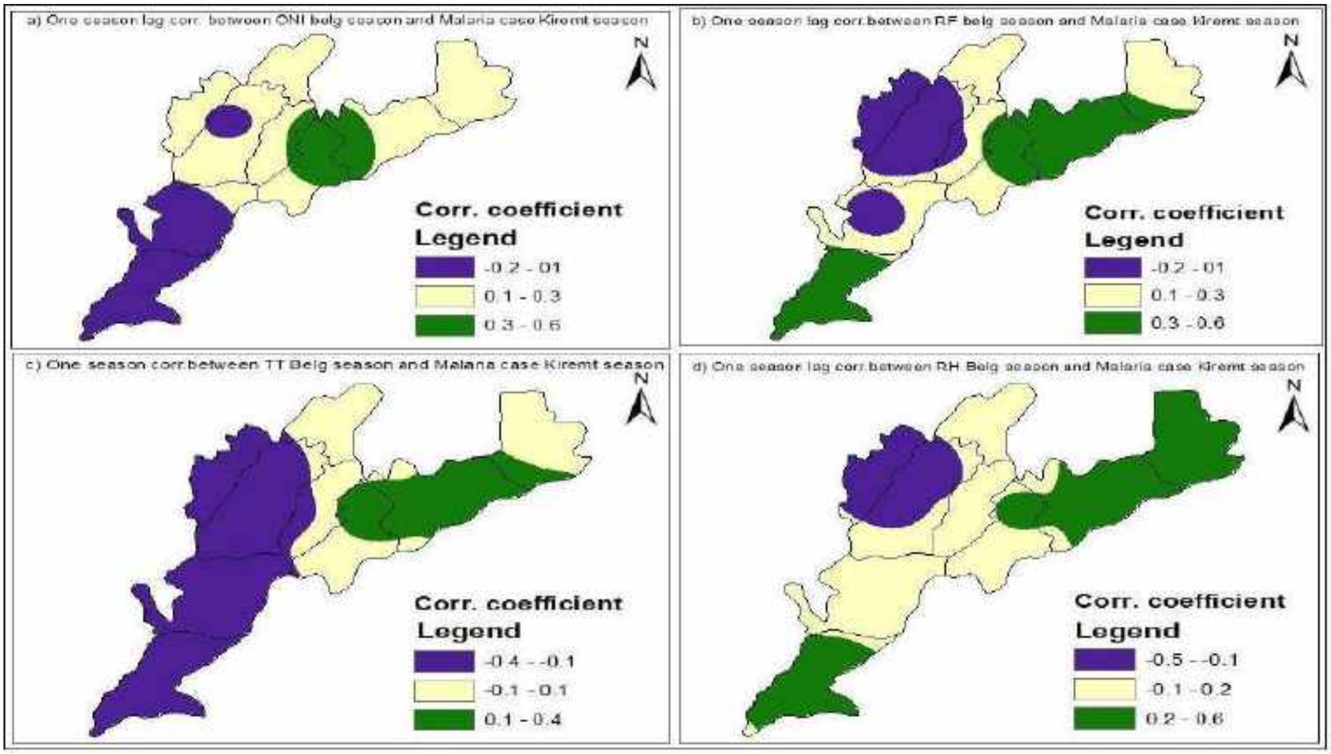


Figure 24. One season lag correlation of ONI, Rainfall, Temperature and Relative humidity during Belg season with malaria cases during Kiremt season.

As figure 25(a, b, c and) shows that during Bega season (zero seasonal lag) the spatial correlation between ONI and Malaria case indicates positive correlations over Adama, Bosat, lume, Fantale and some parts of Ada'a districts, while negative correlation over Adami Tulu Jido Kombolcha, Dugda Bora and few parts of Ada'a districts. The spatial correlation between Rainfall and Malaria case indicates positive correlations over whole parts of East Showa zone. The spatial correlation between Temperature and Malaria case indicates positive correlations over Adama, Bosat and Fantale districts, while negative correlations over Adami Tulu Jido Kombolcha, Dugda Bora, Lume and Ada'a districts. The spatial correlation between Relative Humidity and Malaria case indicates positive correlations over all parts of East Showa zone except over Ada'a district which indicates negative correlations.

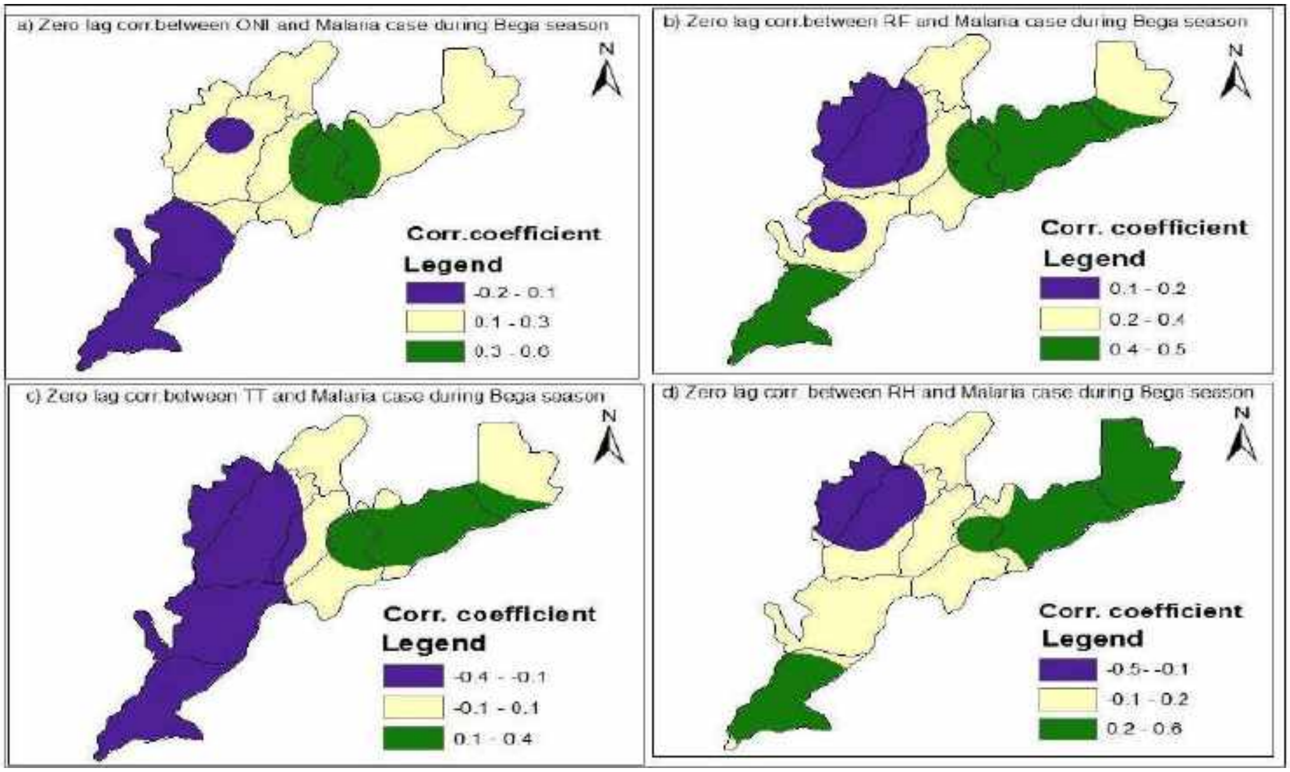


Figure 25 Zero season lag correlation of ONI, Rainfall, Temperature and Relative humidity with malaria cases during Bega season.

Table (5 -7) shows the seasonal correlation between malaria case and climate variability (ONI, rainfall, temperature and relative humidity). Correlation analysis between malaria occurrence and climatic variables, using records of malaria episodes over fifteen years' period (2004 – 2018) and

climatic variables (Humidity, Temperature and Rainfall) around Adami Tulu Jido Kombolcha, Boset, Lume, Fantale, Adama, Ada'a and Dugda Bora districts were done. On Adami Tulu, Jido Kombolcha and Dugda Bora the climatic variables did not show no significant correlation with malaria. The relations between malaria cases with humidity were significant on Bosat during Bega season. The rest two parameters did not have significant influence on malaria transmission in Bosat woreda. The temperature on Lume woreda had significant negative correlation during kiremt and after one season lag.

Table5. Correlation between climate variability and ONI with Malaria cases in East Showa Zone during Kiremt season

No	Stations	Seasonal Lags	Correlation of Malaria case with climate variable during Kiremt Season			
			Humidity	Temperature	Rainfall	ONI
1	Adimi Tulu Jido kombolcha	Zero	0.456	-0.119	0.102	-0.317
		One	0.476	-0.181	-0.059	-0.179
2	Bosat	Zero	0.012	0.225	0.102	**0.519***
		One	**0.522***	0.068	-0.059	0.181
3	Lume	Zero	-0.255	**-0.676****	0.197	0.150
		One	-0.406	**-0.877****	0.458	0.142
4	Fantale	Zero	0.071	0.145	0.045	0.088
		One	0.129	0.083	-0.062	0.184
5	Adama	Zero	-0.428	**0.556***	-0.204	0.351
		One	-0.156	0.375	-0.386	**0.527***
6	Ada'a	Zero	**-0.662****	-0.105	0.028	-0.117
		One	**-0.604***	0.171	-0.102	0.029
7	Dugda Bora	Zero	0.334	-0.019	0.165	-0.395
		One	0.031	-0.522	0.040	0.004
8	East Shoa	Zero	0.107	0.328	-0.148	0.046
		One	0.240	-0.055	-0.132	0.126

Humidity on Fantale District had significant correlation during belg and after one season lag. The temperature on Adama woreda during kiremt had significant correlation with Malaria but the rest parameter has no significant impact. Humidity on Ada'a woreda has significant correlation during kiremt and Bega seasons. ONI had significant correlation with malaria case on Bosat distirict during kiremt season but on Adama distirict during bega season. Generally, humidity and temperature have large relation for malaria distribution on most of the selected districts. But rainfall has no significant relation with malaria distribution relatively on all of the study area. Humidity on Ada'a district and temperature on Lume district negatively correlated with malaria.

Table6. Correlation between climate variability and ONI with Malaria cases in East Showa zone during Belg season

No	Stations	Seasonal Lags	Correlation of Malaria case with climate variable during Belg Season			
			Humidity	Temperature	Rainfall	ONI
1	Adami Tulu Jido kombolcha	Zero	0.137	-0.106	-0.305	-0.345
		One	0.255	-0.102	-0.225	-0.240
		Two	0.175	-0.292	-0.343	-0.364
2	Bosat	Zero	0.438	0.348	-0.305	0.373
		One	0.084	0.078	-0.225	0.498
		Two	0.367	-0.342	-0.343	0.076
3	Lume	Zero	-0.114	0.318	-0.217	-0.204
		One	-0.389	0.069	-0.045	0.126
		Two	-0.330	-0.338	0.064	-0.097
4	Fantale	Zero	0.551*	0.132	0.383	0.368
		One	0.565*	0.214	0.261	0.438
		Two	0.512	-0.071	-0.043	0.022
5	Adama	Zero	-0.068	0.074	-0.168	0.173
		One	-0.400	0.405	-0.390	0.183
		Two	-0.263	0.086	-0.315	0.242
6	Ada'a	Zero	-0.442	-0.500	-0.169	-0.045
		One	-0.467	-0.303	-0.160	-0.031
		Two	-0.383	-0.057	-0.030	0.079
7	Dugda Bora	Zero	-0.258	-0.373	-0.070	0.089
		One	0.214	0.051	0.121	0.318
		Two	-0.317	-0.097	0.028	0.146
8	East Shoa	Zero	0.049	-0.115	0.023	0.121
		One	0.023	0.187	-0.021	0.335
		Two	-0.104	-0.311	0.075	0.053

Table7 Correlation between climate variability and ONI with Malaria cases in East Showa zone during Bega season

No	Stations	Seasonal Lags	Correlation of Malaria case with climate variable during Bega Season			
			Humidity	Temperature	Rainfall	ONI
1	Adami Tulu Jido kombolcha	Zero	0.434	-0.161	0.531	-0.201
2	Bosat	Zero	**0.594***	0.373	0.531	0.206
3	Lume	Zero	0.041	-0.184	0.155	0.168
4	Fantale	Zero	0.473	-0.037	0.267	0.186
5	Adama	Zero	0.321	0.284	0.460	**0.561***
6	Ada'a	Zero	**-0.517***	-0.279	0.109	0.001
7	Dugda Bora	Zero	-0.135	-0.432	0.218	0.041
8	East Shoa	Zero	0.205	-0.308	0.509	0.111

4. Conclusion

The study evaluated the impact of El Nino Southern Oscillation events on malaria transmission and the association between seasonal malaria cases and climate variability including ENSO events as measured by the Oceanic Nino Index at Nino 3.4 region. In this study, climate suitability for malaria transmission is defined as the concurrence of monthly total rainfall greater than 80mm, mean temperature between 18°C-32°C and relative humidity greater than 60%. Monthly Temperature, relative humidity and rainfall data were obtained from National Meteorological Agency (NMA) for the period 1987-2018. Monthly Oceanic Nino Index (ONI) values at Nino 3.4 regions for the same period were downloaded from the Climate Prediction Centre in National Oceanic and Atmospheric administration (NOAA). Monthly malaria case data were obtained from woredas found in the East Showa zone for 2004- 2018 period. The research findings show that seasonality of climate greatly influences the seasonality malaria transmission. From the study area the climatic conditions of Dugda Bora, Adama and Adami Tulu Jido Kombolcha woredas were more suitable for malaria transmission. Result indicates, the rainfalls in June to August were creating favorable climate suitability conditions for malaria spreading in the subsequent three months (September to November) and high percent occurrence of climate conditions suitable for malaria transmission were recorded from September and November. The high numbers of malaria cases were recorded following the main rainy season of the study area. This period is considered as the peak malaria transmission period in the study area after heavy rain in July, August and September. High numbers of malaria case were recorded from September to November and peak in October. Annually high numbers of malaria case were recorded during El Nino years followed by Neutral years. In contrast low numbers of malaria case were recorded during La Nina years. In general, annually El Nino years associated with increasing number of malaria case, in contrast La Nina years associated with decreasing number of malaria case. The climate variability (rainfall, temperature, relative humidity and Oceanic Nino Index at Nino 3.4 region) was weakly to moderately correlate with malaria cases both negatively and positively during all seasons at lags of zero and one season over the study area. From the ENSO events, El Nino has more contribution for malaria spreading in the study area. This information will also be useful for administrators in effectively implementing preventive and control measures for malaria outbreaks in the study area.

5. References

A. Ayanlade, N. (2013). intra-annual climate variability and malaria transmission in nigeria. Bulletin of Geography. Socio-economic Series, 13.

Addisu Workineh Kassa1, B. B. (2014). Their impact varies across the regions of the globe and can result in drought in some areas and flooding in others. Science Journal of Public Health, 4.

al, L. S. (2015). CORRELATION OF CLIMATE VARIABILITY AND MALARIA: A. Ethiop J
Health Sci., 10.

Analysis of impacts of climate variability. (n.d.). International Research Institute for Climate and Society, 20.

Ayanlade, a. (2013). intra-annual climate variability and malaria transmission in nigeria. Bulletin of Geography. Socio-economic Series, 13.

Ayele, F. (2017). Malaria Epidemics in Dembia, Northwest Ethiopia 1952 –. Ethiop. J. Health Dev, 7.

Ayele, F. (2017). Malaria Epidemics in Dembia, Northwest Ethiopia 1952 –. Ethiop. J. Health Dev., 7.

Chisato Imai1, 2. (2016). Associations between malaria and local and. Tropical Medicine, 9.

Élodie Anne Vajda 1, *. a. (2017). Assessing the Risk Factors Associated with Malaria in tropical Medicine and infectious disease, 13.

Gbenga J. Abiodun1, 2. *. (2010). Exploring the Impact of Climate Variability on Malaria Transmission Using a Dynamic Mosquito-Human Malaria Model.

Geneve. (1990). Potential health effects of climate change.

Kovats, R. (2000,2003). El Nino and human health. World Health ˜.

Lindsay SW, B. M. (1996). climate change and malaria transmission.

M. J. Bouma, A. S. (2016). El Nino-based malaria epidemic warning for Oromia, Ethiopia, ∼.

M. J. Bouma1, 2. A. (2016). El Nino-based malaria epidemic warning for Oromia, Ethiopia, ∼. Tropical Medicine and International Health, 8.

M. J. Bouma1, 2. A. (2016). El Nino-based malaria epidemic warning for Oromia, Ethiopia, ∼. Tropical Medicine and International Health, 8., B. (1997). Cycles of malaria associated with El. MH., B. (1996). climate change and malaria transmission.

Musawenkosi L.H. Mabaso a, b. I. (2006). El Nino Southern Oscillation (ENSO) and annual ˜.

Transactions of the Royal Society of Tropical Medicine and Hygiene, 5.

Musawenkosi L.H. Mabaso a, b. I. (2006). El Nino Southern Oscillation (ENSO) and annual ˜. Transactions of the Royal Society of Tropical Medicine and Hygiene, 5.

Sarkar, R. C. (2017). El Niño Southern Oscillation as an early. malaria journal, 7. Sarkar, R. C. (2017). El Niño Southern Oscillation as an early. Malaria journal, 7.

Varun Kumar, A. M. (2014). Forecasting Malaria Cases Using Climatic Factors in. Malaria Research and Treatment, 7.

NATIONAL METEOROLOGICAL AGENCY

METEOROLOGICAL RESEARCH AND STUDIES DIRECTORATE

Trend Analysis of Temperature and Precipitation on Selected Belg Rainfall Benefiting Areas of Ethiopia

Author: - Elias Fiseha
Co-Author: - AklileAssefa

MARCH, 2020
ADDIS ABABA, ETHIOPIA

Abbreviations and Acronyms

amsl	Above mean sea level
bmsl	Below mean sea level
ICTZ	Inter Tropical Convergence Zone
IPCC	Intergovernmental Panel on Climate Change
MK	Mann-Kendall
^0C	Degree Celsius
S	Statistics
SNNP	Southern Nation, Nationalities and People
H0	Null hypothesis
H1	Alternative hypothesis
α(alpha)	Significant level

Abstract

This study mainly focuses on exploring trend analysis of temperature and rainfall across Belg season crop growing and rain benefiting areas in Ethiopia. The study was used an average monthly gridded temperature and rainfall data from National Meteorological Agency of Ethiopia over the period from 1983-2014 for temperature and from 1981-2016 for rainfall. The general objective of this study was to analyze the temporal changes in temperature and rainfall using Mann-Kendall trend test in R-software package. The result of the trend analysis of mean temperature and rainfall indicates that there is an increasing and decreasing trend for all selected zones respectively. The MK trend tests for the average the maximum and minimum temperature trend over most of the study areas show that there is an increasing trend for all selected areas except in zone 8A where insignificant decreasing trend was observed.

Keywords: Belg, Climate change, Trends

1. Introduction

1.1. Background

There are three main seasons in Ethiopia. The main rainy season (June–September), also known as Kiremt, exists over all of Ethiopia except perhaps in southern and southeastern parts. The agricultural season corresponding with this rainfall is referred to as Meher. Both Meher and Kiremt are used interchangeably by the local community. The country is generally dry during the months of October–January, except for the central part, which receives some rainfall. This relatively dry period is locally referred to as Bega. The Belg is the shorter rainy season that extends from the month of mid of February to end of May. However, this season is also identified as the primary source of water in the southern and southeastern part of the nation (Seleshi et al., 2004). Single-season crops such as Wheat, Tef, Sorghum, and Barley are harvested during both Belg and Meher season. Most Long-cycle crops, which include maize, millet, and sorghum, are grown throughout the two seasons (Belg and Meher). Thus, the production of long cycle crops is a result of the combined effect of the two consecutive seasons. Having such a great implication of the Belg season, for the agricultural community by large, it is very useful assessing the temperature and rainfall trend across this particular season for on farm planning and water resource management as well.

Despite the importance of the Belg season for Ethiopian agriculture, particularly to the south and south eastern portion of the country, its erratic and less predictable nature (Godswill et al., 2007) of the season makes the season the most challenging for the agricultural community to manage. On the other hand, various study has shown that the Belg season rainfall has been drastically declining over most parts of Ethiopia (Zeleke et al., 2019; Asaminew et al., 2019; Dawed et al., 2019) and in some extent there has been seemingly a shift on spring rainfall (Zeleke et al 2019).

Due to the noticeable impact of the changing climate as a result of global warming, the rain was being significantly reduced and the temperature increased over time in many areas during the last decades (Birhan 2018). This study focuses on trend detection in Belg seasonal temperature and precipitation for the Belg beneficiary areas of Ethiopia, an area encompassing Zone-I (Northeast), Zone-III (Northwest), Zone-IVA (Central), Zone-IVB (central), Zone-V (East), Zone-VI (South-high lands), Zone-VII (South), Zone-VIIIA (South-South lowlands) and Zone-VIIIB (South-South lowlands) (Diriba Korecha and Asgeir Sorteberg 2013). The time period under consideration is 1981-2016 for precipitation and 1983-2014 for temperature.

1.2. Objective of the study

The General objective of this study was to analyze the rainfall and temperature trends over Ethiopia on Belg season.

1.2.1. Specific objective of the study

Specific research objectives were:

- To show the time series of rainfall and temperature during the Belg/short rainy/ season
- To investigate rainfall and temperature trends in Ethiopia during the Belg/ short rainy/ season

1. Data and Methodology

2.1. Description of the study area

2.1.1. Location

Ethiopia is situated in the Horn of Africa having a total area of approximately 1.14 million Km2 (944,000square miles) (MoFA 2013) with highly variable and complex topography. The country is located within 3-150 N and 33-480 E, bordered with Djibouti to the east, Somalia to the east and south, Kenya to the south, Sudan to the west and Eritrea to the north. Ethiopia has a high central plateau that varies from 1,290m to 3,000 m amsl, with the highest mountain reaching 4,620 m. The climate of the country is mainly controlled by the seasonal migration of the inter-tropical convergence zone ITCZ and associated atmospheric circulation's as well as by its Complex topography. The Belg growing areas of Ethiopia's are central parts of northern highlands, parts of central, southwestern and southern. The total contribution of Belg rainfall is ranging from 5-30% over north, northeastern and eastern highlands, whereas 30-60% over south and south western parts of the country from annual total crop production of the areas. Northern Shewa, East and West Hararge, Arsi, Bale, North and South Wollo, Borena, SNNP start their land preparation and sowing activities during December to February.

2.1.2. Population

The total population of Ethiopia is approximately 114,131,178 people according to World meter elaboration of the latest United Nations data on March 20, 2020.It is equivalent to 1.47% of the total world population. Its rank is 12 in the list of countries by population and 115 per Km^2 (298 people per mi^2) density. The total land area is 1,000,000 Km^2 (386,102 sq. miles) 21.3 % of the population are living in urban (24,463,423 people in 2020) from the total population and the median age is 19.5 years (https://www.worldometers.info/world-population/ethiopia-population/)

2.1.3. Climate

Climatologically, the country has three major seasons namely, Kiremet (June-September), Bega (October- January) and Belg (February-May) (Tsegay, 2001; Gissila et al. 2004; Segele and Lamb 2005; Diro et al. 2010). Since the country locates near the equator, maximum heat from the sun is received.

The length of days and nights are almost equal across the country. The average seasonal minimum and maximum temperatures for Kiremt are 10 and 390C, for Bega 10 and 310C and for Belg 13.3 and 320C respectively. The rainfall of the country is highly variable with latitude and as a result it decreases roughly from the southwest to the northeast. Kiremt is the main rainy season and accounts 50 to 90 % of the total annual precipitation and Belg is identified as the smallest rainy season for most parts of the country (Viste et al., 2012). In general, the climateof Ethiopia is mainly controlled by the seasonal migration of the Intertropical Convergence Zone (ITCZ) and associated atmospheric circulations as well as by the complex topography of the country. Landscapes with contrasting characteristics in terms of physiography and elevation, such as the highlands and the lowlands, experience a variety of climates from desert climate to that typical of equatorial mountains The highlands section of the country are characterized by cool temperate-type climate (Korecha and Sorteberg 2013) and where frost is commonly occurring as a result of thin air and fast radiation (Snyder and Melo-Abreu, 2005).

2.1.4. Topography

Ethiopia is a country rich in geographical diversity that consists of rugged mountains, flat-topped plateaus, deep gorges and river valleys. It is erosion, volcanic eruptions and tectonic movements over the ages that have contributed to the nation’s diverse topography. The highest altitude is at Ras-Dashen (4,620 m amsl) and the lowest altitude is at Kobar Sink (120 m bmsl). A large percentage of the country consists of high plateaus and mountain ranges, dissected by major rivers such as Blue Nile, Tekeze, Awash, Omo, and Wabi Shebelle etc… All in all, Ethiopia consists of 12 rivers basins (3 of them are dry) and 19 lakes. The Blue Nile, the chief headstream of the Nile, rises in Lake Tana in northwest Ethiopia. The Great Rift Valley extends across the Ethiopian plateau, which is divided into two by a series of north-south tending escarpments. The escarpments are very steep towards the rift valley on either side. In general, the western high lands have high rims in their western edges, but low lying plateaus and plains to the east and south.

2.1.5. Data Source

The monthly average rainfall and temperature gridded data used in this study were obtained from the National Meteorological Agency, of Ethiopia (NMA). The gridded data are used to compute the time series and trend of the Belg rain beneficiaries’zones which include Zone-I (North East), Zone-III (South

West), Zone-IVA & IVB (Central), Zone-V (East), Zone-VI (South Highland), Zone-VII (South), Zone-VIIIA & VIIIB (South-South East lowlands) of Ethiopia (Diriba Korecha and Asgeir Sorteberg 2013). The data used for this study was for the time period 1983 to 2014 for temperature and 1981 to 2016 for precipitation. The mean temperature data was taken for this study by calculated the four-month average temperature of the gridded data. The gridded data that were taken from the zones by classified in boxes for each zones as the following figure.

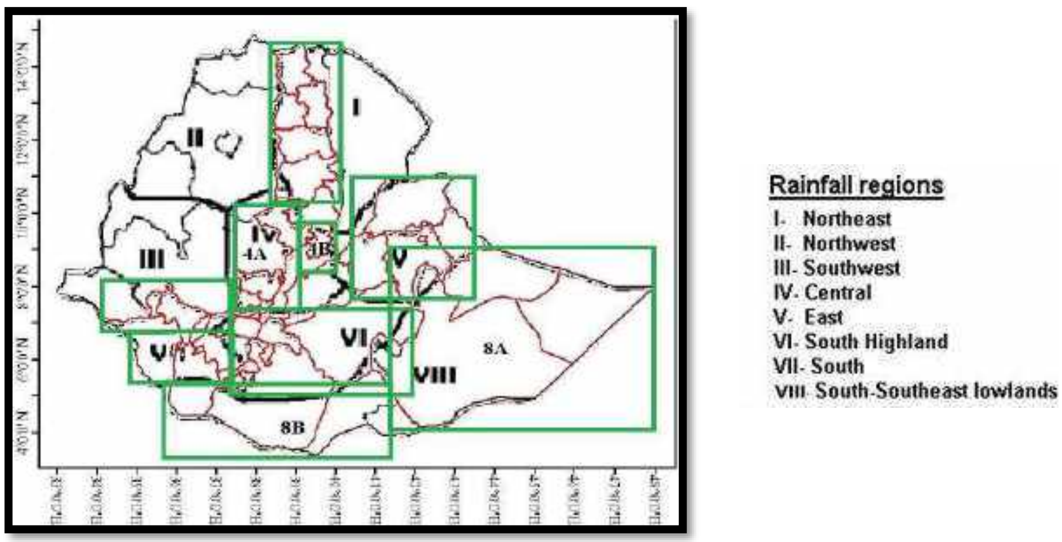


Figure 1: Homogenous rainfall region

2.1.6. Methodology

Mann Kendall test is a statistical trend test widely used for the analysis of trend in climatologic, environmental and in hydrologic time series data (Thorsten Pohlert 2015). There are two to be used this test. The first is a non-parametric test and does not require the data to be normally distributed and the Second test has low sensitivity to abrupt breaks due to inhomogeneous time series. Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set. According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a trend (Pohlert, T. 2016). By using Mann- Kendall test, we want to test the null hypothesis H_0 of no trend, i.e. the observations x_i is randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier is decremented by 1. The net result of all such increments and decrements yields the final value of S (Karmeshu 2012). The computational procedure for the Mann Kendall test considers the time series of n data points and T_i and T_j as two subsets of data where i = 1,2, 3, n-1 and j = i+1, i+2, i+3, …, n. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. The M-K test statistic S is evaluated by using the formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(Xj - Xk) \qquad \text{Equation 1}$$

$$sgn(x_j - x_k) = \begin{cases} +1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases} \text{...Equation 2}$$

Where x_j and x_k are the seasonal values in years' j and k, j > k, respectively. If n < 10, the value of |S| is contrast directly to the theoretical distribution of S derived by Mann and Kendall (Gilbert, 1987). The two tailed test is used. At certain probability level H_0 is rejected in favour of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S which has the probability less than α/2 to appear in case of no trend. A positive (negative) value of S shows an upward (downward) trend respectively. For n ≥ 10, the statistic S is approximately normally distributed with the mean and variance as follows t_p E(S)=0

$$\sigma^2 = \frac{1}{18}\{[n(n-1)(2n+5)] - \sum_{p=1}^{q}[t_p(t_p-1)(2t_p+5)]\} \text{..........................Equation 3}$$

Where q is the number of tied group t_p is the number of data values in the p^th group. The standard test statistic Z is computed as follows

$$z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & If\ S > 0 \\ 0 & If\ S = 0 \\ \frac{S-1}{\sqrt{VAR(S)}} & If\ S < 0 \end{cases} \qquad \text{......................Equation 4}$$

The presence of a statistically significant trend is evaluated using the Z value. A positive value of Z indicates an upward trend and a negative value of Z indicates a downward trend. To test for either an upward or downward monotone trend (a two tailed test) at α level of significance, H_0 is rejected if the $|Z| > Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables.

The Mann-Kendall statistic for the g^th season is calculated as:

$$\boldsymbol{Sg = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(Xjg - Xkg)\ ,\ g\ =\ 1, 2, 3, \ldots \ldots \ldots ;\ m}$$

According to Hirsch et al. (1982), the seasonal Mann-Kendall statistic, S, for the entire series is calculated by

$$\boldsymbol{S = \sum_{g=1}^{m} Sg}$$

In order to performed the Mann-Kendall test for trend in R, we could use the **Kendall package (Rx 64 3.3.2)** developed by A.I. McLeod McLeod, A.I. This package is installed in R-software. The Kendall package has a function named **Mann Kendall** which implements the non-parametric test for monotonic trend detection (upward or downward trend) known as the Mann-Kendall test (McLeod, A.I 2015). In addition, to compare and contrast the results obtained from the Mann- Kendall test, linear trend lines are plotted for each zones using Microsoft Excel 2007.

3. Results

3.1. Temprature analysis

3.1.1. Average maximum temperature

The following graphs are for the four months (Feb-May) average maximum temperature for each of seven Belg beneficiary zones (Zone-I, Zone-III, zone-IV (A&B), Zone-V, zone-VI, zone-VII and zone-VIII (A&B)) show the time series from 1983 to 2014 years.

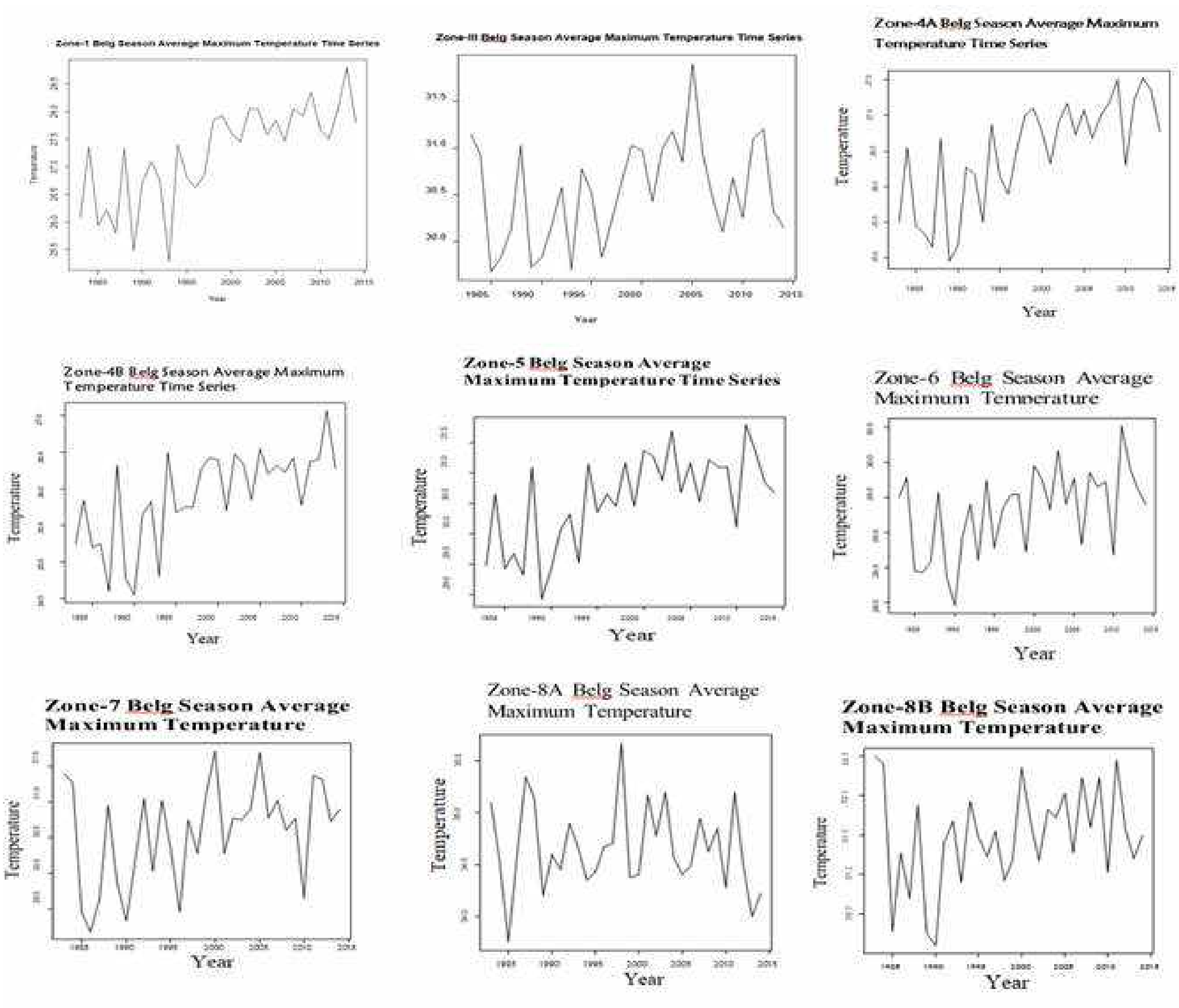


Figure 2: Belg season (4-month) average maximum temperature series

On running MK test in R-software package on average maximum temperature data, the following results in table 1 were obtained for the seven study area zones. When the p value is less than the significance level α (alpha) =0.05, H_0 is rejected. Rejecting H_0 shows that there is a trend in the time series, while accepting H_0 shows no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant. The following table indicates that the Null Hypothesis was accepted for zone-III, zone-VII and Zone- (VIIIA & VIIIB).

Table 1: Results of the Mann-Kendall test for average maximum temperature data of the Belg beneficiary areas of Ethiopia

Selected study areas			Mann Kendall Test			
	Mann-Kendall Statistic(S)	Kendall's Tau	Var (S)	p-value (two tailed test	alpha	Test Interpretation
Zone-I	290	0.589	3792	2.742E-06	0.05	Reject H_0
Zone-III	103	0.209	3797	9.786E-02	0.05	Accept H_0
Zone-IVA	281	0.569	3798	5.48E-06	0.05	Reject H_0
Zone-IVB	225	0.457	3796	0.000277	0.05	Reject H_0
Zone-V	222	0.451	3794	0.0003333	0.05	Reject H_0
Zone-VI	162	0.329	3796	0.0089715	0.05	Reject H_0
Zone-VII	110	0.224	3794	0.076792	0.05	Accept H_0
Zone-VIIIA	-32	-0.0648	3799	0.61498	0.05	Accept H_0
Zone-VIIIB	68	0.138	3799	0.277	0.05	Accept H_0

On plotting the linear trend line of maximum temperature for the Belg beneficiary zones of Ethiopia, the following results in the following figure were obtained.

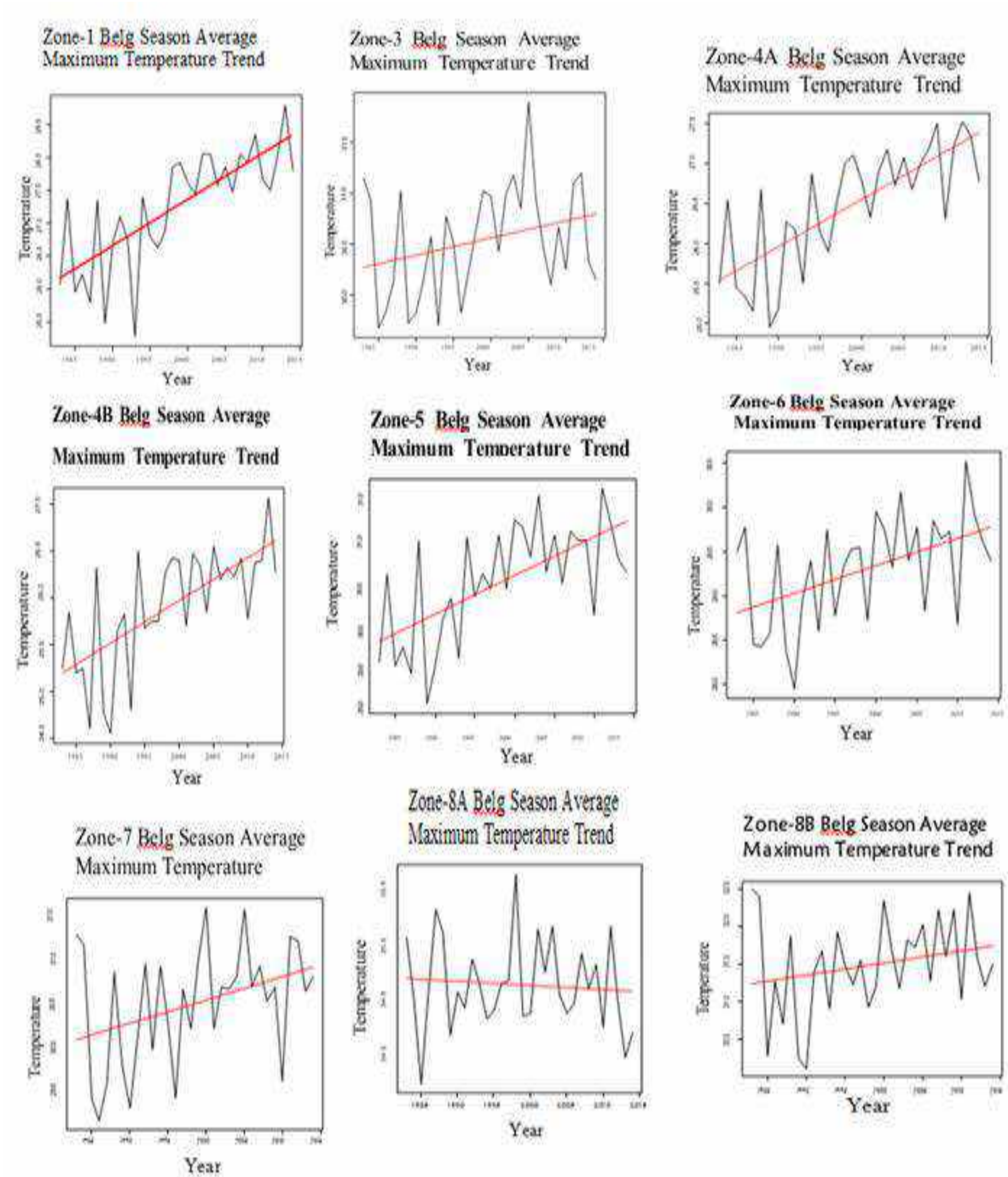


Figure 3: Belg season (4-month) average maximum temperature trend

3.1.2. Average minimum temperature

The following graphs for the four months (February-May) average minimum temperature for each Belg beneficiary area of seven zones (Zone-I, Zone-III, zone-IV (A&B), zone-V, zone-VI, zone- VII and zone-VIII (A&B)) show the time series from 1983 to 2014.

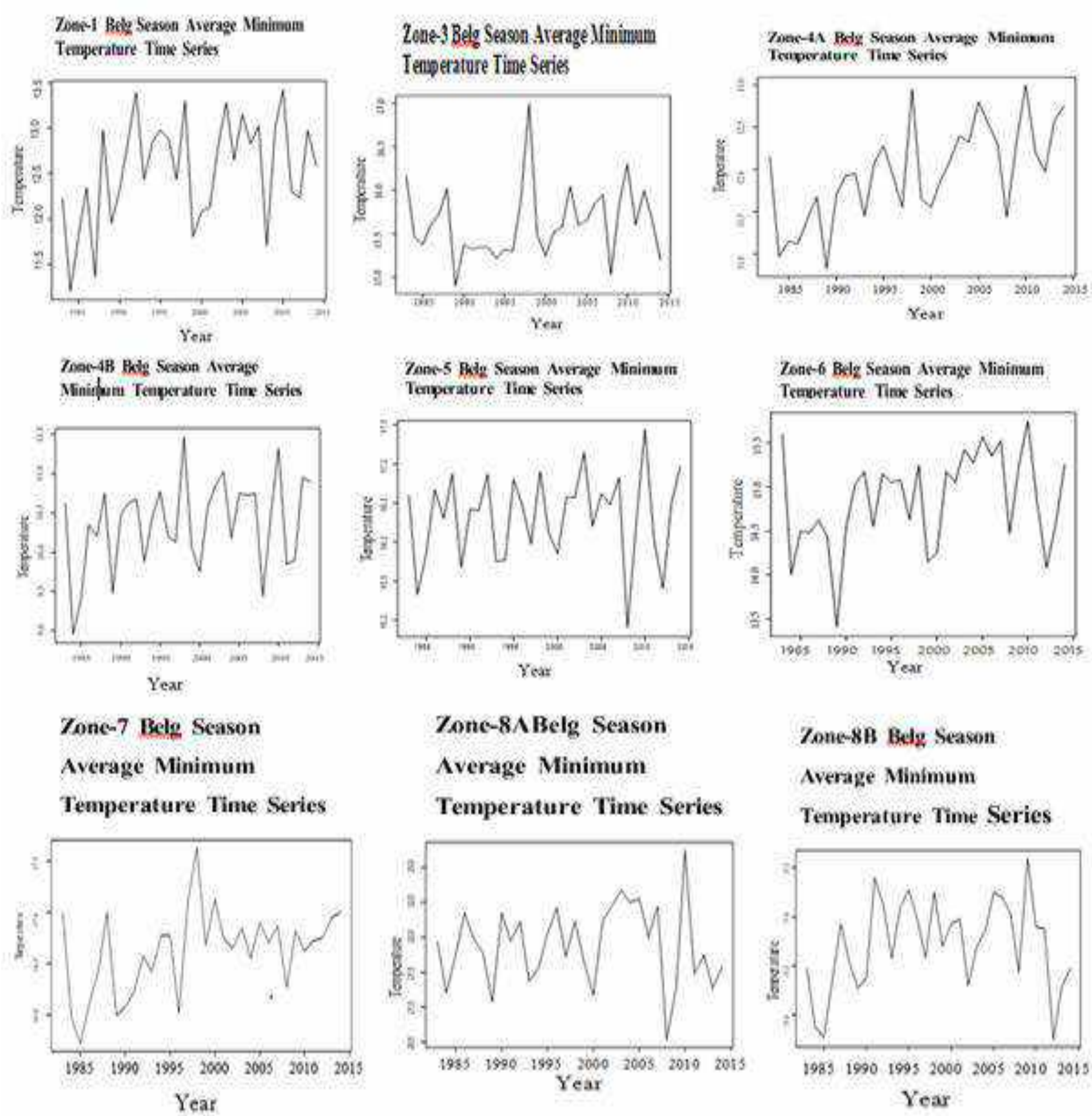


Figure 4: Belg season (4-month) average minimum temperature series

On running Mann-Kendall test on average minimum temperature data, the following results in table 2 were obtained for the seven zones. When the p value is less than the significance level α (alpha) =0.05, H_0 is Rejected. Rejecting H_0 indicates that there is a trend in the time series, while accepting H_0 indicates no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant. The following table indicates that the Null Hypothesis was accepted for 6 selected study areas from the total means that no trend was detected.

Table 2: Results of the Mann-Kendall test for average minimum temperature data of the Belg beneficiary areas of Ethiopia

Selected study areas	Mann Kendall Test					
	Mann-Kendall Statistic(S)	**Kendall's Tau**	**Var (S)**	**p-value (two tailed test**	**alpha**	**Test Interpretation**
Zone-I	114	0.231	3796	0.066644	0.05	Accept H_0
Zone-III	63	0.128	3795	0.31421	0.05	Accept H_0
Zone-IVA	243	0.491	3800	8.64E-05	0.05	Reject H_0
Zone-IVB	104	0.211	3796	0.094572	0.05	Accept H_0
Zone-V	59	0.119	3800	0.34674	0.05	Accept H_0
Zone-VI	131	0.267	3792	0.034772	0.05	Reject H_0
Zone-VII	153	0.311	3795	0.01361	0.05	Reject H_0
Zone-VIIIA	30	0.0609	3797	0.63789	0.05	Accept H_0
Zone-VIIIB	53	0.108	3796	0.39865	0.05	Accept H_0

On plotting the linear trend line of minimum temperature for the Belg beneficiary area of Ethiopia, the following results were obtained

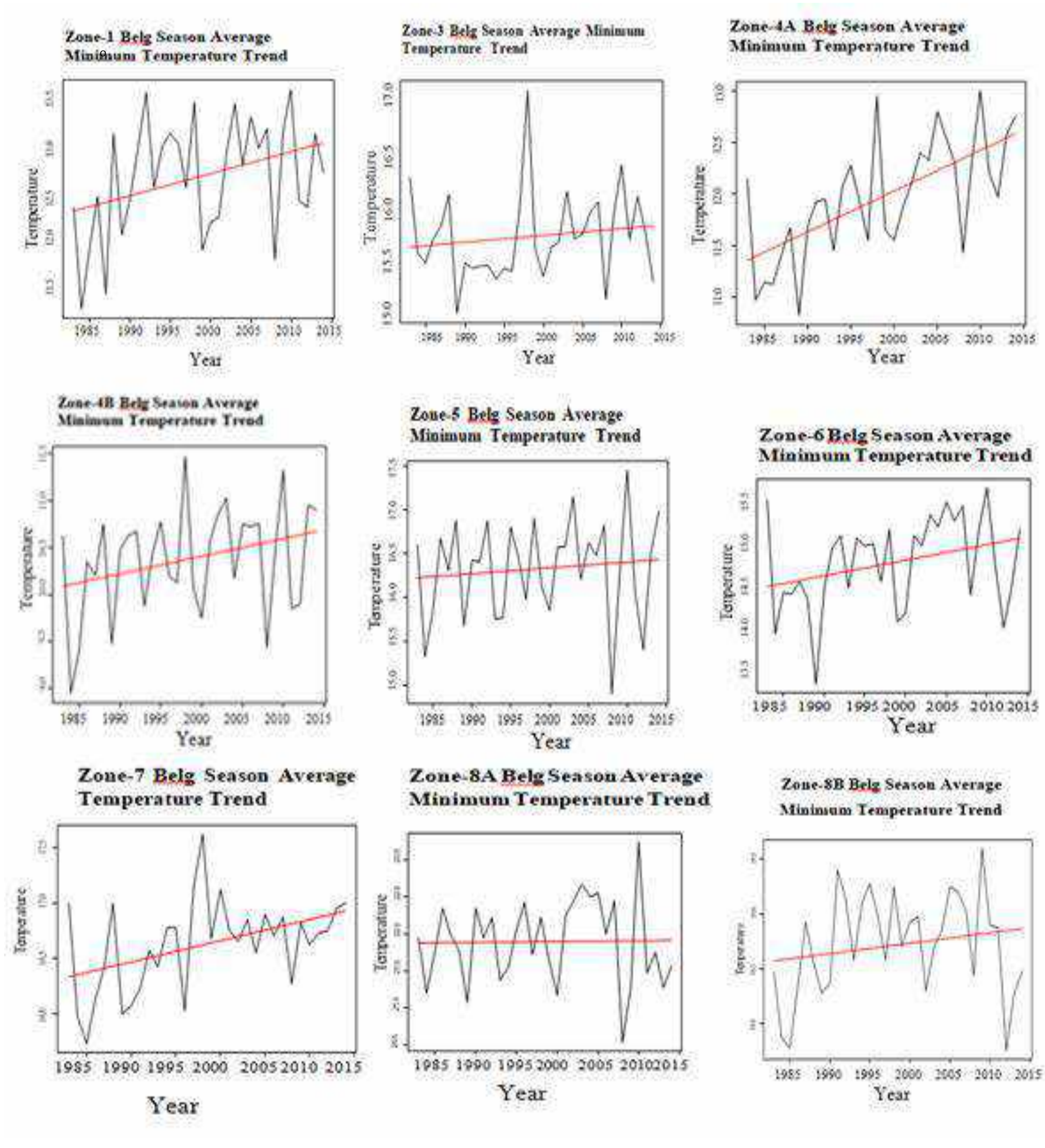


Figure 5: Belg season (4-month) average minimum temperature trend

3.1.3. Mean average temperature

The following graphs for the four months(February-May) Mean Average Temperature for each of 7 zones (Zone-I, Zone-III, zone-IVA & IVB, Zone-V, zone-VI, zone-VII, zone-VIIIA & VIIIB) show the time series from 1983 to 2014 years of gridded data of each zones.

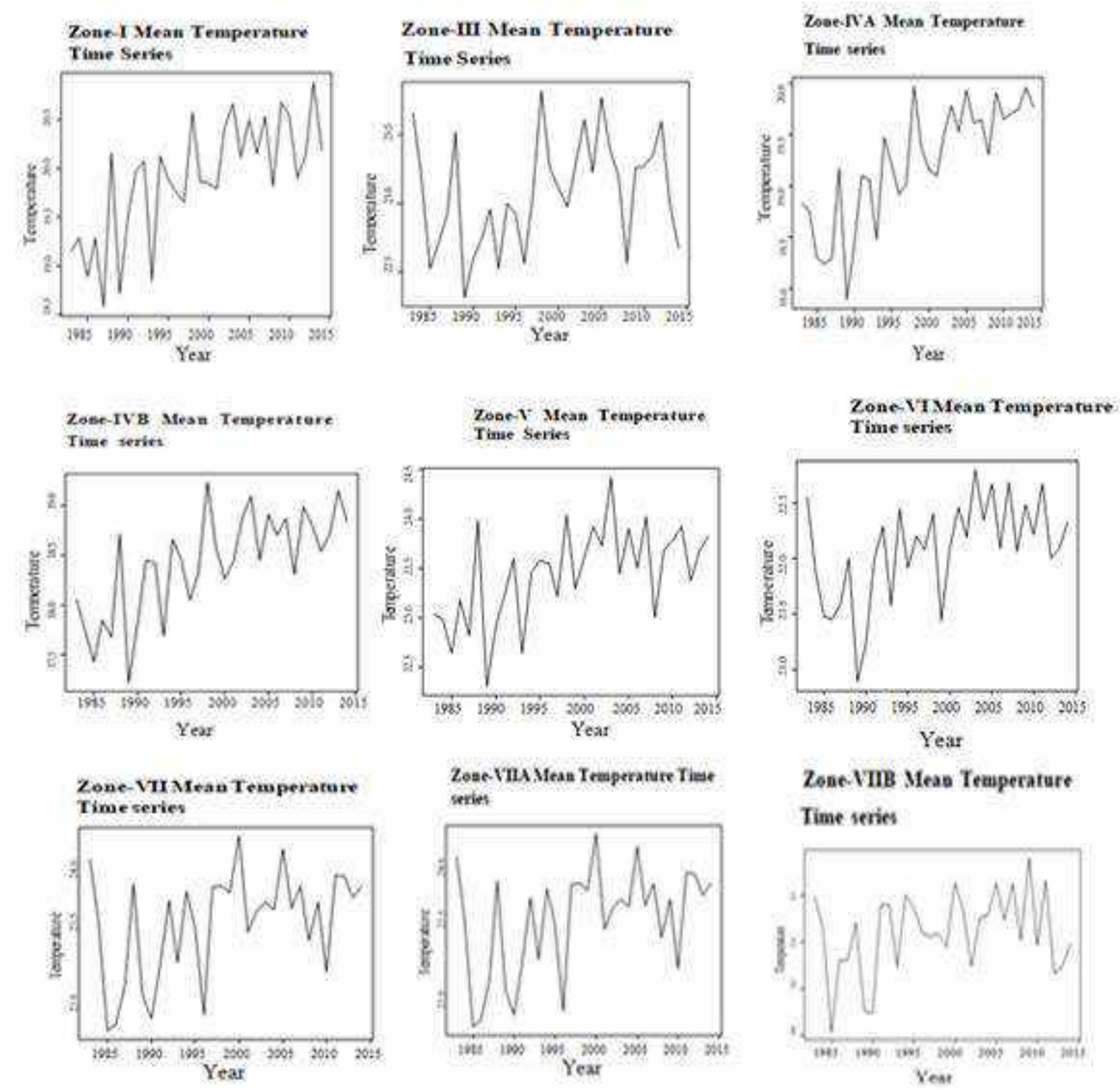


*Figure **6**: Belg season (4-month) average mean temperature time series*

On running Mann-Kendall test in R-package on Mean Average Temperature data, the following results in table 3 were obtained for the 9 selected study areas. When the p-value is less than the significance level α (alpha) =0.05, H_0 is Rejected. Rejecting H_0 indicates that there is a trend in the time series, while accepting H_0 indicates no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant. The Null Hypothesis was accepted for 2 selected study areas (no trend is detected) from the total of 9 as indicating the following table.

*Table **3**: Results of the Mann-Kendall test for average mean temperature data of the Belg beneficiary areas of Ethiopia.*

Selected study areas			Mann Kendall Test			
	Mann-Kendall Statistic(S)	Kendall's Tau	Var (S)	p-value (two tailed test	alpha	Test Interpretation
Zone-I	253	0.511	3802	4.36E-05	0.05	Reject H_0
Zone-III	123	0.249	3798	0.047736	0.05	Reject H_0
Zone-IVA	314	0.634	3801	3.83E-07	0.05	Reject H_0
Zone-IVB	243	0.492	3797	8.59E-05	0.05	Reject H_0
Zone-V	198	0.4	3801	0.0013959	0.05	Reject H_0
Zone-VI	169	0.342	3800	0.0064216	0.05	Reject H_0
Zone-VII	144	0.292	3798	0.02032	0.05	Reject H_0
Zone-VIIIA	-3	-0.00607	3800	0.97412	0.05	Accept H_0
Zone-VIIIB	53	0.107	3797	0.39873	0.05	Accept H_0

On plotting the linear trend line of mean average temperature for the Belg beneficiary area of Ethiopia, the following results in the following figure were obtained.

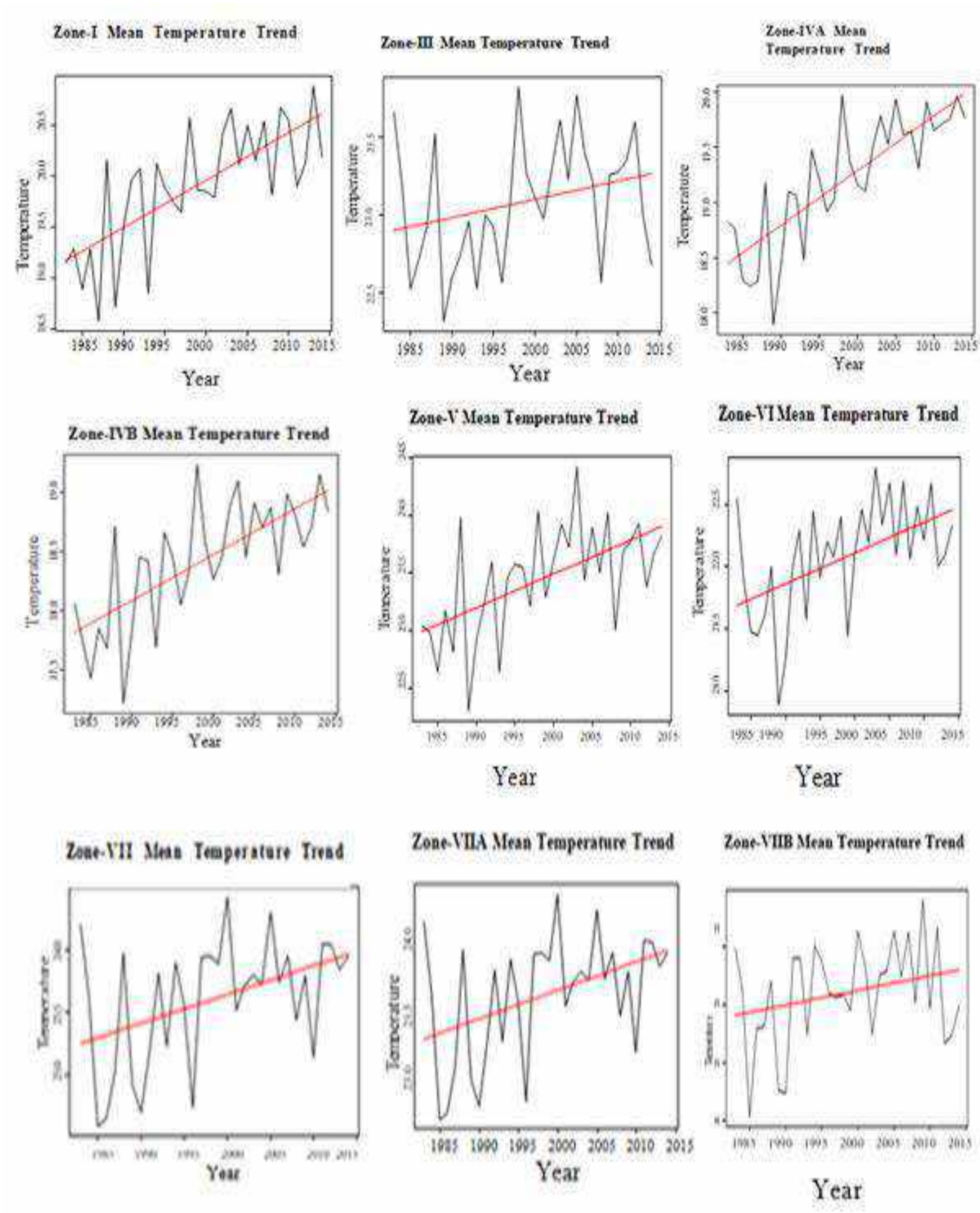


Figure 7: Belg season (4-month) average mean temperature trend

3.2. Rainfall

The following graphs show for the four months(February-May) total rainfall for each of 9 selected study areas (zone-I, Zone-III, zone-IVA, zone-IVB, zone-V, zone-VI, zone-VII, zone-VIIIA and Zone-VIIIB) time series from the time period 1981 to 2016 years of gridded data of each zones.

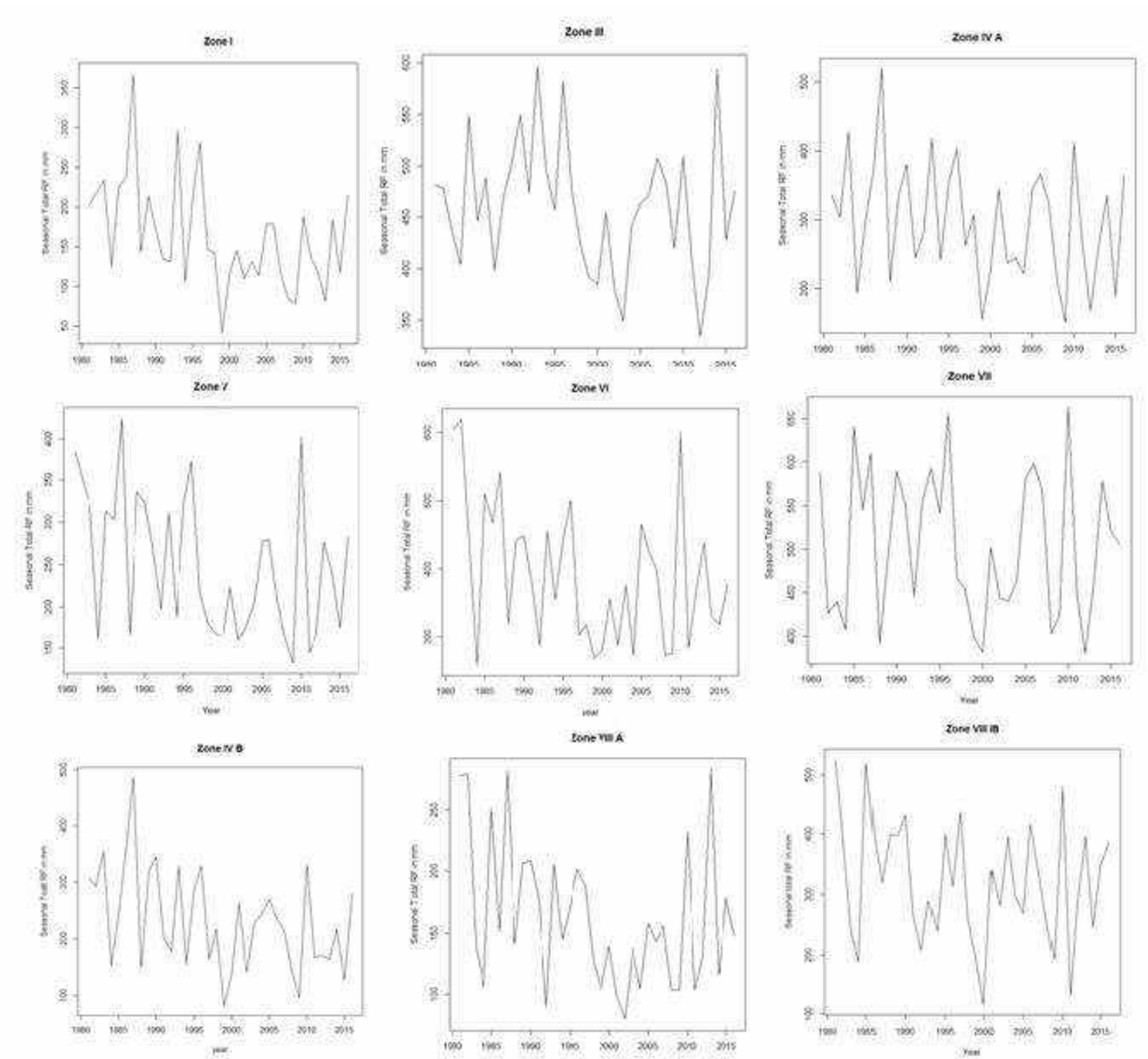


Figure 8: Belg season (4-month) total rainfall time series

On running the Mann-Kendall test on rainfall data, the following results in table 4 were obtained for the nine selected study areas. If the p value is less than the significance level α (alpha) = 0.05, H_0 is rejected. Rejecting H_0 indicates that there is a trend in the time series, while accepting H_0 indicates no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant. Table 4 indicates that the Null Hypothesis was accepted for 5 selected study areas.

Table 4: Results of the Mann-Kendall test for rainfall data for the seven zones

Mann-Kendall test						
	M-K Statistic (S)	Kendall's Tau	Var (S)	P-value (two tailed test)	alpha	Test Interpretation
Selected study areas						
Zone-I	-192	-0.305	5390	0.0092792	0.05	Rejected
Zone-III	-82	-0.13	5390	0.2699	0.05	Accepted
Zone-IV A	-104	-0.165	5390	0.16063	0.05	Accepted
Zone-IV B	-170	-0.27	5390	0.021339	0.05	Rejected
Zone-V	-180	-0.286	5390	0.014763	0.05	Rejected
Zone-VI	-156	-0.248	5390	0.034752	0.05	Rejected
Zone -VII	-32	-0.0508	5390	0.67284	0.05	Accepted
Zone-VIIIA	-136	-0.216	5390	0.065942	0.05	Accepted
Zone-VIIIB	-73	-0.116	5389	0.32669	0.05	Accepted

On plotting the linear trend line for the selected study areas, the following results in were obtained

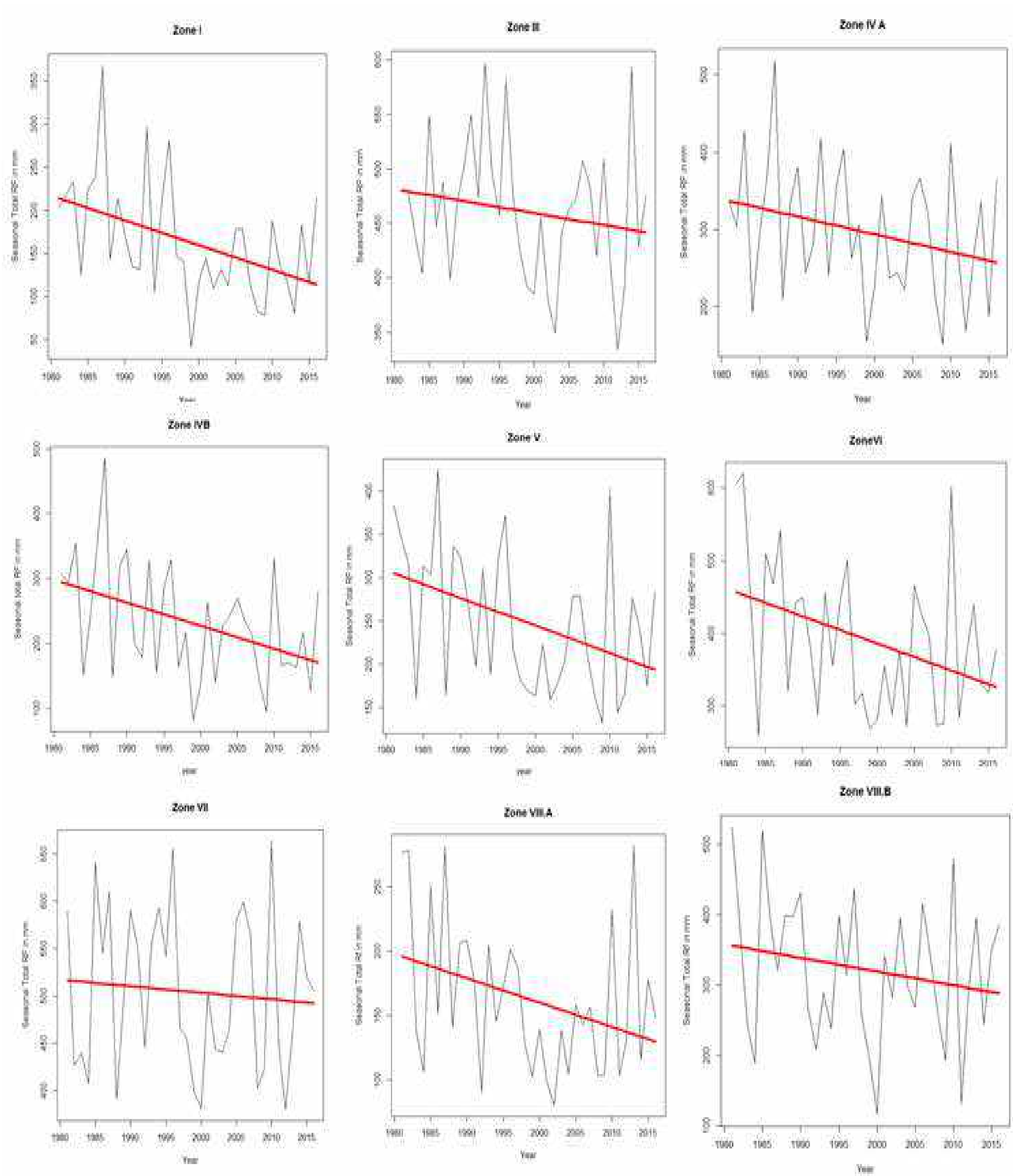


*Figure **9**: Belg season (4-month) total rainfall trend*

4. Discussion and Conclusion

For the mean temperature data, the Mann-Kendall trend test indicates that there is an increasing trend for all zones (selected study areas). The MK test is statically significant for all the zones, except Zone-VIIIA and Zone-VIIIB. For both of zone-VIIIA and zone-VIIIB, therefore, null hypothesis H_o is accepted and thereby implying that no trend can be seen in the data. The Mann- Kendal trend tests for the average maximum temperature show that there is an increasing trend for all study areas except zone-VIIIA whereas the average minimum temperature shows an increasing trend on all zones. The S statistic obtained for temperature data does not show any similarity between zones except increasing trends. A trend lines shows that there is an increasing temperature trend for all zones with large slope in magnitude during the Belg seasons. Especially on Zone-I, zone-IVA, zone-IVB, Zone-V, zone-VI, zone-VII and Zone-VIIIA are show a high increment but on Zone-III and zone-VIIIB are show a slow increment. If temperature shows an increasing trend for the zones in 32 years' time period during Belg season it becomes understand how this may also affect agriculture, human health and water resources when such a trend continuous. Change in temperature pattern can lead to change in agricultural production and expanse drought.

4.2. Rainfall

MK test Statistic (S) shows that there is a decreasing rainfall trend for all zones. The S statistic, however, is not very strong for zone-III, zone-VII and Zone-VIIIB implying that the trend is not strongly decreased when compared to the other zones. However, the MK test result is different for zone-III, zone-IVA, zone-VII, zone-VIIIA and zone-VIIIB, since the null hypothesis H_0 is accepted for all. This means that there is no trend is detected for these five zones. Based on the above results, it is a significant importance to discuss the economic and social impacts that could result if decreasing rainfall trends continue in these zones in the future. As we have seen from the previous rainfall and Temperature trend to be continued for the future, the Belg beneficiary areas are vulnerable to drought and shortage of water resources for all zones. On the other hand, all zones experienced a decreasing rainfall trend during the last 35 years' time period of this study and if this

trend continues in the future then it could have risks in the sustainability of surface water resources and groundwater recharge.

4.3. Conclusion

This study investigated rainfall and temperature trend analysis in the case of selected Belg rainfall areas in Ethiopia. The duration of the study period of temperature and rainfall data analysis were chosen as (1983-2014) 32 years and (1981-2016) 35 years respectively for all selected areas. In general, there was conformity in the results obtained from the Mann-Kendall test and the linear trend line for the nine classified selected study areas of Belg beneficiary areas for the 32 and 34-year time period temperature and rainfall respectively. The linear trend line shows that there is a decrease in rainfall for all seven selected zones. For mean average temperature and average minimum temperature, the trend line indicates that it is increasing for all the zones where as for average maximum temperature increasing for all study areas except zone-VIIIA.

The Mann Kendall test, on the other hand, shows that in the case of rainfall, no trend is noticeable for the areas of (III, VII, IVA, VIIIA and VIIIB); however, a decreasing trend is seen for the rest of the four selected Belg beneficiary zones. For the mean average temperature, the Mann Kendall test indicates that no trend exists for zone-VIIIA and zone-VIIIB, and an increasing trend is observed for the remaining six study areas. In the case of average maximum temperature, the Mann Kendall test shows that no trend exists for areas of zone (III, VII, VIIIA and VIIB), and increasing trend saw for the other zones and also the average minimum temperature has not seen trend for areas of zone (I, III, IVB, V, VIIIA and VIIIB) and increasing trend observed on the other zones. Generally, on the Belg beneficiary areas of Ethiopia the temperature trend increased and the rainfall trend decreased during the previous year. Climate change is also existed on the previous 32 years' data over the country during the Belg season as indicated from the trend. In other words, the trend in temperature and precipitation seen for each zones could imply that the changes are more pronounced for certain locations and less for others.

5. Reference

Birhan Getachew (January 2018), Trend analysis of temperature and rainfall in south Gonder zone, Ethiopia, journal of degraded and mining lands management, Volume 5

Diriba Korecha and Asgeir Sorteberg (November, 2013)." Validation of operational seasonal rainfall forecast in Ethiopia "water resources research", VOL. 49, 7681–7697, doi:10.1002/2013WR013760, 2013

Ethiopian population (2020)-worldometers-https://www.worldometers.info/world-population/ethiopia-population/

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 Netherland

Gilbert (1987). "Statistical Methods for Environmental Pollution Monitoring." Library of Congress Catalog Card Number: 86-26758 ISBN 0-442-23050-8

Hipel KW, McLoed AI (1994). Time series modeling of water resources and environ-mental systems. Elsevier, Amsterdam.

McLeod, A.I., (febuary, 2015). Kendall rank correlation and Mann-Kendall trend test http://www.stats.uwo.ca/faculty/aim

Neha Karmeshu(August,2012)." Trend Detection in Annual Temperature &Precipitation using the Mann Kendall Test."

NMA (National Meteorology Agency). 2007. Climate change national adaptation programme of action (NAPA) of Ethiopia: technical report, National Meteorological Agency, Addis Abeba, pp. 85

Massimiliano Fazzini, Carlo Bisci, and Paolo Billi (2015). He Climate of Ethiopia. Landscapes and Landforms of Ethiopia, World Geomorphological Landscapes, DOI 10.1007/978-94-017-8026-1_3, © Springer Science+Business Media Dordrecht.

MoFA (2013). http://www.mfa.gov.et/: Federal Democratic Republic of Ethiopia, Ministry of Foreign Affairs, Addis Ababa, Ethiopia.

Pohlert, T. (2016) Package "Trend": Non-Parametric Trend Tests and Change-Point Detection. R Package, 26

Seleshi, Y.; Zanke, U. Recent changes in rainfall and rainy days in Ethiopia. Int. J. Climatol. 2004, 24, 973–983

Thorsten Pohlert (March 24, 2015)."Non-Parametric Trend Tests and Change-Point Detection."

IPCC. 2014. The IPCC's Fifth Assessment Report. What's in it for Africa? - Executive Summary. Cambridge University Press, Cambridge, United Kingdom and New York, USA, 35

Viste E., Sorteberg A., 2012: Moisture transport into the Ethiopian highlands. Published online in the International Journal of Climatology, DOI: 10.1002/joc.3409

NATIONAL METEOROLOGY AGENCY TIGRAI METEOROLOGICAL SERVICE CENTER

Analysis of Climate Trend, Variability and community Perception over Eastern Tigray, Ethiopia

Dargie

Fikadu[1]

Habtu

Abraha

[2]

[1, 2] **TIGRAI METEOROLOGICAL SERVICE CENTER**

JULY 2019 MEKELLE, ETHIOPIA

Acronomys and Abbreviations

CC	Climate Change
CSA	Central Statistical Agency
CT	Total Contribution
CV	Coefficient of Variation
DRM	Disaster and Risk Management
ENSO	El Niño Southern Oscillation
EW	Easterly Wave
FAO	Food and Agricultural Organization
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
MAM	March-April-May
NMA	National Meteorological Agency
NMSA	National Meteorological Services Agency
NGOs	Non-Governmental Organizations
NOAA	National Oceanic and Atmospheric Administration
MOARD	Ministry of Agriculture and Rural Development
ONDJ	October-November-December-January
RSCZ	Red Sea Convergence Zone
SD	Standard Deviation
STJ	Sub-Tropical Jet
TEJ	Tropical Easterly Jet
WMO	World Meteorological Organization

Abstract

This study aims to investigate climate trend analysis and community perception in eastern Tigray. Tigray is one of the sensitive regions to climate variation particularly to precipitation and rainfall changes. In this study, we analysis trends in precipitation and temperature at annual, seasonal and monthly time scales for the periods of 1983-2014 over eastern Tigray. Excel spreadsheet were used for analyzing the statistics as well as for the perception analysis, survey based on 127 randomly selected community households, which was carried out in four districts. Non-parametric tests (such as Mann-Kendall and Sen's Slope) and linear regression techniques were used to determine climatic trends. In the survey households are asked their observations about changes on local climate using structured questionnaires. The results show that mean annual temperature ranges between 16.5^{0}C and 19.9^{0}C, while, the mean minimum and maximum rainfall varies between 509.5mm in Atsibi eastern part and 637.8mm in Hawzen western part. From the analysis the monthly coefficient of variation (CV %) for rainfall ranging from 26.3% at Wukro in the South to 34.3% at Atsibi in the East. From the analysis we found that the annual trend of precipitation was decreasing, but not insignificant except over Adigrat which were significant at 95% confidence limit. Both kiremt and belg seasons rainfall showed negative trend in all stations but not statistically significant. But in belg season rainfall decreasing trends are significant at 0.05 levels over Atsibi and Wukro stations. While maximum temperature showed increasing trend with statistically significant over Atsibi, Wukro and Hawzenon stations. While the trend was not significant over Adigrat station. Minimum temperature was decreasing over Adigrat and Hawzen with statistically significant trend and insignificant increasing trend over Atsibi and Wukro stations. Regarding perception, about 87% and 50% respondents perceived Belg and Kiremt rainfall decreasing, respectively and their observation was consistent with statistical findings.

Key words: Tigray, coefficient of variation, climatic trends, Mann-Kendall

1. Introduction

1.1. Background

Ethiopia's climate is changing, and a number of projections emphasizing further changes are on the way. Projections expect warming across the country, which may in all seasons cause a higher frequency of heat waves and higher rates of evaporation (Conway and Shipper, 2011). Also, a likely increase in mean annual rainfall in East Africa highlands, including Ethiopia, is anticipated (Christensen et al., 2007). More specifically, the National Meteorological Agency (NMA) expects rainfall to decline in northern parts, whereas the eastern part of the country might see increasing rainfall of as much as 20% (NMA, 2007). Rising temperatures, increasingly erratic rainfall, and more frequent and severe floods and droughts are major concerns, especially for those who are highly dependent on natural resources, such as agriculture, for their livelihoods. In the agriculture sector, the consensus is that changes in temperature and precipitation will result in changes in land and water regimes that will later affect agricultural productivity (World Bank, 2003).

Ethiopia is a large country comprised of different agro-ecologies and climate features resulting from its location and altitude variations. This suggests the need for climate investigations at the local level. Some studies have been carried out in different parts of the country because large-scale climate projections and trend generalizations may not necessarily reflect situations at the local and agro-ecological level. The following are among those available. Bewket (2009) in his study of rainfall variability and crop production in the Amhara region of Ethiopia found increasing annual and Kiremt (summer) rainfall in Dessie and Lalibela stations. He also learned of a drop in Debretabor (Kiremt) and Dangla (Belg rains) in the central-west part of the country in the period 1975-2003. Dereje et al. (2012) also found positive Kiremt rainfall trends at Bahirdar, Gondar, Srinka, and Mettema stations, whereas negative trends of Belg (spring) rainfall were identified at Kombolcha and Srinka stations in the period of 1978-2008. Another study by Hadgu et al. (2013) explored negative trends for both Belg and Kiremt rainfall in northern Ethiopia, though trends in Kiremt were non-significant. Sileshi and Zanke (2004) and Vest et al. (2013) use no trend for all annual and seasonal rainfall in in Northern Ethiopia in general. These studies, although in the northern and central parts of the country, are good indicators of how climate elements vary across locations in Ethiopia.

Eastern Tigray is an area that is highly vulnerable and sensitive to climate related extreme events such as droughts. The historic drought of 1984/5 left serious damages in this part of the country. From then onwards, reports from DPPC (1999 and2004) and FAO (2008 and 2009) indicated repeated failures in crop production because of localized droughts associated with variable and erratic rainfall in Belg and Kiremt seasons. Reports from these organizations show partial or total failure of production at least in 11 of the last 17 years due to rainfall variability since 1997.Despite increasing intensity and frequency of climate hazard in eastern Tigray, empirical studies are deficient in this field. With global warming a certainty, it is imperative to make investigations on climate elements at the local level. Investigating how farmers perceive climate change and how they respond to the changes will have valuable inputs for further development directions. How local people perceive climate changed determines how they formulate strategies to reduce possible impacts of those changes on their livelihoods (Deressa et al., 2010, Prager & Posthumus, 2010). Therefore, local perspectives can be combined with scientific climate scenarios to draw policy recommendations for future adaptation strategies (Patino and Gauthier, 2009).

Yet, farmers' perceptions and adaptation practices to climate change are context- and location- specific. Societies differ in culture, education, demographics, resource endowments, and bio- physical and institutional characteristics. This heterogeneity influences the way they perceive change in their local climate and the way they respond to the change (Maddison, 2007; Posthu-mus et al., 2010). Some attempts were made to analyze how farmers perceive climate change in Ethiopia. Admassie nd Adnew (2007), Deressa et al. (2010) and Hadgu et al. (2013) investigated farmer's perceptions to local climate change and adaptation strategies.

1.2. Statement of the problem

Agricultural sector of Tigray, particularly, Eastern zone of Tigrai is characterized by climate- related factors that impact on crop production. These factors are scarcity of rainfall, low level of output often leading to food insecurity and famine. The increasing climate variability such as rising erratic rainfall and the resultant water shortage coupled with the continued deforestation and miss- use of woodlands and other land resources has led to the substantial decline in agricultural productivity and rising food insecurity. Though little is known so far, evidences in the study area have shown that water shortage and the changing precipitation levels are affecting crop yields. However, despite a handful of empirical studies, in-depth analysis and well-established scientific evidences on the nature and extent of climate variability, magnitude of climate change impact on agricultural crops and the likely socio-economic consequences on the livelihoods and food security in the study area is virtually lacking. Thus, this study is designed to investigate climate and weather trend and community perception in the study area.

1.3. Significance of the study

This study enables to provide valuable information about climate and trends and have significantly importance for adaptive capacity, particularly in response to climate variability and climate change. Hence, this research helps Communities, governmental organizations and NGOS to fill knowledge gap on the use and exploring of scientific information in the agricultural sector of the study area.

1.4. Objectives of the Study

1.4.1. General Objective

- The overall objective of this study is to investigate climate trend and variability and perception of the community on climate change over the study area.

1.4.2. The specific objectives of the study area

- To investigate the trends and variabilities of seasonal and annual rainfall and temperature,
- To identify community perceptions on trends of local climate

1.5. Research Questions

- Is their significance change of rainfall and temperature during the past 20 and /or 30 yeasr?
- Have farmers' been perceived climate variability during the last 20 and / or 30 years in the study area?

2 LITERATURE REVIEW

2.1. Definition and Concepts

Rainfall totals: Annual and seasonal rainfall totals were determined as sum of rainfall of each day with greater or equal to 1 mm (NMSA, 2001; Segele and Lamb, 2005; Mesay, 2006; Hadgu et al., 2013) for the specified period.

2.2. Agro-climatic zones and seasons in Ethiopia

Three major climatic zones which have been known since ancient times in Ethiopia due to varied topography are Dega, Weina Dega and the Kolla. The Dega (also known as the cool zone) occurs in the central sections of the western and eastern parts of the north- western plateau. The elevation of this region is above 2400m, and daily temperature ranges from near freezing to 16°c while the Weina Dega (the temperate zone) ranges from between 1500m and 2400m in elevation, and consists of parts of the central plateau. The kola or hot zone generally comprises areas lower than 1500m in elevation, the Denakil depression and the Blue Nile valley (NMSA, 1996; Cheung et al., 2008).

According to NMSA (1996), three distinct seasons locally known as Bega (October to January), Belg (February to May) and Kiremt (June to September) are observed in Ethiopia. Of these three seasons, Kiremt is the main rainy season, in which about 85% to 95% of the food crops of the country are produced (Degefu, 1987; NMSA, 1996; Mesay, 2006).While Rainfall distribution and amount during Belg season is highly variable in time and space (NMSA, 1996; Mesay, 2006).The western half of the country, with one dry and one wet season in a year, receives the highest amount of rainfall in Kiremt, which is generally decreasing from 10 months in the south west to only 2 months in the north west (NMSA, 1996; Mesay, 2006; Viste et al.,2012). The central and south- eastern high lands and the adjoining lowlands experience all the three seasons and receives about 60% of the total annual rainfall during the Kiremt (NMSA, 1996). The southern and south-eastern low lands of the country have a bi-modal rainfall pattern with main rainy season occurring from March-May and the second short rains from October- January. On the other hand, the north eastern part of the country receives very small amount of Kiremt rainfall in a year (Mesay, 2006; NMSA, 1996; Viste et al., 2012).

According to Funk et al. (2005); Mesay (2006) and McSweeney et al. (2008), seasonal rainfall in

Ethiopia is driven mainly by the migration of the tropical rain belt, the Inter-Tropical Convergence Zone (ITCZ). Moreover, the main season (Kiremt) rain-producing systems such as the ITCZ, cross equatorial flow from (Mascarene high) southern Indian Ocean, moisture flow from (St. Helena high) Atlantic Ocean and the monsoon low and the associated trough have a great role to play for main season (Kiremt) rainfall performance over Ethiopia. According to Mason and Goddard (2001), El Niño–Southern Oscillation (ENSO) have an impact on a seasonal shifting of the normal rainy seasons in some regions, as a result a shortening or lengthening of the rainy seasons, particularly over tropical regions. In line with this, Gissila et al. (2004) and Segele and Lamb (2005) indicated that there could be a significant tele-connection linkage between ENSO and the Ethiopian Kiremt rainy season. The correlation showing that rainfall could be below average through El Niño episode further more high drought probabilities during strong El Niño years whereas, La Niña events favored further temporal expansion of seasonal activities beyond the normal duration of the rainy season over a region (Gissila et al.,2004). However, Conway (2009) and Conway and Schipper (2011) noticed d that despite clear evidence on the consequences of climate change, the drivers of climate change in the country are poorly understood. In Ethiopia, the distribution of rainfall varies over the diverse agro-ecological zones that exist in the country (Viste et al., 2012) and the appearance remains usually not understood (Conway and Schipper, 2011).

2.3. Weather systems producing seasonal rainfall in Ethiopia

Ethiopia lies in the horn of Africa approximately at 3^0-15^0N latitude and 33^0-48^0 E longitude which has an implication on atmospheric circulation. The country's topography is composed of massive highland complex of mountains and dissected plateaus divided by Great Rift Valley running generally southwest to north east (Mersha, 1999). 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, 1988; Beltrando and Camberlin, 1993; NMSA, 1996 and Conway, 2009). The movement of the 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. 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 (McSweeney et al.,2008). The most important weather systems that cause rain over Ethiopia includes Sub-Tropical Jet (STJ), Inter Tropical Convergence Zone (ITCZ), Red sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ), and Somalia Jet (NMSA, 1996b). The major dominant weather system is ITCZ. It oscillates seasonally with in the tropics and its surface position is influenced by topography and local eddies. Thus, this seasonal oscillation of the ITCZ causes a Variation in the pattern of wind flows over Ethiopia (Romilly and Gebremichael, 2010). According to Mesay (2006),

The major synoptic features that Influences the Weather of Ethiopia include easterly wave (EW), Sub-tropical Jet Stream (STJ) extra-tropical Troughs, Red Sea Convergence Zones (RSCZ), anticyclone over the Indian Ocean and the Mediterranean depression. Moreover, the intensity and areal coverage of the rain is associated, to a great extent with the intrusion and passage of the north-south oriented mid-latitude trough in the westerly wind field. The TEJ and the Tibetan anticyclone are the two important upper level atmospheric features. The strength and position of these atmospheric systems vary from year to year and the rainfall activity too. Regional and global weather systems affecting Kiremt (JJAS) season in Ethiopia include the ITCZ with the dominant effect and the Macarena High pressure in Southern Indian Ocean, the Helena High pressure Zone in the Atlantic, the Congo air Boundary, the Monsoon depression and trough, the Monsoon clusters and the Tropical Easterly Jet (Kassahun,1999). Philander (1990) mentioned that El Niño events are associated with variability in rainfall in equatorial East Africa, like Ethiopia (IPCC, 2007). It has been also noted that the rainfall is highly variable in amount, distribution and becomes unpredictable across regions and seasons (Mersha, 1999; Tilahun, 1999; Tesfaye and walker, 2004). This variability of rainfall and the recurrent droughts in Ethiopia affects the lives of millions of people as livelihood depends on rainfall (Viste et al., 2012).

2.4. Trend of seasonal and annual rainfall in Ethiopia

Over the last decades various studies have been conducted to examine rainfall trends in Ethiopia (NMSA, 2001; Viste et al., 2012; Hadgu et al., 2013). NMSA (2001) reported significant reduction in annual rainfall in the north and southwest part and conversely an increasing trend in the central part of the country. However, Bewket and Conway (2007) observed inconsistent trends in the annual, Kiremt and Belg rainfall among different stations in the country. Meze-Hausken (2004); and Cheung et al.

(2008) did not find any significant trend over the northern and north eastern part of the country. Hadgu et al. (2013) also showed a declining trend in annual and seasonal rainfall amounts in northern Ethiopia, but the trends were non-significant at most of the stations he studied. As indicated by Hadgu et al. (2013), start date of growing season showed Increasing trend whereas, end date and length of growing season declining in the northern Ethiopia.

3. Materials and Methods

3.1. Description of the study area

Eastern Tigrai is one of the seven zones in Tigrai Regional State of the Federal Democratic republic of Ethiopia. Geographically, it is located between 13.79^0-14.68^0 N Latitude and 39.43^0 - 39.99 ^{0}E Longitude. The study area shares border districts with Eritrea in the north and with Afar in the East, with central zone of Tigrai in the West and in the south with south eastern zone of Tigrai.

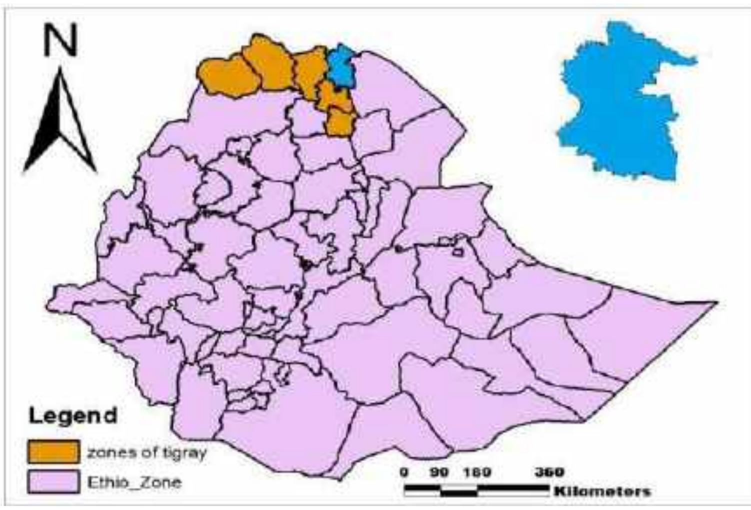


Figure1. Map of the study area

3.2. Agriculture

Agricultural land occupies an area of about 92,195 hectares which is approximately 27.7% of the total surface of the study area. The subsistence agricultural production is almost entirely dependent on Kiremt; Most of the crops are grown by local farmers who use traditional farming methods with respect to the local agricultural zone divisions which are a function of the elevation and climate. Agro-climatic zone of the study area is Dega and Weina- Dega. Its' annual mean temperature vary from 16.5^0C to 19.9^0C, the main crops grown are barley, wheat, maize and mainly livestock breeding. (http://www.dppc.gov.et).

3.3. Data source and station selection

Long-term daily rainfall, maximum, minimum and average temperature gridded data for Eastern Tigray was collected from National Meteorological Agency, for the periods (1983-2014). Temperature and rainfall data was selected parameters because of our agricultural system are highly sensitive to rainfall and temperature. In this study, the annual, seasonal and monthly precipitation totals and temperature measured at four districts were used for the period of 1983- 2014 (rainfall) and 1983-2011 (temperature). Community perception to climate change is a first key step for making decision to adapt. To identify how farming households, perceive the state of rainfall in their locality, surveys were conducted randomly in the study area. The survey covered in four districts and was made in March and April 2019.Households were asked to express their perception on climate/weather changes have been observed on climatic elements and associated extremes in their localities in the last 20/30 years. And communities were asked what their experiences were about extreme events such as drought and others in the stated time.

3.4. Method of data analysis

3.4.1. Variability

Annual rainfall variability is calculated by the coefficient of variation (CV) as

$$CV=SD/\mu$$

Where, **CV**, is coefficient of variation, **SD**, is standard deviation while **μ** is the long-term rainfall mean. According to F.K. Hare (1983), CV (%) values are classified as follows: < 20% as less variable, 20-30% as moderately variable, and > 30% as highly variable. In line with this, Reddy (1990) developed a model to assess the stability of growing season for certain location using the standard deviation (Standard deviation is computed as the square root of variance of the average onset dates) like standard deviation <10 as very high stabilities, 10-20 as high stability, and 20-40 as moderate stability and >40 would be as less stability growing season respectively.

3.4.2. Standardize Rainfall Anomaly

Rainfall anomaly was used to examine the nature of rainfall over the period of study and to determine dry and wet years in the record.

Standardize Rainfall Anomaly (**Z**) was calculated as:

$$Z=(X-\mu)/\sigma$$

Where, X is the annual total, while **μ** and **σ** are the long-term mean and standard deviation respectively. This statistic was able to determine the dry (-ve values) and wet (+ve values) years in the record. Drought indicators based purely on precipitation give a good overall view of the situation. Correspondingly McKee et al. (1993) used standardized rainfall anomalies to classify degree of drought. Hence, standardized rainfall anomaly was used to determine frequency of vulnerability in the study area.

3.4.3. Mann-kendall analysis

Several tests are available for the detection and estimation of trends. In this particular study, Mann-Kendall's test was employed. Mann-Kendall's test is a non-parametric method, which is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or nonlinear (Partal and Kahya, 2006; Yenigun et al., 2008). The Mann-Kendall's test statistic is given as:

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n}\mathrm{sgn}\left(x_j - x_k\right)$$

Where S is the Mann-Kenda1l's test statistics; x_i and x_j are the sequential data values of the time series in the years i and j (j > i) and N is the length of the time series. A positive S value indicates an increasing trend and a negative value indicates a decreasing trend in the data series. The sign function is given as:

$$\mathrm{sgn}(x)=\begin{cases}+1, & x>0\\ 0, & x=0\\ -1, & x<0\end{cases}$$

The variance of S, for the situation where there may be ties (that is equal values) in the x values, is given by:

$$\mathrm{Var}[S]=\frac{\left\{n(n-1)(2n+5)-\sum_{j=1}^{p} t_j(t_j-1)(2t_j+5)\right\}}{18}$$

Where, m is the number of tied groups in the data set and t_i is the number of data points in the i^{th} tied group. For n larger than 10, Z_{MK} approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun et al., 2008) and computed as follows:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases}$$

The presence of a statistically significant trend is evaluated using Mann-K value. In a two-sided test for trend, the null hypothesis (H_0) should be accepted if /Mann - K/ < Z1-a / 2 at a 0.05 level of significance. Z1-a / 2 is the critical value of Mann-K from the standard normal table. For instance, for 5% significance level, value of Z1-a / 2 is 1.96.

3.4.4. Theil-Sen's slop

Theil-Sen slop (Sen, 1968), also known as "Kendall's slope" or "Nonparametric linear regression slope", is an alternative to the standard linear regression slope. It is popular in earth sciences (meteorology and climatology) for measuring temperature and precipitations over. Straight line can represent the Theil Sen Slope, but, it is "distribution free" and permits use of merely ordinal measurement scales. This method could also be used with missing data and remain unaffected by outliers or gross errors (Karpouzos et al., 2010). Slope (change per unit time) was estimated following the procedure of Sen (1968) and a detailed outline of the procedure is given in Partal and Kahya (2006) and Karpouzos et al. (2010).

4. Results and Discussions

4.1 Variability, trend and anomaly of rainfall in Eastern Tigray

4.1.1 Annual rainfall variability

The study area received its long-term mean annual rainfall of 582.3mm ranging from 509.6mm at Atsibi in the East to 637.8mm at Hawzen in the west for the period (1983-2014).

As indicated in Table 1 the Coefficient of variation for the study years, mean annual ranged from 26.3% at Wukro in the South to 34.3% at Atsibi in the East which can be classified as highly variable (Hare, 1983) and this is also similar with the previous studied by Zanke and Seleshi (2004), Segele and Lamb (2005), and Hadgu et al. (2013) in the north and northeastern parts of Ethiopia. On the other hand, the SD Values was higher at all stations (SD= 153.0mm-202.0mm) which implies less stability of the annual rainfall in the study area.

Table1. Descriptive statistics of Annual rainfall characteristics for the study area (1983- 2014)

Stations	Lat	Long	Alt	Max (mm)	Min (mm)	Mean (mm)	SD (mm)	CV (%)	Period
Adigrat	14.28	39.47	2509	1429.0	324.0	599.8	202	33.7	1983 – 2014
Atsibi	13.87	39.74	2511	1265.0	272.0	509.6	175	34.3	1983 – 2014
Wukro	13.79	39.60	1783	1175.0	381.0	582.1	153	26.3	1983 – 2014
Hawzen	13.98	39.43	2243	1460.0	360.0	637.8	190	29.8	1983 – 2014

Note: SD is standard deviation and CV is coefficient of variation.

4.1.2 Seasonal rainfall variability

4.1.2.1 Belg seasonal rainfall variability

Contribution of Belg seasonal rainfall to the annual total rainfall varied from 18.0% at Hawzen in West and 22.8% at Atsibi in the East of the study area during the period (1983-2014). In line with the present study, NMSA (2005) also noted that, contribution of seasonal Belg rainfall to the annual total rainfall in the north, northeastern and eastern parts of Ethiopia ranges 5% to 30%. Moreover, the long year mean Belg seasonal rainfall totals ranged from 114.6mm at Hawzen in West to 119.1mm at Wukro in the South of the study area.

Table2. Descriptive statistics of Belg seasonal rainfall characteristics for the study area (1983- 2014)

Gridded points	Lat	Long	Alt(m)	Max (mm)	Min (mm)	Mean (mm)	SD (mm)	CV (%)	CT (%)	Period
Adigrat	14.28	39.47	2509	310.0	22.0	117.3	75	63.9	19.6	1983 – 2014
Atsibi	13.87	39.74	2511	284.0	12.0	116.1	72	62.0	22.8	1983 – 2014
Wukro	13.79	39.60	1783	254.0	12.0	119.1	68	57.1	20.5	1983 – 2014
Hawzen	13.98	39.43	2243	267.0	20.0	114.6	74	64.6	18.0	1983 – 2014

Note: SD is standard deviation, CV is coefficient of variation and CT is contribution of Belg seasonal rainfall to the annual total rainfall.

The seasonal Belg rainfall also showed marked variability with CV values of 57.1% at Wukro in the South to 64.6% at Hawzen in the west with SD value of 68.0mm and 74.0mm respectively. This implies that the Belg seasonal rainfall in the study area was characterized by high variability according to the classifications of Hare (1983). Similar high seasonal Belg rainfall variability was reported by Hadgu et al. (2013) in the Tigray Region compared to the Kiremt and annual total rainfall during the period 1980-2009. This less stability of Belg rainfall total indicates that seasonal Belg rainfall was not dependable and not easily Predicable during the period (1983-2014).

4.1.2.2 Kiremt seasonal rainfall variability

The contribution of Kiremt rainfall to the respective annual total rainfall varied from 70.9% at Atsibi in the East to 77.1% at Hawzen in the west of the study area during the period (1983-2014). A comparable result of the main season total rainfall contribution was reported by NMSA (2005). In the present study, the total seasonal Kiremt rainfall varied from 361.2mm at Atsibi in the East to 491.8 mm at Hawzen in the East of the study area.

Table3. Descriptive statistics of Kiremt seasonal rainfall characteristics for the study area (1983- 2014)

Gridded points	Lat	Long	Alt	Max (mm)	Min (mm)	Mean (mm)	SD (mm)	CV (%)	CT (%)	Period
Adigrat	14.28	39.47	2509	1158.0	253.0	443.4	175	39.5	73.9	1983 – 2014
Atsibi	13.87	39.74	2511	998.0	190.0	361.2	153	42.2	70.9	1983 – 2014
Wukro	13.79	39.60	1783	921.0	258.0	431.3	137	31.8	74.1	1983 – 2014
Hawzen	13.98	39.43	2243	1209.0	301.0	491.8	168	34.2	77.1	1983 – 2014

Note: SD is standard deviation, CV is coefficient of variation and CT is contribution of Kiremt seasonal rainfall to the annual total rainfall.

The coefficient of variation for the seasonal Kiremt rainfall varied from 31.2% at Wukro in the South to 42.2% at Atsibi in the East of the study area. This indicates that the study area experienced high variability in the Kiremt season rainfall. Similar result was also reported by Zanke and Seleshi (2004), Segele and Hadgu et al. (2013) in the north and northeastern parts of Ethiopia. The calculated SD values also showed that the past Kiremt rainfall was less stable (SD= 137.0mm - 175.0mm). This less stability shows that the seasonal Kiremt rainfall totals was not easily predictable for the study period (1983-2014).

4.1.2.3 Annual rainfall trend

A description of the applied statistical test procedure is given in table 4 below. Statically, the annual rainfall shows decreasing trend in all stations. But significant trends are not found for annual precipitation in Atsibi, Wukro and Hawzen stations. On the other hand, annual rainfall trend in Adigrat is negative and the result is significant at 95% confidence limit during the period of 1983- 2014. The magnitude of the negative trend ranges from 162.0 mm/d in Adigrat to 63.0 mm/d in Wukro station.

Table4. Mann-kendall Annual rainfall trend for the study area (1983- 2014)

	Mann-kandall	Slop
Adigrat	-2.16*	-5.400
Atsibi	-1.4	-3.586
Wukro	-0.86	-2.106
Hawzen	-0.84	-2.678

Note: Mann-k=Mann-kendall trend test, slop (Sen's Slop) = the change rainfall mm/decade; ns= non-significant trend and **, *indicates significant trend at 0.01 and 0.05 significant level.

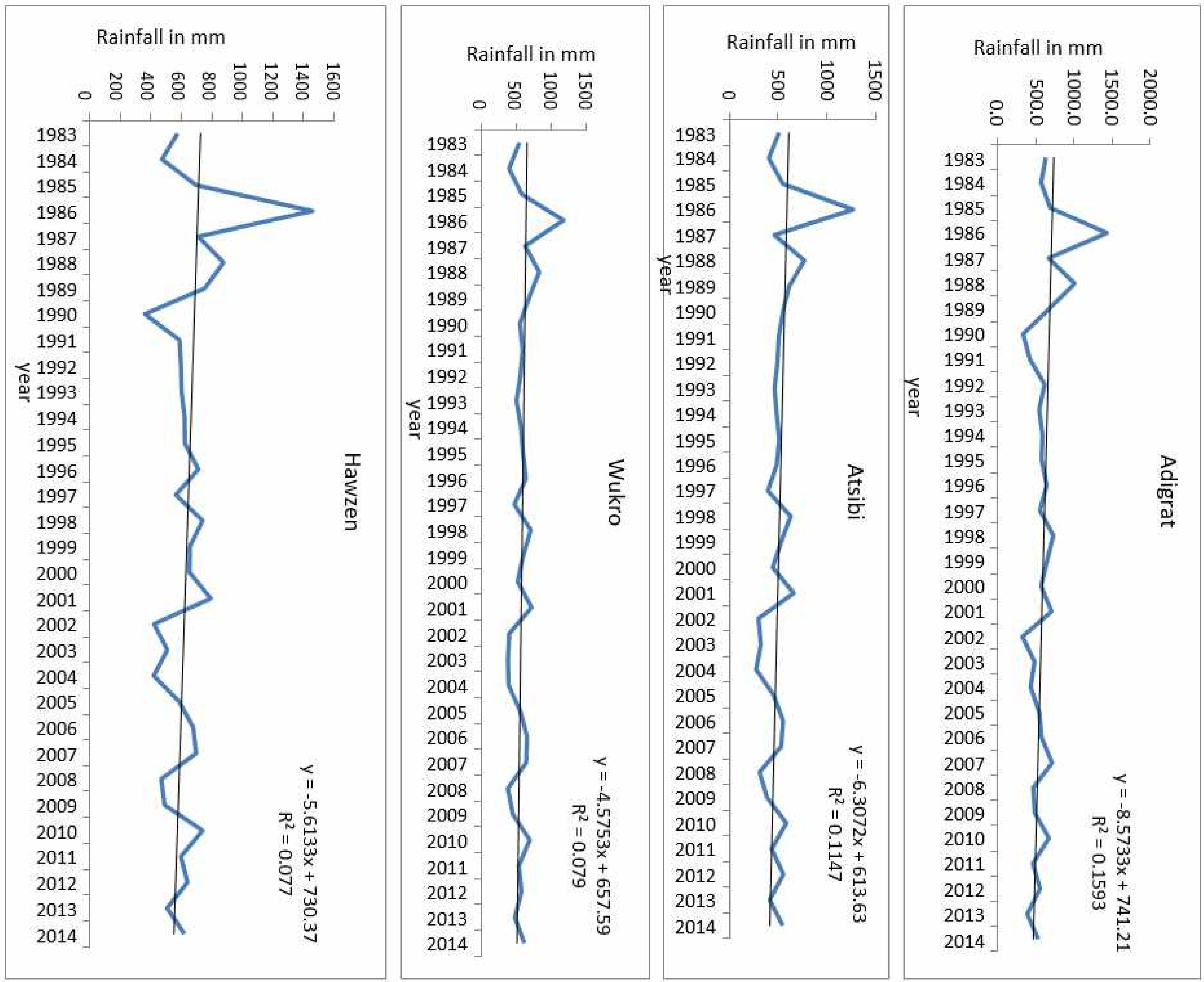


Figure 2: Annual rainfall trend in Adigrat, Atsibi, Wukro and Hawzen stations

4.1.2.4.2 Kiremt rainfall trend

In Eastern Tigrai the rainfall trend shows decreased from year to year in Kiremt season. In Kiremt season the rainfall in 1986 were 1158.0, 998.0, 921.0, 1209.0mm in Adigrat, Atsibi, Wukro and Hawzen stations which was the highest rainfall recorded. Whereas the lowest rainfall recorded was in 1998 (253.0, 190.0, 258.0, 301.0mm in Adigrat, Atsibi, Wukro and Hawzen stations respectively**).**

Mann-kendall analysis shows that Kiremt rainfall was decreasing in all stations. The magnitude of the negative trend ranges from 116 mm/d in Adigrat to 8.82 mm/d in Wukro station, but all these decreasing trends are in significant.

Table 6: Mann-kendall Kiremt seasonal rainfall characteristics for the study area (1983- 2014)

	Mann-kandall	Slope
Adigrat	-1.49	-3.869
Atsibi	-0.44	-0.800
Wukro	-0.05	-0.294
Hawzen	-0.39	-0.644

Note: Mann-k = Mann-kendall trend test, slop (Sen's Slop) = the change rainfall mm/decade; ns = non-significant trend and **indicates significant trend at 0.01 and 0.05 significant level.

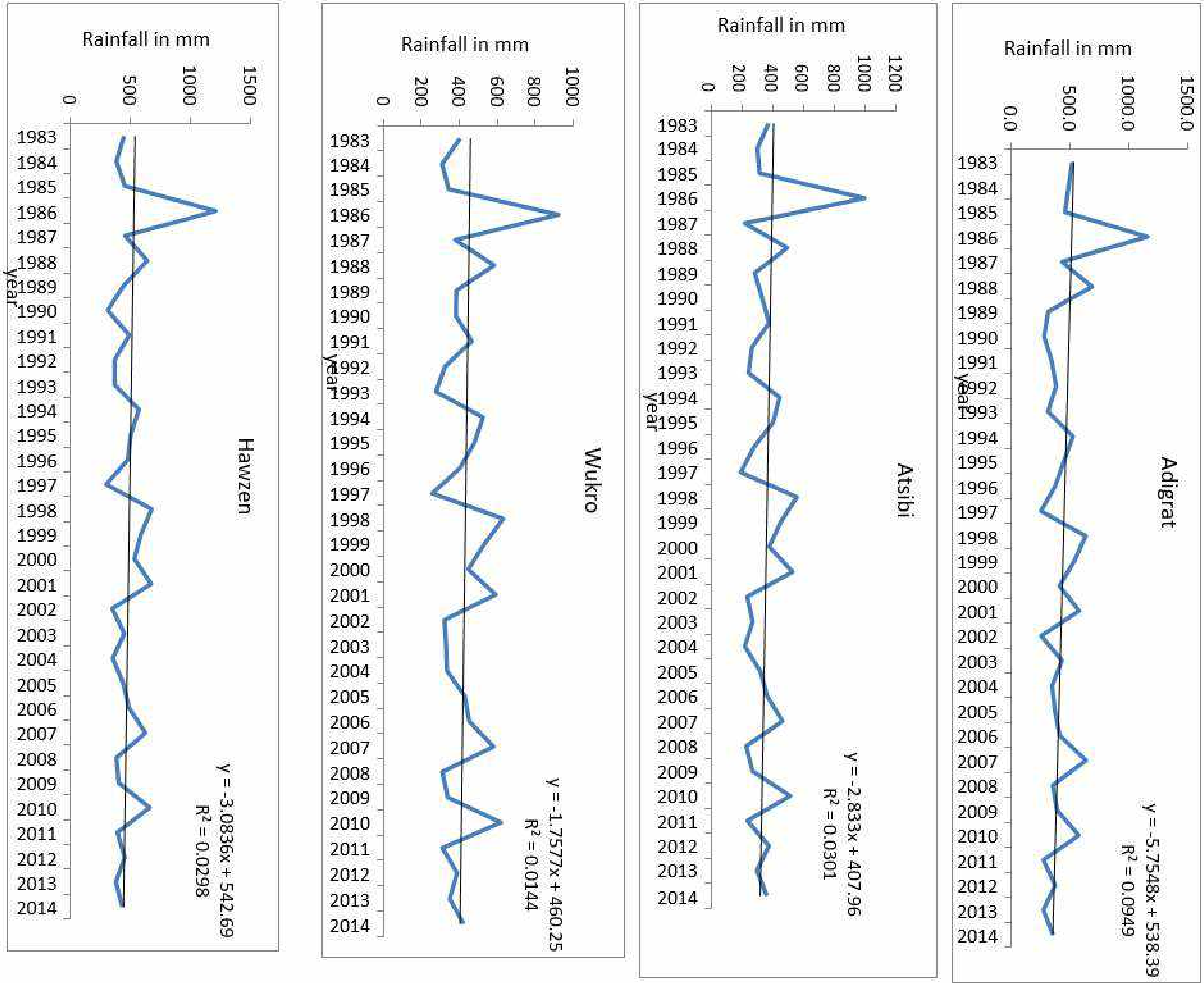


Figure 4: Kiremt seasonal rainfall trend in Adigrat, Atsibi, Wukro and Hawzen stations

4.1.3 Rainfall anomaly

Annual rainfall anomaly showed that periods of 1990, 2002 and 2013 years in Adigrat, 2002, 2003, 2004 and 2008 years in Atsibi and Wukro and 1990, 2002 and 2004 years in Hawzen can be classified as years of moderately dry and year of 1988 and1986 years was moderately wet to extremely wet in all stations respectively.

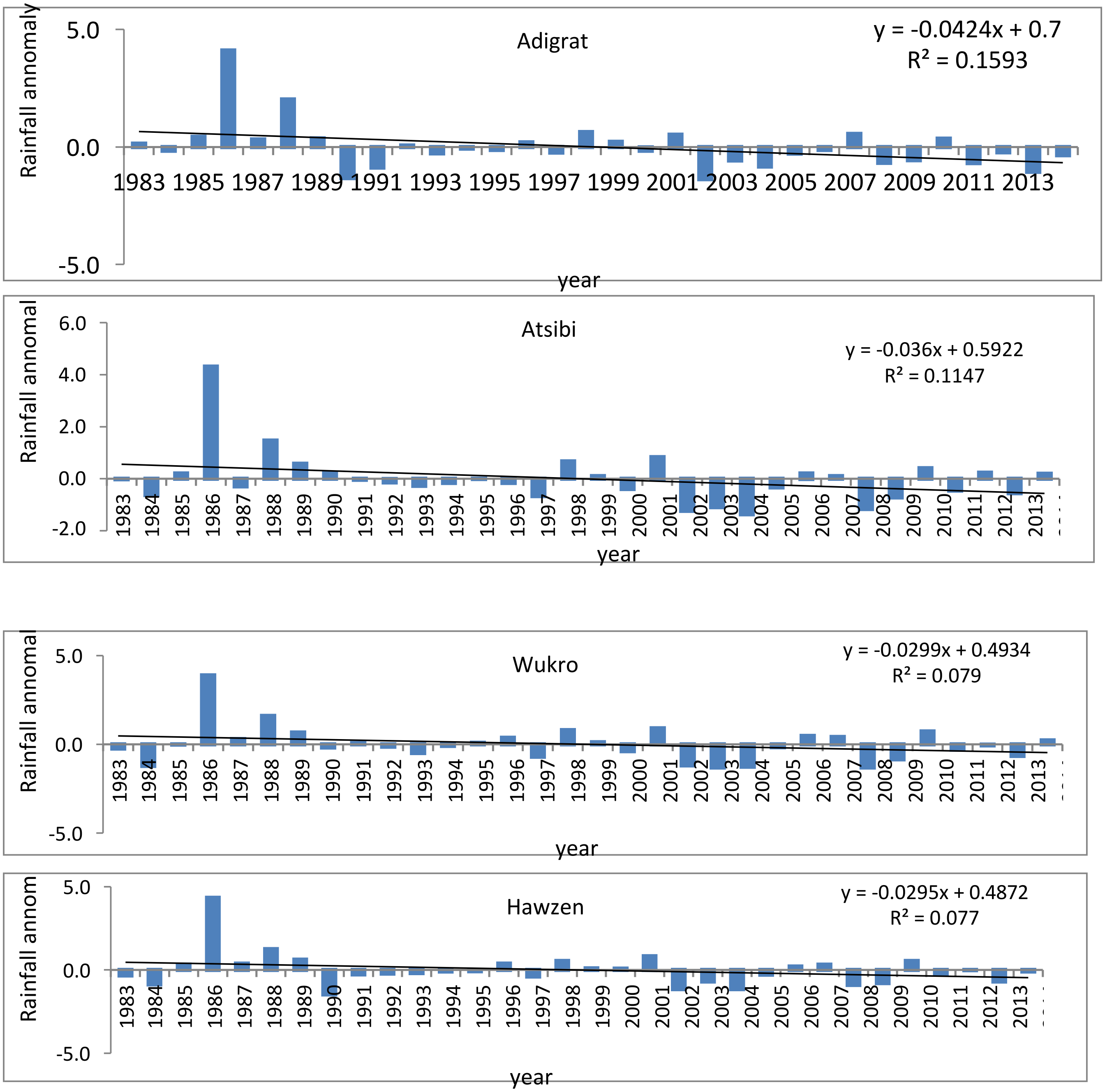
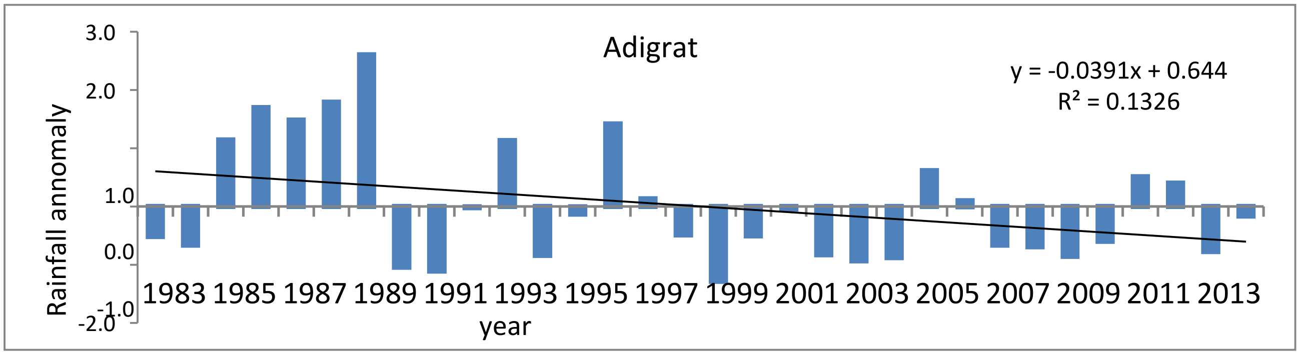


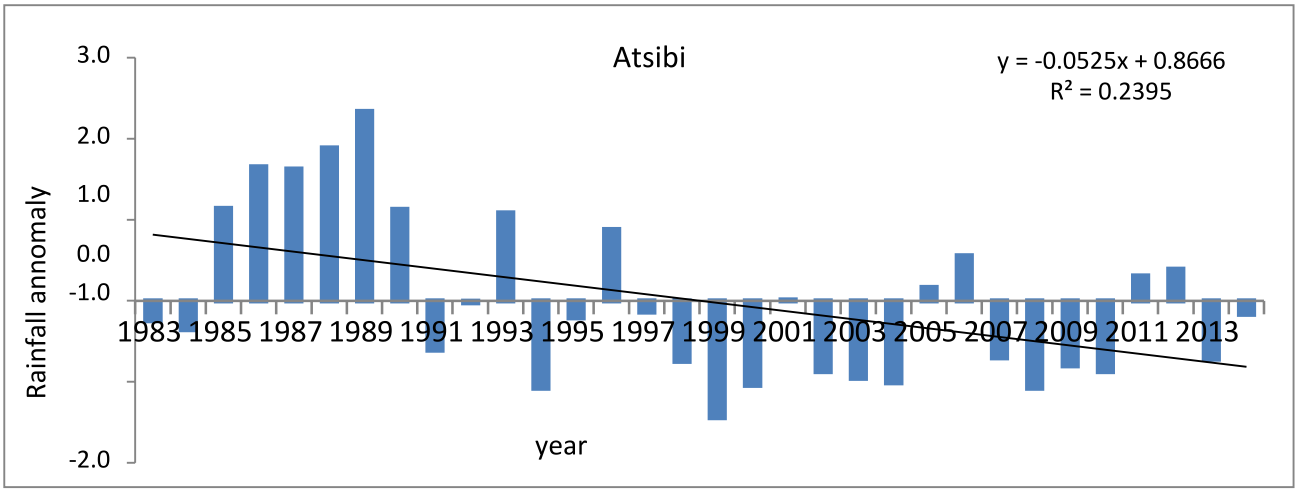
Figure 5: Annual rainfall standardized anomaly in Adigrat, Atsibi, Wukro and Hawzen stations.

4.1.4 Seasonal rainfall anomaly

4.1.4.1 Belg rainfall anomaly

On the other hand, seasonal Belg rainfall anomaly revealed that 50% of the years in the study period (1983-2014) was experiencing rainfall lower than the long year mean (Figure3). The years 1983,1984,1986,1987,1988,1989,1990,1991,1992,1994,1997,1999,2000,2002,2003,2004,2007 and 2009 were lower than the long year mean at all the gridded-points. This indicates that the seasonal Belg rainfall in the study area was decreasing at large. In line with this, Viste et al. (2012), after thorough examination of 1972-2011 rainfall, reported that Northeastern Ethiopia experienced sever to extreme drought. Normalized anomaly rainfall shows a general increasing trend but, it is insignificant (Figure 6)





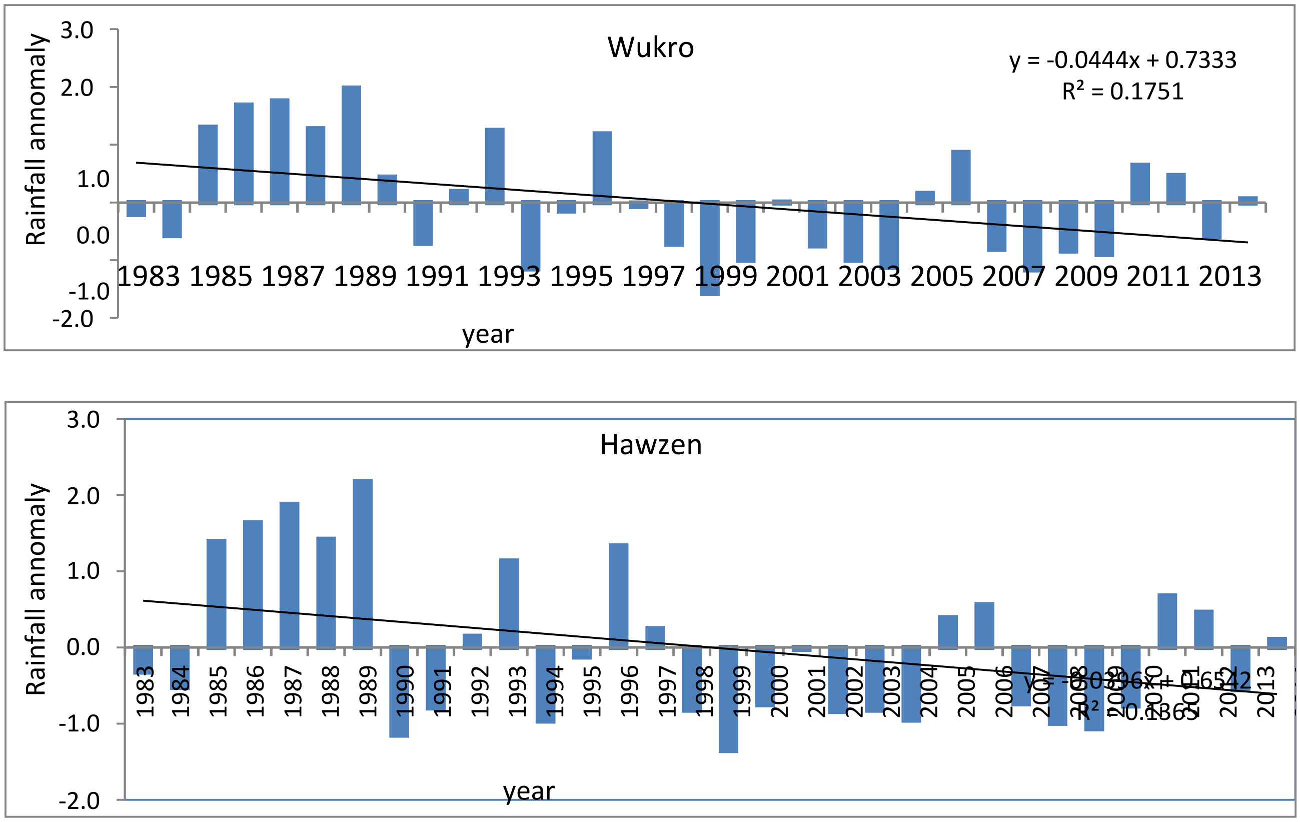


Figure 6: Belg seasonal rainfall standardized anomaly in Adigrat, Atsibi, and Wukro and Hawzen stations

4.1.4.2. Kiremt rainfall anomaly

Kiremt rainfall anomaly showed that less than half of (39%) of the observation years were experiencing an amount higher than the long term means (Figure 7). The years 1997, 2002, 2011 and 2013 in Adigrat, 1997in Atsibi, 193, 1997 in Wukro and 1990, 1997 in Hawzen can be classified as years of moderately drought, as indicated by Hadgu et al. (2012). whereas years of 1988,1998,2007 in Adigrat, 1998, 2001, 2010 in Atsibi, 1988, 1998, 2001, 2007, 2010 in Wukro and 1998, 2001, 2010 in Hawzen were classified as moderately wet and the year of 1986 was extremely wet in all stations. Normalized anomaly rainfall shows a general decreasing trend but, the trend is insignificant (Figure 7)

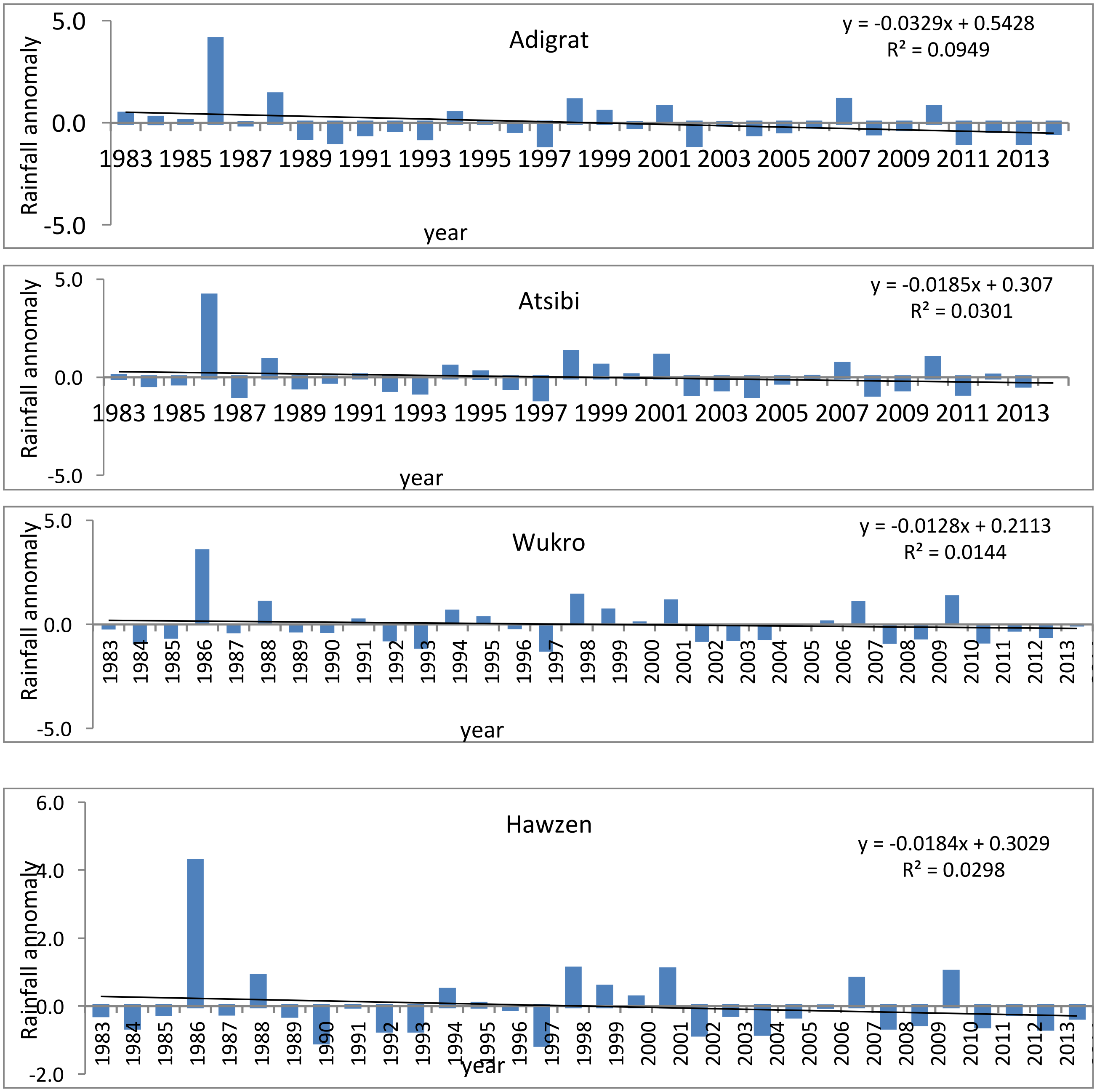


Figure 7: Kiremt seasonal rainfall standardized anomaly in Adigrat, Atsibi, Wukro and Hawzen stations

4.2 Trend of Temperature in Eastern Tigray

4.2.1 Annual maximum temperature trend

Air temperature has crucial impact on the water cycle in the study area. So that analysis of trends in annual and monthly temperature data conducted for the periods of record 1983-2011. The Figure below represents the mean annual maximum temperature and its trend in the period of under examination. Using a linear regression model, the rate of change is defined by the slope of regression line which in this case is about 0.1635 ^{O}C/28 yr in Adigrat, 0.3698 ^{O}C /28 yr in Atsibi, 0.3423 ^{O}C/28 yr in Wukro and 0.4003 ^{O}C/28 yr in Hawzen during the period of 1983-2011. This finding is not similar to global warming rate which is estimated 0.6 ^{O}C for the past century. This result shows that approaching to global warming study has important impact on the regional climate in the study area for the last two decades Statically, annual maximum temperature trend is positive (increases) in all stations. In Atsibi and Wukro the result shows statistically significant at 0.05 levels during the period of 1983-2011, Where as in Adigrat and Hawzen the annual maximum temperature is insignificant.

Table7. Mann-kendall maximum temperature trend for the study area (1983- 2014)

	Mann-kandall	Slop
Adigrat	1.29	0.017
Atsibi	2.42^{*}	0.072
Wukro	2.23*	0.086
Hawzen	1.86^{+}	0.036

Note: Mann-k = Mann-kendall trend test, slop (Sen's Slop) = the change temperature ^{O}C /decade; ns = non-significant trend and **, *, $^{+}$indicates significant trend at 0.01, 0.05 and 0.1 significant level.

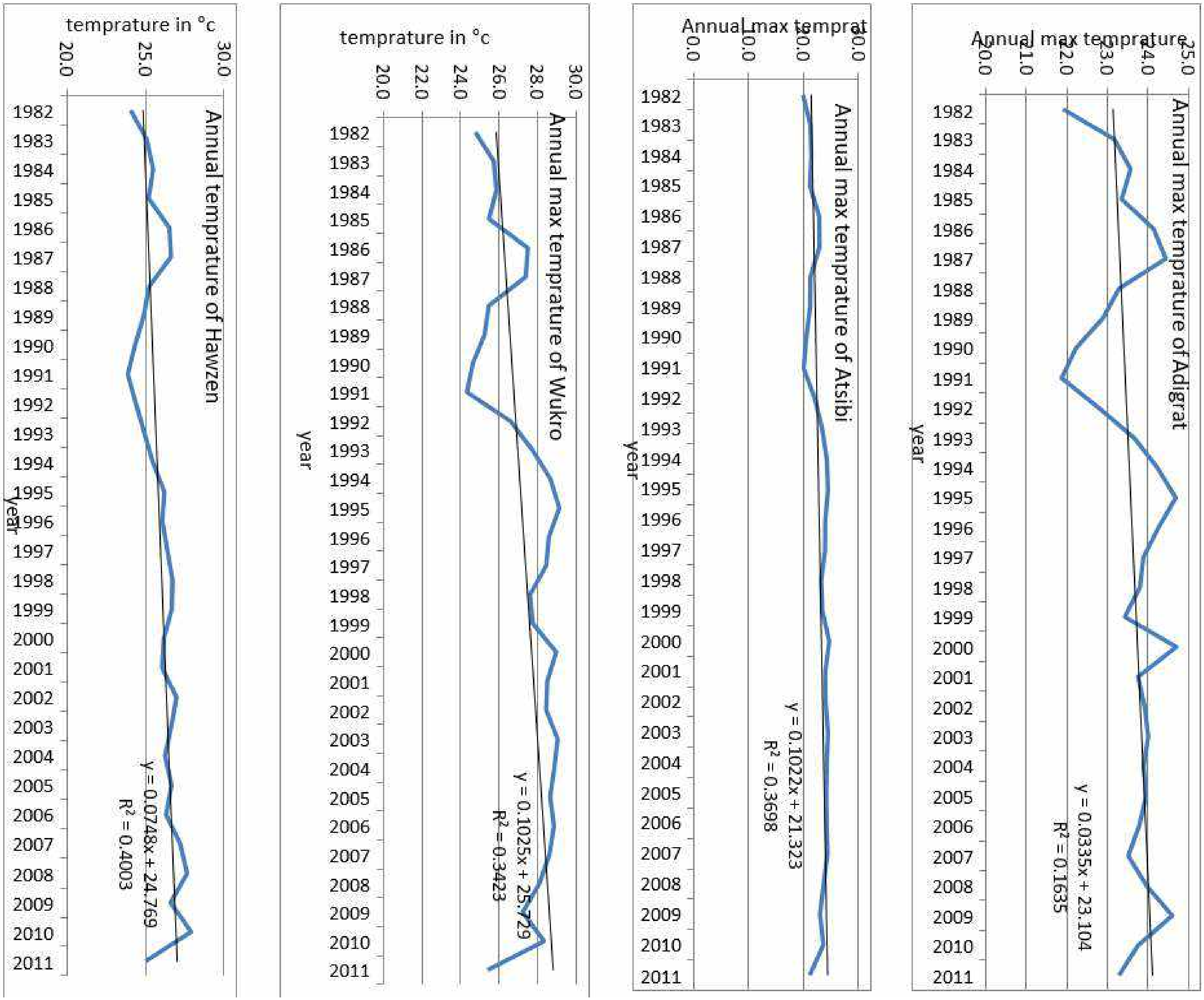


Fig 8: Annual maximum temperature trend in Adigrat, Atsibi, Wukro and Hawzen stations

4.2.2 Annual minimum temperature trend

Statistically, significant trends are not found for minimum temperature data on annual basis, even though there are negative and positive trends for period of record (1983-2011) considered. Overall, annual minimum temperature trend is positive (increases) in Atsibi and Wukro but this result is not statistically significant during the period of 1983-2011. The increase in annual temperature observed in the Atsibi and Wukro stations are caused by increase in summer months, which compensate the slight decrease in the other seasons especially autumn months. And the trends in Atsibi and Wukro stations of annual minimum temperature were found a positive slope which is an increasing trend (1983-2011) Figure 9, On the other hand in Adigrat and Hawzen stations, the annual minimum temperature trend is negative (decreasing) but the trend is insignificant. And the trends in annual minimum temperature were found negative slope which is a decreasing trend in Adigrat and Hawzen stations during the period of (1983-2011).

Table8. Mann-kendall minimum temperature trend for the study area (1983- 2014)

	Mann-kandall	Slop
Adigrat	-1.75^{+}	-0.029
Atsibi	1.52	0.036
Wukro	1.52	0.039
Hawzen	-1.07	-0.017

Note: Mann-k = Mann-kendall trend test, slop (Sen's Slop) = the change temperature ^{O}C /decade; ns = non-significant trend and **, *, $^{+}$indicates significant trend at 0.01, 0.05 and 0.1 significant level.

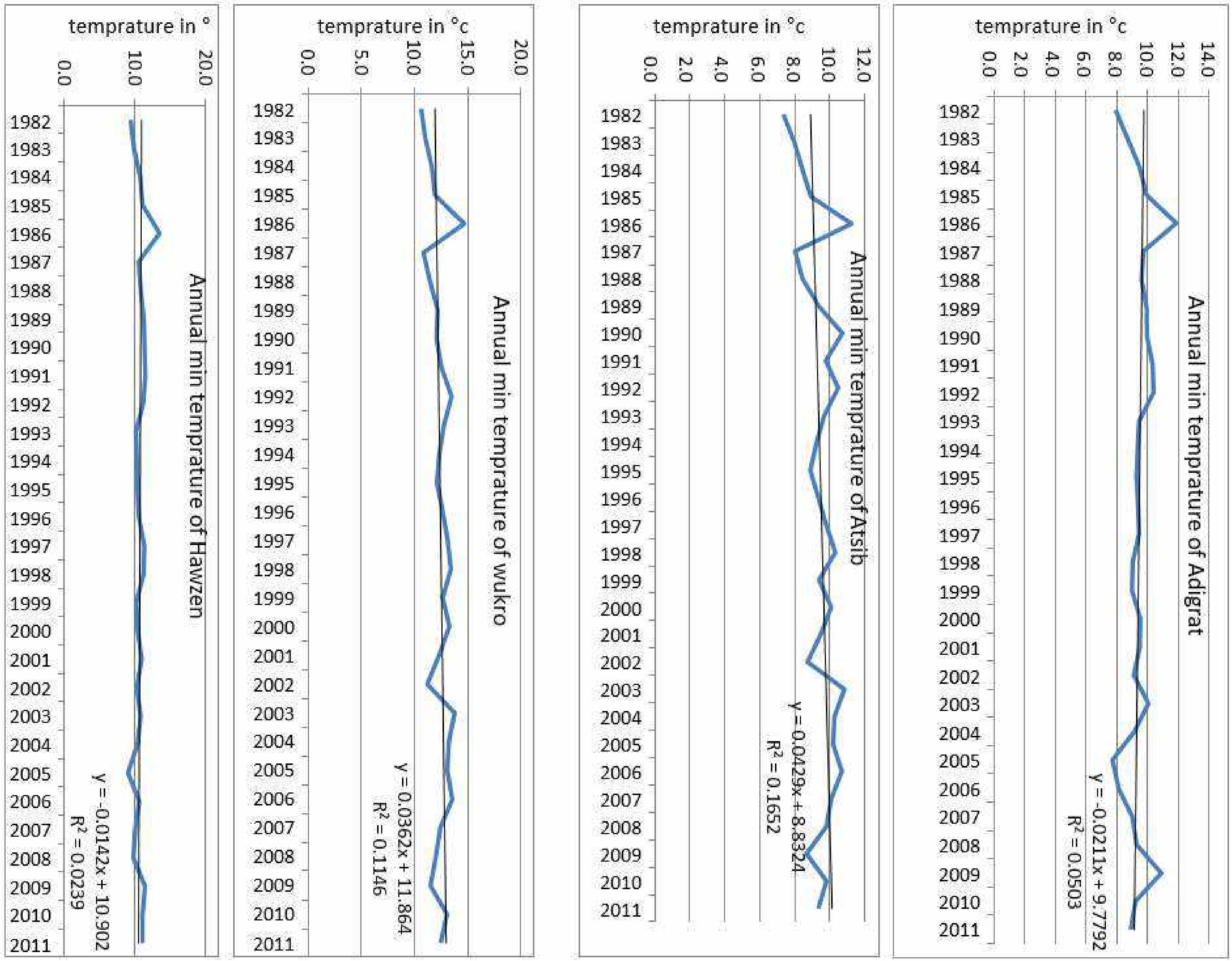


Figure 9: Annual minimum temperature trend in Adigrat, Atsibi, Wukro and Hawzen stations

4.3 Perception of community households on climate and changes

To investigate perception of community on climate change, the 1st question to community households were asked to state their observation about drought during 20/30 years. The result of this analysis is presented below. Generally, an average of 75% in Atsibi, 70% in Hawzen, 63% in Wukro and 61% in Adigrat of respondents observed that they were more experienced with drought in the past 20/30 years.

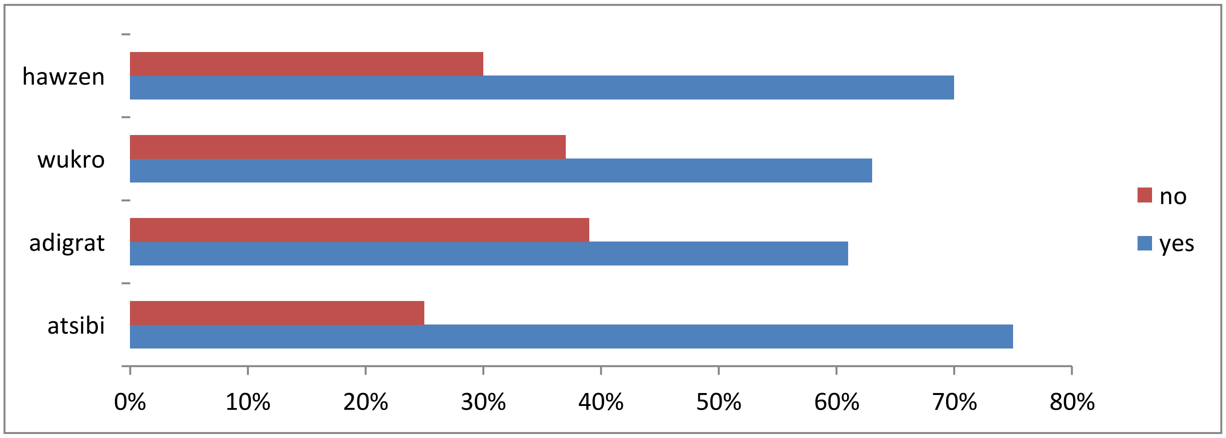


Figure10; Community perception on drought occurrence in Adigrat, Atsibi, Wukro and Hawzen in the past 20/30 years.

The second question to community households were asked to state what they had observed regarding long term (20/30 years) changes in temperature. They were asked to specify what they had observed specifically increase, decrease or no change in temperature. So the result of this analysis shows an average of 57% of respondents are agree with increasing temperature trend and 32% of respondents observed there is no change temperature trend and 11% of the respondents were observed decline trend of temperature.

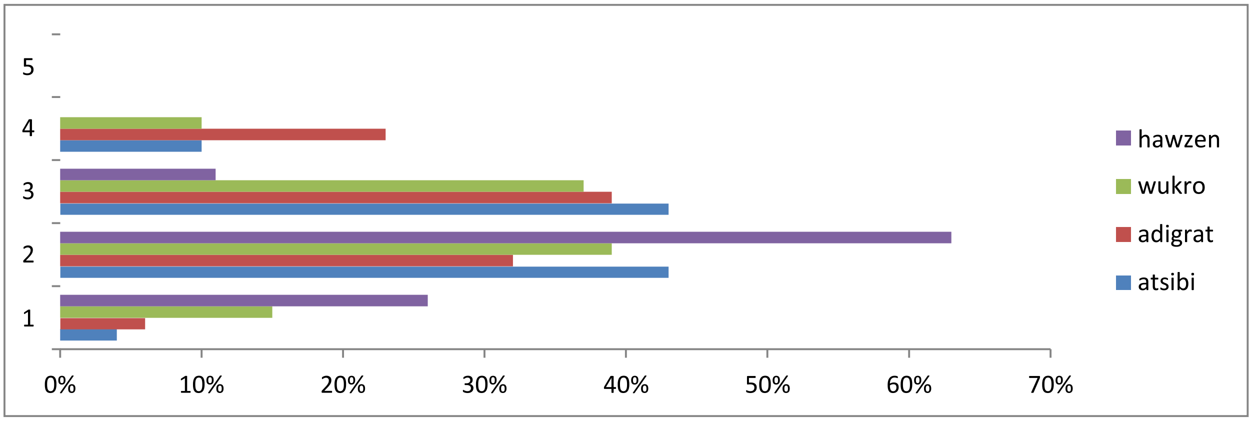


Figure11; Community perception on temp. Trend in Adigrat, Atsibi, Wukro and Hawzen in the past 20/30 years [Note: 1=strongly agree, 2=agree, 3=neutral, 4=disagree, 5=strongly disagree]

On the other hand, community households were asked to specify type of change they observed for rainfall in Kiremt and Belg season in the last two or three decades. there was some variation in perception especially in kiremt seasonal rainfall. Out of 127 community households, 43% of respondents in Atsibi, 48% of respondents in Hawzen and 51% of respondents in Wukro perceived a non-declining Kiremt rainfall (no change trend) in the last 2/3 decades. Whereas Only 48% of community households in Adigrat and 48% of respondents in Hawzen, felt there was a declinig of rainfall trend in Kiremt season. On the other hand, about 79% community households from Atsibi, 74% from Adigrat, 73% from Wukro and 81% respondents from Hawzen presumed a decline trend for Belg rainfall season.

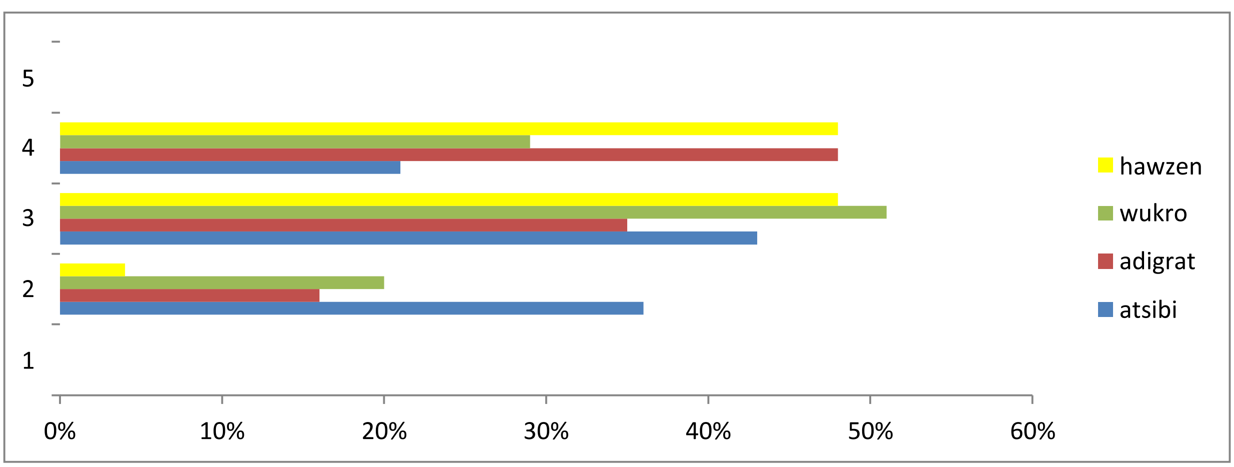


Figure12; community perception on Kiremt season rainfall trend in Adigrat, Atsibi, Wukro and Hawzen in the past 20/30 years [**Note**: 1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, 5 = strongly disagree]

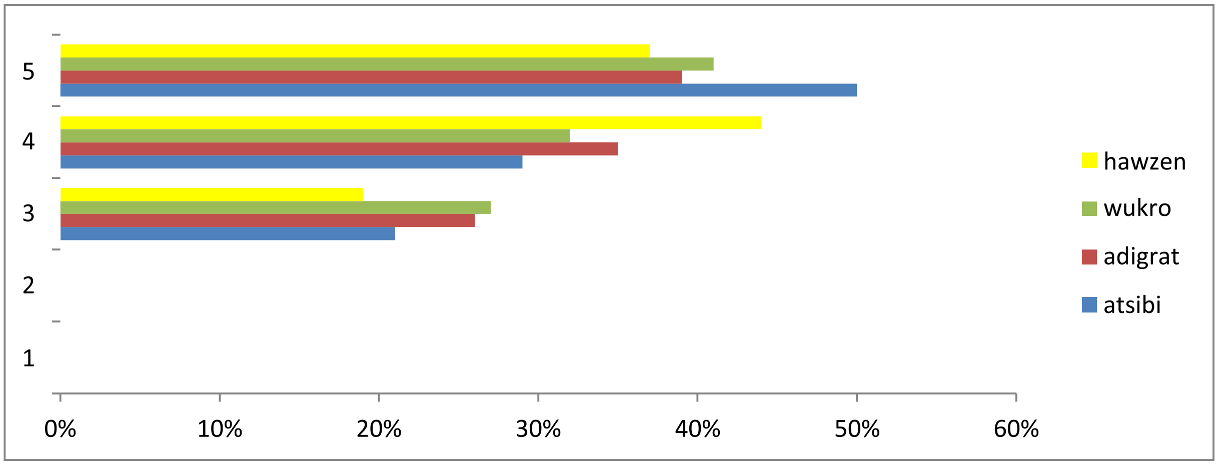


Figure13: community perception on Belg season rainfall trend in Adigrat, Atsibi, Wukro and Hawzen in the past 20/30 years [**Note**: 1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, 5 = strongly disagree]

5. Summary and Conclusion

This study investigated climate and trend analysis and community perception in the case of eastern zone of Tigray. As the result showed that the study area received its long-term mean annual rainfall of 582.3mm ranging from 509.6mm at Atsibi in the East to 637.8mm at Hawzen in the west of the study area. The total seasonal Kiremt and Belg seasonal rainfall varied from 361.2mm at Atsibi in the East to 491.8 mm at Hawzen in the East and 114.6mm at Hawzen in West to 119.1mm at Wukro in the South of the study area respectively. The results of the study area indicate that both Kiremt and Belg seasons had Coefficient of variation ranges from 31.2% at Wukro in the South to 42.2% at Atsibi in the East and 57.1% at Wukro in the South to 64.6% at Hawzen in the west. And the standard deviations also differ from 137.0mm to 175.0mm in Kiremt season and 68.0mm and 74.0mm in Belg season. So the result indicating that Kiremt and Belg seasons in the study area were not easily predictable.

Based on SPI value, the number of drought years has been increasing through time and the study area has encounter successive years of drought particularly since 1990s. Mean annual rainfall have decreased, on average, by 162.0 mm/d in Adigrat to 63.0 mm/d in Wukro station. And mean Kiremt and Belg rainfall trends have decreased by 116 mm/d in Adigrat to 8.82 mm/d in Wukro and 92.0 mm/d in Atsibi to 82.4 mm/d in Wukro station in the past three decades respectively. The decline trend of annual and Kiremt season rainfall was found to be statistically insignificant except the annual rainfall of Adigrat station which was significant at 95% confidence level. Whereas, Belg season rainfall trend was found to be statistically significant decrease at 0.05 level in Atsibi and Wukro stations and non-significant in Adigrat and Hawzen stations.

The mean maximum and minimum annual temperature in the study area ranges from 22.9 ^{O}C to 27.3 ^{O}C in Atsibi and Wukro and 9.5 ^{O}C to 12.4 ^{O}C Adigrat & Atsibi and in Wukro stations respectively. The rate of change of temperature was found to be 0.17, 0.36, 0.72, and 0.86 ^{O}C per decade in Adigrat, Hawzen, Atsibi and Wukro stations for maximum temperature respectively, and- 0.29, 0.36, 0.39 and -0.17 ^{O}C in Adigrat, Atsibi, Wukro and Hawzen stations for minimum temperature respectively during the period of 1983-2011. The Mann-kendall trend analysis test result revealed that the long mean annual maximum temperature has been increasing significantly at 95% confident level in Atsibiand Wukro station and 99% in Hawzen station. Whereas no significant increase in Adigrat station. The test also shows that mean annual minimum temperature has been insignificantly increasing in Atsibi and Wukro stations and significantly decreasing in Adigrat at 99% confidence level & insignificant decrease in Hawzen station.

With regarding to perception of household communities about, 43% of respondents in Atsibi, 48% of respondents in Hawzen and 51% of respondents in Wukro perceived a non-declining Kiremt rainfall (no change trend) in the last 2/3 decades. Whereas only 48% of community households in Adigrat felt there was a declining of rainfall trend in Kiremt season. On the other hand, about 79% community households from Atsibi, 74% from Adigrat, 73% from Wukro and 81% respondents from Hawzen presumed a decline trend for belg rainfall season. Therefore, the perceptions by local community were more or less consistence with reality from Mann-kendall trend test analysis especially in the past 2/3 decades. And 57% of respondents are agree with increasing temperature trend and 32% of respondents observed there is no change temperature trend and 11% of the respondents were observed decline trend of temperature during the past 2/3 decades and this result is agreed with Mann-kendall test analysis.

Generally, from this study, it can be concluded that annual and seasonal rainfall shows negative trend. But the annual rainfall can be significant only for Adigrat and insignificant for Atsibi, Wukro and Hawzen stations. Whereas for Kiremt seasonal rainfall, it can be insignificant in all stations and for Belg rainfall, it can be insignificant for Adigrat and Hawzen and significant decrease in Wukro and Atsibi stations. The annual maximum temperature is also increasing significantly in ATSIBI, Wukro and Hawzen stations and insignificant in Adigrat station. And minimum temperature trend is insignificantly increase in Wukro and Atsibi and significant decrease in Adigrat and insignificant decrease in Hawzen stations during the period of 1983-2014.It is, therefore, imperative to adjust the agriculture activity with the variability situation and design planned climate change adaptation strategies so as to enhance the adaptive capacity and resilience of rainfed dependent small holder communities/farmers.

6. REFERENCE

Ademe mekonnen. 1998. International Rainfall Variability over the Horn Africa. MSc Dissetation, University of Reading, Reading, UK.

Beltrando, G. and Camberlin, P. 1993. International variability of rainfall in the eastern horn of Africa and indicators of atmospheric circulation. International Journal of Climatology 13: 533-546.

Bekele, F. 1992. Ethiopia Climate and Seasons. http://ccb.colorado.edu/ijas/ijasno2/bekele.html, Addis Ababa, Ethiopia.

Misgina Gebrehiwet Abrha and S. Simhadri 2018.Local climate trends and farmer's perception in southern Tigray, northern Ethiopia

Admassie, A. & Adenew, B. (2007). Stakeholders' Perceptions of Climate Change and Adaptation Stratgies in Ethiopia. EEA Research Report. Addis Ababa, Ethiopia: Ethiopians Economic As-sociation

Bewket, W. (2009). Rainfall variability and crop production in Ethiopia Case study in the Amhara region. In H. A. Svein Ege (Ed.), Proceedings of the 16th International Confere- nce of Ethiopian Studies, (pp. 823-836). Trondheim

Blackwell, P. (2012). Kendall's Tau. Retrieved 0414, 2013, from http://www.blackwellpublish ing.com/specialarticles/jcn_10_715.pdf

Dereje, A., Kinde, T., Girma, M., Birru, Y., & Wondimu, B. (2012). Variability of rainfall and its current trend in Amhara region, Ethio- pia. African Journal of Agricultural Research,7(10), 1475-1486

DPPC. (2004). Ethiopian Early Warning System.Addis Ababa - Ethiopia: Disaster Preven-tion and Preparedness Commission (DPPC), June,2004

Burton, I., Diringer, E. and Smith, J. (2006): Adaptation to climate change: international policy options; pew center climate change, Arlington, Virginia,

Cheung, W.H., Senay, G.B. and Singh, A. 2008.Trends and spatial distribution of annual and sea-sonal rainfall in Ethiopia. International Journal of Climatology28: 1723– 1734. (www.international sciencewiley.com). Accessed on October 10, 2014

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

Conway, D. and E.L.F. Schipper.2011. Adaptation to climate change in Africa: challenges and op-portunities identified from Ethiopia. Global Environmental Change, 21(1), 227-237.

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

FAO. (2009). FAO/WFP Crop and Food Security Assessment Mission to Ethiopia, special re- port. FAO Global Information and Early Warning System on Food and Agriculture FAO/World Food

Programme 27 July 2009

Deressa T, R.M., Hassan, C., Ringler, Tekie Alemu and Mahmud Yesuf, 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environmental Change, 19: 248-255.

Eriksen, S., & Noess, L. O. (2003), Pro-Poor Climate Adaptation: Norwegian Development Cooperation and Climate Change Adaptation: Oslo. Norwegian Agency for Development Cooperation.

Feyera Liben M., Charles Wortmann S. and Kindie Fantaye T. 2015. Risks associated with dry soil planting time in Ethiopia. International Journal of Agronomy and Agricultural Research, ISSN: 2223-7054 (Print) 2225-3610 (Online) http://www.innspub. Net Vol. 6, No. 4, p. 14-23, 2015

Funk, C., Senay, G., Asfaw, A., Verdin, J., Rowland J., Korecha, D., Eilerts, G., Michaelsen, J., Amer, S. and Choularton, R. 2005.Recent drought tendencies in Ethiopia and Equatorial Subtropi-cal Eastern Africa. FEWSNET Report Number 01/2005.

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

Girma M. 2005. Using Climatic Outlook to Advice on Sorghum production in the Central High- land Rift Vally of Ethiopia. PhD dissertation submitted to the Department of Soil, Crop and Cli-mates Sciences, University of Free State, South Africa.

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

Hadgu, Kindie Tesfaye, Girma Mamo and Belay Kassa4., 2012. Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception

Hadgu Gebre, 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 Gebre, Testate, K. and Mamo, G., 2014. Analysis of climate change in Northern Ethiopia: implications for agricultural production. Theoretical and Applied Climatology ISSN 0177-798X.Vol.117: P 3-17.

Houghton, J. T., Ding, Y. D. J. G., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., and Johnson, C. A. 2001. Climate change: Contribution of Working Group I. 41

Hulme, M. 1987. Secular changes in wet season structure in central Sudan. Journal of Arid Environment 13: 31-46.

Meze-Hausken, E., 2004. Contrasting climate variability and meteorological drought with per- ceived drought and climate change in northern Ethiopia. Clim. Res. 27, 19–31.

Mugalavai, E.M., Emmanuel, C., Kipkorir, E.C., Raes, D., Rao, M.S., 2008. Analysis of rainfall onset, cessation and length of growing season for western Kenya. Agric. For. Meteorol. 148, 1123–1135

NMSA (National Meteorological Services Agency). 1996.Climate and Agro-climatic Resources of Ethiopia. Meteorological Research Report Series.Vol.1, No. 1, Addis Ababa.

NMSA (National Meteorological Services Agency). 2001. Report submitted to initial national communication of Ethiopia to the United Nations Framework Convention on Climate Change, Ad-dis Ababa, Ethiopia.

NMSA. 2005. Agro meteorological Bulletin Seasonal Agro Meteorological Bulletin Belg, 2005, Volume 15 No. 15, Addis Ababa, Ethiopia

Oxfam, (2006). Causing Hunger: An Overview of the Food Crisis in Africa. Briefing Paper. 39 pp.http://www.oxfam.org/en/policy/briefingpapers/bp91_africa_food_crisis.

Philander, S. and G. H. 1990. El Niño, La Niña and the Southern Oscillation. Academic Press Inc.: San Diego, California. Pp293.

Segele Z. T. and Lamb. J. 2005.Characterization and variability of Kiremt rainy season over Ethi-opia. National Meteorological Services Agency of Ethiopia, Addis Abeba, Ethiopia and Cooperative Institute for Mesoscale Meteorological Studies and School of Meteorology, Norman, OK, USA. Meteorology and Atmospheric Physics 89: 153–180.

Seleshi Y, Zanke U (2004). Recent changes in rainfall and rainy days in Ethiopia. Int. J. Climatol. 24:973-983.

UN-OHRLLS, (2009). The impact of climate change on the development project of the least de-veloped countries and small island developing states.

UNFCCC, (2007). Climate Change: Impacts, Vulnerabilities and Adaptation in DevelopingCountries.UNFCCCSecretariat,Bonn.http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/txt/pub_07_impacts.pdf.

Viste E., Korecha D, and Sorteberg, A. 2012. "Recent Drought Precipitation Trends in Ethiopia." Theoretical and Applied Climatology, Springer-Verlag. Odi: 10.1007/s00704-012-0746.

Van Emden, H.F., S.L. Ball and M.R. Rao. 1988. Pest disease and weed problems in pea lentil and faba bean and chickpea. p. 519-534. In: R.J. Summerfield (ed.), World Crops: Cool Season Food Legumes. ISBN 90-247-3641-2. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Woldeamlak, B. 2009. Rainfall variability and crop production in Ethiopia Case study in the Amhara region in: Proceedings of the 16th International Conference of Ethiopian.

Webb P. and Braun J. 1994. "Famine and Food Security in Ethiopia: lessons for Africa." John Wil-ly and Sons. New York. Pp. 10-56.

NATIONAL METEOROLOGICAL AGENCY

GAMBELLA REGION METEOROLOGICAL SERVICE CENTER (GRMSC)

The Effect of Climate Variability on Malaria Outbreak over Abol Woreda in Gambella Regional State of Ethiopia

Tesfahun Alemu[1] Shimelis Shiferaw[2] Tadesse Mekonen[3] Yohanis Kumsa[4]

JUNE, 2019

Acronym and Abbreviations

CQ	Chloroquine
E.C	Ethiopian Calendar
G.C	Gregorian Calendar
GPNRS	Gambela Peoples National Region State
ITNs	Insecticide Treated Bed Nets
MJJASO	May, June, July, August, September And October
NDJFMA	November, December, January, February, March And April
NMA	National Meteorology Agency
SNNPRS	South Nation Nationalities And People Region State
SP	Sulfadoxine Pyrimethamine

Abstract

In Ethiopia, malaria is seasonal and unstable, causing frequent epidemics. It usually occurs at altitudes greater thean400 m above sea level. Occasionally, transmission of malaria occurs in areas previously free of malaria, including areas less than 500 m above sea level. For transmission of malaria parasite, climatic factors are important determinants as well as non-climatic factors that can negate climatic influences. Indeed, there is a scarcity of information on the correlation between climatic variability and malaria transmission risk in Ethiopia. In general, and in the study area in particular. Therefore, the aim of this study was to determine the level of correlation between meteorological variables and malaria cases. Meteorological data obtained from National Meteorological Agency for the period of 2012-2018 and Malaria information from Gambela Town. During the last ten years (2012-2018), a fluctuating trend of malaria transmission was observed with P. falciparum becoming predominant species. Spearman correlation analysis showed that monthly total rainfall and relative humidity were positively related with malaria but monthly average temperature negative. Also regression analysis indicates that, monthly average temperature ($p = -0.40005$), relative humidity ($p=0.405$) and total rainfall ($p = 0.33$), at one month lagged effect were significant meteorological factors for transmission of malaria in the study area. The study concludes that Malaria incidences in the last decade seem to have a significant association with meteorological variables. And the study recommended that in future, prospective and multidisciplinary cooperative research involving researchers from the fields of parasitology, epidemiology, botany, agriculture and climatology is necessary to identify the real effect of meteorological factors on vector- borne diseases like malaria.

Key words Agriculture, Climatology, and Malaria

1. Introduction

1.1 Background

Malaria is a disease caused by Plasmodium falciparum parasite that is transmitted by mosquitoes and it is a disease that affects millions of people mainly in the tropical region (reference). About 90% of the reported malaria cases worldwide come from Africa. There are several species of anopheles' mosquitoes that transmit malaria in Africa, and these are namely Anopheles mosquitoes and Anopheles funfests. But Anopheles mosquitoes is the most efficient vector transmission of malaria and more than 90% of its blood meals are from human being, thus optimizing the chance of transmitting the malaria parasite (reference). In addition, parasites Plasmodium falciparum is transmitted to humans through the bite of these female mosquitoes (i.e. Anopheles mosquitoes). The disease is associated with fever, headache, chills, shivering and loss of appetite, vomiting, general body weakness and joint pains (Githeko, 2009; Makundi et al, 2006).

The interest of this research was to know if there is any relationship between malaria cases and weather parameters like increase of malaria's patients due to increase of temperature, rainfall and relative humidity in both long rainfall seasons over Abol woreda. Furthermore, after knowing the existence of their relationship, the project attempted to provide better strategies that will be used to reduce morbidity and mortality of people due to malaria like provision of treated bed nets, indoor spraying mosquitoes' killer, spraying insecticide over stagnant water, drainage of stagnant water, also to convince government to increase fund for malaria control programs. Moreover, in areas like Gambela which have intense year round transmission of malaria it is important to provide continuous anti malaria protection to pregnant women and children less than five years, which is not occurring at present. This necessary study was conducted to determine the correlation between meteorological parameters and malaria case occurrence over last seven years in study area.

1.2 Statement of the Problem

Malaria outbreak leads to increased rate of morbidity and mortality. This occurs mostly in children under five years, pregnant women and their new born because of their weaker immune systems. While the majority of healthy adults bitten up twice a day by malarial mosquitoes during rainy season and withstand the malaria parasite many children are hospitalized. Furthermore, insecticide in the vector is still a problem in Abol woreda during rainy season. On other hand sudden hot spells have strong effects which lead discomfort to people. Over study Woreda Malaria is a major threat to public health and economic development in. Current estimates indicate that most children die of malaria each year in woreda. Efforts to eradicate malaria have failed and parasite resistance to the most commonly used and affordable anti-malarial drugs is developing rapidly. Insecticide resistance in the vector is also an evolving problem. A malaria vaccine is the subject of much research but its testing is incomplete and full deployment remains a distant goal.

1.3 Objective of the study woreda

1.3.1 General objectives

The study was designed to investigate the Effect of climate Variability on Malaria Outbreak over Abol woreda in Benishangul Regional State of Ethiopia

1.3.2 Specific Objective

The study had the following specific objectives: -

- To assess climate variability impact on malaria in Abol woreda state and prepare mechanisms to reduce the impact.
- To give awareness for the community of the people at woreda the climate impact on malaria outbreak and to mitigate the climate factors and reduce malaria reproduction ways.
- To reduce information gap between the community and climate service centers.

1.4 Significance of the study

To design mechanisms of reducing climate variability impact on malaria during Kermit season. To create early warning mechanisms for climate impacts on malaria outbreak. To preparing dissemination of information about climate impact on malaria outbreak for the communities with GRMSC. Identifying climate variability impact on malaria out break and give awareness for climate varying activities and awareness creation for public about climate variability and the effect on health of human being due to malaria out breaking seasons.

2. LITERATURE REVIEW

This section review previous works that have been carried out in different study areas to determine the relationship between malaria cases and weather parameters.

2.1 Malaria cases

Plasmodium falciparum malaria is one of the major health problems in tropical and subtropical areas of the world. About two fifths of the world's population lives under constant threat of infection by the parasite. Every year 300-500 million people are infected and 1.5-3 million die. The vast majority of these are children under five years and pregnant women. Moreover, malaria continues to be a major public health burden in Ethiopia, a country with the world largest population at risk of stable malaria after Nigeria and the Democratic Republic of Congo. In addition, about 5 million Ethiopian's people are at risk with this disease while half million cases per year is among the pregnant women alone. (Mubyazi, 2005; Wort et al, 2004). The rate of development of the malaria parasite within the female mosquito and the daily survival of the vector both depend on ambient temperature. The life cycle of mosquito larvae depends on temperature, thus at temperature below 16°C development of Anopheles mosquito stops and below 14°C they die (reference). In cold temperature the larvae develop very slowly may be eaten by predators and may never live to transmit the disease. Once larvae grow to become adults, the rate at which they feed on humans is depending upon surrounding temperature (reference). The female mosquitoes (Anopheles mosquitoes) feed on humans every four days at temperature of 17°C, while at temperature of 25°C they take blood meals from humans every two days.

Thus at temperature between 16°C and 36°C the daily survival is high and rapidly drops at temperature above 36°C. Also rainfall increases the breeding habitats for mosquitoes which cause to an increase population size and rates of malaria transmission. (Githeko, 2009; Minakawa et al, 2002). However, there are many variables that affect malaria transmission in addition to climatic changes, so that changes in malaria risk must include the basis of environmental conditions like deforestation, increase in irrigation, and swamp drainage (Zhou et al, 2005). Analysis of time series and weather parameters have been conducted in many parts of the world and have indicated that increase in rainfall is correlated with change in malaria incidence which results on population dynamics of the Anopheles species mosquito vector. Additionally, vector borne diseases are influenced by temperature, humidity, surface water, wind and biotic factors such as vegetation, host species, parasites and human intervention. The rise or fall of temperature affects the life cycle of both vector species and pathogenic organisms such as bacteria and viruses and also disease transmission (Thomson et al, 2005; Darkly et al, 2005).

2.2 Mosquito life cycle

The mosquitoes require stagnant water to lay their eggs. Due to that rainfall is associated with undergoing change and development of malaria vector population and spread of the disease. So malaria vector increase during the onset of rainy season because vector breeding sites are not flushed out during the end of rainfall season (reference). Also, temperature and relative humidity plays a major part in the life cycle of the malaria vector which favors development of the parasite within the mosquito and the daily survival of the vector. On other hand low temperature and relative humidity shortens life span of the mosquitoes (Yaounde et al, 2007). All mosquitoes need standing or stagnant water to complete their life cycle.

The life cycle of all mosquitoes consists of four distinct life stages: egg, larva, pupa and adult. The first three stages occur in water, but the adult is an active flying insect that feeds upon the plant nectar or blood of humans or animals (reference). The female mosquito lays the eggs directly on water or on moist substrates that may be flooded with water. The eggs later hatch within 24-48 hours into the larva, the elongated aquatic stage most commonly observed as it swims in the water. In about 7-10 days the larva transforms into the pupa where internal changes occur for about two days to form adult mosquito. The newly emerging mosquito has to stand on still water for few minutes to dry its wing before it can fly away. When flies it seek a protective environment in the surrounding vegetation to allow its wings to complete development (Ranchi et al, 2007). Thereafter, female mosquito requires sugar solution from plant nectar throughout their life to maintain energy for flying, mating, and seeking hosts for blood meals several days after emerging from water. This female mosquito takes a blood meal because needs extra protein to develop her eggs. On other hand, male mosquitoes do not bite humans except they feed only on plant nectar. Male mosquitoes have a life span of one or two weeks while female mosquitoes can live for a period of four weeks and producing multiple batches of eggs (Ranchi et al, 2007).

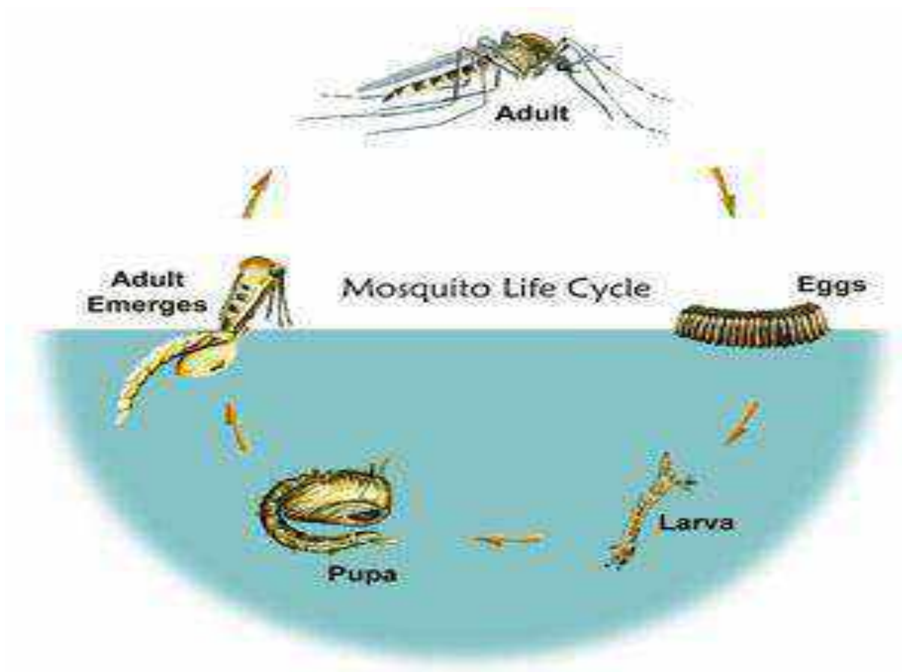


Figure 1. Stages of mosquito life cycle. (Source: Ranchi et al, 2007)

2.3 Stages of plasmodium malaria parasite

Plasmodium requires two hosts (human and mosquitoes) to complete its life cycle. When female Anopheles mosquito bites a healthy human being, it releases Plasmodium, which lives in its body as sporozoite (infectious form). The parasites initially multiply (asexual reproduction) within the liver cells and then attack the red blood cells (RBCs) resulting in their burst. Thereafter bursting of red blood cells (RBCs) is associated with release of a toxic substance called haemozoin which is responsible for the chill and high fever recurring every three to four days. In the RBCs, sporozoites change into gametocytes (sexual stage) which then multiply. When a female Anopheles mosquito bites an infected person, these parasites (gametocytes) enter the mosquitoes' body and undergo further development. Also the Gametocytes multiply and develop inside the intestine of mosquito to form sporozoites that are stored in their salivary glands. When these mosquitoes bite a human, the sporozoites are introduced into his/ her body, thereby initiating malaria (Roy, 2006).

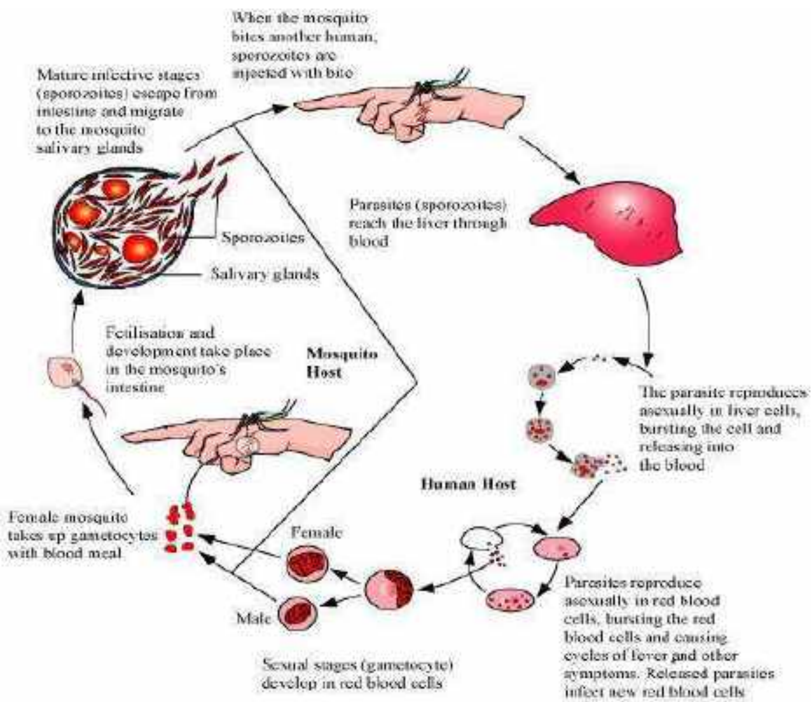


Figure 2. Stages of Plasmodium malaria parasite (Source: Roy et al, 2006)

3. Data and Methodology

3.1 Description of the Study Area

The study has been conducted Ethiopia in Gambela Region, one of the regional states of Ethiopia situated in south-western part of Ethiopia. In this regional classification, the Gambela Regional State has been established as the Gambela Peoples' National Regional State (GPNRS) with the power and authority of exercising self-rule, self-determination and governance. Administratively the region is divided in to three nationality Zones, thirteen districts and one Town administration. The Agnwa Zone: consists of Gog, Abobo, Jor, Gambella and Dima districts/werdas. The Nuar Zone: consists of Jikaw, Lare, Makuey, Wanthwoa and Akobo districts/werdas while, the Majang Zone: consists of Meti and Mangashi district/werdas. In addition to these, the Itang special district and Gambella Town Administration are among the fourteen district of the region. They all comprise a total of 258 local kebele administrations.

The Gambella People National Regional State (GPNRS) is located in the south western part of Ethiopia about 766 kilo meters from Addis Ababa. It is situated in the low lands of Baro-Akobo River basin between 6°22'and 8030'N latitude and 33°10'and longitude. The Region shares boundary with Beneshangul Gumuz and Oromiya region in the north, Southern Nations Nationalities and People Regional State (SNNPRS) and South Sudan Republic in the south and Oromiya National Regional State and southern Nations, Nationalities and People Regional State in the east and South Sudan Republic in the west. The region has five indigenous ethnic groups namely Agnua, Nuer, Majang, Komo and Opo; besides, other Nation Nationalities and people coming from high lands are living together, collaboratively in harmonization and synchronization.

The region has a total area of approximately 34,063 square km or 3,203,380 hectare of land. According to the Central Statistical Agency Abstract (2011) which was calculated based on the 2007 Population and Housing Census, the population of the region is now estimated to be 368,999. The urban and rural distribution of population of Gambella region indicates that the overwhelming majority of the population is living in rural areas. The population density has increased from 10 in 2007 to 12.5 people per sq km in 2009(DHS 2005). Animal husbandry is the main economic activity of the region. Also subsistence farming, traditional fishing, hunting, gathering of wild animals and plants are used as source of living in the rural parts of the region (GRDPPA, 2006).

3.2 Climate characteristics of study area

Despite the variation of climatic conditions throughout the year, the weather is not attractive because of its low altitude. Gambela experiences average daily temperature of 32°C to 38°C degrees centigrade with a daily range of about 1.2°C centigrade. The highest temperature occurs in January, February, March, and April during which the mean maximum temperatures are about 38°C centigrade. The minimum temperatures are in June, July and August when the temperatures go down to about 17°C centigrade. The mean relative humidity is about 70% and drops down to as far as 47%. The total average annual rainfall ranges between 821 mm to 1,200 mm. Long rains occur between May, June July, August, September, and October (MJJASO) and long dry occur between November, December, January, February, march, and April (NDJFMA) each year. Furthermore, the major economic activity over Gambella region is agropastural and Animal husbandry is the main economic activity of the region. Also subsistence farming, traditional fishing, hunting, gathering of wild animals and plants are used as source of living in the rural parts of the region (GRDPPA, 2006).

3.3 Data collection

Malaria microscopically confirmed positive malaria cases were obtained after the permission reported to woreda health office. Therefore, for this study, seven years (2012) monthly malaria cases series data were obtained from Abol woreda heath offices which were reported from health centers, clinics and hospitals. Meteorological data collected from the Gambella regional Meteorology service center and head office of NMA, the previous seven years (2012-2018) monthly minimum, maximum, total rainfall and relative humidity of the town was obtained.

During malaria data collection, any malaria intervention activities that had been taken in each year to control malaria were collected using a well-prepared checklist from different responsible offices agencies or individuals in order to minimize the confounders that can negate meteorological influences. But in the study area there were no special factors that attribute the increased or decreased occurrence of malaria cases. Again, other factors like antimalarial drug resistance of the study area were obtained from Hinari and Enterz-PubMed web site and through personal communication.

In the study area, Coartem was the most abundant and commonly used antimalarial drug until resistance was reported. In Ethiopia, the increased resistance of P. falciparum to Chloroquine (CQ) and sulfadoxinepyrimethamine (SP) necessitated a change as first-line antimalarial drug for the treatment of

P. falciparum. Consequently, Artemether/Lumefantrine (Coartem (AL) was adopted in 2004 but it became available in all regions of the country in 2005 [27-29]. Currently the common drug used for treatment of P. vivax malaria in the study area and throughout country is Chloroquine because data on Chloroquine resistance to P. vivax is malaria is not sufficient enough to warrant a change. Again, in the study area P. vivax is the common malaria species and self-treatment is also common, so there is a danger that P. vivaxi has developed or will develop the resistance to Chloroquine.

3.4 Data analysis

Average yearly mean temperature, total rainfall and relative humidity and total malaria positive case (January through December for each year) were calculated. All data from meteorological and clinical records were checked for completeness and cleaned of any inconsistencies. The data were entered to Excel 2007 to observe the correlation between meteorological variables and malaria cases, the monthly malaria cases were regarded as the dependent variables, while meteorological variables such as monthly mean temperature, total monthly rainfall and monthly relative humidity were independent variables.

Spearman correlation analysis was conducted to examine the type and strength of relationship between meteorological variables and malaria cases. Then to observe independent effect of each independent variable on outcome, variable linear regression was fitted. Since there might be autocorrelation among independent variables over time, autocorrelation analysis was conducted. When the correlation coefficient for the association between these independent variables was large than 0.5, these variables were analyzed in different regression model to reduce multi collinearity. The distribution of malaria and meteorological data was examined and all were approximately normally distributed.

4. Result and Discussion

4.1 Annual trends of malaria cases in Abol woreda

CA fluctuating trend of malaria cases reported through the years 2012 to 2018 was observed. An increase in malaria cases occurrence from 2012-2014 with peak cases occurring in 2014 and malaria cases were reduced the following two years (2015 and 2018) then raised (2016 and 2017) but a remarkable increase peak in monthly June 2017 was observed. During the last seven years, a total of 52189 microscopically confirmed malaria cases were reported in the town with the annual total cases of malaria ranged from 5088in 2012to 10750 in 2014 with 7456 mean annual malaria cases occurring. There was statistically significant inter annual variation of malaria cases occurrence in the study area ($p = 0.007$) (Figure 4). A high fluctuation of malaria cases at species level was also observed with statistically significant ($p < 0.001$) inter- annual variation of both P. vivax and P. falciparum malaria cases occurrence. With the exception of some years, a high predominance of P. falciparum over P. vivax was observed within the last seven years. Thus the remarkable increment in total malaria cases was mainly due to the increment of P. falciparum rather than P. vivax.

4.2 Monthly and seasonal variation of malaria cases in Abol woreda

2012-2018 despite the apparent fluctuation of malaria trends in the study area malaria cases occurred in almost every month of the year. The highest peak of malaria cases in almost all years was observed during June with exception that in 2014 the highest cases were observed during October. There was statistically significant variation of monthly malaria cases occurrence ($p = 0.036$) (Figure 3). The season with the highest average total malaria cases occurrence were summery (June, July, and August) and spring (September, October and November) and the minimum malaria cases was observed during winter (February, march, and April).

For total malaria cases, the seasonal variation was statistically significant ($p = 0.007$). At species level, both P. vivax and P. falciparum maximum cases were observed in spring followed by summery (June, July, August and Sep) and the minimum being during winter (February, March, and April).In all seasons P. falciparum cases were higher than P. vivax. In years of high malaria cases, the summery peak was more pronounced when compared with other seasons of years.

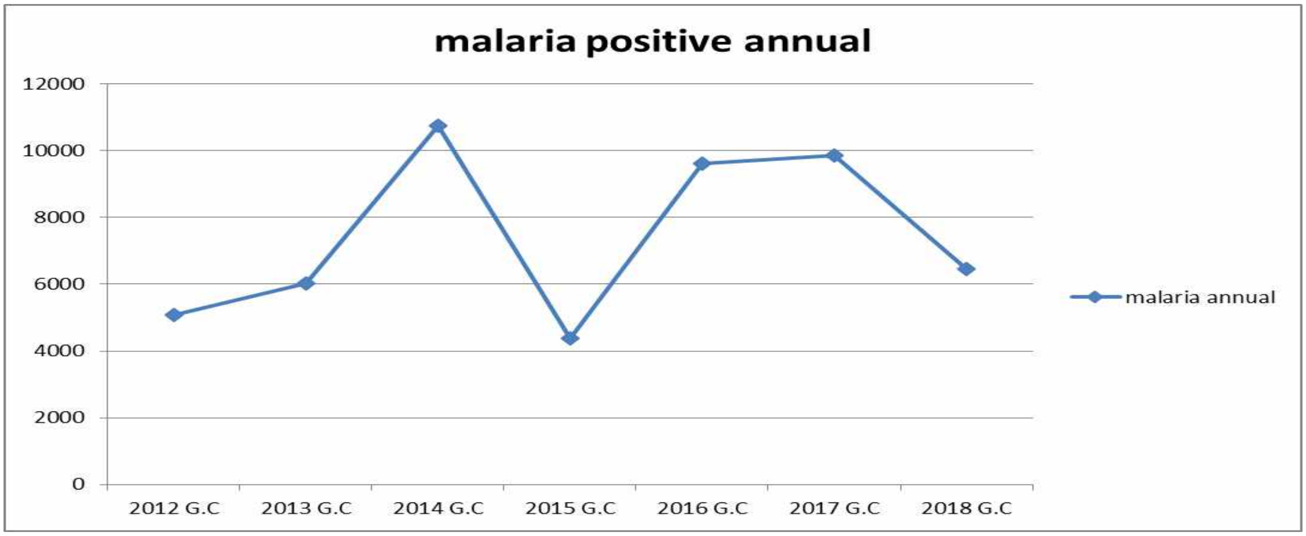


Figure 14. Annual trends of total malaria cases

Annual trends of total malaria cases in Abol town, 2012-2018 the figure shows that an increase in malaria cases occurrence from 2012-2014 with peak cases occurring in 2014 and malaria cases were minimum in 2015.

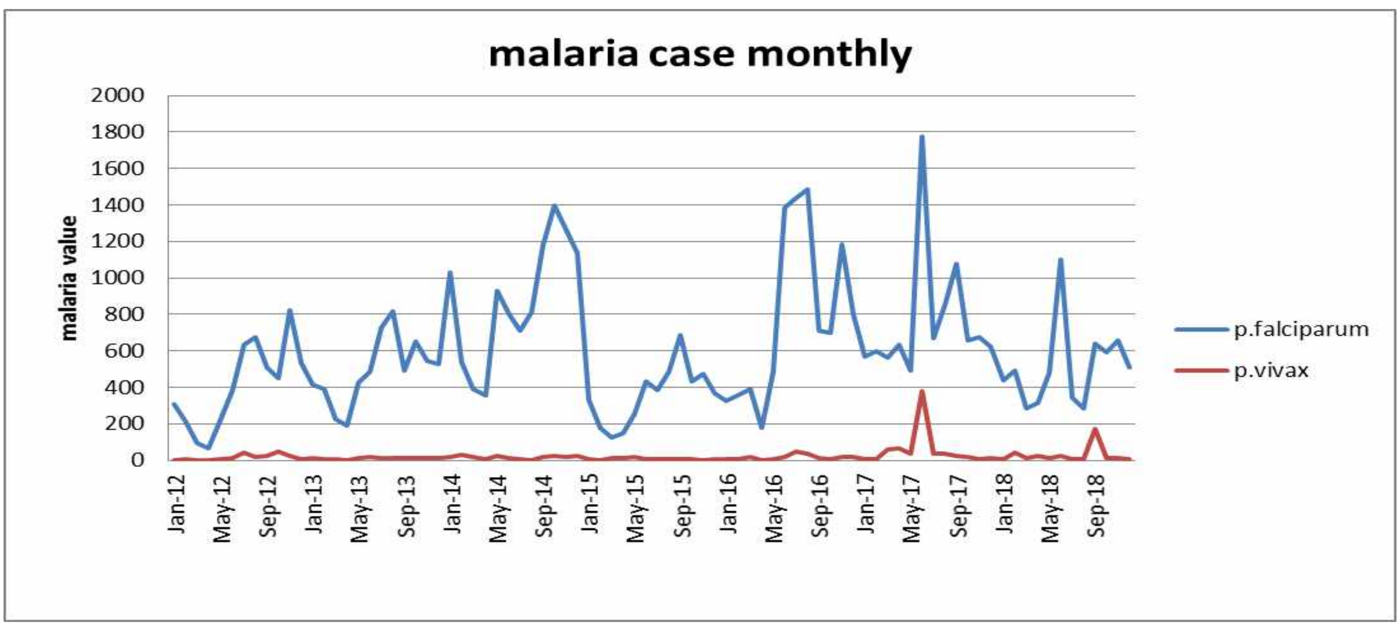


Figure 15 Relative annual trends of P. falciparum and P. vivax malaria in Abol town,

Figure 5 Relative annual trends of P. falciparum and P. vivax malaria in Abol town, 2012-2018 the figure demonstrates that a high fluctuation of malaria cases at species level in the study area. With the exception of some years, a high predominance of P. falciparum than P. vivax was observed. Thus the remarkable increment in total malaria cases was mainly due to the increment of P. falciparum rather than P. vivaxi.

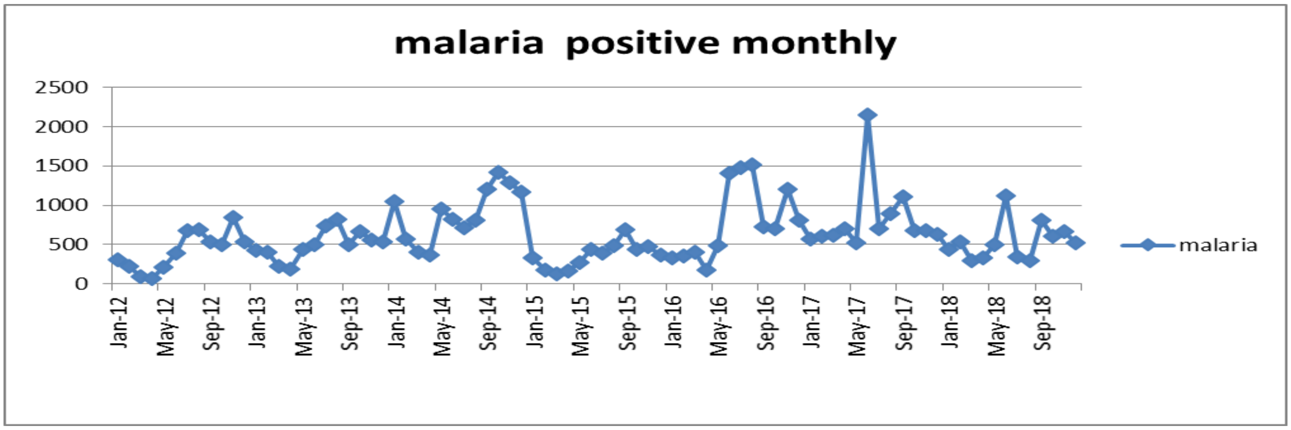


Figure 16. Figure 3 Monthly and seasonal variation of total malaria cases in Abol town, 2012- 2018

The Figure 6 indicates that in the study area malaria cases occurred in almost every month of the year. The highest peak of malaria cases in almost all years was observed during June with exception that in 2014 the highest cases were observed during October. Again the season with the highest average total malaria cases occurrence was summery (June, July, August and September) and the minimum malaria cases was observed during winter (February, March and April).

4.3 Trends of meteorological factor variations in Abol woreda

2012-2018G.CUnlike malaria cases, from 2012- 2018 there was no statistically significant inter- annual variations of all measured meteorological factors (temperature, rainfall and relative humidity) in the study area. But there were statistically significant ($P < 0.001$) inter- monthly and inter- seasonal variations among those measured meteorological variables.

The Abol woreda, annual mean temperature ranged from as low as 28.1°C in 2013 to as high as 29.5°C in 2016 and a slight fluctuating trend of temperature through the years 2012 to 2018 was observed. But a high fluctuating trend of rainfall was reported through the years 2012 to 2018 with 1163.5 mm mean annual rainfall and maximum total rainfall was observed in 2014 (1323.7 mm) and the minimum rainfall was observed in 2018 (1043.2 mm). In the last seven years, a fluctuating trend of relative humidity was observed at three different years. The average relative humidity at ranged from 49.4%

to 53.1% in the last seven years (Figure 4).

The figure demonstrates that in the town, annual mean temperature ranged from as low as 28.1°C in 20013 to as high as 29.5°C in 2016 and a slight fluctuating trend of temperature through the years2012 to 2018 was observed. It also shows a high fluctuating trend of rainfall was reported through the years 2012 to 2018 with (1163.2 mm) mean annual rainfall and maximum total rainfall was observed in 2014 (1323.7 mm) and the minimum rainfall was observed in 2018 (1043.2mm). In the last seven years, a fluctuating trend of relative humidity was observed at different years.

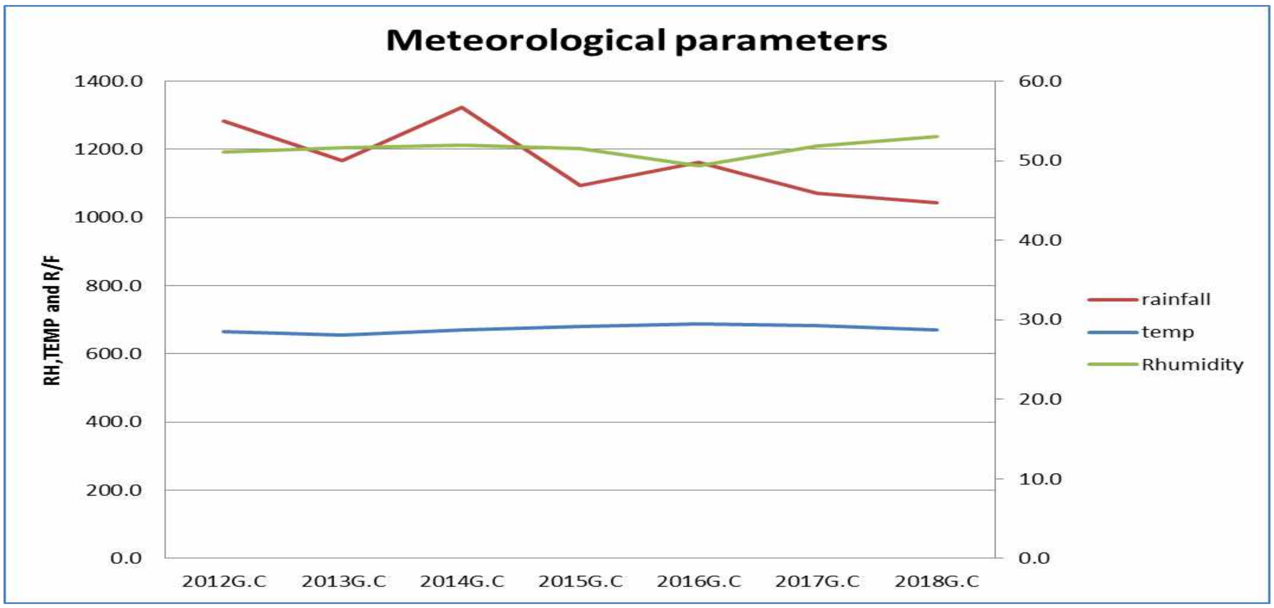


Figure 17. Annual meteorological factors variation in Abol woreda, 2012 -2018.

4.4 Correlation between malaria cases and meteorological variables

An association between monthly malaria cases and meteorological variables (temperature, rainfall and relative humidity) was observed. However, there was high simple relationship between monthly total rain fall and monthly total malaria cases than other meteorological variables in the study area (Figure 5). These relationships among malaria and meteorological variables were father checked by Spearman's correlation and linear regression analyses.

Spearman's correlation analyses were conducted relating both monthly total and each species of malaria cases to various meteorological measures (mean temperature, total rainfall and average relative humidity) at both a zero-month effect and one month lagged effect. At zero-month effect, none of meteorological variables was statistically significantly correlated with malaria. Monthly mean temperature was negatively correlated with monthly total malaria cases occurrence but other variables were positively related (Table 1).

Table 1. Correlation between meteorological variables and monthly total malaria cases, one month lagged effect in Abol woreda, 2012-2018G.C

Meteorological Parameters	Multiple R	R Square	P-Value	Correlation Coefficient
Mean Temp	0.400052	0.160042	0.000163	-0.40005
Total Rainfall	0.326597	0.106665	0.00243	0.326597
Mean Relative Humidity	0.404875	0.163923	0.000133	0.404875

Unlike the relation between total monthly malaria cases occurrence and meteorological variables at zero-month effect, there was statistically significant (p =0.000163) positive correlation between the variables were not likely to yield equations or models that are useful for predicting malaria cases occurrence in the study area. At one month lagged effect, monthly total rainfall was statistically significant (p = 0.00243) meteorological factors for monthly total malaria case occurrence/transmission in Abol woreda. At individual levels and together these meteorological variables gave small beta (correlation coefficient) and small R square value (the coefficient of determination).

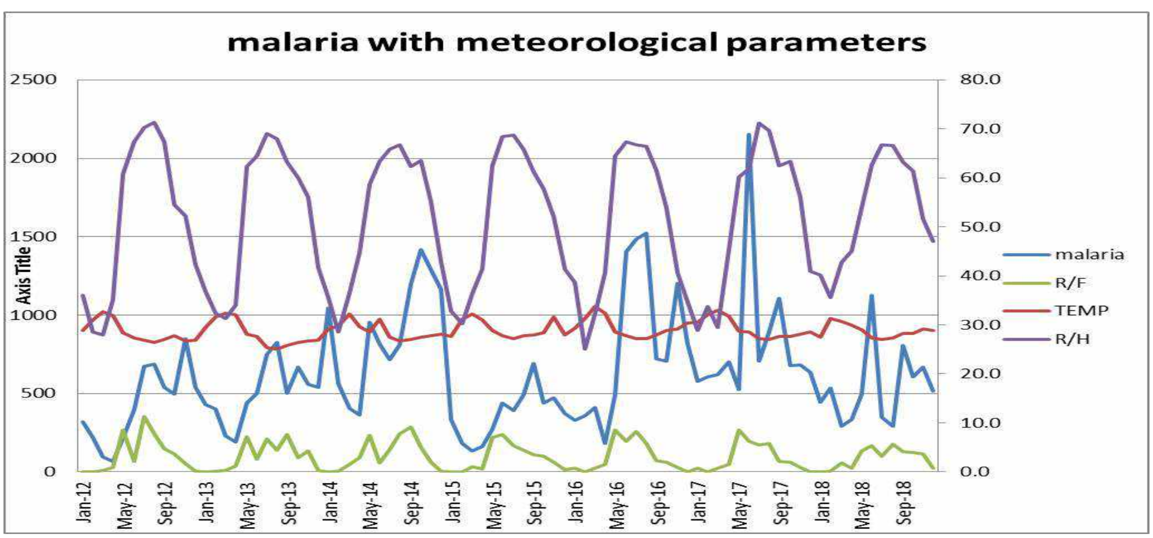


Figure 18. Relationship between monthly malaria cases and meteorological variables in Abol woreda, 2012-2018G.C.

The figure demonstrates association between monthly malaria cases and meteorological variables (temperature, rainfall and relative humidity) in the same graph. There was fluctuation of malaria cases with rainfall fluctuation in the figure. However, other Meteorological variables were less likely fluctuates.

4.5 Discussion

The transmission of malaria can be determined by climatic or non- climatic factors. But even leaving these on-climatic issues aside, the effect of climate itself on the intrinsic probability of malaria transmission, remains controversial. So, climate variability that impacts on the incubation rate of Plasmodium and breeding activities of Anopheles is considered one of the important environmental contributors to malaria transmission dynamics. For example, temperature rise is expected to increase transmission and prevalence of malaria by reducing the interval between mosquito blood meals, thus decreasing the time to produce new generations and by shortening the incubation period of the parasite in the mosquitoes. Saprogenic cycles take about 9 to 10 days at temperatures of 28°C but higher than 30°c and below 16°C have negative impact on parasite development. Also the minimum temperature for P. falciparum and P. vivax parasite development approximates to 18°C and 15°C, respectively and the daily survival of the vector is dependent on temperature as well. At temperatures between16°C and 36°C, the daily survival is about 90%. The highest proportion of vectors surviving the incubation period is observed at temperatures between 28° - 32°C.So, temperature of 20°C to 30°C and relative humidity greater than 60% are optimal for Anopheles survive long enough to acquire and transmit the parasite. The result of our study revealed that during the last seven years, a fluctuating trend of occurrence of malaria cases was observed in Abol woreda. An increase in malaria cases occurrence from 2012-2014 with peak cases occurring in 2014 and malaria cases were reduced the following years (2015 and 2018) but a remarkable increase in 2017 was observed. All year, the remarkable increment of total malaria cases was mainly due to an increase of P. falciparumwith little increase of P. vivaxi. Resistance of P. falciparum to the commonly used drug(chloroquine) during these years may have contributed to total malaria case occurrence in those years with remarkable malaria increase, from all meteorological variables only annual rainfall was increased and showed a positive relationship and it was statistically significant (p = 0.00243).

The occurrence of malaria was reduced during two years 2015 and 2018. It coincides with the increased availability of the new drug Coartem for P. falciparum malaria at national and local level. A decrease in malaria cases occurrence after the 2014 maximum occurrence was observed. This study was increasing attention to malaria control and preventive activities by different responsible bodies, increasing awareness of the community on use of ITNs and other malaria control activities. Increased accessibility of ITNs to community, increment of budget for malaria control and prevention activities (personal communication and data not shown) might contributed the decrement in malaria case occurrence in addition to meteorological factors. It is likely that the excessive flooding due to heavy rains in 2014 might have also impaired mosquito breeding and flushed out the mosquito larvae. From all the months, the highest monthly malaria cases occurrence was observed during June in 2017 which was the main contributor for 2017 annual malaria cases increase. In this month a small increase of minimum temperature during September after summer rainfall, because correlation analysis at one month lagged effect Minimum temperature, was the first meteorological variable that significantly affects malaria transmission in the study area. Some other non-climatic factors, such as road constructions and some other activities in the town which increased the number of breeding sites of mosquitoes might have contributed to the peak malaria occurrence (personal observation) or it might be due to increase of temperature from 28.5°C in 2012 to 29°C in 2014 or annual rainfall was increased from 1116 mm in 2012 to 1323 mm in 2014 or might be due to resistance of P. vivax for currently available drug (chloroquine) in the market.

According to correlation findings, monthly maximum and mean temperature at zero-month effect and maximum temperature at one month lagged effect were negatively correlated but other meteorological factors were positively related with total monthly malaria case occurrence. The finding implies that meteorological variables can affect malaria transmission either positively or negatively even if the correlation was less likely linear.

This finding contradicts with the findings in Shuchen County, China and Highlands's of Madagascar which showed that all meteorological variables are positively correlated with malaria. The present study was undertaken at different altitude in Abol. Correlation between malaria and climate vary with altitudes. The correlation coefficient for the association between monthly malaria cases and some meteorological factors was greater than other meteorological factors. This indicates that one meteorological factor plays greater role in malaria cases occurrence or transmission than others which coincide with the finding from Dehradun, Uttaranchal, India [19] Shushes county, China, Rwanda, Madagascar and east Africa Highlands. In this study, the correlation coefficient for the association between monthly mean minimum temperature and monthly malaria cases was greater than that of the correlation coefficient for the association between any other measured meteorological variables and monthly malaria cases. Our results suggest that mean minimum temperature was the most significant factor that correlated with malaria transmission dynamics in the study area. The results of a similar study conducted in Rwanda suggested that monthly malaria cases occurrence or incidence in high altitude regions is related to change in minimum temperature, while in low altitude zone rainfall and mean minimum temperature was the most significant meteorological factor. It is also similar to the findings in Madagascar; China and east African Highlands; all suggested that minimum temperature was most significant factor for malaria transmission over other meteorological factors.

Therefore, a rise of temperature, especially minimum temperature, would enhance the survival of Plasmodium and Anopheles during different seasons and thus accelerate the transmission dynamics of malaria and spread it into populations that are currently malaria free and immunologically naïve. The monthly total rainfall was the most significant factor that determines malaria transmission in the study area after to minimum temperature. However, the effect of rainfall on the transmission of malaria is very complicated, varying with the circumstances of particular geographical regions and depending on the local habits of mosquitoes. Rainfall may prove beneficial to mosquito breeding if moderate, but it may destroy breeding sites and flush out the mosquito larvae when it is excessive. This study indicates that total monthly rainfall was associated with occurrence of malaria in the town with a month lageffect. On the other hand, the correlation coefficients for the linear regression between the monthly mean and maximum temperature and monthly malaria cases were negative. This is important in the hot months, in which an increase in temperature would limit vector and parasite survival and therefore cause a decrease in malaria transmission rates. This finding contradicts which the findings in Shucher County, China which concluded that an increase in monthly maximum temperature should cause an increase rather than a decrease in malaria rates. This variation could be due to differences in local climatic condition in China and Abol woreda. That is the large number of months in Abol woreda that are hotter than months in China - this makes sense in the hot months, in which an increase in temperature would limit vector and parasite survival and therefore may cause a decrease in malaria transmission rate. The most likely explanation for the finding that increases in temperatures is correlated with a decrease in malaria cases is the significant autocorrelation between monthly temperatures. This hypothesis is supported by the finding of high negative correlation between temperature and relative humidity.

This indicates that, for a given amount of moisture in air, an increase in temperature cause a decrease in relative humidity, which can limit Anopheles survival. The correlation between maximum temperature and rainfall may also lead to an explanation of the negative correlation coefficient between maximum temperature and malaria cases occurrence. The negative correlation between maximum temperature and rainfall in hotter months may decrease Anopheles breeding or increase dryness which may bathe limiting factor for malaria transmission. Both the correlation and regression analyses suggests that temperature, rainfall and relative humidity act on monthly malaria case total occurrence with a lag of one month. Although all meteorological variables were less likely to predicts the occurrence of malaria in Abol woreda. This finding contradicts the findings in Dehradun, Uttaranchal, India, such as County, China, Rwanda, Madagascar and east Africa Highlands which concluded that at one month lagged effect meteorological variables were highly likely correlated with malaria occurrence and the prediction was higher than this finding with higher R square value.

This variation might be due to the fact that this study was conducted in lowlands in which malaria is endemic. In lowlands, the factors that contribute to malaria transmission dynamics are microclimate variation due to anthropogenic effects and other non- climatic factors like, health system, population growth, population movement and others. At zero-month time effect none of meteorological variables were statistically significantly correlated with monthly P. falciparm cases occurrence and total monthly malaria cases but there was statistically significant positive correlation between monthly P. vivax cases and minimum temperature and statistically significant negative correlation between monthly P. vivax case occurrence and maximum temperature. This might be due to the fact that P. vivax requires a little lower temperature than P. falciparum. Thus, minimum temperature variability could have more effect on P. vivaxthan P. falciparm by shortening the extrinsic phase and little change in maximum temperature have more negative effect on the development of P. vivax than P. falciparum. Seasonality and year (time trend) played a role in the transmission of malaria in the town. From the time series analysis, none of the measured meteorological variables were able to predict malaria transmission dynamics.

In general, there was a fluctuation in malaria cases during the last seven years. Many factors might be responsible for seasonal changes, e.g., climatic variables, ecologic and environmental factors, host and vector characteristics, and social and economic determinants such as change in health care infrastructure. Thus the range of vector borne disease is not solely determined by meteorological variability. Social, biological and economic factors such as mosquito control measures, population immunity, local ecological environment (vegetation, introduction of irrigation), governmental policy, availability of health facilitates and drug resistance have also an impact of malaria transmission dynamics. Also in the study there were different malaria control activities in each year like insecticide spraying, elimination of mosquito breeding sites, health education about malaria distribution of ITNs and some malaria drugs and other activities to decrease mortality and morbidity of malaria.

5. Conclusion and Recommendation

In Ethiopia malaria is the leading health problem where it accounts for the most outpatients and inpatients hospital attendances and is among the leading causes of hospital deaths for all ages in the country, and the most vulnerable groups are children under five years and pregnant women. Normally malaria cases increase during the rainy season. For Abol woreda this situation occurs during the months of May to October (MJJASO) and to a less extent during NOVEMBER to APRIL (NDJFMA) when the area receives long rains and long dry seasons. Gambela region is situated south western part of Ethiopia and is an area with holo endemic malaria transmission with seasonal peak. Furthermore, wet years occurred in Gambela rainfall were above normal that caused floods to most parts of Gambela region. The heavy rainfall and floods increase the spreading of insect-borne diseases such as malaria. Malaria epidemics occur when weather conditions favor this vector borne disease, and the highest peaks of malaria cases in Abol woreda occurred in long rainfall seasons on June and in short rainfall on month of April. Therefore, the purpose of this study was to investigate the relationship between malaria cases and weather parameters over Gambela region.

The goals of malaria control may never be achieved without strong involvement of those scientists who are directly affected by this terrible disease in their daily life. Until recently, true participation of African scientists in the international effort to control malaria has been minimal sequenced malaria genome, novel biochemical drug targets unique to malaria parasites have been discovered (e.g., apicoplast enzymes) and new compounds have entered clinical trials. The investigations of human and parasite gene polymorphisms related to the pathogenesis of severe malaria in children with different genetic backgrounds, in ethnic groups and with hemoglobin apathies conducted in different sites in Africa have provided morbidity and mortality data that can be used by national and local decision makers as prognostic markers and for guidance in patient management. Nevertheless, translation of the findings on human and/or parasite genes to immediate interventions in the field remains a big challenge Even though the result of trend analysis found that meteorological variables were less likely linearly correlated and predicts malaria cases occurrence in the study area, the changes in the current month meteorological factors would have effects on next month malaria case occurrence that provides an early warning which enables the health care system to be well prepared and to allocate scarce resource effectively to reduce mortality and morbidity of malaria. In the study area to decrease morbidity and mortality of malaria more attention should be given to microclimate change due to anthropogenic effect and other non- climatic factors that affects malaria transmission dynamics rather than meteorological variability due to global warming or climate change. In general, transmission of malaria is very complicated and detailed ecological and epidemiological studies are still needed to assess the true local risk. Further studies that account for all possible confounding factors and that are done at a smaller spatial scale, will improve our understanding of which factors will most affects malaria transmission dynamics in the study area.

6. REFERENCE

Drakeley C.J, Carneiro I, Reyburn H, Malima R, John P.A, Lusungu J, Theander G.T, Nkya W.M, Lemnge M.M, & Riley E.M. 2005. Relationship between altitude and intensity ofmalaria transmission in the lowlands, Ethiopia. Journal of Medicine and Entomology, 40:706-17.

Githeko, AK. 2009. Altitude dependent and Independent variations in Plasmodium falciparum prevalence in Northern Tanzania. Journal of Infectious Diseases, 15:89-98.

Makundi EA, Malebo HM, Mhane P, Mitua AY, Warsame M. 2006. Malaria and climate change. Centre for Global Health Research: Kenya Medical Research Institute. 40-43.

Minakawa N, Sonye G, Mogi M, Githeko A, Yan G. (2002). . Morogoro Municipal Council. (2008). United Republic of Ethiopia, Morogoro Municipal Profile. Journal of Malaria, 5:58

Msemo, H.E. 2010. The effects of climatic factors on the distribution and abundance of malaria vectors in Kenya. Journal of Medicine and Entomology, 39: 833-41.

Mubyazi G, Boch P, Kamugisha M, Kitua A, & Ijumba A. 2005. Association between climate variability and malaria risk in Ethiopia. Msc thesis Department of Meteorology, University of Nairobi.

Renchie, D, L. & Johnsen M. 2007. Chlorprogua dapsone for treatment of drug-resistant f alciparum malaria in Ethiopia. Lancet 358: 1218– 1223

Roy, H. E., Steinkraus, D. C. 2006. Mosquito life cycle. United States: University of Arkansas cooperative extension services Bizarre interactions and endgames: entomopathic fungi and their arthropod hosts. Annual Review of Entomology, 51: 331-35

NATIONAL METEOROLOGICAL AGENCY EASTERN AMHARA
METEOROLOGICAL SERVICES CENTER

Assessing the Effect of Rainfall Variability and Farmers Perception on Teff Production: A Case Study in Guba Lafto Districts, North Wollo Zone, Ethiopia

WAGAYE BAHIRU
ENDALAMAW WENDE
LUBABA MOHAMMED
HASSEN ADEM
YIMER MOHAMMED
YILMA DEMSSIE

JULY 2019
COMBOLCHA,
ETHIOPIA

Abstract

Agriculture of Ethiopia highly depends on rainfall which is affected by climate variability and change. This study assessed the variability of rainfall and its impact on Teff production over Guba Lafo district. This study composed of two components which are determining the climate variability, trend and its impact on Teff production as well as community perception on climate variability. The analyzed result showed that rainfall trends showed decreasing in belg while increasing in both annual and kiremt. However; the detected trends are non-significant in the time series. Over the last periods trends of rainfall events such as onset date, cessation date and length of the growing period were changed non-significantly in the study area. The variability of seasonal rainfall causes fluctuations in production of major crops. Due to high correlations between crop production and seasonal rainfall, small changes in amount and distribution of seasonal rainfall causes significant negative impacts on crop production that varies from reduced yield to the total loss of the crop. As result Teff production exhibits the largest year to year variations in study area. This high inter-annual variability is caused by rainfall variability where in the rainfall components of amount of rain, number of rainy day, onset and cessation date and length of growing period often play the biggest role. The result of the regression analysis shows rainfall characteristics contributed 86% in explaining the variations in the yield of Teff per hectare in the study area.

1. Introduction

1.1. Background

Agriculture plays a dominant role in the economy of Ethiopia, contributing 41% gross domestic product (GDP), 80% of the employment and the majority of foreign exchange earnings (Gebre-egziabher et al., 2011). It is a challenge to access climate information relevant to agricultural activities to enable the farmers to make prior decision about which crops to plant, where to plant and whento plant will increase the ability of agricultural sector to make informed decision (Zermoglio, 2011). Climate variability plays a great role in agricultural production having a direct impact from the start of land preparation to the final harvest (Mesike and Esekhade, 2014). According to Deepaket al. (2015) averaged globally over Africa, find that 32–39% of the maize, rice, wheat and soybean year-to year yield variability was explained by rainfall and temperature variability. Crop yield varies from season to season owing to variation in climate during the growing seasons (Bewket, 2009; Ayalew et al., 2012; Hadgu et al., 2013). The main weather parameter affecting crop growths are rainfall, temperature and radiation (Hadgu et al., 2014). Having knowledge on sequences of rainfall variability, events can assist acquiring specific information for agricultural planning (Mandal et al., 2013). Within variable seasonal rainfall patterns, understanding the events of the occurrence of rain features like; onset and end date of rainy season, dry spells are crucial to decrease the adverse effects and exploit opportunities (Yemenu and Chemeda, 2013).The study of past and future inter seasonal rainfall variability in terms of onset, end date and length of rainy season, number of rainy days, length of dry spell within the growing period and its trend is important for agricultural purposes in the dry land area than annual and seasonal totals (Hadgu et al., 2013).

Ethiopia 's climate is prone to both extended rainfall deficits and excesses (Korecha, 2013). Rainfall is a critical climatic element which means that the main source of water for crop production as irrigation covers only 5% of the cultivated land in the country (Awulachew et al., 2010). Most of the study revealed that agricultural sectors of the country have been highly affected by climate related hazards (NMSA, 2001). Studies in Ethiopia have shown that the causes for rainfall variability are erratic nature of rainfall; distribution; late onset and early offset contribute to decline in crop yields with reasonable amount in almost all parts of the country (Godswill et al., 2007). Similarly, Bewket (2009) stated that rainfall variability has historically been found as a major cause of food insecurity in Ethiopia. Assessing the characteristics of temperature and rainfall for a location is useful for choosing the most appropriate enterprises, and the most productive plant cultivars (Mavi and Tupper, 2004). In recent years, a case study made in parts of Ethiopia by Stefan and Krishnan (2000) suggested that 50 percent below average rainfall would give a poverty rate of about 60 percent. Other study examined the impact of rainfall variability on the Ethiopia economy, and found that rainfall variability in the country led to a production deficitof20%, and increase in poverty rates by25% which coasted by the economy over one-third of its growth potential (Hagos et al., 2009). According to Muluneh (2015), mean annual rainfall of 882.3 mm with CV range of 12 -15% and SD rang of ±94mm-±130.5mm in the North Eastern Amhara (NEA) during the period of study (1992-2012). In north eastern Ethiopia experienced moderate rainfall variability and less stability of rainfall 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 (Muluneh 2015, Hadgu et al. 2013, and Bewket, 2009). Ethiopia's Teff is the most ancient indigenous staple food, is one of the most important crops for farm income, food and nutrition security in Ethiopia. It is gluten-free, rich in phosphorous, copper, aluminum and thiamine and is an excellent source of protein, amino acids and carbohydrates. Teff is higher in calcium, iron and zinc content than corn, wheat, or rice (Baye, 2014). Being labeled as one of the latest super foods of the 21st century, like the ancient Andean grain quinoa, Teff's international popularity is rapidly growing (Collyns, 2013). In Ethiopia, Teff is the first in terms of area coverage produced by 6.6 million holders and its production is 44.7 million quintals from 2.9 million hectares of land. Teff gives the national average grain yield of 15.4qt/ha (CSA, 2015). In Guba- lafto district, teff is the first produced production covers4, 345.5 hectares and produce 69,790.3 quintals (SWZAO, 2018).

1.2. Statement of the problem

Ethiopia is facing its worst drought in decades because of a strong El Nino weather phenomenon which irreducibly 20-60% rainfall amount at northern, northeast and central highland of Ethiopia (Korecha, 2013). The seriousness of the food shortage problem varies from one area to another depending on the local climate variability and state of the natural resources. For the past three decades' food shortage records included 1984/85, 1994/95 and 2000/01 years were strongly associated to nationwide famines have been recorded in Ethiopia (Deressa, 2006). The long-term effects of chronic malnutrition are estimated to cost the Government of Ethiopia approximately 16.5 percent of its GDP every year (USAID, 2014). The World Food Program (WFP) plans to help approximately 6.5 million vulnerable Ethiopians with food and nutritional aid needs in 2014 (WFP, 2013).

Most of the food shortage area in Ethiopia which were concentrated along two broad belts, generally described as drought and famine prone areas. One of these is the mixed farming production system area of highland Ethiopia, involving central and northeastern highlands stretching from Northern Shewa through Wello into Tigray. The land resources mainly the soils and vegetation of this part of the country have been highly degraded because of the interplay between some environmental and human factors such as relief, climate, population pressure and the resultant over-cultivation of the land, deforestation of vegetation and overgrazing. The second belt is based on pastoral economy of lowland Ethiopia, ranging from Wello in the north through Hararghe and Bale to Sidamo and Gamo Gofa in the south. Apparently, this belt is generally considered as resource poor with limited potential and hence highly vulnerable to drought (Markos, 1997). There are only a few studies on the effects of climate variability on crop production in Ethiopia (Admassu, 2004; Lemi, 2005; Bewket, 2009) either at national or regional scales which mask local scale variability like North Wollo Zone. So, understanding local climate variability is crucial for agricultural planning, mitigating the adverse effects of recurring drought and capitalizing fully when more abundant rains occur.

1.3. Significant of the study

This study was designed to investigate the characteristics of local rainfall variability and its effect on teff (Eragrostis tef) crop performance and quantify their relations and taking in to account the farmer perception of climate related problems in the study area. The study was help the local community or farmers, agriculture extension experts and decision maker of that district by creating awareness of impact rainfall variability on Teff yield gave farmers perception about rainfall variability which is supported by rainfall data. Those issues may hopefully help to increase the understanding the rural population in the study area are struggling with. It may also lead to recommendations such as adaptation of type of crops, diversification of the cropping strategies, water harvesting, most favorable seeding time can hopefully improve the rural livelihoods situation for farmers to be able produce a surplus and end up in a better situation when improving Teff productivity.

1.4. General objective of the study

The general objective of the study was to investigate the impact of rainfall variability and local community perceptions on teff production.

1.5. Specific objectives

- ✓ To determine the nexus between rainfall characteristics and Teff production; and
- ✓ To assess the perception of local community on the rainfall characteristics, variability and trends.

2. Materials and Methods

2.1. Description of the study area

Gubalafto District is located in North Wollo Zone of Amhara National Regional State (ANRS), Ethiopia. It is located in between11.57º - 11.99º N latitude, and 39.2º - 39.8º E longitudes with an area of about 900.49 km^2.It is bordered on the south by the Debub Wollo Zone, on the west by Delanta and Wadla, on the northwest by Meket, on the north by Gidan, on the northeast by Kobo, on the East by Afar region and on the southeast by Habru District.

2.1.1. Topography and climate characteristics

The topography of the District is mostly characterized by a chain of mountains, hills and Valleys ranging from 1379- 3809 meter above sea level (masl). It is characterized by 20% flat, 30% undulating, 35% mountainous and 15% gorges or Valleys. Gubalafto district has three agro ecological zones, lowland that ranges from 1500-1800, mid-altitude (Weynadega) ranges from 1900-2200 and highland (Dega) ranges 2300-3300masl District agricultural office (2012). Agro ecological distribution of the study area accounts 17% of Kolla, 37% of Dega and 46% of Weynadega. The District has bimodal rainfall pattern. Kiremt (summer) which extends from June to September is the main rainy season with its peak in July and August and the short rainy season Belg (spring) occurs between February to May. The study area is highly prone to frequent shortage of rainfall and receives an annual rainfall ranging between 300-400 mm on average.

Table 2.1. Geographical locations of six weather stations for the study area

Station name	Latitude(north)	Longitude(east)	Altitude(meter)	Years of observation
Delib	11.96°	39.42°	3276	1984-2018
Gobye	11.94°	39.67°	1633	1984-2017
Hara	11.84°	39.74°	1509	1984-2018
Sanka	11.89°	39.94°	1986	1984-2018
Sirinka	11.75°	39.61°	1861	1984-2018
Woldia	11.83°	39.59°	1894	1984-2018

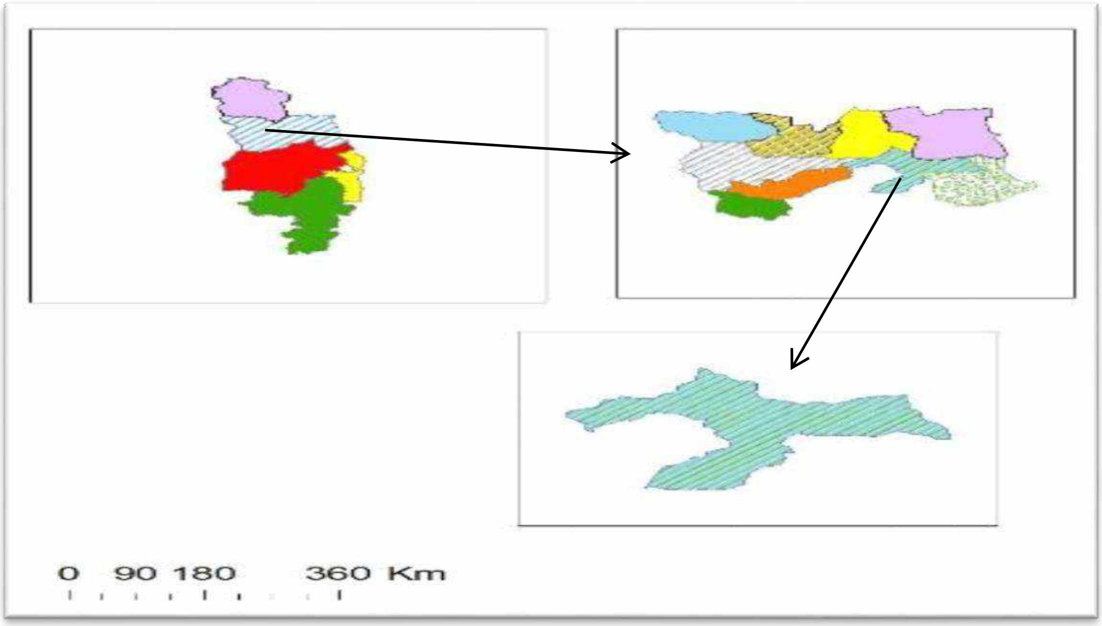


Fig .2.1 Map of the study area

2.2. Data sources and method of analysis

Both primary and secondary data were used in this study. The primary data include information sourced from administration of structured interview to the rural farmers in the study area while the secondary data (Rainfall and crop yield) were also collected. Observed daily rainfall data was obtained from the National Meteorological Agency of Ethiopia (NMA) and from East Amhara Meteorological Centre (1984-2018) and Teff yield was collected from North Wollo Agricultural Office (2010-2018).

2.3. Method of data analysis

Data analysis was under taken using GIS, INSTAT, Gen stat and, XLSTAT software and excels spreadsheet. Rainfall variability has been computed using coefficient of variation (CV), Standardized Anomaly method (SRA) and Precipitation Concentration Index (PCI). Trends were evaluated using Sen 's slope estimator and Mann-Kendall trend test

$$CV = SD / \mu$$

When CV < 20% it is less variable, CV from 20% to 30% is moderately variable, CV > 30% is highly variable, CV>40% very high and CV>70% indicate extremely high inter-annual variability of rainfall

$$SRA = (X - \mu) / \sigma$$

Where, SRA is implying the standardized rainfall anomaly,

X is an actual rainfall,

μ is long-term mean malaria cases of the area (1987-2018) and **σ** is Standard deviation.

The drought severity classes are extreme drought (SRA <-1.65), Severe drought (-1.28 >SRA> -1.65), moderate drought (-0.84 >SRA > -1.28), and no drought (SRA> -0.84).

$$PCI = \frac{(\sum_{i-1}^{12} pi2)}{(\sum_{i-1}^{12} pi)2} * 100$$

Where; Pi the monthly rainfall in month i

PCI values of less than 10 indicate uniform monthly rainfall distribution in the year, PCI 11-15 indicates moderate precipitation concentration, PCI 16- 20 indicates irregular distribution. PCI values above 20 correspond to substantial monthly variability (a strong irregularity) in rainfall amounts.

The Mann-Kendall's test statistic is given as:

Several tests are available for the detection and estimation of trends. In this particular study, Mann-Kendall's test was employed. Mann-Kendall's test is a non-parametric method, which is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or nonlinear (Partal and Kahya, 2006; Yenigun et al., 2008). The Mann-Kendall's test statistic is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k)$$

Where S is the Mann-Kenda1l's test statistics; x_i and x_j are the sequential data values of the time series in the years i and j (j > i) and N is the length of the time series. A positive S value indicates an increasing trend and a negative value indicates a decreasing trend in the data series. The sign function is given as:

$$\operatorname{sgn}(x) = \begin{cases} +1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0 \end{cases}$$

The variance of S, for the situation where there may be ties (that is equal values) in the x values, is given by:

$$\mathrm{Var}[S] = \frac{\left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5) \right\}}{18}$$

Where, m is the number of tied groups in the data set and t_i is the number of data points in the i^{th} tied group. For n larger than 10, Z_{MK} approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun et al., 2008) and computed as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \text{ if } S > 0$$
$$= 0 \text{ if } S = 0$$
$$= \frac{S+1}{\sqrt{VAR(S)}} \text{ if } S < 0$$

The presence of a statistically significant trend is evaluated using Mann-K value. In a two-sided test for trend, the null hypothesis (H_0) should be accepted if /Mann - K/ < Z1-a / 2 at a 0.05 level of significance. Z1-a / 2 is the critical value of Mann-K from the standard normal table. For instance, for 5% significance level, value of Z1-a / 2 is 1.96.

Sen's Slope Estimator test;

The magnitude of trend is predicted by the Sen's estimator. The slope (Ti) of all data pair computed as (Sen, 1968). This test is applied in cases where the trend is assumed to be linear, depicting the Quantification of changes per unit time. Positive value of Qi indicates an upward or increasing trend and a negative value indicates downward or decreasing trend in the time series

2.4. Correlation analysis

Correlation and regressions techniques are important in showing the relationship between climatic parameters and crop production, and to identify the most predictor variable. Lemi 2005; Bewket, 2009; Tunde, 2011; Rowhani et al., 2011; Adamgbe and Ujoh 2013 and Akinseye et al. (2013) used the same methodology in their study of the relationship between climate variables and crop production. The Pearson correlation coefficient(r) was analyzing to evaluate the linear relationship between the climatic parameter (rainfall) and the crop yields (Teff). Correlation coefficient(r) value close to +1 indicates a strong positive correlation while correlation coefficient closes to -1 indicates as a strong negative correlation and correlation coefficient of 0 was interpreted as indicators of no correlation or association between climate variables and crop yield. Pearson's correlation coefficient (r) which was calculated by equation:

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{\left[n\Sigma x^2 - (\Sigma x)^2\right]\left[n\Sigma y^2 - (\Sigma y)^2\right]}}$$

Where r is Pearson's correlation coefficient, y is the observed yield, x is rainfall characteristics and n is number of observation.

2.5. Multiple linear regression analysis

Multiple regression analysis was used to determine the contribution of the rainfall characteristics to crop yield. The analysis described the effects of the independent variables jointly on the yields of the crops. Regression model for the study was also computed as:

$Y=a+b1x1+b2x2+b3x3+b4x4+bnxn+e$, Where; Y = the value of the dependent variable (Teff yield/ ha); a = Y intercept b1, b2, b3, b4, ⋯ bn = regression coefficients (each b represents the amount of change in Y (Teff yield/ha) for one unit of change in the corresponding x-value when the other x values are held constant; x1, x2, x3, x4, ⋯ xn = the independent variables (i.e. rainfall onset, cessation, duration, Kiremt(summer season) total rainfall and number of rain days respectively); and e = the error of estimate or residuals of the regression.

3. Result and Discussions

3.1. Rainfall variability and trends

The mean annual and seasonal rainfall variability at the 6 stations is presented in Table. The study area is characterized by bimodal rainfall pattern and much of the rainfall is concentrated in the Kiremt season (June-September). The small rains during Belg (spring) season which begin from February and extends to May. It receives a mean annual rainfall ranging from 566.3mm at Hara to 876.4mm at Sirinka station with areal mean annual rainfall 703. 3mm.The variability of annual rainfall was lowest at Sirinka (CV=19.9%) and highest at Hara (CV=35.8%). This implies that the annual rainfall was more unreliable and unpredictable at Hara areas. At the seasonal level, the mean kiremt total rainfall varies from 402.9mm at Hara to 596.2mm at Gobye areas with areal mean kiremt rainfall 489.2mm during the last 35 years (1984-2018).

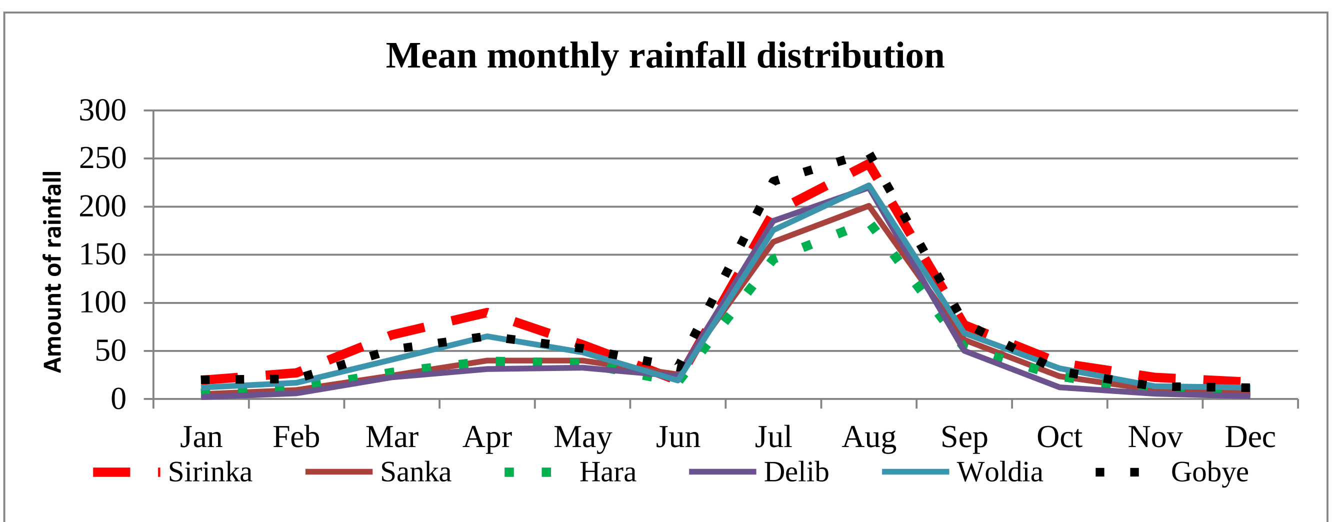
The contribution of kiremt rainfall to the average annual rainfall across station is also very high, it ranges from 61.1% at Sirinka to 83.3% at Delib and followed by Sanka which is 73.9% (Table). This is supported by Bewket and Conway 2007; Ayalew et al., 2012 in the Amhara regional State of Ethiopia, kiremt rainfall had contributed 55 to 85% to the annual rainfall totals. During Belg season, Sirinka received the highest mean Belg(Spring) rainfall (241.9mm) and Delib received the lowest mean Belg rainfall(92.9mm) with areal mean Belg rainfall 154. 5mm.The spring (belg season from February -May) rainfall also contributes a considerable amount (15.6%-27.6%) for the annual total rainfall at Delib and Sirinka stations respectively. In line with this in the Amhara regional state of Ethiopia belg rainfall had contributed 8 to 24% to annual rainfall totals (Bewket and Conway 2007; Ayalew et al., 2012). The result also indicated that Belg rainfall variability for all stations were extremely high variable (CV>40%).This implies that the Belg rainfall was characterized by high variability according to the classifications given in Hare (1983). Therefore, based on Hare (1983) classification, the study area has been vulnerable to drought during belg season (CV > 30%). Moreover, during Bega season (October-January) the mean total rainfall was ranging from 12.5mm at Woldia to 75.7mm at Gobyefor the last 35 years.

On the other hand, the contribution of Bega rainfall to the annual rainfall is less which varies from 1.7% at Woldia to 9% at Gobye areas. In addition, the coefficient of variation in Bega rainfall shows extremely variable (CV=50%) in all stations. Likewise, the mean monthly rainfall of the stations in the Gubalafto district varied from 9.7 to 221.4mm in the period of 1984-2018(fig). Comparatively the monthly rainfall was low from October to February, but started to increase in June. Moreover, relatively intensive rainfall was received between June and August. The minimum monthly rainfall was recorded at Delib in January while that of maximum monthly rainfall was recorded at Gobye in Agust. Generally, Rainfall in Gubalafto district showed moderate inter-annual variability as shown by the coefficients of variations (Table). The seasonal rainfall variability was higher than the annual rainfall variability. The Belg and the Bega rainfalls are found much more variable than the Kiremt rainfall in which the coefficient of variation is lower than 30%.

Table 2: the coefficients of variations

Stations	Kiremt rainfall			Belg rainfall			Bega rainfall			Annual rainfall	
	Mean	CV (%)	CT (%)	Mean	CV (%)	CT (%)	Mean	CV (%)	CT (%)	Mean	CV (%)
Sirinka	535.8	28.6	61.1	241.9	45.3	27.6	20	124.2	2.3	876.4	19.9
Sanka	451.2	29.2	73.9	114.3	54.7	18.7	44.3	109.3	7.3	609.8	26.2
Hara	402.9	41.1	71.1	117.3	64.4	20.7	46.4	100.6	8.2	566.3	35.8
Woldia	479.7	35.5	65.6	173.4	45.1	23.7	12.5	142.6	1.7	731.4	20.6
Delib	496.5	27.1	83.3	92.9	60.2	15.6	23.7	125.7	3.9	596.3	31.5
Gobye	596.2	37.3	71.0	192.6	63.6	22.9	75.7	84	9.0	839.7	29.2
Areal	489.2	25.2	69.6	154.5	45.6	21.9	36.7	80.3	5.2	703.3	17.6

A similar conclusion that Belg and Bega rainfalls are more variable than Kiremt rainfall was arrived at by Woldeamlak and Conway (2007) in their study that analyzed rainfall data from 12 stations in drought-prone areas of Amhara Region, Ethiopia. Mean annual and seasonal rainfall (mm), coefficient of variation (CV %) and contribution of seasonal rainfall to the annual rainfall (CT %) for representative meteorological stations



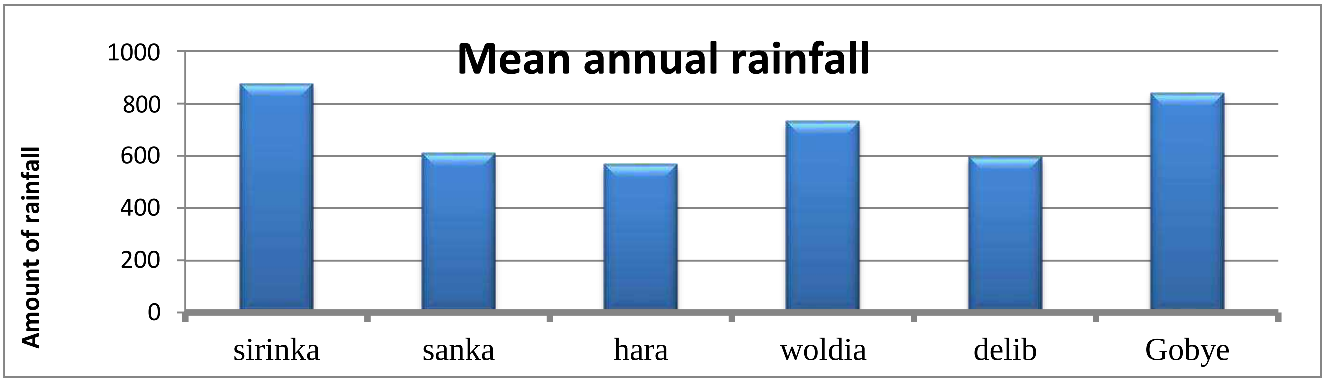


Fig.2 The mean monthly and annual rainfall at Gubalafto Wereda (district)

Annual and Seasonal rainfall anomaly

The standardized rainfall anomalies (SRA) were also calculated to assess the inter-annual rainfall fluctuations at the study area. The rainfall in the Gubalafto district was characterized by sporadic fluctuation of wet and dry years in a periodic pattern. The result of the standardized rainfall anomaly on the annual basis showed 42.8% dry tendency dominates while 57.1% dominates wet tendency over the study area. Likewise, the standardized anomalies of areal kiremt rainfall revealed that 48.6%weak to strong negative departure from the long term mean rainfall and 51.4% recorded above the long term average rainfall. According to drought assessment method by Agnew and Chappel (1999), there have been seven driest years in the Gubalafto, with varying severity. During Kiremt (summer season) there were two extreme (1987 and 2015), one severe (1984) and four moderate (1989, 1992, 2004 and 2009) dry years. In contrast, years like 1994, 1998 and 2012 were experienced severe wet while that of 2018 was showing extremely wet and two moderate wet years were observed (1988 and 1999 in the zone over the period of record.

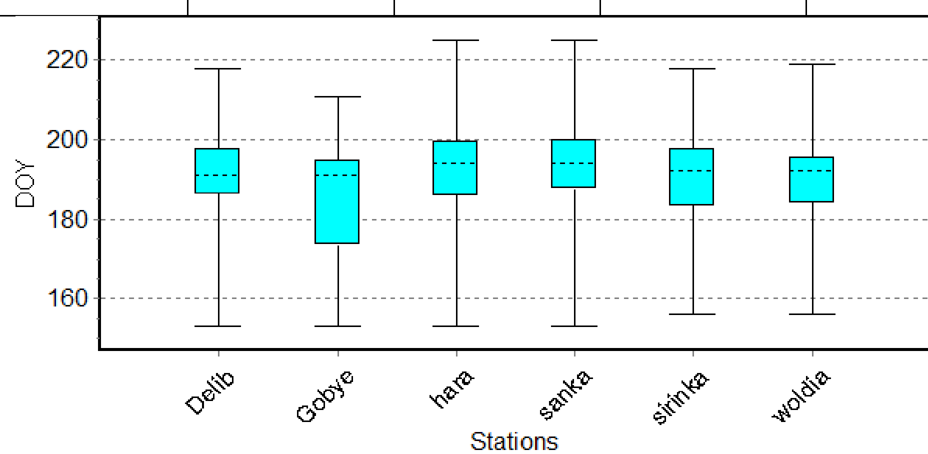
3.2. The onset, cessation date and length of growing period

The mean onset date was varied from 184.4DOY (2-Jul) at Gobye to 193.8DOY (11-Jul) at Woldia areas with areal mean onset date is 189.7DOY (7-Jul). The observed variability of Kiremt onset was varied from 7.2% at Sirinka to 15 % at Woldia areas. This shows that the onset date of Kiremt growing season have been experienced dependable patterns across Sirinka while at Woldia the patterns couldn't be easily be understood and consequently decisions pertaining to crop planting and related activities should be taken with great care. In addition, the mean cessation date ranged from 265DOY (21-Sep) at Hara to 273.4 DOY (29-Sep) at Gobye areas with areal mean cessation date is 269.9DOY (25-Sep) during the last 35years (1984-2018). Therefore, at all the probability levels considered, the end of the season is extended more at Gobye compared to other areas. The observed low Coefficient of variation values (4.4%-7.6 %) of cessation of Kiremt rainfall in the present study indicates that the ending dates for Kiremt rainfall vary over a short time span and the patterns could be more understood, and decisions pertaining harvesting and storage could be made easily. More over the lowest mean length of the growing period was 72.6 days which was registered at Hara while the highest mean length the growing season was 83.9 days at Gobye areas with areal mean length of the growing period is 78 days. The coefficient of variation on the length of growing period ranged from 22.3% at Sirinka to 28.3% at Hara areas over the last period. Higher coefficients of variation (>13%) in LGP, gives less confidence in crop selection based on maturity period.

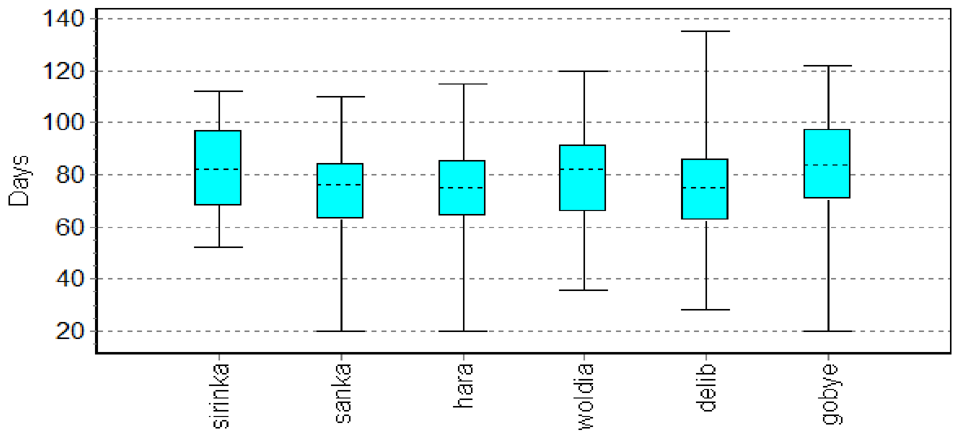
Table3. Descriptive statistics of the onset, cessation and length of the kiremt rainy season during1984-2018

Stations	Onset		Cessation		Length of growing period	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
Sirinka	189.7	7.2	272.4	4.7	82.1	22.3
Sanka	192.7	7.4	269.8	7.6	73.6	28.6
Hara	191.9	8	265	6	72.6	28.3
Woldia	193.8	15	270.5	5.2	80	22.4
Delib	190.7	7.3	268.2	6.6	75.6	27.8
Gobye	184.4	8.8	273.4	4.4	83.9	25.2
Areal	189.7	7.6	9.9	4.9	78	21.1

Onset



Cessation



LGP

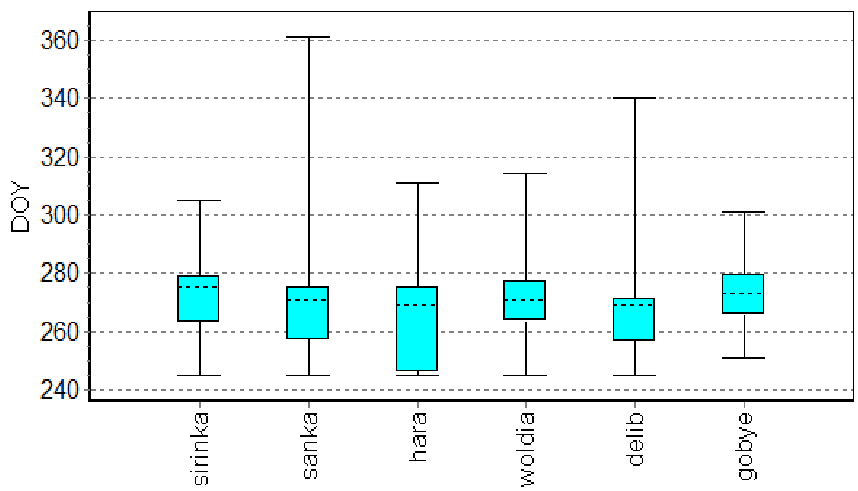


Fig 4: Onset, Cessation and LGP

3.3. Number of rainy and dry days

The number of rainy days observed in the given duration varied from 48.2 days at Sirinka to 53.7 days at Delib with areal mean of 51.2 days. The interannual variability of number of rainy days varied from 21.9% at Sirinka to 36.4% at Hara areas. On the other hand, the mean number of dry days was ranging from 68.3 days at Delib to 73.8 days at Sirinka station with areal mean of 70.8 days with coefficient of variation 20.9%.

Table4.4. Summary statistics of number of rainy and dry days in the study area

Stations	Number of rainy day(NRD)			Number of dry day(NDD)		
	Mean	SD	CV (%)	Mean	SD	CV (%)
Sirinka	48.2	10.6	21.9	73.8	10.6	14.3
Sanka	53.2	15.5	29.2	68.8	15.5	22.6

Hara	49.1	17.9	36.4	72.9	17.9	24.6
Woldia	49.8	12.2	24.5	72.1	12.2	16.9
Delib	53.7	14.5	27	68.3	14.5	21.2
Gobye	53.1	18.1	34	68.9	18.1	26.2
Areal mean	51.2	14.8	28.8	70.8	14.8	20.9

3.4. Probability of dry spell lengths

The results of the study revealed that dry spell lengths of the considered days: 5,7,10, and 15 days' length varies from place to place over the study areas given in (Figure). The information on the length of dry spells could be used for deciding a particular crop or variety, supplementary irrigation water demand and for others agricultural activities. As indicated in the figure the probability of dry spell occurrence during belg and kiremt seasons are different among stations.

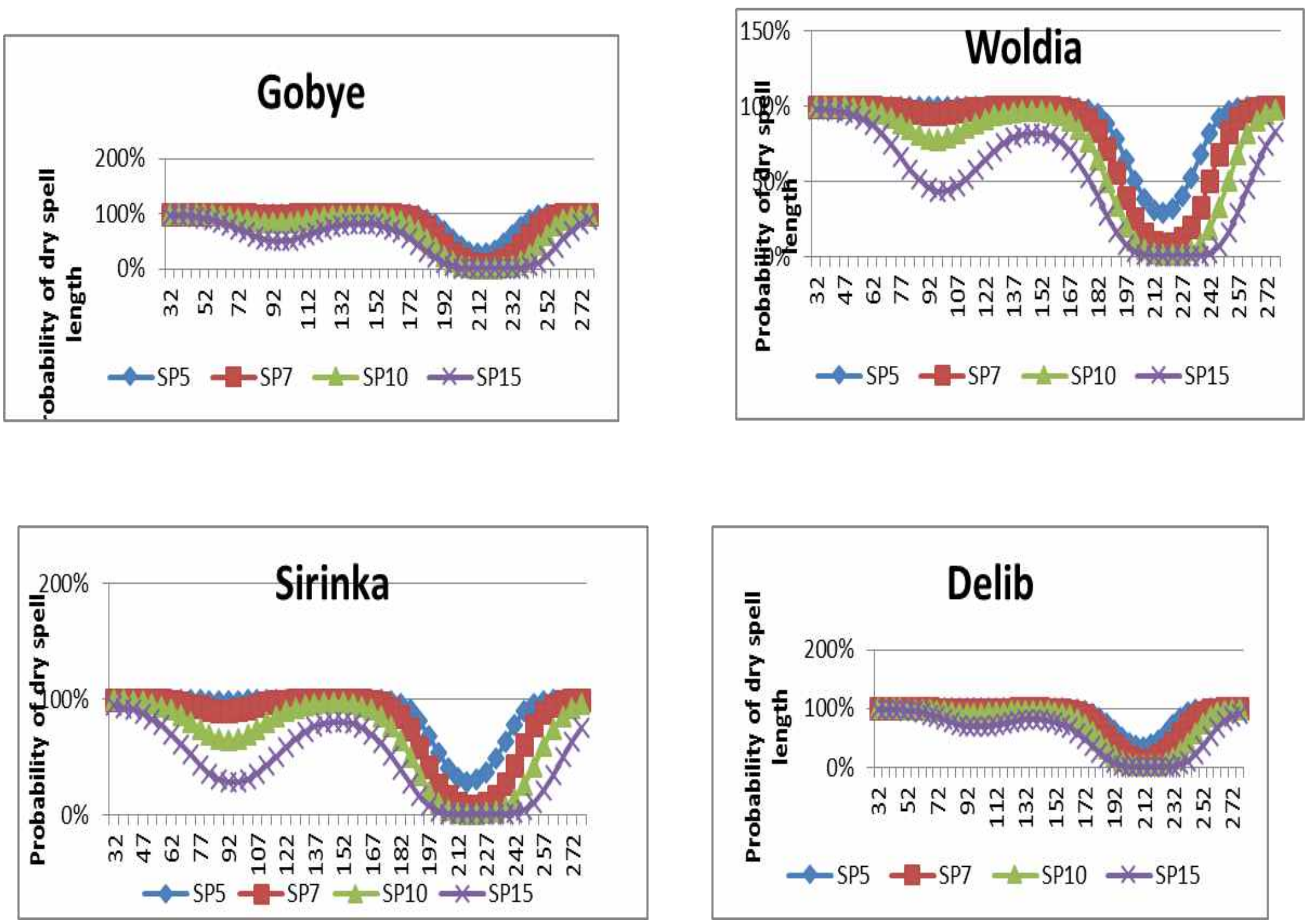


Fig5: probability of Dry Spell

Observations of climatic data illustrate that the probability of dry spells occurring within the growing seasons varies from month to month. To consider the intensity of dry-spells, we further assessed the probability that dry spells will exceed specific numbers of consecutive days. More over the probability of the occurrence of dry spells of 5, 7, 10, and 15 days were above 40% in all areas during the small (belg) rainy season. The probability of 7, 10, and 15 days' dry spell occurrence starting from end of June until the peak rainy period (July and August) becomes zero at all areas where as the probability of 5 day dry spells occurrence were more than 30% at all stations during the main rainy season. The probabilities of 5,7 days' dry spell occurrence rapidly increase after the first decade of September (245 days of the year) while 10, and 15 days' dry spells were gradually increase from the first decade of September to end of September. Generally, the shorter dry spell events have higher probability of occurrence, compared to the longer ones in general. 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 Hara, Delib, and Gobye areas as compared to other areas. Hence crop production during this particular period needs a due attention and monitoring of planted crops. This implies that the risk of planting long cycle before June is above 65%.

3.5. The number of very heavy rainfall and simple daily rainfall intensity

The average number of days with very heavy rainfall per year varies from 1.7days at Hara to 8.5 days at Gobye with areal mean very heavy rainfall 4.8 days. The coefficient of variation revealed that extremely variable in the number of very heavy rainfall at all stations for the past 35 years. On the other hand, the si mple daily intensity of rainfall on average per rainy day ranged from 8.2 mm per day at Hara to 11.4 mm per day at Gobye for the last 3 decades. The coefficient of variation showed that moderate fluctuations of intensity of rainfall at Sirinka, Woldia and Gobye stations while at Sanka, Hara and Delib extremely variation of rainfall intensity in the study area.

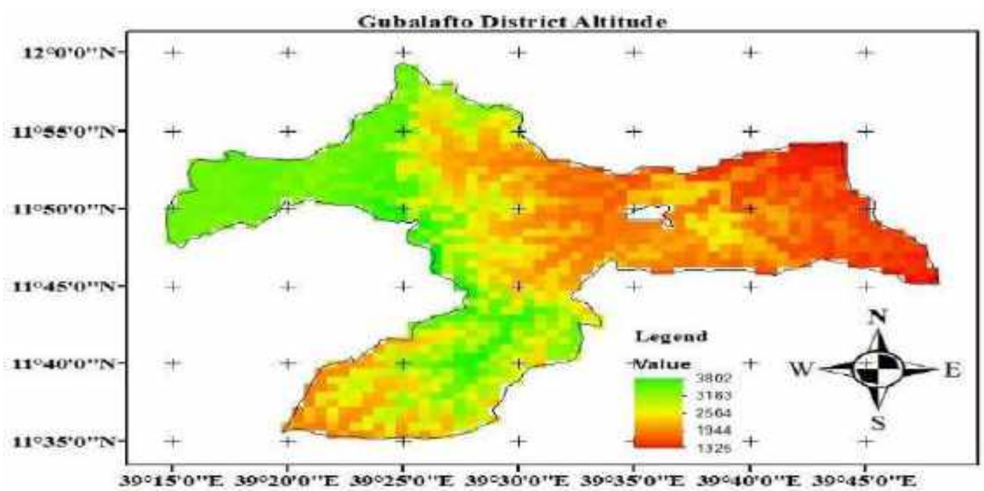
Excessive rains are generally associated with crops loss due to floods that wash away the crops or make them rot in the gardens. Moreover, too much rain affects post-harvest handling of the crops and can result into substantial post-harvest losses. Besides, in the early stages of crop production, excessive rains can lead to erosion of top soils and leaching of soil nutrients, thereby affecting productivity. Other effects of excess rainfall on crop production include poor pollination, seed and fruits formation. In general Heavy rainfall events leading to flooding can wipe out entire crops over wide areas, and excess water can also lead to other impacts including soil water logging, and reduced plant growth.

Table5. Summary statistics of number of very heavy rainfall and rainfall intensity in the study area

Stations	Number of very heavy rainfall		Rainfall intensity	
	Mean	CV (%)	Mean	CV (%)
Sirinka	7.8	52.6	11.2	24.4
Sanka	2	78	8.8	34.2
Hara	1.7	80	8.2	39.9
Woldia	5.7	60.1	9.9	27.6
Delib	3.2	82	9.2	40
Gobye	8.5	51.8	11.4	21.6
Areal	4.8	51.5	9.7	28

3.6. Rainfall Spatial Distribution (Methodology)

To analyses spatial rainfall distribution data wererasterized to generate five-point station surface data by the simple kriging interpolation technique using ARCGIS 10.1 software. This is becausesimple kriging



interpolation technique takes account of the spatial correlation pattern with the least interpolation error (Beck et al., 2005).

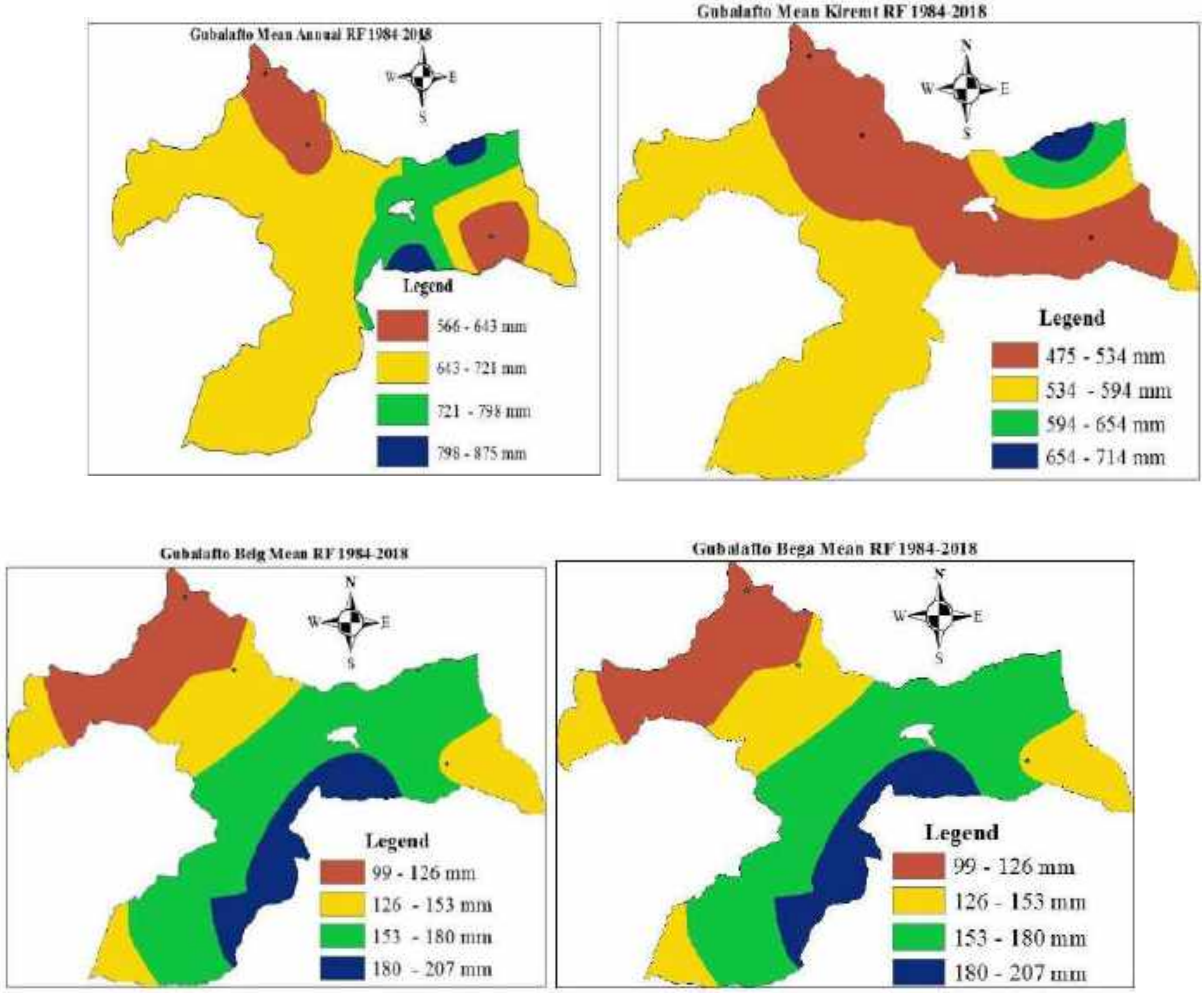


Fig6: Trends of annual and seasonal (Belg and Kiremt) rainfall totals at 6 stations during 1984- 2018

3.7. Trends of annual and seasonal rainfall

The Mann–Kendall trend test shows anon-significant increasing trends of annual rainfall at Sirinka, Sanka, Hara, Delib, and Woldia by a factor of 1.8, 0.79, 2.3, 0.17 and 1.4 mm per annual respectively. The mean annual areal total rainfall has also shown a non- significant increasing trend of 1.4mm per year. In line with this Abiy Gebremichael et al., (2014) reported that annual rainfall showed an increasing trend by 3.93 mm/year in Indibir station over the study period of 1982- 2012.On the contrary significant decreasing trend was observing in annual rainfall at Gobye by 10.5mm per annual. On the other hand, the kiremt seasonal rainfall showed increasing trend at all stations. However, the detected trends were statistically significant at Hara and Woldia stations only in the study area. In line with this study by Getaneh (2015) also reported that kiremt seasonal rainfall shows an increasing trend by a factor of

6.38mm per year in kombolcha station during the period 1992-2012. The Belg rainfall also showed a non-significant decreasing trend at all statins except Hara. Similarly, Dereje et al., (2012) also found decreasing trend of Belg rainfall was identified at Kombolcha and Sirinka stations. Generally, the result showed that the areal annual and Kiremt rainfall have been anon-significant increasing trends while the Belg rainfall has been anon significant decreasing trends wereobserving in the Gubalafto district over the last periods.

Table6: Trends of annual and seasonal (Belg and Kiremt) rainfall totals at six stations during 1984-2018.

Stations	**Annual Rainfall**				**Kiremt Rainfall**				**Belg Rainfall**			
	ZMK	Q	P-value	% change	ZMK	Q	P-value	% change	ZMK	Q	P-value	%change
Hara	0.153	2.33	0.2	14.4	0.272	5.54	0.025	48.1	0.145	1.9	0.22	56.7
Woldia	0.069	1.4	0.57	6.7	0.199	4.8	0.01	35	-0.144	-1.7	0.238	-34.3
Sanka	0.05	0.79	0.65	4.5	0.167	3.2	0.16	24.8	-0.06	-0.5	0.59	-15.3
Sirinka	0.07	1.8	0.55	7.2	0.18	4.29	0.13	28	-0.14	-2.4	0.25	-34.7
Gobye	-0.31	-10.5	0.01	-43.8	0.04	1.4	0.72	8.2	-0.07	-1	0.58	-18.2
Delib	0.01	0.17	0.94	1	0.14	2.6	0.26	18.3	-0.21	-1.7	0.08	-64
Areal mean	0.09	1.4	0.43	6.9	0.213	4.3	0.074	30.8	-0.092	-1.1	0.446	-24.9

Zmk is mann-kendall's trend test, Q is sen's slope (change per year or decade), * indicates statistically significant trend when p-value<5% (0.05), **is non-significant when p-value ≥5% or at 0.05 probability level.

3.8. Trends of onset, cessation and length of growing period

The Mann-kendall's trend test on starting of kiremt rainfall showed a decreasing trend at Sirinka, Sanka, Woldia and Gobye stations by a factor of -2.5, -0.7, -3.8 and -0.1 days per decade respectively (Table). However, the detected trend was significant only at Gobye. In line with this Getaneh (2015) reported that non- significant decreasing trend was observed at Lalibela station in start date of the kiremt growing season in the North Eastern, Ethiopia for the period 1992-2012.

Table7: Trends of onset date, cessation date and length of growing period during kiremt season at six stations for the period 1984-2018.

Stations	Rainfall feature	Mann-Kendall's trend test		
		Kendall's Tau	Sens's slope	P-value
Sirinka	Onset	-0.13	-0.25	0.28
	Cessation	0.151	0.26	0.21
	LGP	0.151	0.26	0.21
Sanka	Onset	-0.077	-0.07	0.53
	Cessation	0.273	0.6	0.02
	LGP	0.273	0.6	0.02
Hara	Onset	0.127	0.3	0.29
	Cessation	0.326	0.75	0.01
	LGP	0.326	0.75	0.01
Woldia	Onset	-0.221	-0.38	0.07
	Cessation	0.281	0.54	0.02
	LGP	0.281	0.54	0.02
Delib	Onset	0.059	0.11	0.63
	Cessation	0.226	0.47	0.06
	LGP	0.226	0.47	0.06
Gobye	Onset	-0.019	-0.01	0.88
	Cessation	-0.05	-0.11	0.69
	LGP	-0.05	-0.11	0.69
Areal	Onset	-0.073	-0.14	0.55
	Cessation	0.159	0.29	0.19
	LGP	0.159	0.29	0.19

The decreasing trend in onset date shows early starting of kiremt rain fall in the past 3 decades. On the contrary anon –significant increasing trend of the onset date was observing at Hara and Delib by a rate of 0.3 and 0.11 days respectively. This implies that late onset of kiremt rainfall for the past years. More over the areal onset date has been showed anon –significant decreasing trend at Gubalafto district. Similarly, the cessation date has been increasing at all stations except Gobye. However, the detected trends were significant at Hara, Sanka and Woldia stations. A study by Hadigu et al., (2013) reported that significantly increasing trends of cessation of kiremt season rainfall at Mekele and Adigudum stations in the Nothern Ethiopia. The length of the growing period showed a non-significant decreasing trend at Gobye whereas at Sirinka, Sanka, Hara, Woldia and Delib have been increasing trends. However, the detected trends were significant at Sanka, Hara and Woldia stations. Generally, the mann-kendal trend test showed that the onset date has been decreasing non-significantly by 1.4 days per decade while that of cessation date has been showing anon –significant increasing trend by 3 days per decade in the study area. Likewise, the length of growing period also increasing trends observed. However, the detected trend was non -significant.

3.9. Trends of number of rainy and dry days

The Mann-kendall's trend test in the number of rainy days indicated that increasing trends at all stations except Gobye. However, the detected trends were statistically significant at Hara, Sirinka and Sanka stations. Conversely the observed trend was anon-significant decreasing trend at Gobye station. On the other hand, the number of dry days showed that decreasing trends at all stations except Gobye.However the observed trends were statistically significant at Hara and Sirinka only. In line with this, Degefu, W. (2014) reported that number of rainy day was significantly decreasing by 2.8 days a year at Sawla. Conversely significantly increasing by 6 days/ year at Welayta-Sodo in the Omo-Ghibe River Basin. Generally, the study area is characterized by anon –significant increasing trend of number of rainy days by about 2.2 days per decade while that of dry days has been a non –significant decreasing trend by a factor of 2.6 days per decade for the past years.

Table8: Trends of number of rainy and dry days at six stations during 1984-2018

stations	Number of rain days			Number of dry days		
	ZMK	Q	p-value	ZMK	Q	p-value
Hara	0.252	0.68	0.035	-0.252	-0.68	0.04
Woldia	0.227	0.33	0.06	-0.227	-0.33	0.06
Sanka	0.125	0.27	0.035	-0.125	-0.27	0.289
Sirinka	0.259	0.38	0.03	-0.259	-0.38	0.03
Gobye	-0.049	-0.09	0.69	0.049	0.1	0.69
Delib	0.037	0.11	0.76	-0.037	-0.11	0.76

Areal mean	0.139	0.22	0.244	-0.146	-0.26	0.22

3.10. Trends of the number of very heavy rainfall and simple daily intensity index

Based on the Mann-kendall's trend test result the number of very heavy rainfall showed statistically non -significant increasing trends at Woldia, Sirinka and Delib stations. Conversely at Gobye non- significant declining tendency was observed during summer season. On the other hand, at Hara and Sanka showed no trend for the last 35 years. Moreover, the during the summer season the simple daily intensity index has been showing increasing trend in all studied stations except Gobye. However, the probability value of simple daily intensity of rainfall revealed statistically significant trend at Delib only for the last 35 years of observation. Generally, the number of days with very heavy rainfall has shown statistically non –significant increasing tendency during summer season in the study area. Likewise, non –significant increasing trend of simple daily intensity index was shown at Gubalafto district during the main rainy season (June-September).

Table9: Trends of number of very heavy rainfall and simple daily intensity index during summer (kiremt) rainfall season in the study area

stations	Number of very heavy rain days			Simple daily intensity index		
	ZMK	Q	p-value	ZMK	Q	p-value
Hara	0.196	0	0.133	0.210	0.04	0.078
Woldia	0.175	0.08	0.156	0.145	0.04	0.227
Sanka	0.135	0	0.297	0.183	0.03	0.125
Sirinka	0.187	0.1	0.126	0.072	0.02	0.554
Gobye	-0.097	-0.05	0.438	-0.149	-0.06	0.218
Delib	0.139	0.02	0.271	0.264	0.07	0.026
Areal mean	0.076	0.02	0.531	0.149	0.03	0.213

3.11. Variations and trends in crop production (Teff)

The highest Teff yield per hectare was 20.8 quintal per hectare in 2016 while the lowest yield of 8.6 quintal per hectare was recorded in 2015 at Gubalafto district. The mean yield was 16.2 quintal per hectare with moderate year to year variation in the study area for last years.

Table 10: Summary of statistics of yield (Qt/ha) of Teff crops in the study area (2010-2018)

Statistics	Teff production
Min	8.6
Max	20.8
Mean	16.2
Std	3.6
CV (%)	22.5

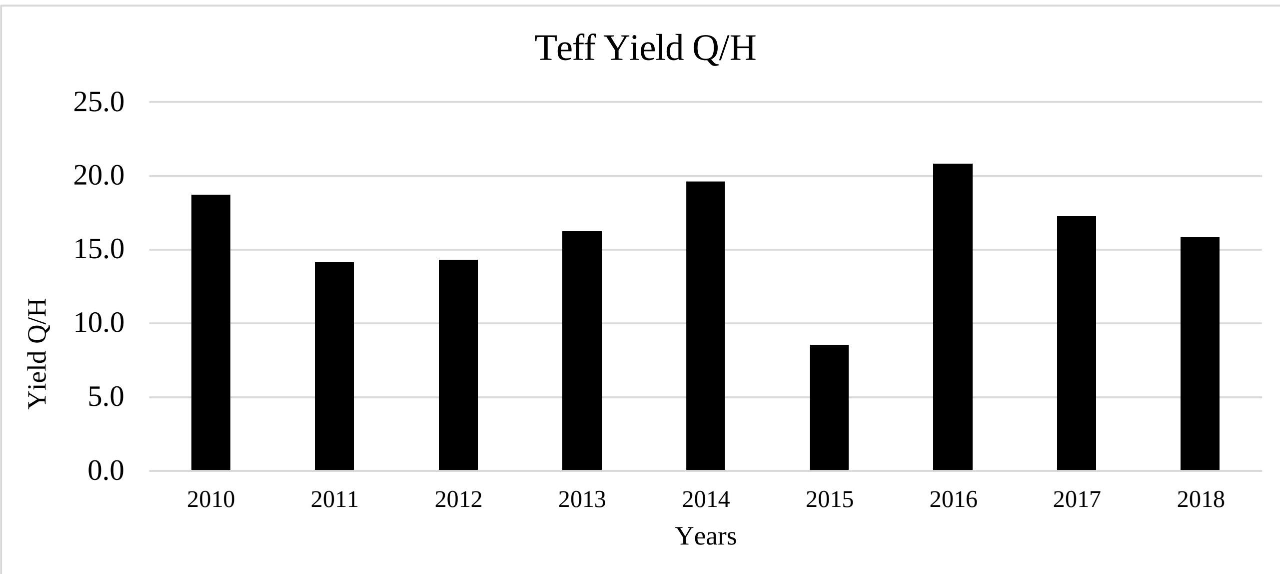


Fig7: Mean annual Teff production in Gubalafto district

3.12. Trends of Teff crop production in the study area

Table showed the Man Kendall's trend test of Teff yield result over the study period (2010-2018) in Gubalafto district. The Man Kendall's trend test has been showing anon-significant decreasing trend of Teff yield by 0.23 quintal per hectare in the study area

Table 11: Trends of Teff yields in the study area for the period 2010-2018

Mann-kendall's trend test	
Kendall's Tau	-0.111
Sen's Slope	-0.23
P-value	0.761

3.13. Relationship between rainfall characteristics and crop yield (Teff)

The correlation between rainfall characteristics and the selected crop production were computed and the result is presented in Table 2.

Table12: Correlation between production of crops and rainfall characteristics

Rainfall characteristics	Correlation(r)
Onset	-0.1
Cessation	0.54
Length of growing period	0.53
Number of rainy days	0.54
Amount of rainfall	0.52
Number of dry days	-0.54
Number of very heavy rainfall	0.31
Simple daily intensity index	0.48

The correlation between rainfall characteristics and teff yield shows that rainfall amount; number of rainy days, cessation date, and length of growing period shows strong positive correlations with Teff yield in the study area. This implies that the higher the amount of rainfall spread over the number of rain days with extended duration in a year, the higher the yield of Teff per hectare in the area.

3.14. Crop production (Teff) anomalies and kiremt rainfall variability

Figure 8 shows anomalies of meher crop production (Teff) and kiremt rainfall variability at the district level. Teff production was below mean in the year 2011 and 2015 when Kiremt rainfall was also below the mean for the same period. Above average Teff production was observed in 2010, 2014, 2016, 2017 and 2018 Kiremt rainfall was above average during those years.

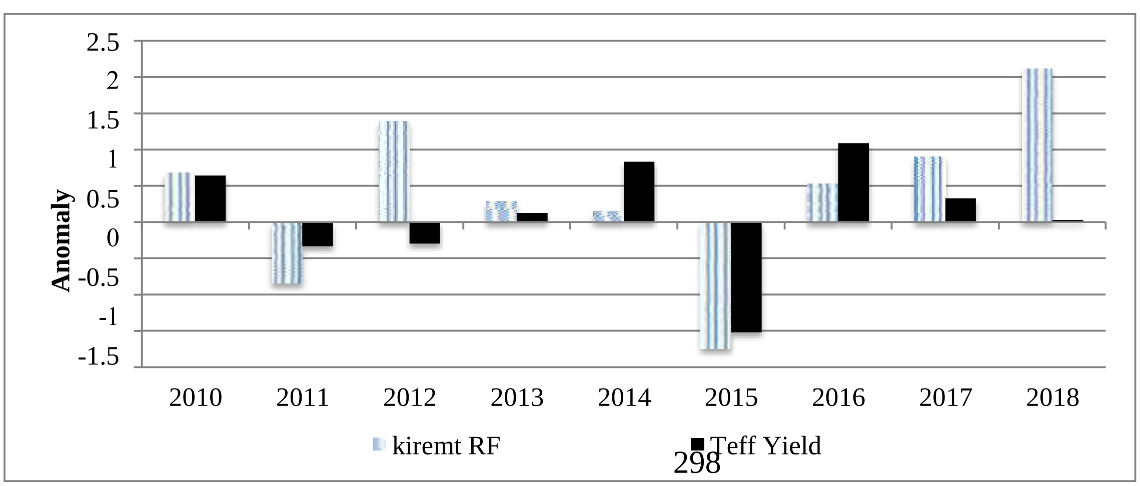


Figure 8: shows anomalies of meher crop production (Teff) and kiremt rainfall variability at the district level

3.15. Regression analysis of rainfall characteristics and teff yield

The results of linear regressions of precipitation on crop yields are presented in (Table 12). Linear regression analysis was carried out in order to determine the relationship between the rainfall variables and crop yields. The analysis described the effect rainfall characteristics (independent variable) jointly on the yields of the crops. Model summary of regression analysis showed that R^2 for Teff yield was 86% in table below. This implies that climate alone explained these percentages of variation observed in the crop yield in the study area. Other factors such as farm management techniques and edaphic factors could be responsible for the remaining percentages.

Equation of the regression model: Yield = -3.36281-0.05697*kiremt RF+0.72535*NRD Table. Analysis of variance (ANOVA) of Teff yields with rainfall characteristics

Source	DF	SS	ME	F	P-value	R	R^2
Regression(model)	5	91.3	18.3	3.7	0.15	0.93	0.86
Residual(error)	3	14.8	4.9				
Total	8	106.1	3.0				

Where DF is degree of freedom, SS is sum square, ME is mean square and R^2 is coefficient of determination.

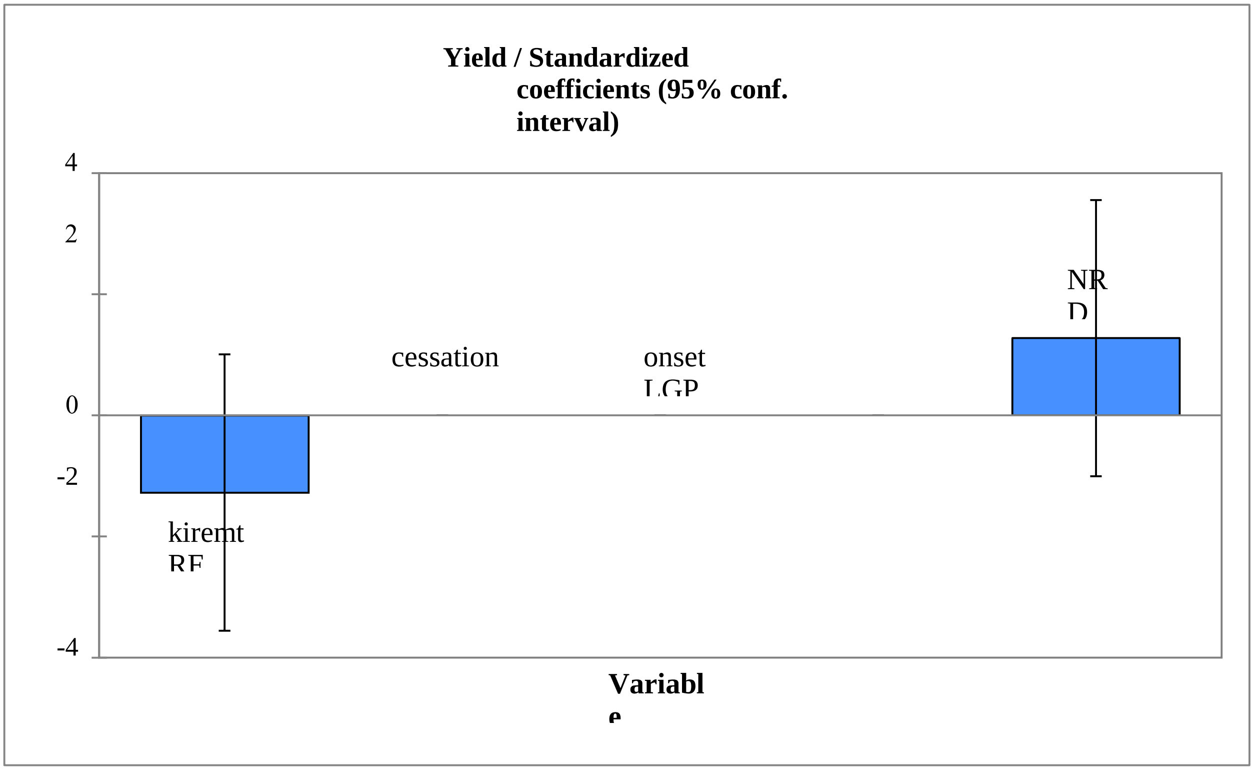


Fig 9: yield standardize coefficent

3.16. Characteristics of respondents in the study area

From total 203 respondents included in the survey, 72% were male and the rest 28% were female. The majority of the farmers (83%) fall between the economic active ages (36-50yrs). Around 66% of the respondents were 20-35years old and about 54% were above 50 years old. Furthermore, marital statuses of respondents were; 63% married, 31% single and 6% divorced from the sampled households. From the total respondents around 57% household heads respondents were illiterate with no formal education, 27% had primary education and 12% had secondary education and 7% had graduate with formal education (Table13).

Table13: Summary of demographic characteristics of the respondents in the study area

Demographic characteristics of the respondents(N=203)		**Frequency**	**Percentage (%)**
Sex of the respondents	Male	146	72
	Female	57	28
Marital status of the respondents	Single	63	31
	Married	128	63
	Divorce	12	6
Educational level	Illiterate	116	57
	Primary School Complete	57	27
	Secondary School Complete	25	12
	Graduate	7	3
Age of the respondents	20-35	66	33
	36-50	83	41
	>50	54	27

3.17. Perception of farmers on annual and seasonal rainfall variability and trend

Perception of farmers on trends and variability of seasonal and annual rainfall totals and its distribution is presented in figure below. The results showed that more than 81.2% of the farmers in the study area perceived a decreasing trend of Kiremt and Belg rainfall totals. On the contrary, 2.5 % of the respondents reported that mean of Kiremt and Belg rainfall was increasing pattern over time in the study area. On the other hand, 4.4-8.9% of the farmers at gubalafto district perceived no change in the belg and kiremt rainfall in the last 20 years. The result also 5.4-6.9% of the respondents reported that the amount of belg and kiremt rainfall has been fluctuating over time in the study area.

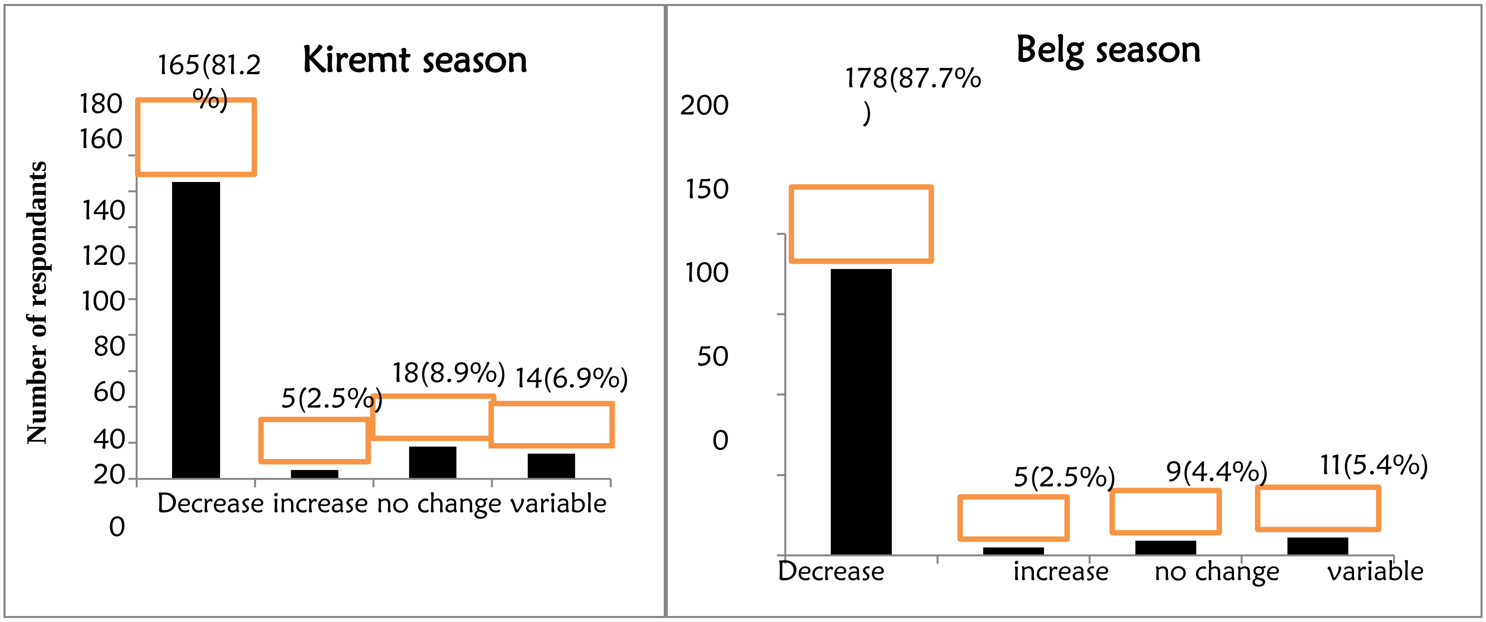


Fig14: Farmers perception on amount and distribution of summer (Kiremt) and spring (Belg) season rainfall variability and trends

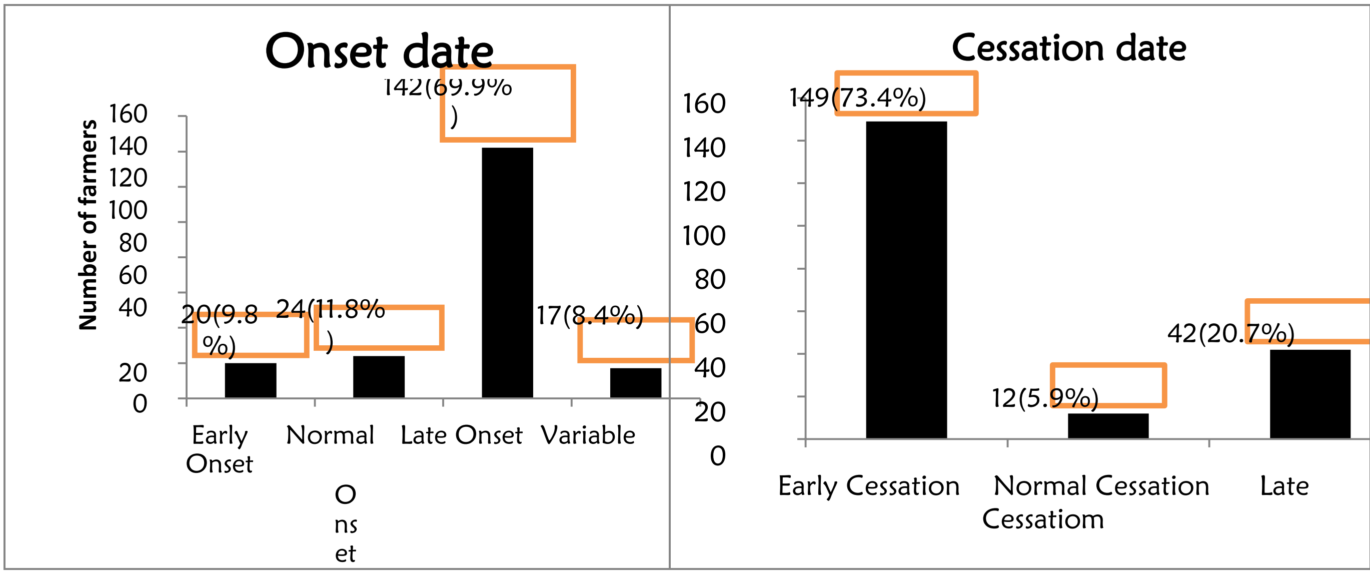
3.18. Perception of farmers on trends of Onset, Cessation dates and the LGP

Farmers in the study area perceived that rainfall events such as onset date, cessation date and Length of Growing Period (LGP) have been changed (Figure). It has been indicated that 69.9% and 20.7% of the farmers at Gubalafto district had perceived increasing onset and cessation of Kiremt rainfall respectively and consequently, 100% believed decreased in LGP.Moreover, about

9.8 and 73.4% of farmers at the study area had noticed decrease in frequency of onset and cessation date in Kiremt rainfall, respectively while more than 63.6% perceived decrease in LGP.

3.19. Farmers' perception on teff production in the study area

Fig15: Farmers perception about onset and cessation date variability and trends



Results showed that Teff is one of the significant crops cultivated in the study area because it is a staple food crop foremost farmer. However, 92.1% of the respondents reported that Teff yield is a decreasing pattern over time due to shortage of rainfall (46.5%), variability of rainfall distribution (31.5%) and variability of onset and cessation (13.4%) etc. Onthe other hand 6.9% of the respondents reported no change of the crop over time.

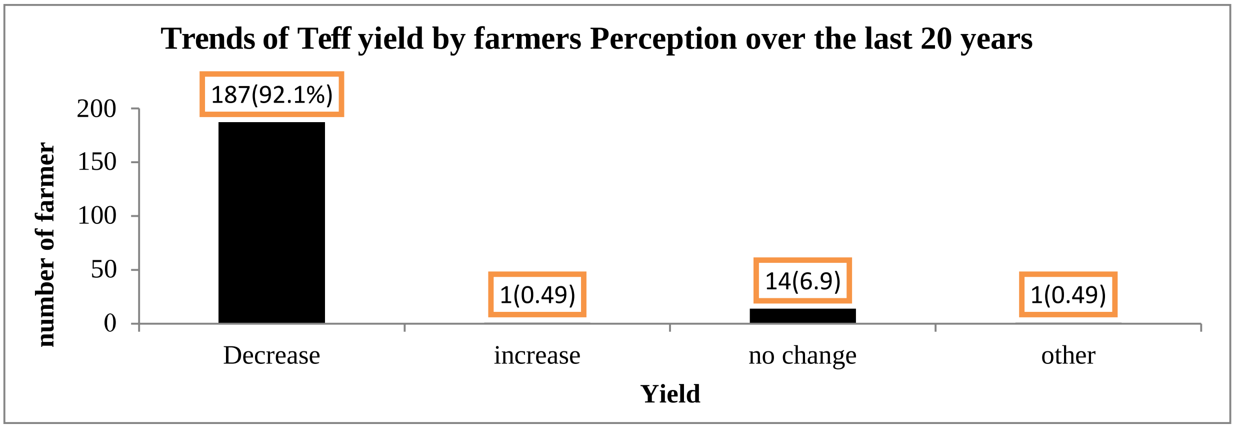


Fig16: Farmers perception on the trend of Teff yield in the study area

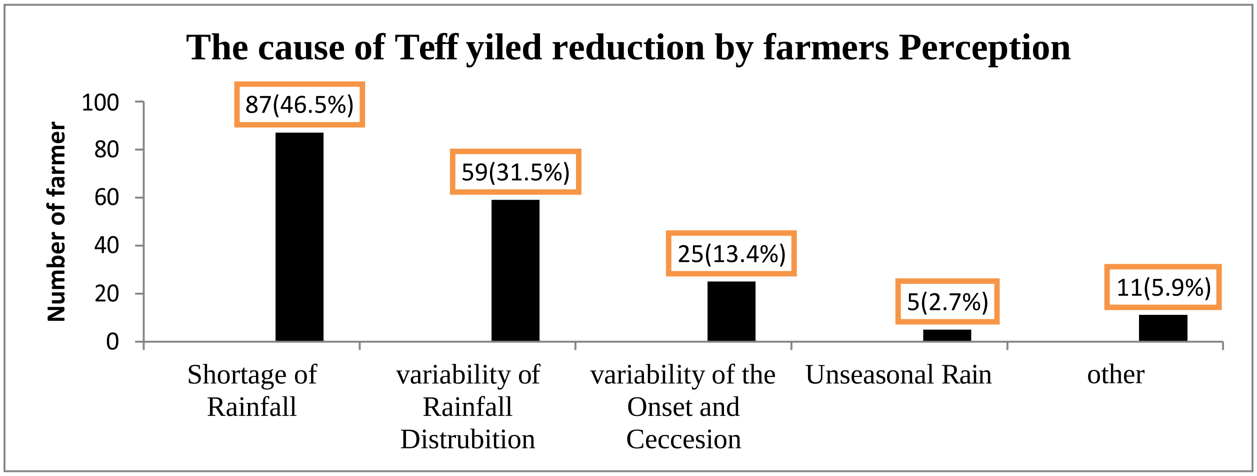


Fig17: the reduction of Teff yield in the study area by farmers' perception

3.20. Perception of farmers on climate related hazards and other natural risks

The study results revealed decline in crop yield, increase in pest and disease; increased extreme climatic events such as drought, flood, thunder and other related events have devastating impacts on crop production in the Gubalafto district (figure). Therefore, the results of 32% and 1.5% of respondents revealed that Teff yield was reduced by pest and diseases respectively in the study area. Likewise, almost 39%, 6.5%, 0.5% and 20.5 % of the respondents confirmed that Teff yield is a decreasing trend over time due to severe drought, flood, thunder and other extreme climatic events respectively in the study area.

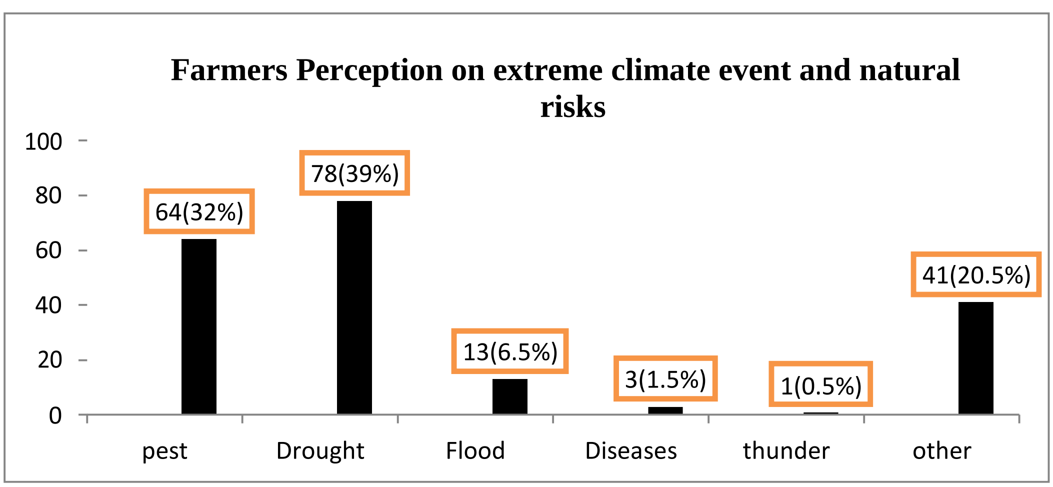


Fig 18: farmers' perception on extreme climate and natural risk

4. Conclusions

Ethiopia's agriculture is almost exclusively rain fed, so rainfall variability comprises an important source of uncertainty in agricultural production decisions. Information on seasonal Kiremt and seasonal Belg rainfall amount is important in the rain fed agriculture of Ethiopia since more than 85% of the population is dependent on agriculture particularly on rain fed farming practices (Tuffa A., 2012). But climate variations influence agricultural production and hence it affects crop productivity and land use pattern. This study investigated assessing the impact of rainfall variability and Farmers perception on Teff production. A case study in Gubalafto Districts, North Wollo Zone, Ethiopia. The analysis on long term rainfall data for the study area showed large inter- annual and seasonal variation in the amount and distribution of rainfall. The rainfall trends showed decreasing in belg while increasing in both annual and kiremt. However; the detected trends are non-significant in the time series. Over the last periods trends of rainfall events such as onset date, cessation date and length of the growing period were changed non-significantly in the study area. The variability of seasonal rainfall causes fluctuations in production of major crops. Due to high correlations between crop production and seasonal rainfall, small changes in amount and distribution of seasonal rainfall causes significant negative impacts on crop production that varies from reduced yield to the total loss of the crop. As result Teff production exhibits the largest year to year variations in study area. This high inter-annual variability is caused by rainfall variability where in the rainfall components of amount of rain, number of rainy day, onset and cessation date and length of growing period often play the biggest role. The result of the regression analysis shows rainfall characteristics contributed 86% in explaining the variations in the yield of Teff per hectare in the study area.

5. References

Admassu Seifu. 2004. Rainfall variation and its effect on crop production in Ethiopia, MSc. thesis Addis Ababa University. Addis Ababa, Ethiopia.

Awulachew, S.B., Erkossa, T. and Namara, R.E. 2010. Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. Report for IWMI.

Ayalew Dereje, Kindie Tesfaye, Girma Mamo, Birru Yitaferu and Wondimu Bayu, 2012. Outlook of future climate in northwestern Ethiopia. Agricultural Sciences 3(4):608-624.

Baye Kaleab. (2014). Teff: nutrient composition and health benefits. Retrieved from https://books.google.com/books?id=HYoZBQAAQBAJandpg.

Beck, C., Grieser, J., Rudolf, B., 2005. A New Monthly Precipitation Climatology for the Global Land Areas for the Period 1951 to 2000. Offenbach, Germany, German Weather Service, Climate status report 2004, pp. 181–190

Bewket Weldeamlak. 2009. Rainfall variability and crop production in Ethiopia; Case study in the Amhara region; proceeding of the 16th International Conference of Ethiopian Studies, Addis Ababa, Ethiopia.

Collyns, Dan. (2013). Quinoa brings riches to the Andes. Retrieved from http://www.theguardian.com/world/2013/jan/14/quinoa-andes-bolivia-peru-crop.

CSA (Central statistical Agency).2015. Agricultural sample survey Report on area and production of major crops, Central statistical Agency of Ethiopia. Addis Ababa, Ethiopia V.1 statistical bulletin 584.

Deepak, K. R., James, S. G., Graham, K. M., and Paul, C. W. 2015. Climate variation explains a third of global crop yield variability.Nature Communications | 6:5989 | DOI: 10.1038/ncomms6989 | www.nature.com/naturecommunication

Deressa, T.T. 2006. Measuring the economic impact of climate change on Ethiopian Agriculture: Ricardian approach" CEEPA DP 25, university of Pretoria, South Africa.

Gebre-egziabher, Z., Stage, J., Mekonnen, A. and Alemu, A. 2011. Climate change and the Ethiopian economy: A computable general equilibrium analysis. Environment for Development Discussion Paper Series, p.24.

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 Netherland.

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

Hadgu Gebre, Tesfaye Kindie, Mamo Girma and Kassa Belay. 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.

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: Int. Water Manage. Inst. p.37.

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

Mandal, K.G., Kumar, A., Ghosh, S., Kundu, D.K., Panda, R.K., Mohanty, R.K., Raychaudhuri, M., Padhi, J., Majihi, P. and Sahoo, D.K. 2013. Analysis of rainfall and soil characteristics of kuanria canal command for water resource management research bulletin.

Markos Ezera. 1997. Demographic responses to ecological degradation and food insecurity: Drought prone areas in Northern Ethiopia. Amsterdam: Thesis Publisher Ph. D. Dissertation.

Mavi, H.S. and Tupper, G.J.2004. Agro meteorology: principles and applications of climate studies in agriculture. Food Products Press®, an imprint of the Haworth Press, Inc., 13: 904-1580.

Mesike, C. and Esekhade, T. 2014. Rainfall variability and rubber production in Nigeria. Africa Journal of Environ Science, 8 (1): 54-57.

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 (National Meteorology Service Agency). 2001. Initial national communication of Ethiopia to the United Nations framework convention on climate change (UNFCCC), Addis Ababa, Ethiopia, pp. 113.

North Wollo Zone Agriculture Office, 2018. Meher season pre-yield assessment report (Amharic Version) unpublished report, Woldia, Ethiopia.

Stefan, D. and P. Krishnan. 2000. Vulnerability, seasonality and poverty in Ethiopia. Journal of development studies, 36(6): 25-53.

USDIA Foreign Agricultural Service. (2013, May). Ethiopia grain and feed annual report. USDIA. Retrieved from http://gain.fas.usda.gov/ Addis Ababa_Ethiopia_5-24-2013.pdf.

World Food Program. (2013, December). Ethiopia. Retrieved from WFP website http://www.wfp.org/countries/ethiopia.

Yemenu, F. and Chemeda, D. 2013. Dry and wet analysis of two rainy seasons for decision support in agricultural water management for crop production in central highlands of Ethiopia. Journal of Biological and Agricultural Health care, 3(11):1-6

Zermoglio, M.F. 2011. Climate information to support adaptation decisions in Africa. Technical report to international resources group and U.S. Agency for international development

NATIONAL METEOROLOGY AGENCY

WEST AMHARA METEOROLOGICAL SERVICE CENTER

Characterization of Rainy Season and ENSO Effect in Amhara Region, Ethiopia

Lead Author: Tilahun Wubu
Members: Melkamu Belay
Nigatu Melsie
Sisay Kelemu
Endeg Aniley

ADDIS ABABA,

ETHIOPIA JULY, 2019

Acronyms and Abbreviations

CSA	Central Statistical Agency
CV	Coefficient of Variation
DOY	Day of Year
DRM	Disaster and Risk Management
ENACT	Enhanced National Climate Service
ENSO	El Niño Southern Oscillation
EOS	End of the season
EW	Easterly Wave
FAO	Food and Agricultural Organization
FMAM	February- March-April-May
GDP	Gross Domestic Product
GHG	Green House Gases
GIS	Geographical Information Systems
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
JJAS	June-July-August-September
LGS	Length of Growing Season
LYM	Long Year Mean
MAM	March-April-May
MOA	Ministry of Agriculture
MOARD	Ministry of Agriculture and Rural Development
NDD	Number of Dry Days
NGOs	Non-Governmental Organizations
NMA	National Meteorological Agency
NMSA	National Meteorological Services Agency
NOAA	National Oceanic and Atmospheric Administration
NRD	Number of Rainy Days
ONDJ	October-November-December-January
RSCZ	Red Sea Convergence Zone
SD	Standard Deviation
SOS	Start of the season
SSA	Sub-Saharan Africa
STJ	Sub-Tropical Jet
TEJ	Tropical Easterly Jet

Abstract

This study was designed to characterize rainfall variability and ENSO effect on rainy seasons of Amhara Region, Ethiopia. In order to characterize the rainfall variability of the region Enhancing National Climate Services (ENACTS) climate dataset for 30 years' period (1987-206) and Sea Surface Temperature Anomaly data were obtained from National Meteorological Agency of Ethiopia and NOAA, respectively. For this study Coefficient of variation, Standardized rainfall anomaly, and the presence of a statistically significant trend using Mann-Kendall's test were used to measure variability and trends of rainfall over region respectively. Results indicated that the variability of mean onset and end date of Kiremt season was less variable while the duration of rainfall was moderately variable in the region.

Calculated onset, cessation and duration of rainfall features for Kiremt season have shown a non-significant decreasing trend specially, Eastern parts of the region. The results of correlation analysis indicated that ENSO had weak linkage with Belg (spring) seasonal rainfall variability, Whereas, ENSO had significant linkage with Kiremt (summer) seasonal rainfall variability especially Eastern parts of the region. In order to offset impacts of rainfall variability and Impacts of ENSO over the region appropriate adaptation mechanism should be set.

Key words: ENSO, Amhara region, ENACTS

1. Introduction

1.1 Background

The economy of Ethiopia mainly depends on rain fed agriculture, which is highly vulnerable to the amount and distribution of rainfall. Both spatial rainfall anomalies over the region and temporal variability within the wet season itself can be prominent and leading to decrease significantly. Changes in rainfall conditions have a direct and immediate impact on the performance of agricultural sector as well as on the country's total GDP (Hassan, 2006; FAO, 2006). Rainfall in much of the country is often erratic and unreliable; rainfall variability and associated droughts have historically been major causes of food shortages and famines (Wood, 1977; Pankhurst and Johnson, 1988). According to von Braun (1991), for instance, a 10% decrease in seasonal rainfall from the long-term average generally translates into a 4.4% decrease in the country's food production. It was further noted that in a study conducted in Oromiya region at Debre Zeit and Kulumsa areas (Ethiopia), using wheat as a model crop, a 24 to 33% crop yield reduction was observed due to rainfall and temperature variation (MoWR, 2001). Different researches had been conducted to assess the spatial and temporal patterns of rainfall in different parts of the country. Wing et al. (2008) in studied the trends and spatial distribution of annual and seasonal rainfall in different parts of Ethiopia using data from 134 stations in 13 watersheds between 1960 and 2002, and showed no significant changes in annual watershed rainfall for any of the watersheds examined, rather a significant decline in June to September rainfall (that is, Kiremt) were recorded in watersheds located in the southwestern and central parts of Ethiopia. Similarly, Osman and Sauer born (2002) noted that summer rainfall in the central highlands of Ethiopia declined in the second half of the 20th century. On the other hand, Seleshi and Zanke (2004) failed to find such a trend over central, northern, and northwestern Ethiopia. Instead, similar to Verdin et al. (2005) they found a decline of annual and Kiremt rainfall in eastern, southern, and southwestern Ethiopia. Woldeamlak and Conway (2007) argued declining of annual rainfall in the northwestern part rather there were no clear trend of annual rainfall during their observation time. Generally, Wing et al. (2008) in many parts of Ethiopia, Woldeamlak and Conway (2007) in drought prone areas of Amhara region (Northwestern Ethiopia), Seleshi and Zanke (2004) in central, northern, and northwestern Ethiopia and Conway et al. (2004) in the central Ethiopian highlands and Conway (2000) in northeastern Ethiopian highlands agreed that there is no significant and clear trend in the annual rainfall pattern. Contrasting results of trend in annual and seasonal rainfall in some parts of the country as explained by Easter ling et al. (2000); Seleshi and Zanke (2004) might have been steamed from the use of different periods, some studies have been based on a real average (Seleshi and Demaree, 1995; Osman and Sauerborn, 2002) while others have been based on too few stations to be fully representative of the spatial variability in the study regions (Meze-Hausken, 2004; Seleshi and Zanke, 2004). Rainfall is not well approximated by normal distributions (IPCC, 2001). However, as it has been noted by IPCC (2001) and Moberg and Jones (2005), development and analyzes regional/local specific daily rainfall data is important for a number of indices. In this day and age, assessing changes in rainfall condition has got due attention because of its importance for economic activities such as agriculture, energy production and drinking water supply, management and utilization of resources and due to their role in natural hazards such as droughts, floods, landslides and severe erosion. Thus, the point of this study is to present evidence that the timing of the rainy season (i.e., variation of the start and end dates) and dry spell conditions is an important contributor to seasonal total rainfall, and that where sea surface temperatures (SSTs) affect seasonal total rainfall, it is often through their impact on the timing, rather than on the rate of precipitation during the rainy season.

1.2. Statement of the problem

Agricultural sector of Amhara region is characterized by climate-related factors that impact on crop production. These factors are plenty of rainfalls in one side western part of the region but not supported modernized farming, on the other side scarcity of rainfall, low level of output often leading to food insecurity and famine in the eastern part. The increasing climate variability such as rising erratic rainfall and the resultant water shortage coupled with the continued deforestation and miss-use of woodlands and other land resources has led to the substantial decline in agricultural productivity and rising food insecurity. Though little is known so far, evidences in the study region have shown that water shortage and the changing precipitation levels are affecting crop yields. However, despite a handful of empirical studies, in-depth analysis and well- established scientific evidences on the nature and extent of climate variability, magnitude of climate change impact on agricultural crops and the likely socio-economic consequences on the livelihoods and food security in the study area is virtually lacking. Therefore, this study is designed to investigate characterize seasonal rainfalls and ENSO impact on seasonal rainfalls.

1.3. Significance of the study

The findings of this study enable to provide valuable information and scientific knowledge of Climate characteristics of the study area that plays significant role for adaptive capacity particularly in response to climate variability. Hence, this research helps decision makers, local Communities and NGOS to fill knowledge gap on the use and exploring of scientific information in the agricultural sector of the study area.

1.4. Objectives of the study

1.4.1. General objective

The objective of this study is to characterize rainfall variability and ENSO impact on rainy season in the study region.

1.4.2. The specific objectives of the study area

To characterize rainfall variability based on ENACT climate data, and (ii) to investigate the relationship between ENSO and Rainy season of the study area.

1.2.3. Scope of the study

This study characterizes the past rainfall variability and ENSO impact on rainy season of Amhara region, using forty ENACT climate data and SST sourced from NMA and NOAA respectively.

2. Literature Review

2.1. Agro-climatic zones and seasons in Ethiopia

Three major climatic zones which have been known since ancient times in Ethiopia due to varied topography are Dega, *Weina Dega*and the *Kolla*. The *Dega* (also known as the cool zone) occurs in the central sections of the western and eastern parts of the north- western plateau. The elevation of this region is above 2400m, and daily temperature ranges from near freezing to 160c while the *Weina Dega* (the temperate zone) ranges from between 1500m and 2400m in elevation, and consists of parts of the central plateau. The kola or hot zone generally comprises areas lower than 1500m in elevation, the Denakil depression and the Blue Nile valley (NMSA, 1996; Cheung *et al.,* 2008).

According to NMSA (1996), three distinct seasons locally known as *Bega* (October to January), *Belg* (February to May) and *Kiremt* (June to September) are observed in Ethiopia. Of these three seasons, *Kiremt* is the main rainy season, in which about 85% to 95% of the food crops of the country are produced (Degefu, 1987; NMSA, 1996; Mesay, 2006).While Rainfall distribution and amount during *Belg* season is highly variable in time and space (NMSA, 1996; Mesay, 2006).The western half of the country, with one dry and one wet season in a year, receives the highest amount of rainfall in *Kiremt,* which is generally decreasing from 10 months in the south west to only 2 months in the north west (NMSA, 1996; Mesay, 2006; Viste*et al.,*2012). The central and south- eastern high lands and the adjoining lowlands experience all the three seasons and receives about 60% of the total annual rainfall during the *Kiremt* (NMSA, 1996). The southern and south-eastern low lands of the country have a bi-modal rainfall pattern with main rainy season occurring from March-May and the second short rains from September-October. On the other hand, the north eastern part of the country receives very small amount of *Kiremt* rainfall in a year (Mesay, 2006; NMSA, 1996; Viste*et al.*, 2012).

According to Funk *et al.* (2005); Mesay (2006) and McSweeney*et al.* (2008), seasonal rainfall in Ethiopia is driven mainly by the migration of the tropical rain belt, the Inter-Tropical Convergence Zone (ITCZ). Moreover, the main season (*Kiremt*) rain-producing systems such as the ITCZ, cross equatorial flow from (Mascarene high) southern Indian Ocean, moisture flow from (St. Helena high) Atlantic Ocean and the monsoon low and the associated trough have a great role to play for main season (*Kiremt*) rainfall performance over Ethiopia. According to Mason and Goddard (2001), El Niño–Southern Oscillation (ENSO) have an impact on a seasonal shifting of the normal rainy seasons in some regions, as a result a shortening or lengthening of the rainy seasons, particularly over tropical regions. In line with this, Gissila *et al.* (2004) and Segele and Lamb (2005) indicated that there could be a significant teleconnection linkage between ENSO and the Ethiopian *Kiremt* rainy season. The correlation showing that rainfall could be below average through El Niño episode further more high drought probabilities during strong El Niño years whereas, La Niña events favored further temporal expansion of seasonal activities beyond the normal duration of the rainy season over a region (Gissila *et al.*,2004). However, Conway (2009) and Conway and Schipper (2011) noticed that despite clear evidence on the consequences of climate change, the drivers of climate change in the country are poorly understood. In Ethiopia, the distribution of rainfall varies over the diverse agro-ecological zones that exist in the country (Viste *et al.*, 2012) and the appearance remains usually not understood (Conway and Schipper, 2011).

2.2. Weather systems producing seasonal rainfall in Ethiopia

Ethiopia's topography is composed of massive highland complex of mountains and dissected plateaus divided by Great Rift Valley running generally southwest to north east (Mersha, 1999). 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, 1988; Beltrando and Camberlin, 1993; NMSA, 1996 and Conway, 2009). The movement of the 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. 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 (McSweeney *et al.*,2008). The most important weather systems that cause rain over Ethiopia includes Sub-Tropical Jet (STJ), Inter Tropical Convergence Zone (ITCZ), Red sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ), and Somalia Jet (NMSA, 1996b). The major dominant weather system is ITCZ. It oscillates seasonally with in the tropics and its surface position is influenced by topography and local eddies. Thus, this seasonal oscillation of the ITCZ causes a Variation in the pattern of wind flows over Ethiopia (Romilly and Gebremichael, 2010). According to Mesay (2006),

The major synoptic features that Influences the Weather of Ethiopia include easterly wave (EW), Sub-tropical Jet Stream (STJ) extra-tropical Troughs, Red Sea Convergence Zones (RSCZ), anticyclone over the Indian Ocean and the Mediterranean depression. Moreover, the intensity and areal coverage of the rain is associated, to a great extent with the intrusion and passage of the north-south oriented mid-latitude trough in the westerly wind field. The TEJ and the Tibetan anticyclone are the two important upper level atmospheric features. The strength and position of these atmospheric systems vary from year to year and the rainfall activity too. Regional and global weather systems affecting *Kiremt* (JJAS) season in Ethiopia include the ITCZ with the dominant effect and the Macarena High pressure in Southern Indian Ocean, the Saint Helena High pressure Zone in the Atlantic, the Congo air Boundary, the Monsoon depression and trough, the Monsoon clusters and the Tropical Easterly Jet (Kassahun,1999). Philander (1990) mentioned that El Niño events are associated with variability in rainfall in equatorial East Africa, like Ethiopia (IPCC, 2007). It has been also noted that the rainfall is highly variable in amount, distribution and becomes unpredictable across regions and seasons (Mersha, 1999; Tilahun, 1999; Tesfaye and walker, 2004). This variability of rainfall and the recurrent droughts in Ethiopia affects the lives of millions of people as livelihood depends on rainfall (Viste *et al.*, 2012).

2.3. Trend of seasonal and annual rainfall variability in Ethiopia

Over the last decades' various studies have been conducted to examine rainfall trends in Ethiopia (NMSA, 2001; Viste *et al.*, 2012; Hadgu *et al.*, 2013). NMSA (2001) reported significant reduction in annual rainfall in the north and southwest part and conversely an increasing trend in the central part of the country. However, Bewket and Conway (2007) observed inconsistent trends in the annual, *Kiremt* and *Belg* rainfall among different stations in the country. Meze-Hausken (2004); and Cheung *et al.* (2008) did not find any significant trend over the northern and north eastern part of the country. Hadgu *et al.* (2013) also showed a declining trend in annual and seasonal rainfall amounts in northern Ethiopia, but the trends were non-significant at most of the stations he studied. As indicated by Hadgu *et al.* (2013), start date of growing season showed Increasing trend whereas, end date and length of growing season declining in the northern Ethiopia.

2.4. Definition and Concepts

Onset of rainy season: was defined as a date when 20 mm and 10 mm or more rainfall is accumulated over three consecutive and one or two rainy days after a starting date (1st of June for the *Kiremt* season and 1st of March for the *Belg* season*)* with no dry spell length greater than 8and 9 days in the next 30 days as used in Tesfaye and Walker (2004) and Mesay (2006) respectively. End of growing season: Defined as the end of the rainy season of any day after 1st of September for *Kiremt* and 1st of May for

Belg season when the soil water balance reaches zero (Stern *et. al.;* 1982). The same method was used by several authors to determine end date of growing season (Mamo, 2005; Mesay, 2006; Feyera *et al.*, 2015). Length of growing season: Length of *Kiremt* and *belg* growing season was determined as the difference between the end and start of rainy season (Mamo, 2005; Mesay, 2006; Feyera, 2013; Hadgu*et al.*, 2013; Hadgu *et al.*, 2014; Feyera *et al.*, 2015). Number of rainy and dry days: The number of rainy and dry days was determined by Counting all days with rainfall ≥ 1mm as rainy and those days with < 1mm as dry days respectively as outlined by (NMSA, 2001). Different researchers used the same definition (Segele and Lamb, 2005; Mesay, 2006; Hadgu*et al.*, 2013). At Mekelle, Alamata and Edagahamus, Hadgu*et al.* (2013) observed length of growing season of 85, 79 and 66 days, respectively. Models projection has also shown moderate reduction (< 20%) in the length of the Growing period across Africa including Ethiopia (Thornton *et al.,* 2006). Rainfall totals: Annual and seasonal rainfall totals were determined as sum of rainfall of each day with greater or equal to 1 mm (NMSA, 2001; Segele and Lamb, 2005; Mesay, 2006; Hadgu *et al.*, 2013) for the specified period. Dry spell probability: The dry spell probabilities were determined as consecutive number of days with rainfall less than 1 mm per day exceeding 3, 5, 7, 10 and 15 consecutive days. Dry spell length was analyzed by Markov Chain analysis (Stern *et al.*, 2006; Sreenivas *et al.*, 2008; Stern and Cooper, 2011) using INSTAT^{+} v3.37 software. The probability of maximum dry spells On calendar and on crop calendar basis at lengths of 5, 7, 10, 15 and 20 days were computed using Markov chain model to obtain an overview of dry spell risks and to study dry spells risk in the growing season, respectively.

2.5. El Nino–Southern Oscillation (ENSO) and ENSO Modoki

Pacific LA Niña Modoki when cold SST anomalies prevail in the central Pacific and warm anomalies prevail in eastern and western Pacific, which is analogous to La Niña phase of ENSO.

2.6. El Nino –Southern Oscillation (ENSO)

El Niño–Southern Oscillation (ENSO) is the dominant pattern of large-scale variability in the tropical Pacific that has global impacts on precipitation and surface temperature patterns that are of great relevance to society (Ropelewski and Halpert 1987; Halpert and Ropelewski et al., 1992; Trenberth et al. 1998; Yeh et al. 2018). The El Nino, which is the warm phase of ENSO, develops when large amounts of warm water, from the western pacific pool, accumulate off the coast of Peru. This helps to enhance the atmospheric convection in the eastern Pacific, east of the datelines and bring copious amounts of rainfalls over most of the neighboring landmass. In the opposite phase of the phenomena, called the La Niña, the equatorial cold tongue and the coastal cold waters are enhanced owing to the strengthened trade winds. The warm/cold oceanic state combined together with the respective atmospheric condition is known as the ENSO, which is explained by a simple mechanism proposed by Bjerknes (1969). The positive ocean-atmosphere feedback of Bjerknes type amplifies, for example, initial warm perturbations in the eastern Pacific into large anomalies through ocean atmosphere interactions and eventually develops an ENSO event.

3. Materials and Methods

3..1 Study area

Amhara region covers an estimated area of 170,752 km^2 and located approximately between 8.7°-13.8°N and 35.2°-40.2°E (Fig. 1). The region shares common borders with the state of Tigrai in the north, Afar in the east, Oromiya in the south, Benishangul/Gumuz in the south and west, and the Republic of Sudan in the west. It consists of 11 administrative zones, one special zone, 105 woredas, and 78 urban centers and its' population size 17, 221,976. 8,641,580 were men and 8,580,396 women; urban inhabitants' number 2,112,595 or 12.27% of the population according to central statistical agency (CSA) of Ethiopia reported in 2007. About 85% of the people are engaged in agriculture. The State is one of the major Teff (staple food) producing areas in the country. Barely, wheat, oil seeds, sorghum, maize, wheat, oats, beans and peas are major crops produced in large quantities. Cash crops such as cotton, sesame, sunflower, and sugarcane grow in the vast and virgin tract of the region's lowlands.

The water resources from *Lake Tana* and all the rivers found in the region provide immense potential for irrigation development. About 450,000 hectares of arable land is irrigable and suitable, especially for horticultural development. The State of Amhara is topographically divided into two main parts, namely the highlands and lowlands. The highlands are above 1500 meters above sea level and comprise the largest part of the northern and eastern parts of the region. The highlands are also characterized by chains of mountains and plateaus. Ras Dejen (4620 m), the highest peak in the country, Guna (4236 m), Choke (4184m) and Abune-Yousef (4190m) are among the mountain peaks that are located in the highland parts of the region.

The lowland part covers mainly the western and eastern parts with an altitude between 500-1500 meters above sea level. Areas beyond 2,300 meters above sea level fall within the "Dega" climatic Zone, and areas between the 1,500-2,300 meter above sea level contour fall within the "Woina Dega" climatic zone; and areas below 1,500 contour fall within the "Kola" or hot climatic zones. The Dega, WoinaDega and Kola parts of the region constitute 25%, 44% and 31% of the total area of the region, respectively. The annual mean temperature for most parts of the region lies between 15°C-21°C. The State receives the highest percentage (80%) of the total rainfall in the country. The highest rainfall occurs during the summer season, which starts in mid-June and ends in early September.

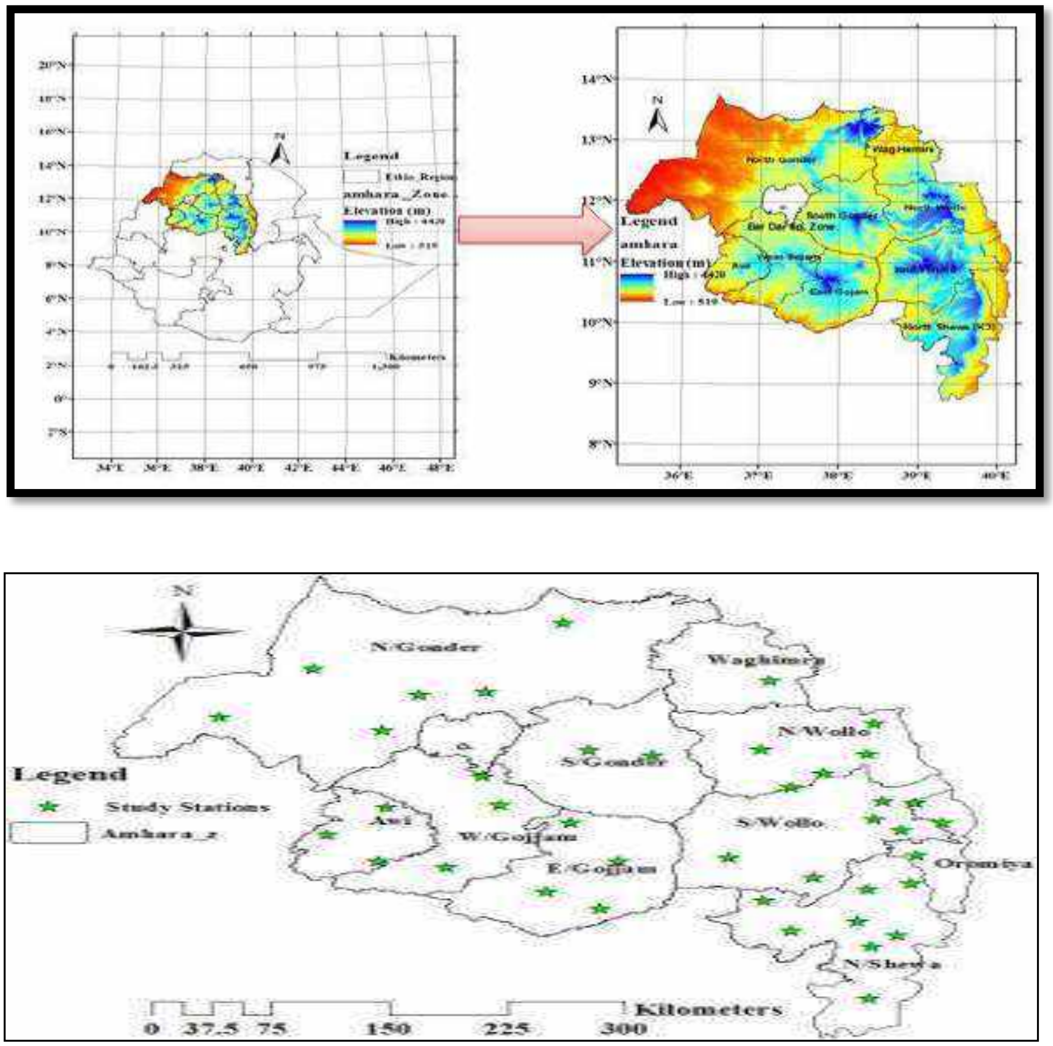


Figure 1: - Location of Study area

3.2. Data sets and method of analysis

Long-term daily rainfall data located in Amhara regional state of Ethiopia was collected from the National Meteorological Agency (NMA), Addis Ababa for the periods (1987-2016). Forty ENACT data was selected for the study with a reasonably good geographic distribution in the study area. (a) Forty ENACT data was selected for the study with a reasonably good geographic distribution in the study area. And (b) Sea surface Temperature Anomaly from NOAA web site https://www.cpc.ncep.noaa.gov/data/indices/sstoi.indices.

Table 1. Geographic information of the selected Meteorological stations used for this study.

Meteorological station	Latitude (^{0})	Longitude (^{0})	Altitude (mm)	Period
Adet	11.27	37.49	2179	1987 - 2016
Ayehu	10.66	36.79	1725	1987 - 2016
Aykel	12.48	37.03	2150	1987 - 2016
B/Dar	11.59	37.39	1800	1987 - 2016
Bati	11.08	40.02	1660	1987 - 2016
Chagni	10.95	36.50	1620	1987 - 2016
Cheffa	11.30	39.86	1400	1987 - 2016
Combolcha	11.00	39.78	1903	1987 - 2016
Dangila	11.25	36.84	1921	1987 - 2016
Debark	13.26	37.85	1900	1987 - 2016
D/Birhan	09.73	39.61	2720	1987 - 2016
D/Markos	10.33	37.75	2515	1987 - 2016
D/Sina	09.85	39.76	2000	1987 - 2016
D/abor	11.87	38.00	2612	1987 - 2016
D/Work	10.66	38.17	2475	1987 - 2016
Dessie	11.12	39.63	2540	1987 - 2016
Eneway	09.90	39.15	2650	1987 - 2016
G/Ketema	12.51	37.41	2128	1987 - 2016
G/Meskel	10.23	39.00	2480	1987 - 2016
Haik	11.31	39.68	1985	1987 - 2016
Kemisse	10.72	39.87	1445	1987 - 2016
Kobbo Agri.	12.16	39.63	1470	1987 - 2016
Lalibela	11.88	38.98	2500	1987 - 2016
Lay_Birr(SF)	10.59	37.18	1707	1987 - 2016
Majete	10.42	39.84	1700	1987 - 2016
M/Meda (RS)	10.35	39.59	3040	1987 - 2016
M/Selam	10.70	38.80	2600	1987 - 2016
Metema	12.76	36.42	900	1987 - 2016
Motta	11.08	37.89	2440	1987 - 2016
N/mewcha	11.81	38.36	3000	1987 - 2016

Quara	12.23	35.89	648	1987 - 2016
Sekota	12.63	39.03	1850	1987 - 2016
Shahura	12.09	36.82	2205	1987 - 2016
Sh/Robit	10.00	39.53	1160	1987 - 2016
Sh/Gebeya	09.16	39.60	2500	1987 - 2016
Sirinka	11.62	39.34	2000	1987 - 2016
W/tena	11.47	39.15	3000	1987 - 2016
Wereilu	10.48	39.28	2690	1987 - 2016
Woldia	11.83	39.59	1960	1987 - 2016
Yetnora	10.14	38.06	2540	1987 - 2016

3.3. Variability

Rainfall variability is a prominent and an unavoidable aspect of rain fed farming all over the world. Annual rainfall variability is calculated by the coefficient of variation (CV) as

$$CV=SD/\mu$$

Where, **CV**, is coefficient of variation, **SD**, is standard deviation while **μ** is the long-term rainfall mean. According to F.K. 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, the timing, variability and quantity of seasonal and annual rainfall were important factors in regard to climate and cultivation. Unexpected break in rainfall early in the growing season would able farmers to recover and resume production despite the loss of some of their crops (Hulme, 1990). However, a break in the middle or latter part of the growing season occurs, all of the crops sown may suffer irreversible damage with dire economic consequences to farmers (Hulme, 1990). Hence, identifying stability of onset of growing period plays a pivotal role for decision making in agricultural activities. In line with this, Reddy (1990) developed a model to assess the stability of growing season for certain location using the standard deviation (Standard deviation is computed as the square root of variance of the average onset dates) like standard deviation <10 as very high stabilities, 10-20 as high stability, and 20-40 as moderate stability and >40 would be as less stability growing season respectively. From the assessment of stability of growing season best possible sowing date was determined.

3.4. Rainfall anomaly

Rainfall anomaly was used to examine the nature of rainfall over the period of study and to determine dry and wet years in the record. Rainfall anomaly (Z) was calculated as:

$$Z = \frac{X - \bar{X}}{SD}$$

Where, **X** is the annual average, while **$\bar{x}$** and **SD** are the long-term mean and standard deviation respectively. This statistic was able to determine the dry (-ve values) and wet (+ve values) years in the record. Drought indicators based purely on precipitation give a good overall view of the situation. Correspondingly McKee et al. (1993) used standardized rainfall anomalies to classify degree of drought. Hence, standardized rainfall anomaly was used to determine frequency of vulnerability in the study area. The drought severity classes (Agnew and Chappel, 1999) are extreme drought ($Z < -1.65$), severe drought ($-1.28 > Z > -1.65$), moderate drought ($-0.84 > Z > -1.28$ and no drought ($Z > -0.84$).

3.5. Precipitation concentration index

A measure of temporal distribution of precipitation in a location can be characterized by different models such as the Gin index (GI), the concentration index (CI) and the precipitation concentration index (PCI). PCI of Oliver (1980) further developed by De-Luis et al. has equally been expressed as an indicator of rainfall concentration for annual. We are using the technique to examine 30- years rainfall data for Amhara region.

$$PCI = \frac{\left(\sum_{i-1}^{12} \text{pi2} \right)}{\left(\sum_{i-1}^{12} \text{pi} \right) 2} * 100$$

Where; Pi the monthly rainfall in month i

The classification of PCI values according to Oliver (1980) is presented in Table 2

Table 2: - Temporal distribution of Precipitation

PCI Value	Significance (Temporal Distribution)
PCI ≤ 10	Uniform Precipitation Distribution (low precipitation concentration)
10<PCI ≤ 15	Moderate Precipitation Distribution
16<PCI ≤ 20	Irregular Precipitation Distribution
PCI >20	Strong Irregularity of Precipitation Distribution

3.6. Rainfall trend analysis

Several tests are available for the detection and estimation of trends. In this particular study, Mann-Kendall's test was employed. Mann-Kendall's test is a non-parametric method, which is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or nonlinear (Partal and Kahya, 2006; Yenigun et al., 2008). The Mann-Kendall's test statistic is given as:

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n}\operatorname{sgn}\left(x_j-x_k\right)$$

Where S is the Mann-Kenda1l's test statistics; x_i and x_j are the sequential data values of the time series in the years i and j (j > i) and N is the length of the time series. A positive S value indicates an increasing trend and a negative value indicates a decreasing trend in the data series. The sign function is given as:

$$\operatorname{sgn}(x)=\begin{cases}+1, & x>0\\ 0, & x=0\\ -1, & x<0\end{cases}$$

The variance of S, for the situation where there may be ties (that is equal values) in the x values, is given by:

$$\operatorname{Var}[S]=\frac{\left\{n(n-1)(2n+5)-\sum_{j=1}^{p}t_j(t_j-1)(2t_j+5)\right\}}{18}$$

Where, m is the number of tied groups in the data set and t_i is the number of data points in the i^{th} tied group. For n larger than 10, Z_{MK} approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun et al., 2008) and computed as follows:

$$
Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases}
$$

The presence of a statistically significant trend is evaluated using Mann-K value. In a two-sided test for trend, the null hypothesis (H_0) should be accepted if /Mann - K/ < Z1-a / 2 at a 0.05 level of significance. Z1-a / 2 is the critical value of Mann-K from the standard normal table. For instance, for 5% significance level, value of Z1-a / 2 is 1.96.

The presence of a statistically significant trend is evaluated using the Z_{MK} value. In a two-sided test for trend, the null hypothesis H_0 should be accepted if $| Z_{MK} | < Z_{1-\alpha/2}$ at a given level of significance. $Z_{1-\alpha/2}$ is the critical value of Z_{MK} from the standard normal table. E.g. for 5% significance level, the value of $Z_{1-\alpha/2}$ is 1.96. The Sen.'s estimator of slope: - This test is applied in cases where the trend is assumed to be linear, depicting the quantification of changes per unit time. This method could be used with missing data and remain unaffected by outliers or gross errors (Karpouzos et al., 2010). The slope (change per unit time) was estimated following the procedure of Sen. (1968). A detailed outline of the procedure is given in Partal and Kahya (2006) and Karpouzos et al. (2010).

The two-sided test is carried out at 100(1 – α) % of confidence interval to obtain the true slope for non-parametric test in the series" (Mondal et.al. 2012). The positive or negative slope Qi is obtained as upward (increasing) or downward (decreasing) trend.

Correlation: - The correlation is one of the most common and most useful statistics. A correlation is a single number that describes the degree of relationship between two variables. It is defined as the measure of linear association between two variables. A single value, commonly referred to as the correlation coefficient, is often needed to describe this association. The value has two special properties. First, it is bounded by -1 and 1. If the correlation is exactly -1, there is a perfect, negative linear association between the two variables; the scatter plot of the two variables falls along one line with negative slope. Conversely, if the correlation is exactly 1, there is a perfect, positive linear correlation. Secondly, the square of the correlation describes the amount of variability in one variable that is described by the other variable. This variable is called variance. The degree of the association is assured by the significance. The significance of the correlation is used to determine minimum threshold for the correlation coefficient at a given significance level.

4. Results and Discussion

4.1. Rainfall variability and ENSO impact on seasonal rainfall in Amhara region.

4.1.1. Characteristics of rainfall

According to INSTAT climate guide definition a time series analysis of daily rainfall of a specific area from the past record gives a good picture to decide the possible onset date, cessation date and length of growing season for *Belg* and *Kiremt* season in the region. Starting date of *Belg* season in the region was undefined for all of stations when we analyzed the data to determine the starting of the rain. These show us difficult to predict *Belg* season though *Belg* growing areas. The result is not consistent with Mesay (2006). Whereas, end dates of *Belg* season experienced in May 01 for all stations. Mean onset date of Kiremt season is ranged from May 19 to July 18 (Figure 4). In line with this, Onset appears to progress from west to east in the region. The apparent slow progression of onset for eastern parts of the region is leading to short length of growing period. While western parts have long length of growing period. The climatology of cessation date in Kiremt is ranged from September 21 to November 06 in the Eastern and Western parts of the region respectively. Generally, we observed from onset and cessation date in this region, long and short duration of rain were observed over western and eastern parts of the region in Kiremt season respectively that implies 58 days in Kobo and 179 days in Chagni.

To know the information about the starting and ending date of the season is crucial for agricultural purpose as well as other sectors to take proper actions. The result found in this study was consistent with Segele and Lamb (2005). Figure indicated that the variability of mean onset and end date of Kiremt season were less variable while the duration of rainfall was moderately variable in the region. The variability of onset date is more variable than end dates of the rainfall in the region. The standard deviation of onset, end date and length of growing period were very high stability to moderate stability respectively in the region according to Reddy (1990).

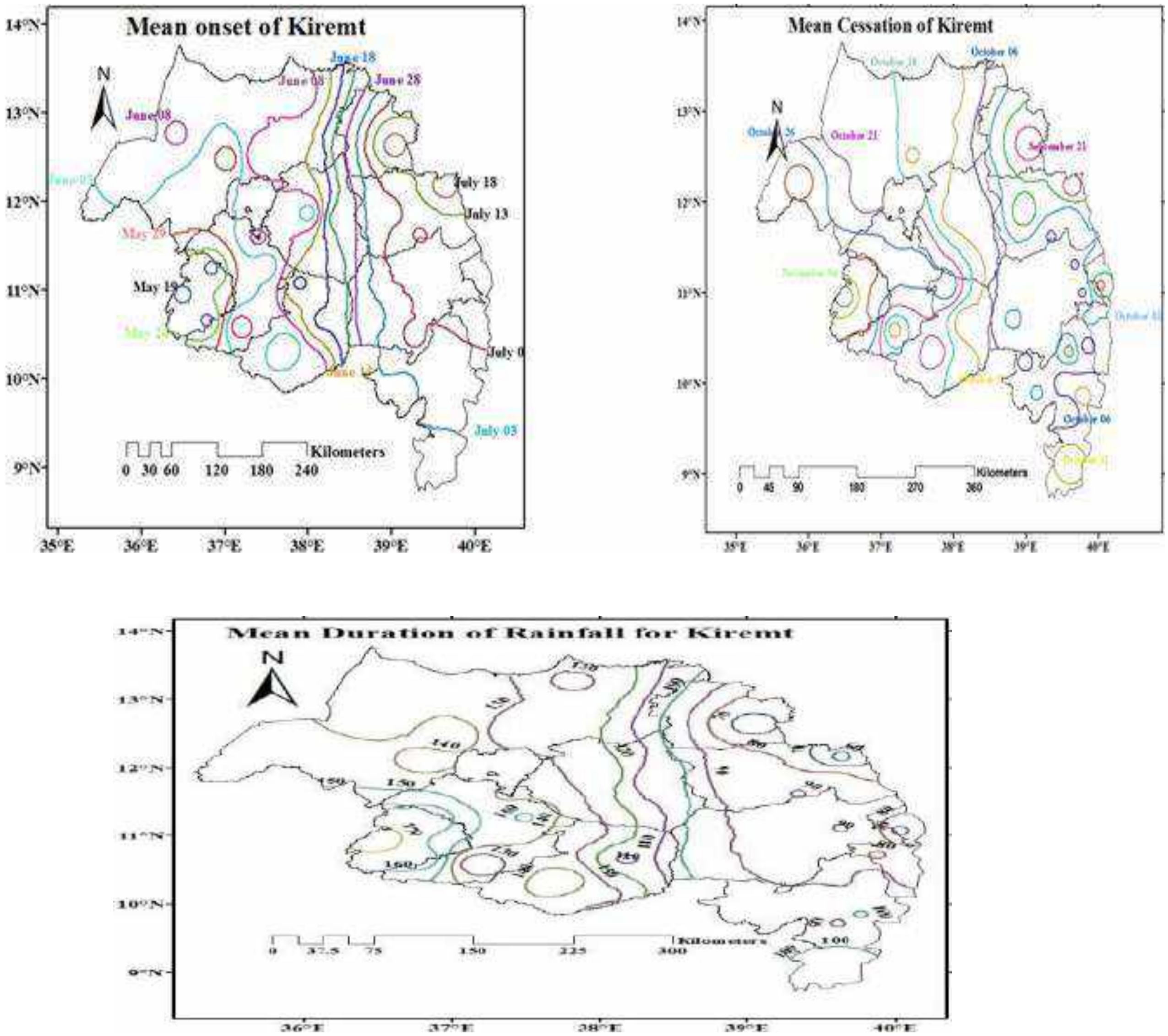


Figure 2: - Climatology of onset, cessation and duration of rainfall for Amhara region

4.1.2. Annual mean rainfall features

The areal annual mean rainfall in the region was found to be 965.5 mm and it varied from 773.8 (lowest in 2015) to1120.2 mm (highest in 2006) with standard deviation (SD) of 86.4mm and coefficient of variation (CV) 8.96% (Table 3). The average areal annual rainy days which were between 78 days (1991) and 111 days (1997). It also observed that the average spatial and temporal rainfall is ranged from 520.4mm (Bati) to 1597.9mm (D/Sina) and the lowest and highest annual rainfall was recorded 206mm (2015) at Kobbo and 2968.0mm (1997) at D/sina in the region in the study period. In line with this, the annual mean rainfall variability's (CV) is less variable for most of stations except some stations like Sh/Gebiya, Majete, Lalibela, Kobo, Kemissie, D/Sina and Debark are moderately variables.

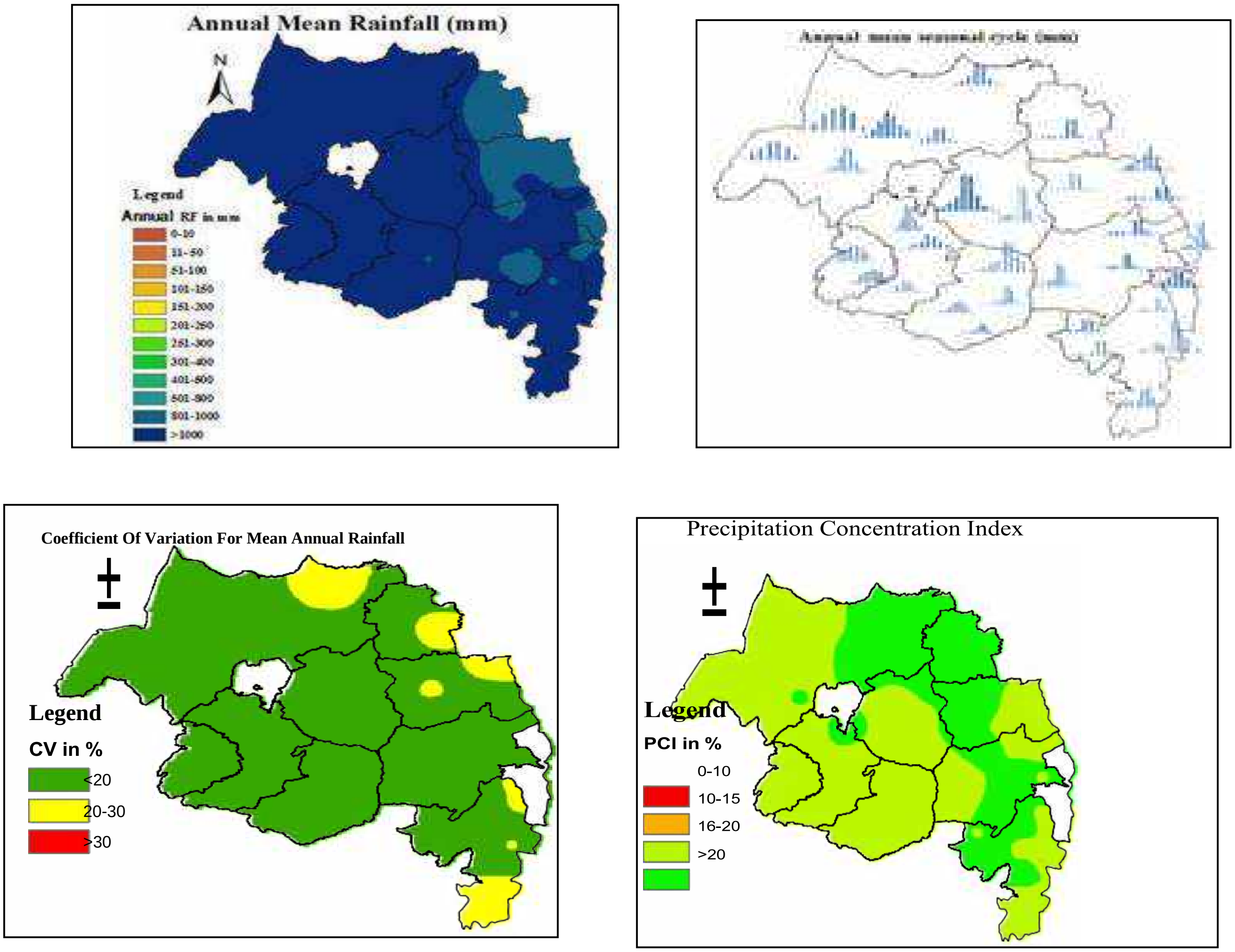


Figure 3. Climatology of Annual, Seasonal Cycle, CV of Annual rainfall and Annual Precipitation Concentration Index

This indicated that good reliability of rainfall in the study period. Hence, agricultural operations like planting/sowing can be undertaken successfully during this period. However, the calculated standard deviations of all station in the study region are higher that range from Bati (89.6mm) to D/sina (319.6mm) that indicates high variation. In Ethiopia, the season is unique and also has different agro-ecological zones that studied in different time. The seasons classified based on annual mean rainfall pattern, monthly rainfall distribution and meteorological governing systems (Haile etal., 1987). In the similar manner, the rainfall regime in Amhara region is classified into three seasons. There are *Bega* (October to January), *Belg* (February to May) and *Kiremt* (June to September). There was existed spatial and temporal variability in precipitation concentration in the region. The precipitation distribution ranges from highly to very high concentrated across the region (Figure 3). Figure 3 showed that the rain fall patterns were mono-modal and bi-modal over western &Eastern parts of the region respectively.

Table 3: - Descriptive statistics of annual rainfall characteristics for the study area (1987-2016)

Station	Annual Rainfall					Mean Rainy days	PCI (%)	Mean Monthly Rainfall (mm)
	Max (mm)	Min (mm)	Mean (mm)	CV (%)	SD (mm)			Highest (CT %)
Adet	1507.0	840.0	1092.5	15.9	174.2	116	17.5	27.1
Ayehu	1331.0	833.0	1086.5	12.8	139.4	128	15.5	20.6
Aykel	1288.0	766.0	1078.5	12.2	131.3	110	18.0	26.5
B/Dar	1587.0	967.0	1329.2	12.9	171.2	106	22.2	31.6
Bati	678.0	331.0	520.4	17.2	89.6	70	22.3	33.6
Chagni	1813.0	959.0	1490.9	16.2	242.1	141	16.3	21.3
Cheffa	1074.0	417.0	791.1	16.3	152.5	75	20.0	30.2
Combolcha	1114.0	638.0	908.3	14.6	132.3	88	19.5	29.5
Dangila	1822.0	1070.0	1467.1	13.4	197.1	137	17.2	23.7
Debark	1765.0	738.0	1036.5	22.5	233.5	104	20.4	30.4
D/Birhan	1008.0	598.0	815.6	11.8	95.9	92	23.8	34.8
D/Markos	1577.0	921.0	1208.0	11.0	132.4	137	18.7	23.8
D/Sina	2968.0	951.0	1551.3	20.6	319.6	110	14.6	24.7
D/abor	1815.0	903.0	1349.1	16.0	216.2	119	19.8	28.8
D/Work	1201.0	559.0	792.3	19.2	152.2	90	19.6	31.1
Dessie	1376.0	625.0	925.4	18.7	172.7	81	22.1	32.4
Eneway	1040.0	492.0	786.9	17.3	136.1	87	23.5	33.7
G/Ketema	1354.0	649.0	913.5	17.7	162.0	98	21.7	30.2
G/Meskel	1154.0	523.0	839.5	16.6	139.3	71	19.8	29.1
Haik	1371.0	673.0	1001.2	16.5	165.4	90	18.1	27.9
Kemisse	1059.0	377.0	751.0	23.8	178.9	71	21.2	32.0
Kobbo Agri.	1023.0	206.0	592.6	26.2	155.2	61	18.0	30.8

Lalibela	957.0	292.0	696.2	20.8	145.0	82	23.7	35.1
Lay_Birr(SF)	1344.0	644.0	903.1	16.6	149.9	118	15.4	23.8
Majete	1550.0	462.0	1053.4	21.3	224.9	93	16.4	27.9
M/Meda	1125.0	485.0	777.8	17.9	138.9	90	22.1	34.2
M/Selam	1176.0	527.0	810.1	16.5	133.4	101	16.4	27.1
Metema	1238.0	588.0	917.5	16.8	154.4	86	19.4	26.0
Motta	1345.0	810.0	1091.9	13.8	150.6	113	17.4	26.1
N/mewcha	1706.0	672.0	1004.1	19.0	191.2	109	19.8	30.7
Quara	1250.0	894.0	1051.8	10.0	104.9	107	18.9	24.8
Sekota	735.0	307.0	532.8	20.4	108.7	50	26.4	36.0
Shahura	1470.0	842.0	1158.3	14.6	168.7	101	20.2	27.6
Sh/Robit	1580.0	638.0	1055.0	19.6	207.2	81	18.9	32.7
Sh/Gebeya	1666.0	523.0	1108.1	28.5	316.1	87	15.4	26.0
Sirinka	1224.0	715.0	949.0	15.0	142.5	88	15.0	25.8
W/tena	943.0	445.0	721.6	16.3	117.9	78	22.6	33.0
Wereilu	921.0	351.0	663.9	19.1	126.7	71	26.4	36.0
Woldia	864.0	523.0	718.5	14.4	103.6	73	18.2	29.7
Yetnora	1544.0	695.0	1037.7	19.3	200.3	108	17.7	27.3

4.1.3. Seasonal rainfall characteristics

4.1.3.1. Belg (spring) rainfall

Belg (FMAM) is a short (small) rain season for Amhara region specially, for Eastern Amhara. It extends from mid-February to mid-May. The Belg mean rainfall is ranging from82.4mm (Wereilu) to 363.9 mm (D/sina) and also the lowest and highest rainfall values are 0mm (B/dar) and 837mm (Sh/gebiya) and with coefficient of variability and standard deviation were found to be 35.9% (D/birhan) to 82.9% (kemissie) and 41.7mm (Quara) to 174.3mm (Sh/gebiya) respectively (Table 4). That noted us highly to extreme variable for all stations which implies difficult for agricultural activities for the belg season in the region specially; Belg growing areas. Thus, the rainfall of Belg season varies in time and space in the region. The contributions of the stations that contributed more than 20 % in Belg season over Eastern parts of the study region are Chefa (20.1%), Combolcha (20.8%), D/sina (23.5%), Haik (23.3%), Kobbo (24.9%), Majete (23.8), M/selam (22.0%), Sh/robit (20.1), Sh/gebiya (25.2%), Sirinka

(27.1%), W/tena (20.2%) and Woldia (22.9%) from the annual mean rainfall the rests are 15% to 20% contributions (Table 2). On the other hand, the western parts of the region have received less than 15% of contribution in Belg season for most of stations except few stations, like yetnora (16.9%), N/mewucha (17.1%), D/work (15.8%), D/markos (16.7%) and Ayehu (16.6%) rainfall from annual mean (Table 4 & Figure 4). Hence, the Belg rainfall is not satisfactory for growing of crops which need more water in the time of germination to maturity stages.

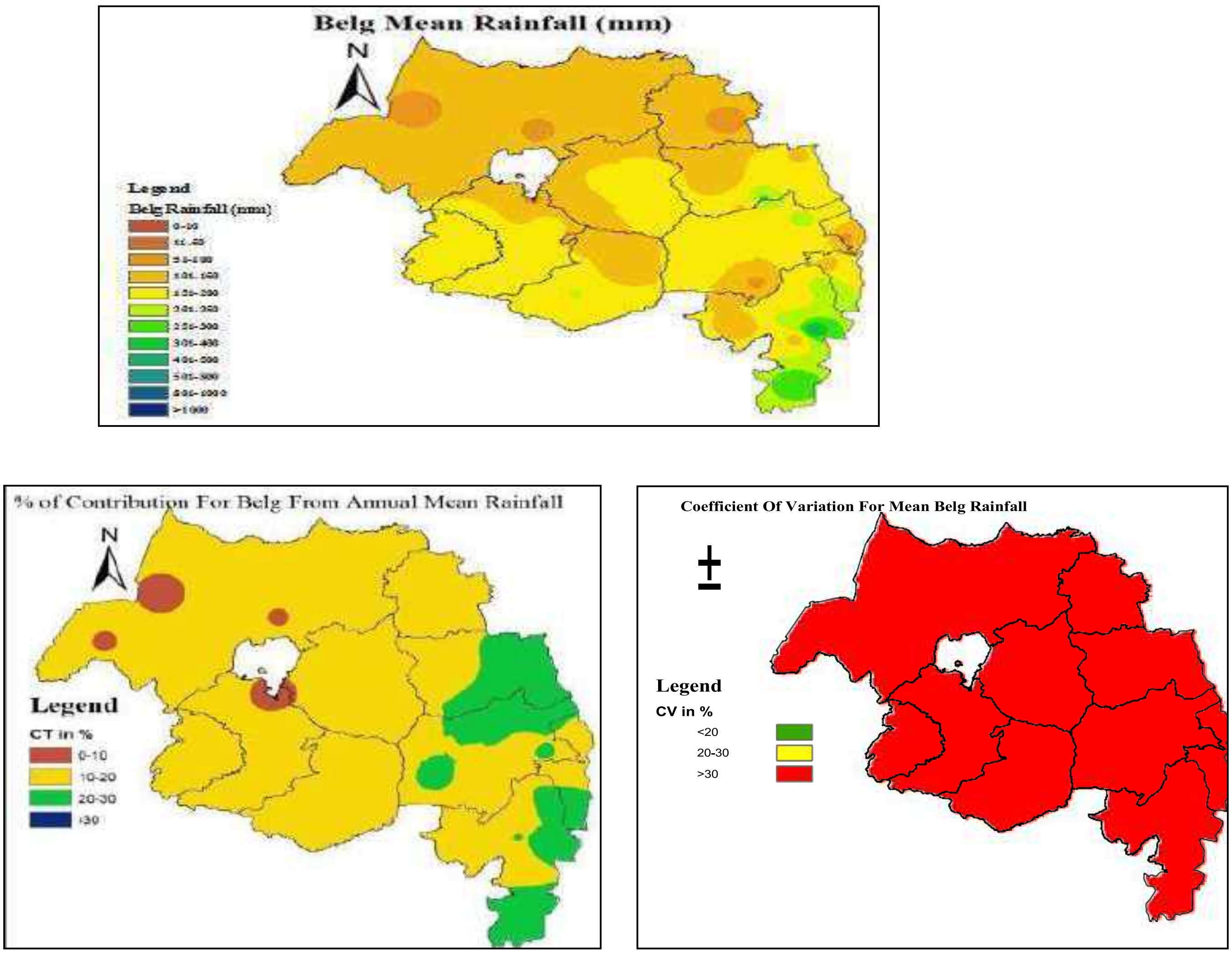


Figure 4. Climatology of Belg (spring) Rainfall, % of CT for Belg from Annual mean and CV of Belg Rainfall

Table 4:- Descriptive statistics of "Belg" rainfall characteristics for the study area (1987-2016)

Belg Rainfall						
Station	Max (mm)	Min (mm)	Mean (mm)	CV (%)	SD(mm)	CT (%)
Adet	377.0	16.0	157.5	61.9	97.5	14.4
Ayehu	345.0	55.0	180.7	43.3	78.3	16.6
Aykel	290.0	8.0	136.1	51.3	69.8	12.6
B/Dar	279.0	0.0	91.7	72.6	66.5	6.9
Bati	243.0	16.0	82.9	57.6	47.7	15.9
Chagni	485.0	63.0	189.8	44.4	84.3	12.7
Cheffa	323.0	18.0	159.2	48.9	77.8	20.1
Combolcha	429.0	33.0	189.0	46.8	88.4	20.8
Dangila	442.0	30.0	186.9	52.1	97.4	12.7
Debark	262.0	33.0	128.2	46.8	60.0	12.4
D/Birhan	236.0	26.0	123.5	35.9	44.4	15.1
D/Markos	396.0	27.0	202.2	46.2	93.5	16.7
D/Sina	786.0	161.0	363.9	44.5	162.0	23.5
D/abor	332.0	41.0	159.2	47.0	74.8	11.8
D/Work	248.0	31.0	125.3	48.8	61.1	15.8
Dessie	381.0	6.0	167.9	52.8	88.6	18.1
Eneway	289.0	34.0	119.6	49.3	59.0	15.2
G/Ketema	215.0	5.0	88.6	61.2	54.2	9.7
G/Meskel	293.0	37.0	148.2	38.7	57.4	17.6
Haik	483.0	36.0	233.7	45.8	107.0	23.3
Kemisse	553.0	17.0	137.3	82.9	113.8	18.3
Kobbo Agri.	498.0	25.0	147.5	63.7	93.9	24.9
Lalibela	273.0	19.0	108.5	52.8	57.3	15.6
Lay_Birr(SF)	314.0	29.0	150.3	47.4	71.3	16.6
Majete	473.0	83.0	251.1	42.1	105.8	23.8
M/Meda (RS)	326.0	52.0	149.9	43.2	64.7	19.3

M/Selam	322.0	79.0	178.5	36.6	65.4	22.0
Metema	190.0	28.0	87.4	57.1	49.9	9.5
Motta	412.0	46.0	139.9	55.3	77.3	12.8
N/mewcha	426.0	36.0	171.3	42.1	72.1	17.1
Quara	204.0	39.0	103.9	40.1	41.7	9.9
Sekota	226.0	16.0	83.8	58.4	48.9	15.7
Shahura	399.0	30.0	120.4	60.4	72.7	10.4
Sh/Robit	542.0	52.0	212.1	55.8	118.4	20.1
Sh/Gebeya	837.0	62.0	278.7	62.5	174.3	25.2
Sirinka	448.0	55.0	257.0	45.7	117.5	27.1
W/tena	274.0	12.0	145.8	45.3	66.1	20.2
Wereilu	212.0	13.0	82.4	59.7	49.2	12.4
Woldia	358.0	37.0	164.3	52.0	85.5	22.9
Yetnora	316.0	23.0	174.9	46.6	81.4	16.9

4.1.3.2. Kiremt rainfall

Kiremt (JJAS) is the main rain season and useful for all economic sectors in Amhara region. It extends from June to September. The Kiremt mean rainfall is between 383.3 (Kobo) to 1157.3 mm (D/sina) and its variability is less variable (<20) (Table 5 & Figure 5) for most stations which implies reliable for agriculture, health, construction and water sectors. On the other hand, some of stations are moderate variable that lead to less reliable for agriculture but, Kobo station is highly variable (34.8%). Most of stations that contributed more than 70 % in Kiremt season over the study region to the annual mean rainfall. On the other hand, some stations of the region have contributed less than 70% in Kiremt season, like D/sina (61.7%), Haik (68.2%), kobo (64.7%), M/selam (69.6%), Sh/robit (68.9%), Sh/gebiya (65.2%), sirinka (58.7%) and Woldia (67.2%) rainfall from annual mean (Table 3). These indicated that Kiremt rainfall is crucial for economic movement in the region. In general, Kiremt rainfall is more reliable for economic activities for all sectors, especially for agriculture and water sectors.

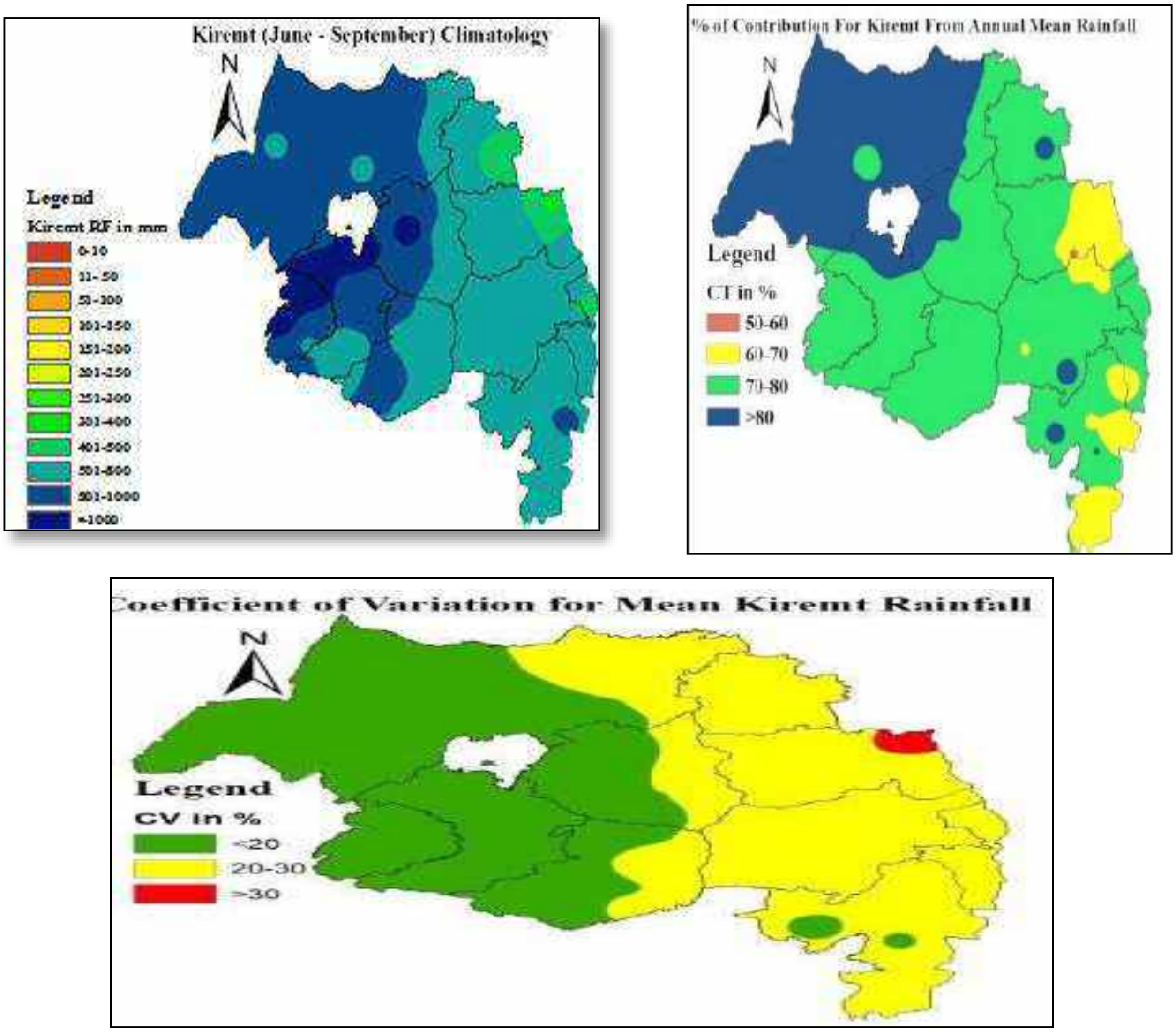


Figure 5. Climatology of Kiremt Rainfall, % of CT from Annual Mean Rainfall and CV

Table 5: - Descriptive statistics of "Kiremt" rain characteristics for the study area (1987-2016)

Kiremt Rainfall						
Station	Max(mm)	Min(mm)	Mean(mm)	CV (%)	SD (mm)	CT (%)
Adet	1277.0	574.0	826.1	18.8	155.2	75.6
Ayehu	1065.0	509.0	782.7	14.4	112.5	72.0
Aykel	1032.0	548.0	843.8	12.7	106.9	78.2
B/Dar	1455.0	766.0	1157.3	16.4	189.5	87.1
Bati	571.0	190.0	404.3	22.8	92.0	77.7

Chagni	1389.0	795.0	1110.1	15.1	167.1	74.5
Cheffa	897.0	241.0	565.4	27.5	155.2	71.5
Combolcha	874.0	356.0	644.0	20.2	129.9	70.9
Dangila	1463.0	796.0	1146.4	12.9	148.2	78.1
Debark	1439.0	539.0	841.4	24.4	204.9	81.2

D/Birhan	892.0	342.0	659.0	16.7	109.7	80.8
D/Markos	1069.0	575.0	893.3	12.1	108.0	73.9
D/Sina	1524.0	406.0	956.9	29.4	281.0	61.7
D/abor	1493.0	676.0	1087.0	17.6	191.0	80.6
D/Work	1063.0	423.0	601.7	23.2	139.6	75.9
Dessie	1119.0	418.0	697.7	24.8	173.3	75.4
Eneway	830.0	380.0	646.2	17.0	110.1	82.1
G/Ketema	1203.0	572.0	767.8	18.7	143.9	84.0
G/Meskel	984.0	366.0	651.0	21.8	141.6	77.5
Haik	1055.0	362.0	682.7	24.1	164.3	68.2
Kemisse	907.0	278.0	563.2	29.5	166.0	75.0
Kobo Agri.	627.0	136.0	383.3	34.8	133.5	64.7
Lalibela	829.0	145.0	547.5	26.1	142.9	78.6
Lay_Birr(SF)	994.0	392.0	643.1	17.9	115.2	71.2
Majete	1064.0	221.0	675.8	27.9	188.5	64.2
M/Meda	836.0	283.0	585.9	23.4	137.1	75.3
M/Selam	988.0	328.0	564.1	22.5	126.9	69.6
Metema	1071.0	514.0	782.3	17.4	135.9	85.3
Motta	998.0	529.0	816.7	14.9	121.5	74.8
N/mewcha	1178.0	399.0	745.6	21.3	158.9	74.2
Quara	1107.0	735.0	863.9	10.1	87.3	82.1
Sekota	632.0	231.0	431.1	25.1	108.0	80.9
Shahura	1280.0	753.0	976.3	14.7	144.0	84.3
Sh/Robit	1323.0	259.0	727.4	29.2	212.2	68.9
Sh/Gebeya	1114.0	263.0	722.0	28.0	202.5	65.2
Sirinka	817.0	327.0	556.9	23.7	132.2	58.7
W/tena	722.0	277.0	538.5	21.6	116.2	74.6
Wereilu	747.0	240.0	555.1	22.8	126.6	83.6
Woldia	653.0	229.0	483.1	23.1	111.7	67.2
Yetnora	1210.0	494.0	788.1	21.3	167.8	75.9

4.2. Rainfall trend analysis

Trends of annual mean rainfall for most stations were found to be statistically insignificant while few stations like Adet and Sh/Gebya have been decreasing trend significantly whereas, D/Birhan and Motta have been increasing trend significantly and also slightly decreasing trend for Wereilu, Kemissie and kobo stations.

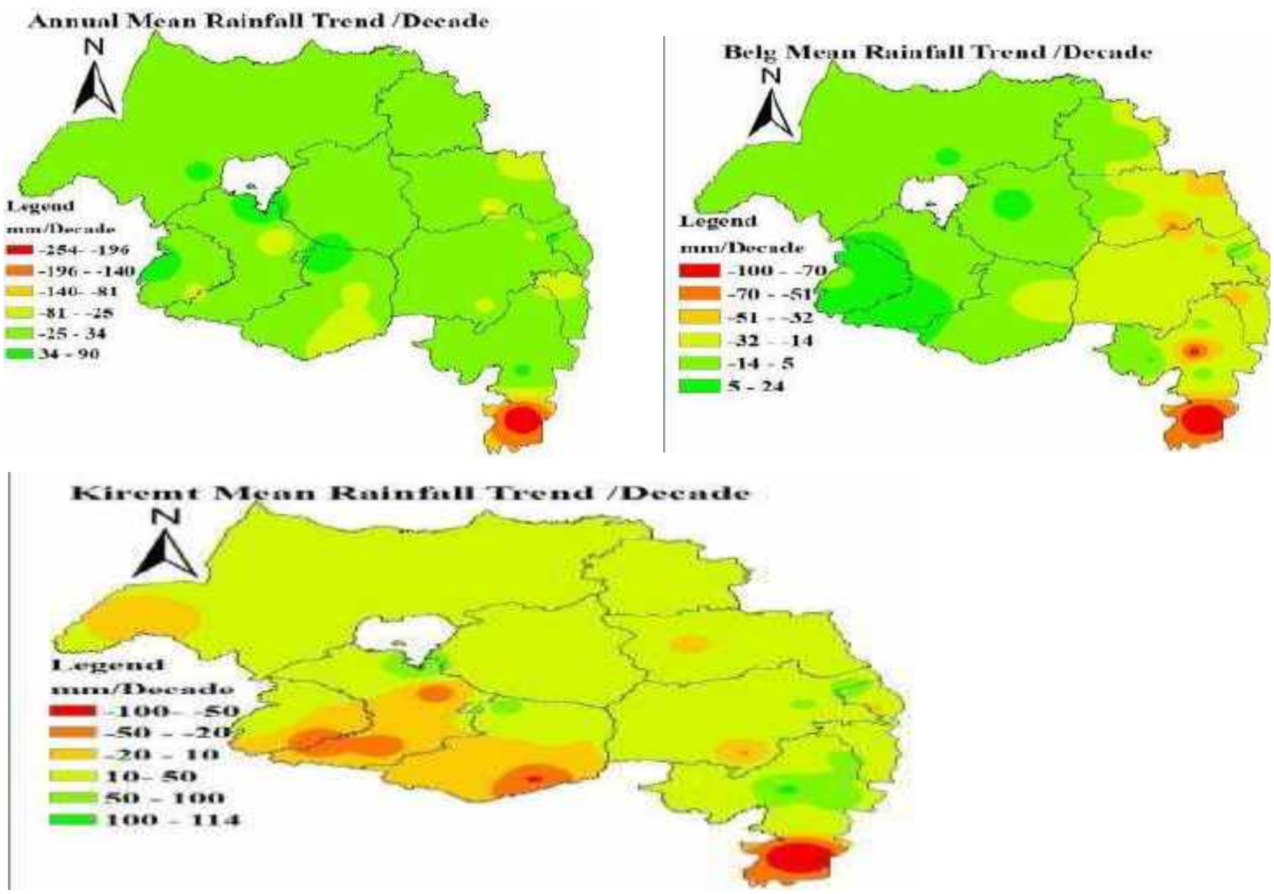


Figure 6: - Trends of Mean Annual, Belg and Kiremt Rainfall per Decade

On the other hand, the rate of change of annual mean rainfall for Adet, D/birhan, Kemissie, kobo, Motta, Sh/gebiya, and woreilu were -71, 46, -72, -48, 90, -254, and -34 mm/decade respectively. Trends of *Belg* rainfall in the study area were statistically insignificant for most of stations but decreasing trend except some stations like Ayehu, Chagni, Dangla, D/markos, D/tabor, Enwary, G/ketema, Motta, Shahura and Layber increasing trend. However, D/work, Kemissie, kobo, Sh/robit, Sh/gebya and Sirinka are statistically decreasing trendsignificantly (Table 2). In line with to this, the rates of change of *Belg* mean rainfall for Debre work, Kemissie, Kobo, Sh/robit, Sh/gebiya, and sirinka were -30, -43, -40, -74, -89, and -54 mm/decade respectively. The *Kiremt* rainfall in the study area was statistically insignificant trend for most of stations while increasing trend except some stations like Adet, Ayehu, Layber, Wereilu and Yetnora decreasing trend. However, Aykel, Motta and Sh/robit were statistically increasing significant trend (Table 3). In the similar manner, B/dar, chefa and D/birhan slightly increase but, Sh/Gebiya is negatively slightly deceasing. Similarly, the rate of Kiremt mean rainfall for Aykel, B/dar, Cheffa, D/birhan, Motta, andSh/gebiya were observed 48, 87, 78, 41, 60, and 114 mm/decade respectively. To sum up, Annual, *Belg* and *Kiremt* mean rainfall trend and rate were observed statistically insignificant for most of the region except Mijar shenkora (Figure 6 and Table 6).

4.3. Trend analysis of onset, cessation and rainfall duration (LGP) for kiremt season

Onset of most stations revealed that decreasing trend (Table 6). On the other hand, few stations like Adet, B/dar, D/markose and Lalibela have been decreasing trend except B/dar (at $p < 0.1$). similarly Debark and M/selam have shown significantly decreasing trend at $p<0.05$ and $p<0.01$ probability level respectively. The rate of change of mean onset for Adet, B/dar, Debark, D/markos, Lalibela and M/selam were observed -7, 8, -11, -6, -5 and -9 days/decade. Cessation of most stations have experienced decreasing trend. Among from those stations like Haik, M/selam ($p<0.1$) and Sh/gebiya ($p<0.001$) indicated that decreasing trend significantly except M/selam increasing trend. The rate of change of cessation for Haik, M/selam and Sh/gebiya were experienced -5,3 and -6 days/decade. In line with this, the duration of rainfall (LGP) of most stations revealed that increasing trend but not significant statistically. However, few stations like Sh/gebiya, Sh/robit, B/dar and M/selam have been decreasing trend significantly (at $p< 0.05$ and 0.01) respectively except M/selam increasing trend. The rate of change of rainfall duration (LGP) for B/dar, Dessie, M/selam, Sh/robit and Sh/gebiya were observed -10, -6, 13, -8 and -13 days/ decade. Generally, most stations of onset, cessation and duration of rainfall for Kiremt season have been decreasing trend but not significant specially, Eastern parts of the region.

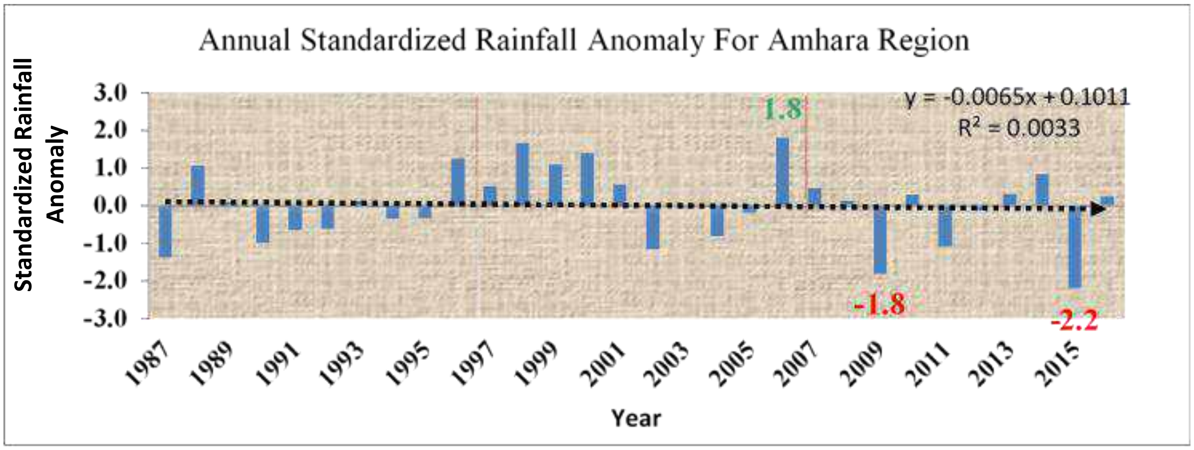
Table 6: - Trend detection of Annual, Belg, and Kiremt rainfall and change/yr. characteristics for the study area (1987-2016)

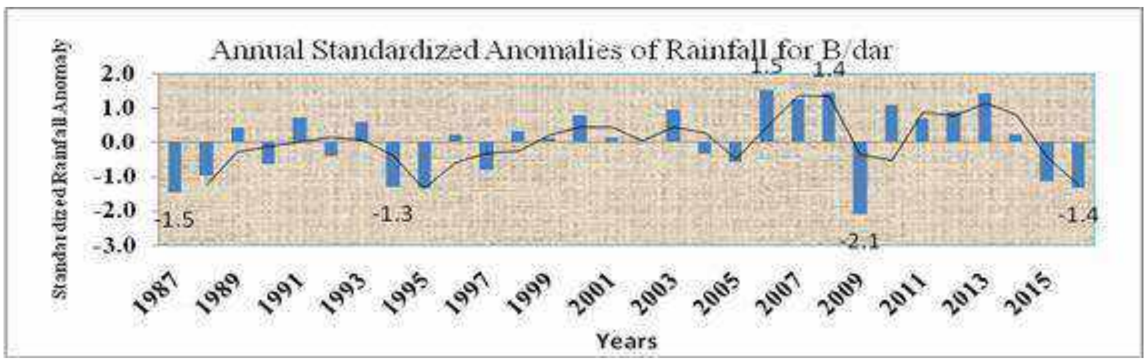
Rainfall Trend and change in (mm/year)												
	Belg		Kiremt		Annual		Onset		Cessation		LGP	
Station	ZMK	Slope	ZMK	Slope	ZMK	Slope	ZMK	slope	ZMK	slope	ZMK	slope
Adet	-0.5	-1.3	-1.1	-4.0	-2.6**	-7.1	-1.7+	-0.7	-1.2	-0.4	0.5	0.3
Ayehu	1.2	2.4	-1.5	-3.7	-1.1	-3.5	-0.7	-0.2	-1.3	-0.4	-0.1	-0.1
Aykel	-0.3	-0.5	2.0*	4.8	0.7	2.2	-0.1	0.0	0.3	0.1	0.5	0.5
B/Dar	-0.5	-1.1	1.7+	8.7	1.5	6.9	1.7+	0.8	-1.4	-0.3	-2.3*	-1.0
Bati	-1.3	-1.3	0.2	0.4	-1.0	-2.3	1.4	0.3	0.0	0.0	0.0	0.0
Chagni	0.2	0.2	0.9	3.8	1.2	6.0	-1.4	-0.3	0.6	0.2	1.4	0.6
Cheffa	-0.1	-0.2	1.8+	7.8	1.3	4.7	-0.5	-0.1	-0.1	0.0	0.2	0.1
Combolcha	-0.9	-1.8	1.1	3.8	-0.4	-1.5	0.0	0.0	-1.0	-0.3	-1.2	-0.4
Dangila	0.6	1.1	0.3	1.1	0.6	2.7	-1.0	-0.4	-0.8	-0.2	0.2	0.2
Debark	-0.4	-0.8	0.3	1.3	-0.3	-1.0	-2.1*	-1.1	-1.5	-0.4	0.7	0.3
D/Birhan	-0.6	-0.6	1.8+	4.1	2.4*	4.6	-0.8	-0.2	-0.7	-0.1	-0.5	-0.1
D/Markos	0.1	0.2	0.2	0.5	-0.4	-0.8	-1.8+	-0.6	-0.8	-0.1	1.4	0.6
D/Sina	-1.2	-3.0	1.0	5.7	0.0	0.3	-0.3	-0.1	-1.0	-0.3	-0.6	-0.2
D/abor	0.4	1.1	0.5	4.0	0.5	1.3	0.3	0.2	0.0	0.0	-0.1	-0.1
D/Work	-2.0*	-3.0	0.2	1.2	-1.5	-3.4	1.6	0.6	0.1	0.0	-1.5	-0.7
Dessie	-0.9	-1.8	1.2	5.8	0.5	2.5	1.0	0.1	-0.5	-0.2	-1.9+	-0.6
Enwary	0.4	0.6	1.4	2.5	0.6	1.4	1.1	0.2	-1.3	-0.3	-1.0	-0.3
G/Ketema	0.4	0.7	0.7	2.8	0.9	2.7	0.4	0.2	-0.6	-0.1	-0.5	-0.3
G/Meskel	-0.5	-0.8	0.7	2.3	0.1	0.8	-1.5	-0.3	-0.7	0.0	0.4	0.1
Haik	-1.6	-3.9	0.7	2.2	-0.7	-3.5	-0.1	0.0	-1.9+	-0.5	-1.1	-0.4
Kemisie	-2.7**	-4.3	0.8	2.8	-1.7+	-7.2	-0.8	-0.2	-0.8	-0.3	-0.4	-0.3
Kobbo Agri.	-2.6*	-4.0	0.3	1.0	-1.7+	-4.8	-1.0	-0.3	0.8	0.2	0.8	0.4
Lalibela	-0.6	-0.8	0.1	0.4	-0.2	-1.2	-1.9+	-0.5	-0.1	0.0	0.4	0.2
Lay_Birr(SF)	0.8	1.6	-1.2	-2.7	0.0	0.0	-0.6	-0.1	-1.3	-0.6	-0.9	-0.5
Majete	-0.6	-2.1	1.2	5.6	0.1	0.1	-1.2	-0.2	-0.7	-0.2	-0.2	-0.1
M/Meda	-0.7	-1.0	1.3	3.8	0.7	2.5	-1.2	-0.3	0.4	0.1	-0.1	0.0
M/Selam	-0.7	-1.8	1.1	2.8	0.5	1.6	-3.1**	-0.9	1.7+	0.3	2.9**	1.3

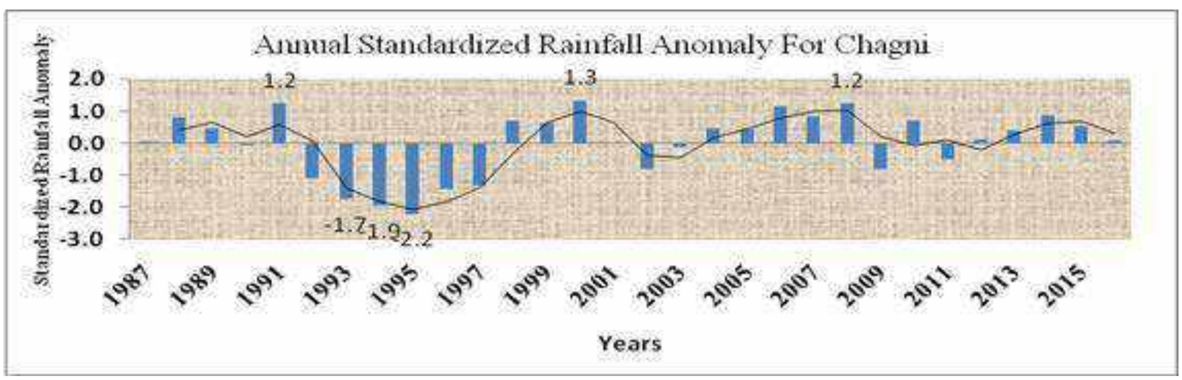
Metema	-1.2	-1.2	0.7	1.6	-0.1	-0.2	0.5	0.0	-0.1	0.0	-1.3	-0.4
Motta	0.3	0.5	2.4*	6.0	2.8**	9.0	-0.4	-0.1	1.2	0.3	0.9	0.3
N/mewcha	0.0	0.0	0.2	1.0	0.5	1.4	-1.1	-0.3	0.4	0.1	0.5	0.1
Quara	-0.2	-0.3	0.1	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0
Sekota	-1.4	-1.2	0.4	1.1	0.1	0.4	-1.3	-0.3	-0.4	-0.1	0.9	0.4
Shahura	0.3	0.3	0.9	2.9	0.9	3.6	0.2	0.1	-1.5	-0.4	-0.4	-0.2
Sh/Robit	-3.3***	-7.4	2.5*	11.4	0.2	1.0	0.2	0.0	-1.5	-0.1	-2.5*	-0.8
Sh/Gebeya	-2.7**	-8.9	-1.9	-8.8	-3.2**	-25.4	1.2	0.5	-3.7***	-0.6	-2.5*	-1.3
Sirinka	-2.1*	-5.4	0.9	3.2	-1.1	-4.0	-0.3	-0.1	-1.1	0.0	0.2	0.1
W/tena	-0.9	-1.4	0.7	2.3	0.2	0.7	-1.6	-0.3	-1.3	0.0	1.3	0.3
Wereilu	-1.4	-2.0	-0.7	-2.2	-1.7+	-3.4	-0.1	0.0	-0.7	0.0	0.1	0.0
Woldia	-1.4	-2.7	1.0	4.0	-0.5	-1.3	-0.1	0.0	-0.6	0.0	0.5	0.2
Yetnora	-0.2	-0.3	-1.3	-5.3	-1.4	-6.8	-0.7	-0.3	-0.8	-0.2	0.0	0.0

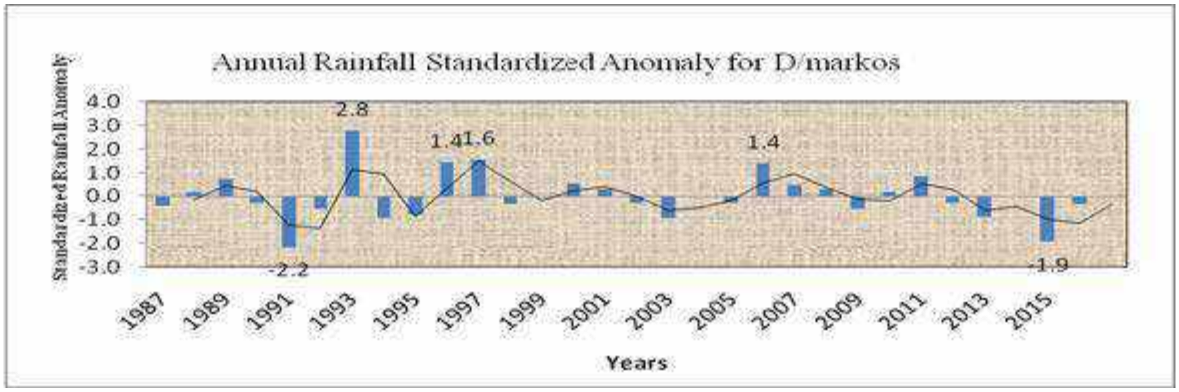
4.4. Inter-annual and seasonal rainfall variability

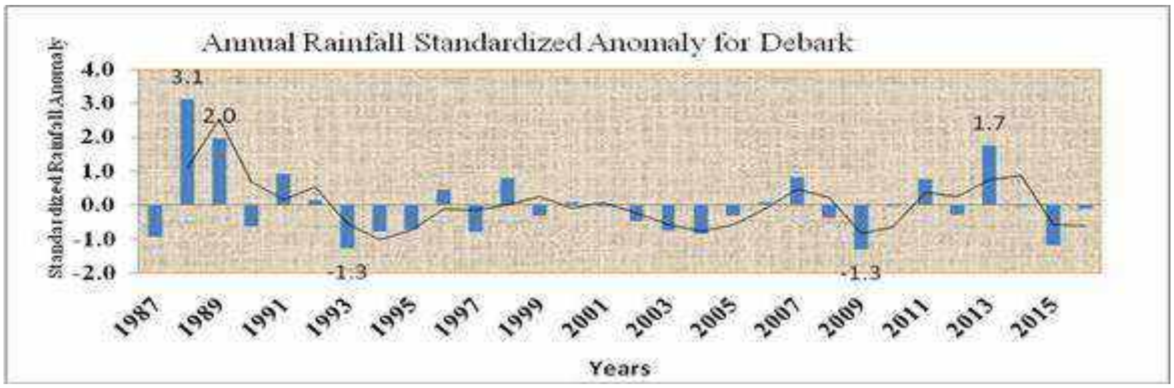
The standardized annual rainfall anomalies of most stations had negatively rainfall anomalies since 1987 to the mid of 1990's (Figure 7). Whereas, from 1996 year positively anomaly become improve in the study region. The frequencies of dry years were observed over Eastern parts more than western parts of the region during the study period. The 2015 is the driest year that is 2.0 times the standard deviation below from the mean (1987-2016) which is extreme dry in the eastern parts of the region. In addition, the wettest and driest years were observed in 2006 and 2009, 2015. Generally, the oscillations of dry years range from 33.3% (Metema) to 56.7 % (Enwary) were observed in 1987-2016 periods for the study region. The frequencies of dry and wet years in the following sample stations were shown.

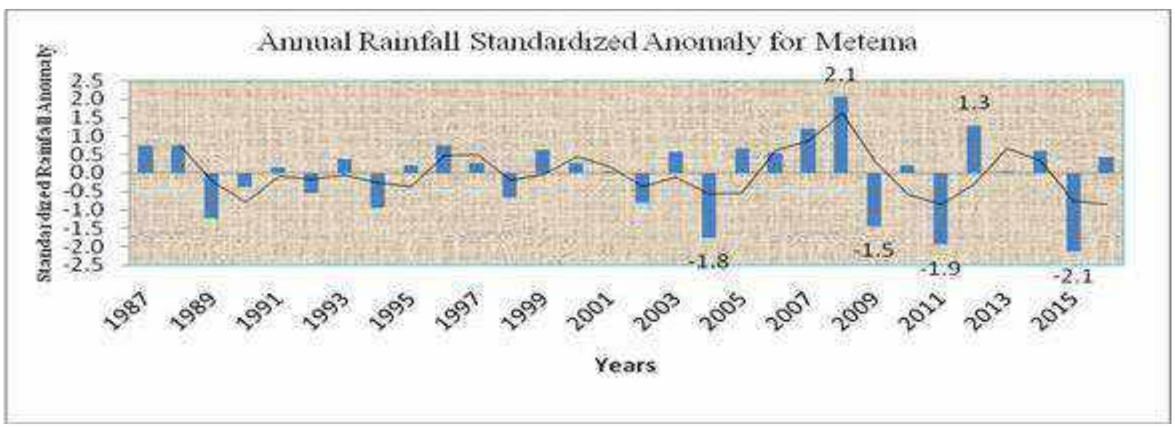

Annual Standardized Rainfall Anomaly For Amhara Region
Standardized Rainfall Anomaly
Year
y = -0.0065x + 0.1011
R² = 0.0033
1.8
-1.8
-2.2

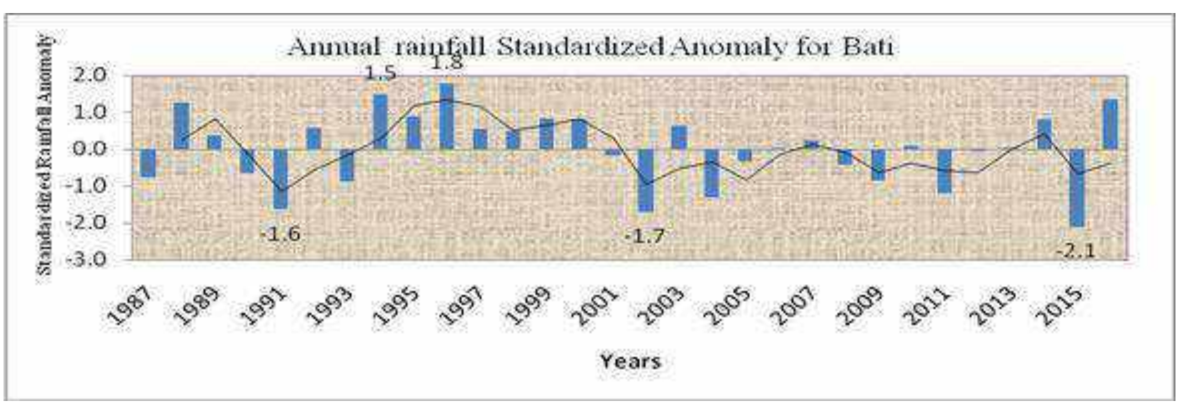

Annual Standardized Anomalies of Rainfall for B/dar
Standardized Rainfall Anomaly
Years
1.5
1.4
-1.5
-1.3
-2.1
-1.4

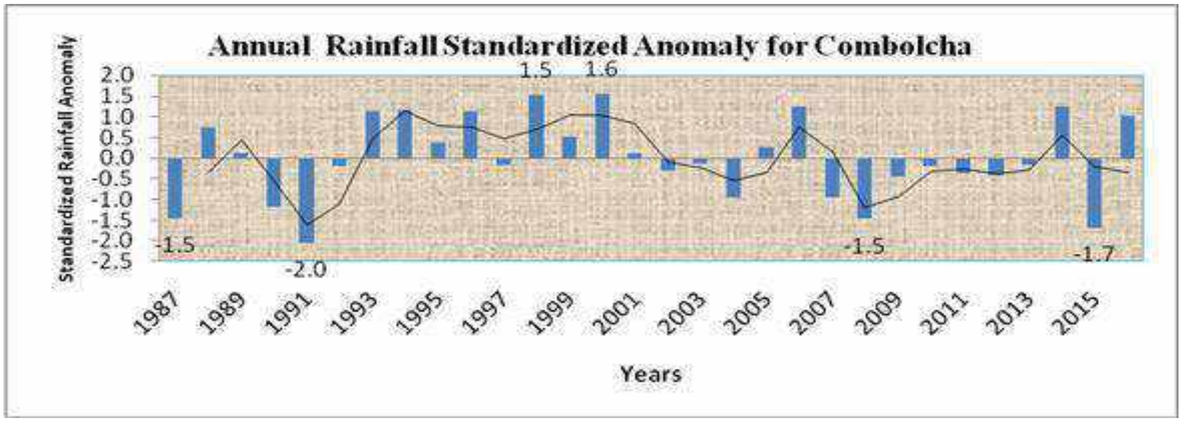

Annual Standardized Rainfall Anomaly For Chagni
Standardized Rainfall Anomaly
Years
1.2
1.3
1.2
-1.7
1.9
2.2

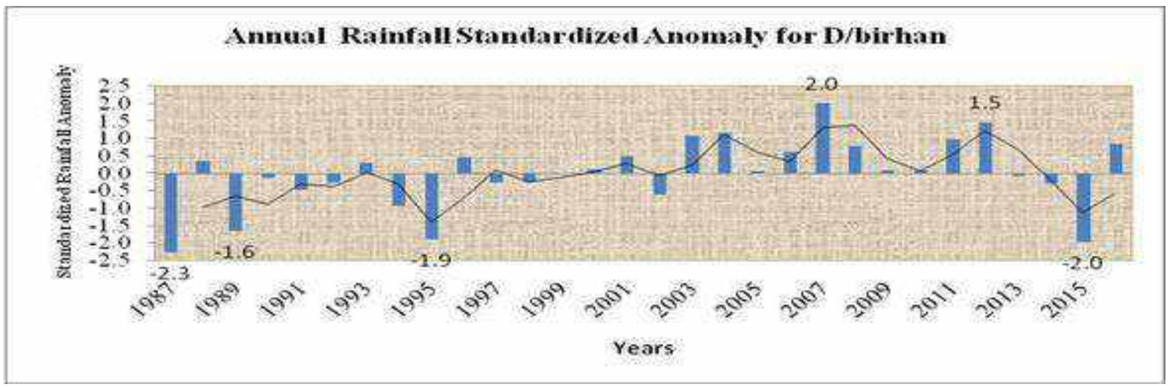

Annual Rainfall Standardized Anomaly for D/markos
Standardized Rainfall Anomaly
Years
2.8
1.4
1.6
1.4
-2.2
-1.9

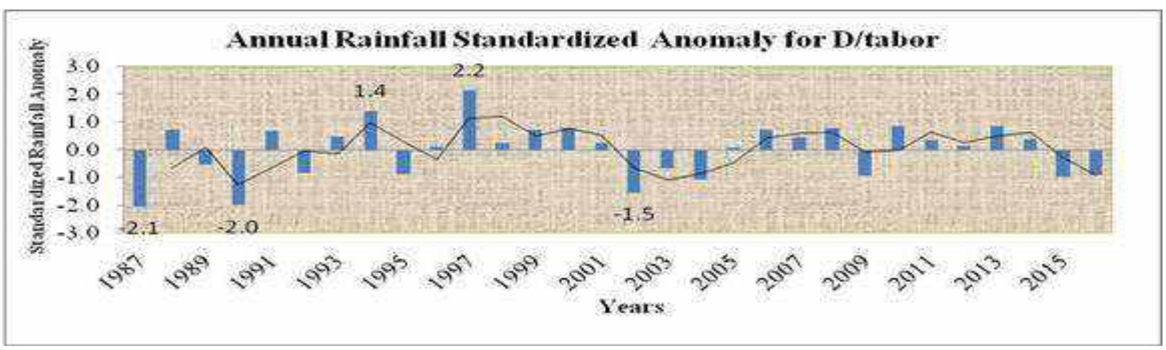

Annual Rainfall Standardized Anomaly for Debark
Standardized Rainfall Anomaly
Years
3.1
2.0
1.7
-1.3
-1.3

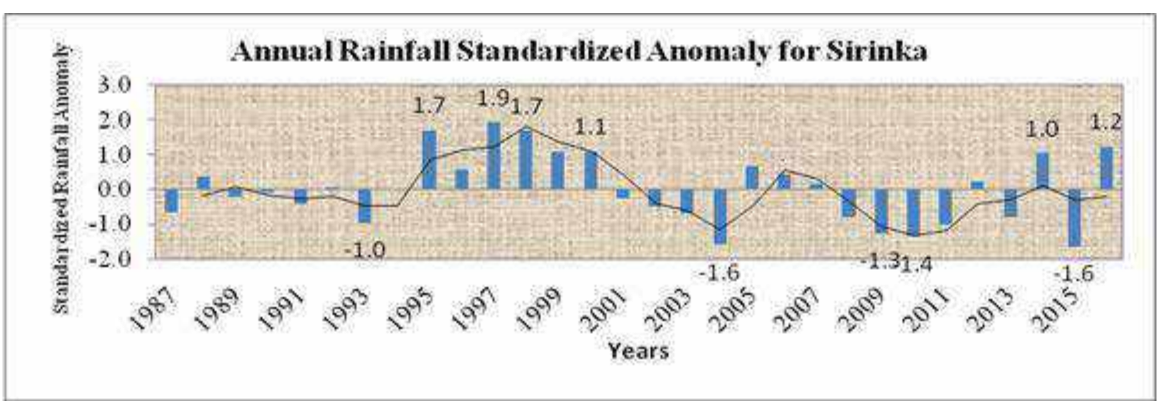

Annual Rainfall Standardized Anomaly for Metema
Standardized Rainfall Anomaly
Years
2.1
1.3
-1.8
-1.5
-1.9
-2.1


Annual rainfall Standardized Anomaly for Bati
Standardized Rainfall Anomaly
Years
1.5
1.8
-1.6
-1.7
-2.1


Annual Rainfall Standardized Anomaly for Combolcha
Standardized Rainfall Anomaly
Years
1.5
1.6
-1.5
-2.0
-1.5
-1.7


Annual Rainfall Standardized Anomaly for D/birhan
Standardized Rainfall Anomaly
Years
2.0
1.5
-2.3
-1.6
-1.9
-2.0


Annual Rainfall Standardized Anomaly for D/tabor
Standardized Rainfall Anomaly
Years
1.4
2.2
-2.1
-2.0
-1.5


Annual Rainfall Standardized Anomaly for Sirinka
Standardized Rainfall Anomaly
Years
1.7
1.9
1.7
1.1
1.0
1.2
-1.0
-1.6
-1.3
1.4
-1.6

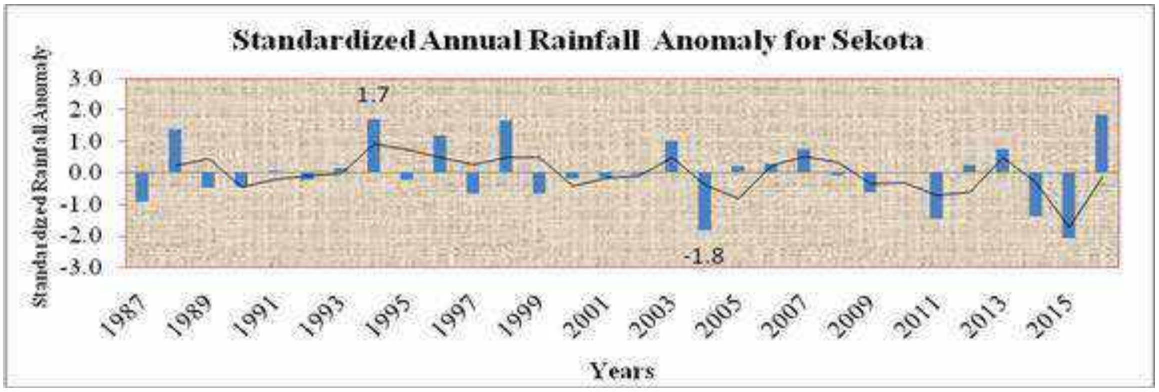
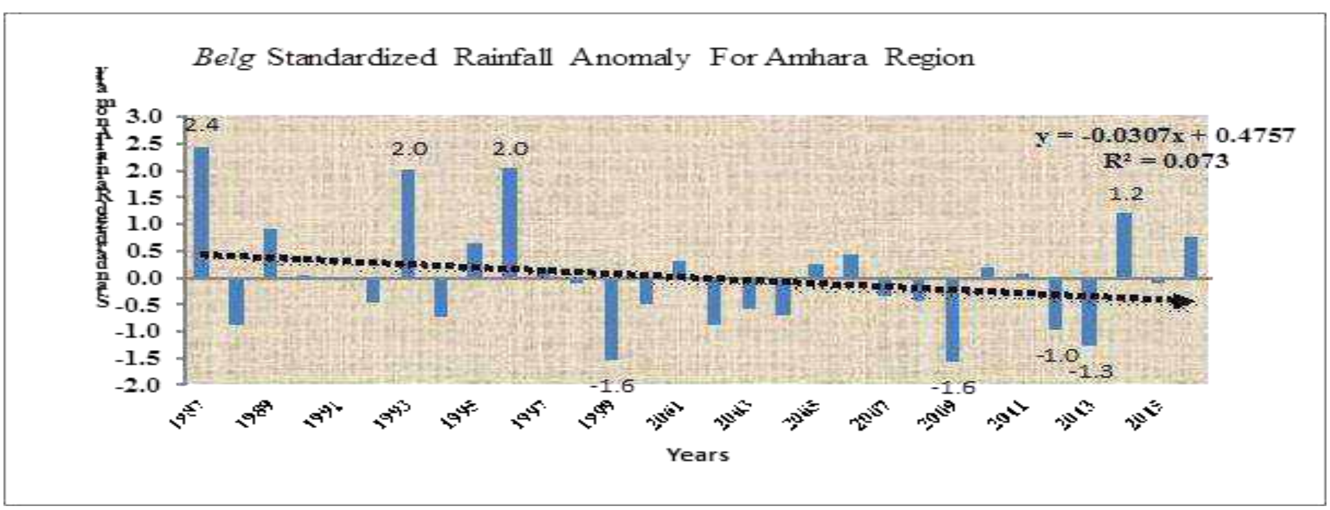
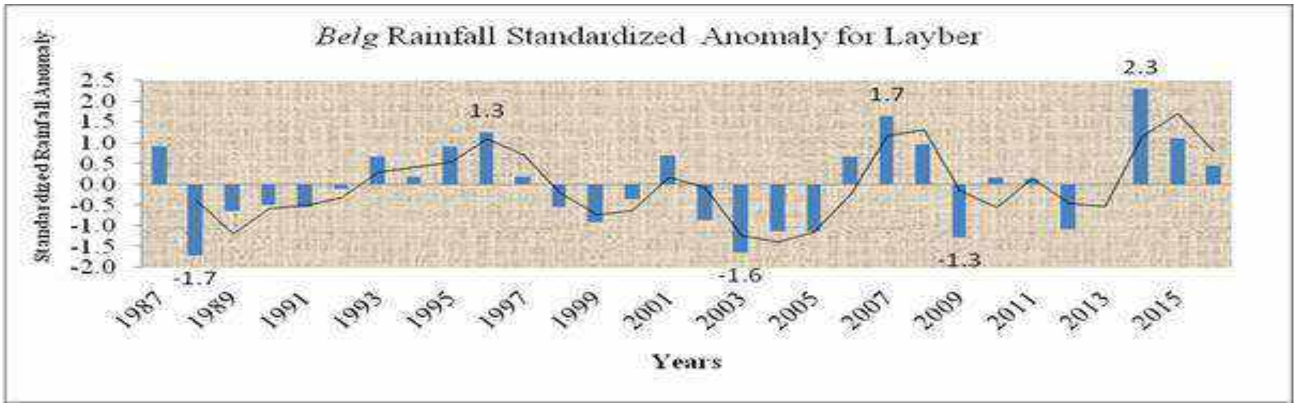


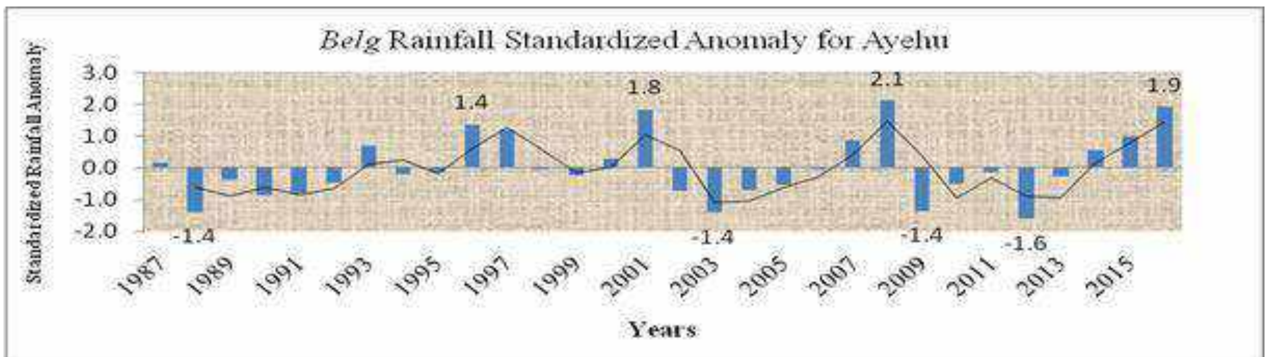
Figure 7: - Annual standardize rainfall anomaly for areal and Sample stations

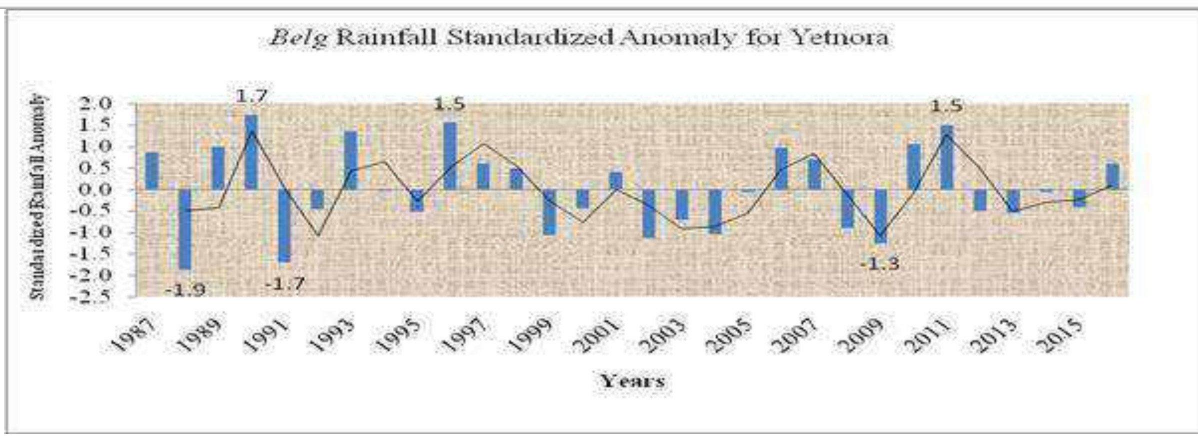
4.5. Seasonal rainfall fluctuations

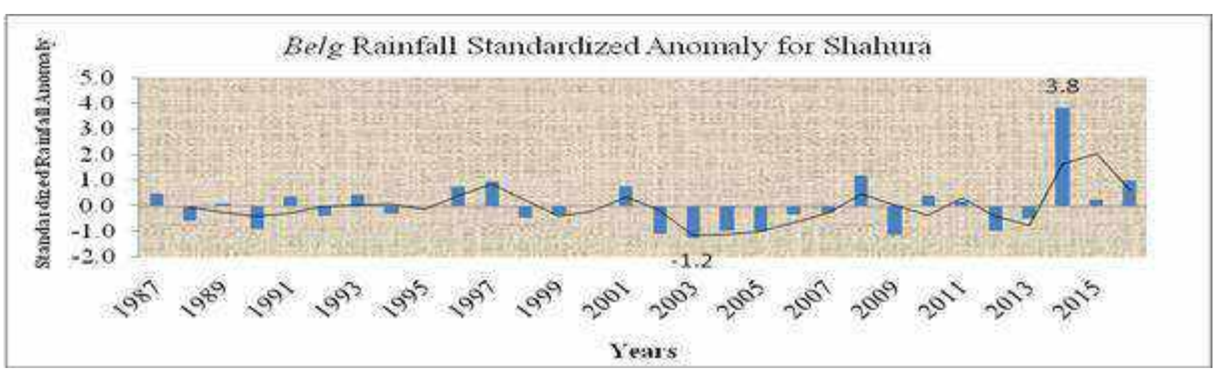
The *Belg* standardized rainfall anomaly revealed that more than half of the observation periods dry years (Figure 8). This means that there appears to be high inter-seasonal variations in this season between 1987 and 2016.These indicated that the *Belg* season is difficult for agricultural operations in *Belg* growing areas. Whereas, the wettest years recorded from the beginning of 1987s to mid - 1995 in the region (Figure 8) and the results are consistent with Viste and Ayalew (2012). In general, *Belg* rainfall is high inter seasonal variability and erratic in spatially and temporally in the region. The following sample figures informed us the *Belg* rains large decreased in this region.

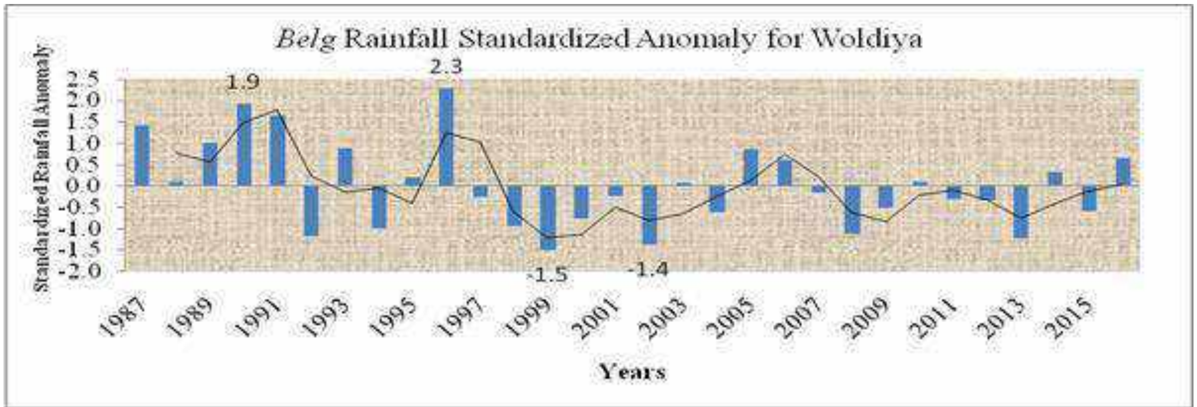


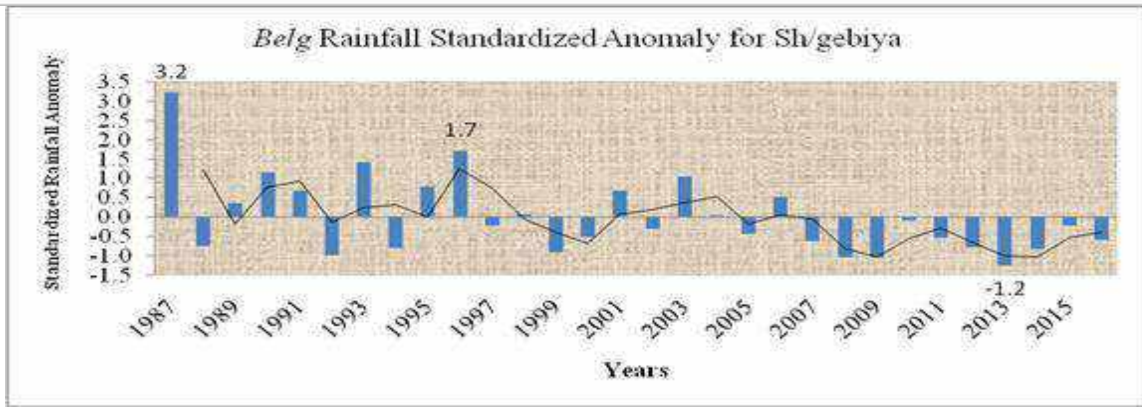

Belg Rainfall Standardized Anomaly for Layber
Standardized Rainfall Anomaly
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1.3
1.7
2.3
-1.7
-1.6
-1.3
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years

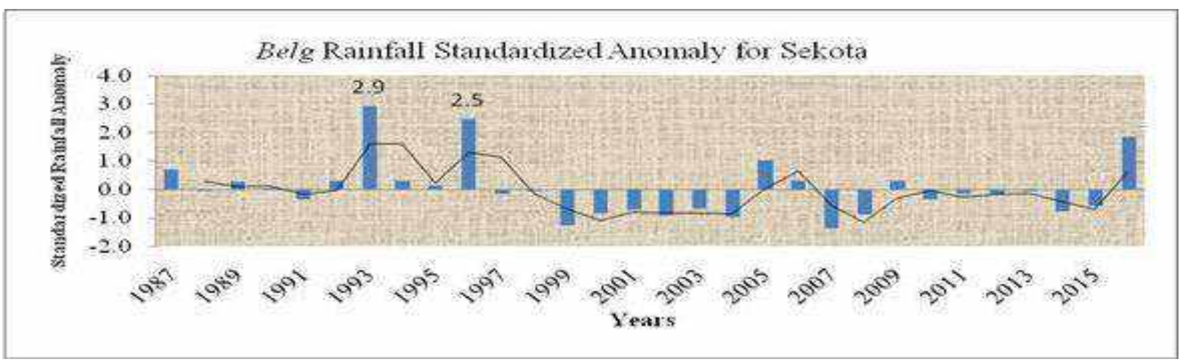

Belg Rainfall Standardized Anomaly for Ayehu
Standardized Rainfall Anomaly
3.0
2.0
1.0
0.0
-1.0
-2.0
1.4
1.8
2.1
1.9
-1.4
-1.4
-1.4
-1.6
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years

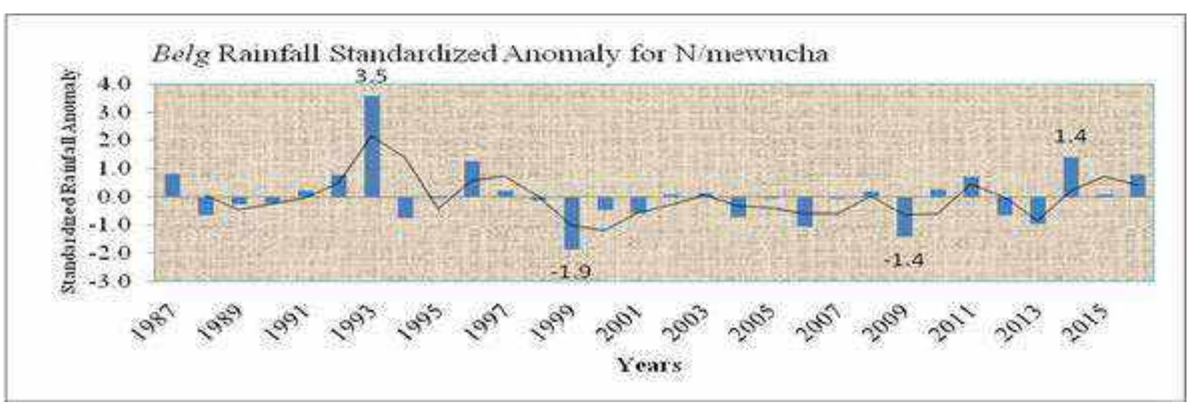

Belg Rainfall Standardized Anomaly for Yetnora
Standardized Rainfall Anomaly
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
1.7
1.5
1.5
-1.9
-1.7
-1.3
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years


Belg Rainfall Standardized Anomaly for Shahura
Standardized Rainfall Anomaly
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
3.8
-1.2
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years


Belg Rainfall Standardized Anomaly for Woldiya
Standardized Rainfall Anomaly
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1.9
2.3
-1.5
-1.4
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years


Belg Rainfall Standardized Anomaly for Sh/gebiya
Standardized Rainfall Anomaly
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
3.2
1.7
-1.2
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years


Belg Rainfall Standardized Anomaly for Sekota
Standardized Rainfall Anomaly
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
2.9
2.5
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years


Belg Rainfall Standardized Anomaly for N/mewucha
Standardized Rainfall Anomaly
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
3.5
1.4
-1.9
-1.4
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years

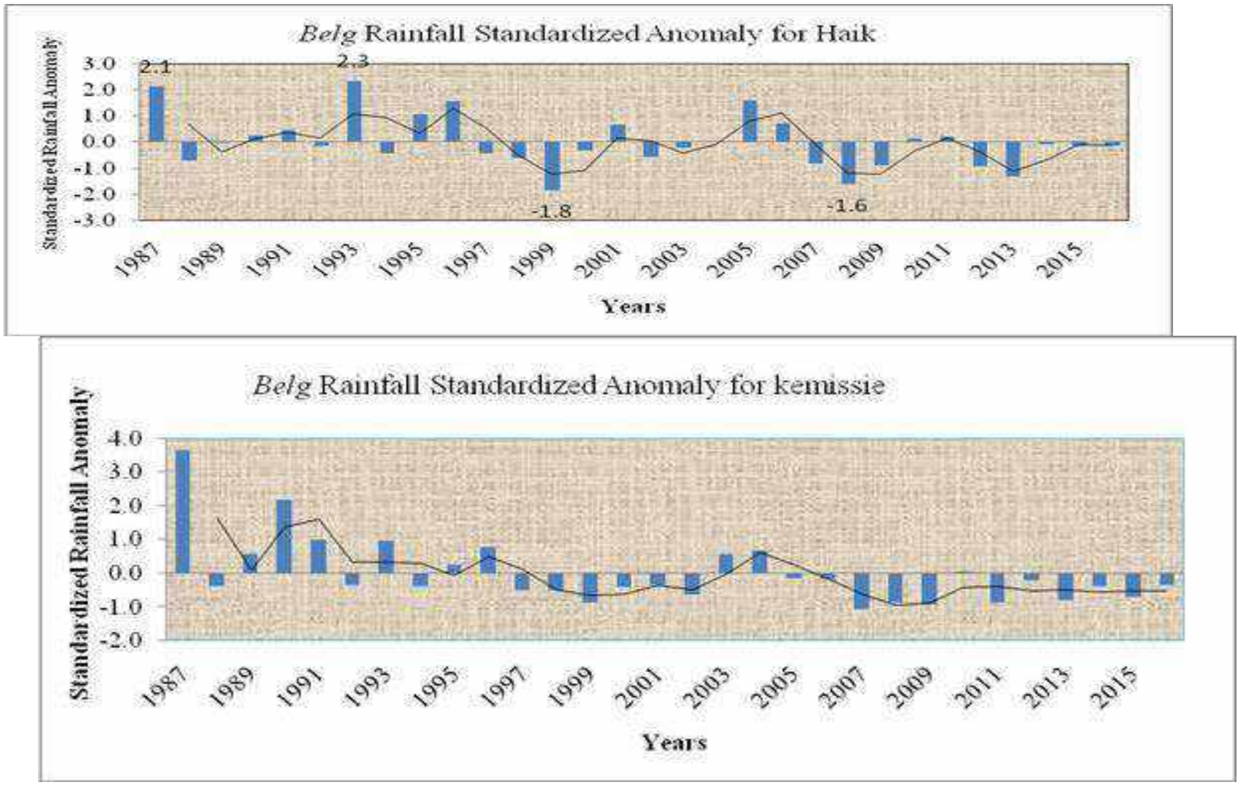
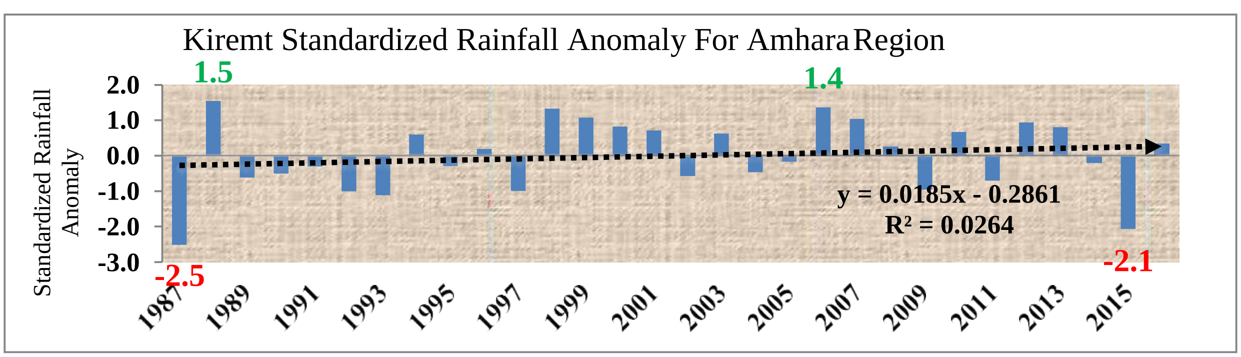
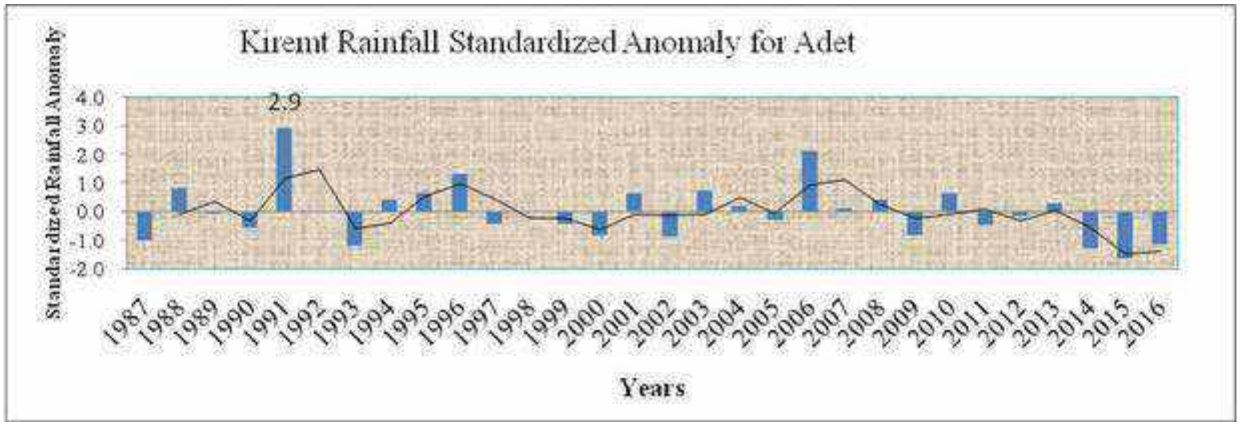
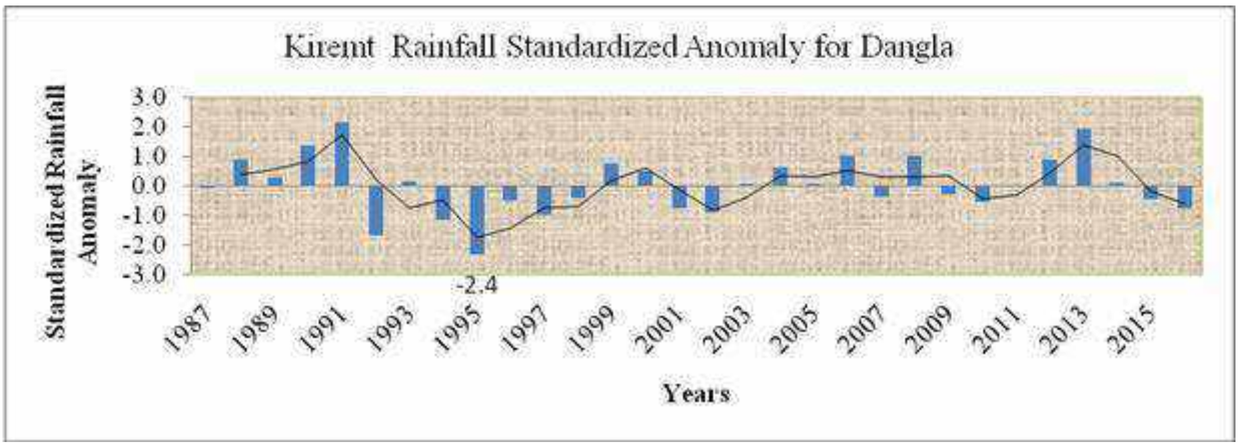


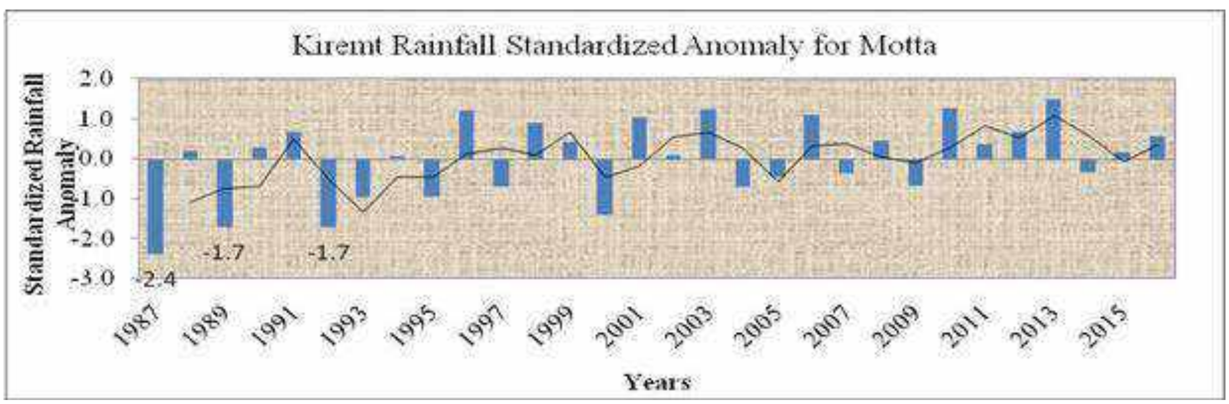
Figure 8: - Belg standardize rainfall anomaly for areal and Sample stations

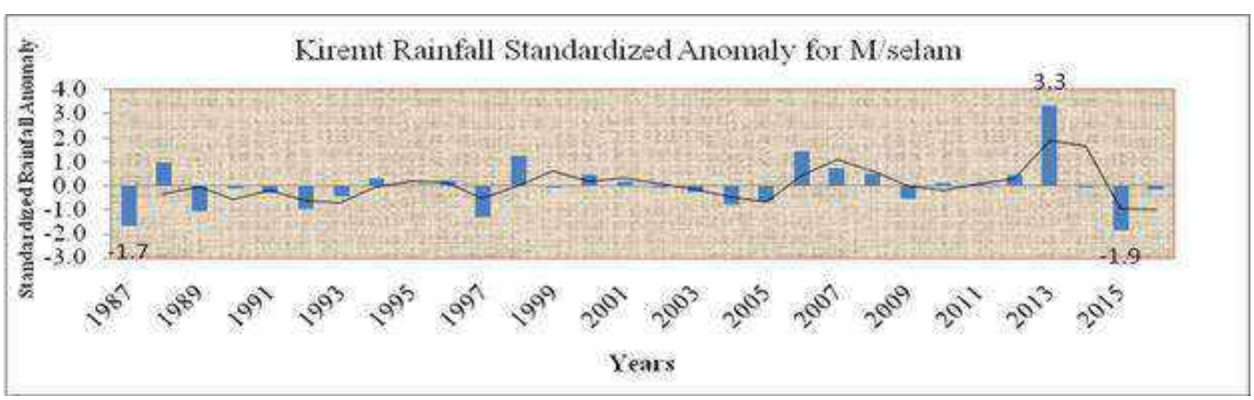
On the other hand, Kiremt standardized rainfall anomaly showed that equal chance of dry and wet years happened alternatively (Figures 9). Negative anomalies were frequently happened in the end of 1980s to in the beginning of 1990s.The driest years in the region were 1987 and 2015 which are less than from two times the standard deviation of the average. However, Kiremt rainfall shows good progress since 1995 for all sample stations in this region. Similar results reported by Ayalew (2012).

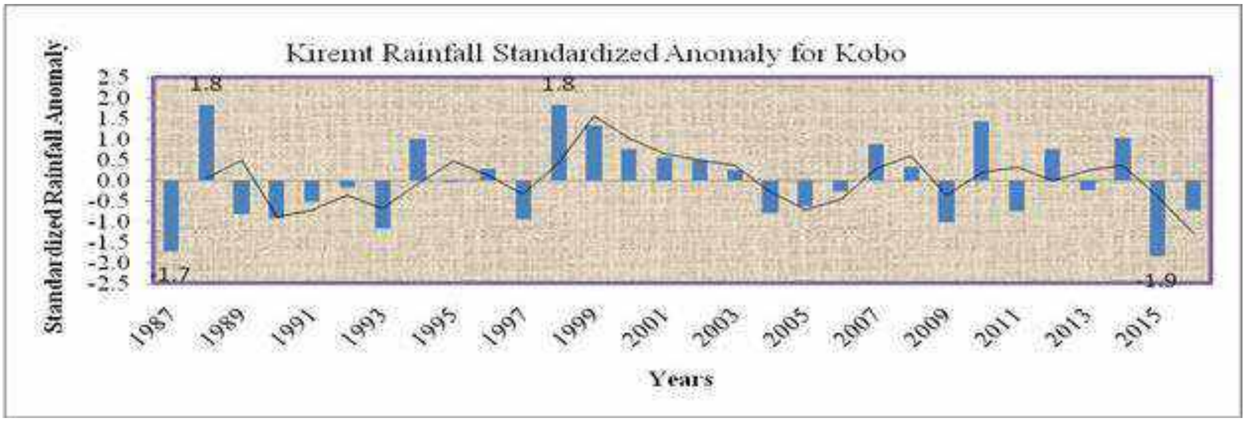


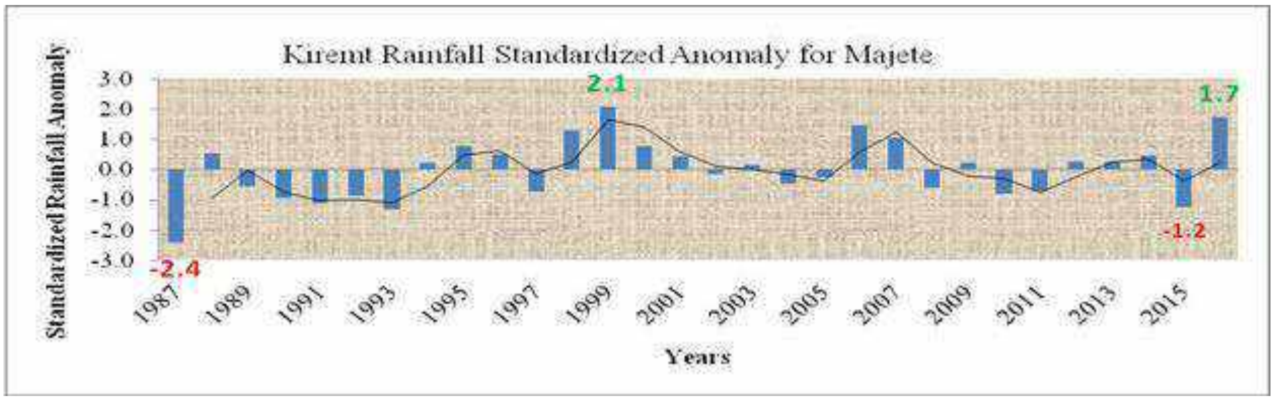

Kiremt Rainfall Standardized Anomaly for Adet
Standardized Rainfall Anomaly
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
2.9
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
Years

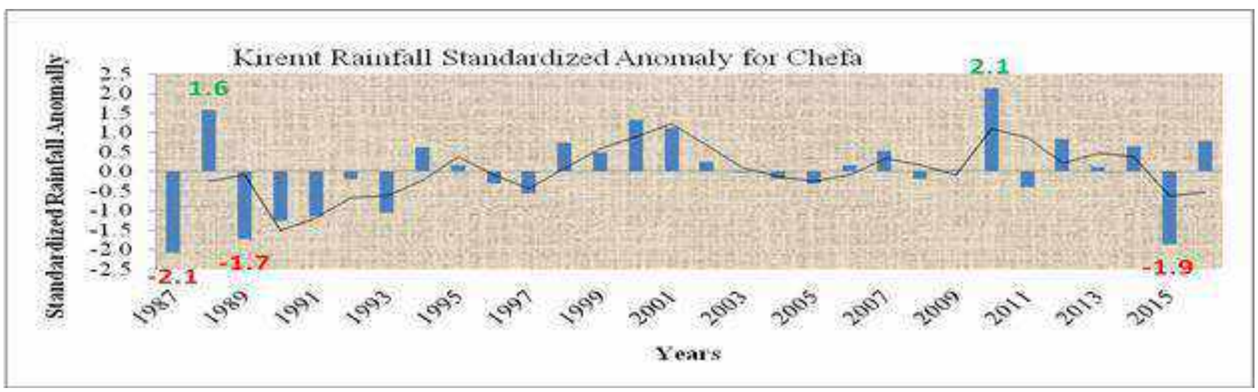

Kiremt Rainfall Standardized Anomaly for Dangla
Standardized Rainfall Anomaly
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-2.4
1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Years

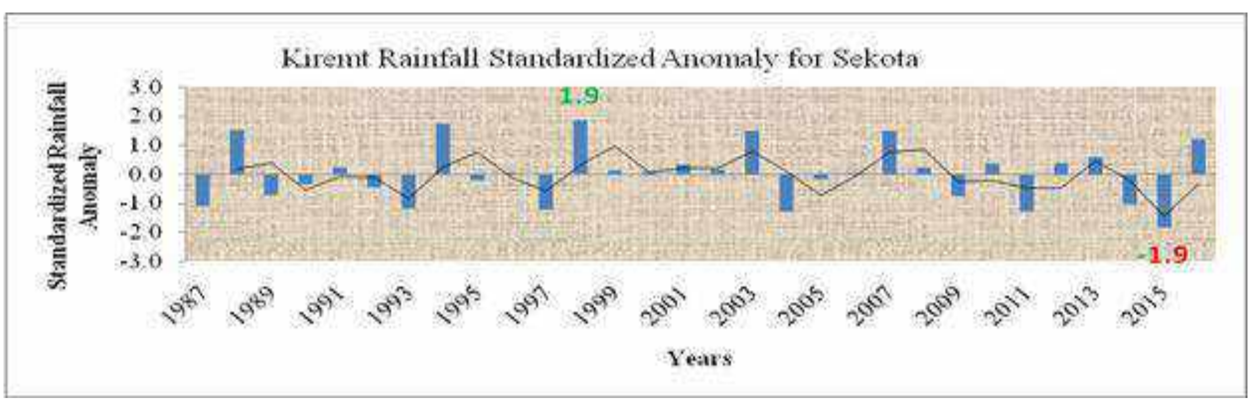

Kiremt Rainfall Standardized Anomaly for Motta
Standardized Rainfall Anomaly
2.0
1.0
0.0
-1.0
-2.0
-3.0
-2.4
-1.7
-1.7
1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Years


Kiremt Rainfall Standardized Anomaly for M/selam
Standardized Rainfall Anomaly
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
3.3
-1.7
-1.9
1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015
Years


Kiremt Rainfall Standardized Anomaly for Kobo
Standardized Rainfall Anomaly
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
1.8
1.8
-1.7
-1.9
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years


Kiremt Rainfall Standardized Anomaly for Majete
Standardized Rainfall Anomaly
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
2.1
1.7
-2.4
-1.2
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years


Kiremt Rainfall Standardized Anomaly for Chefa
Standardized Rainfall Anomally
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
1.6
2.1
-2.1
-1.7
-1.9
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years


Kiremt Rainfall Standardized Anomaly for Sekota
Standardized Rainfall Anomaly
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
1.9
-1.9
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Years

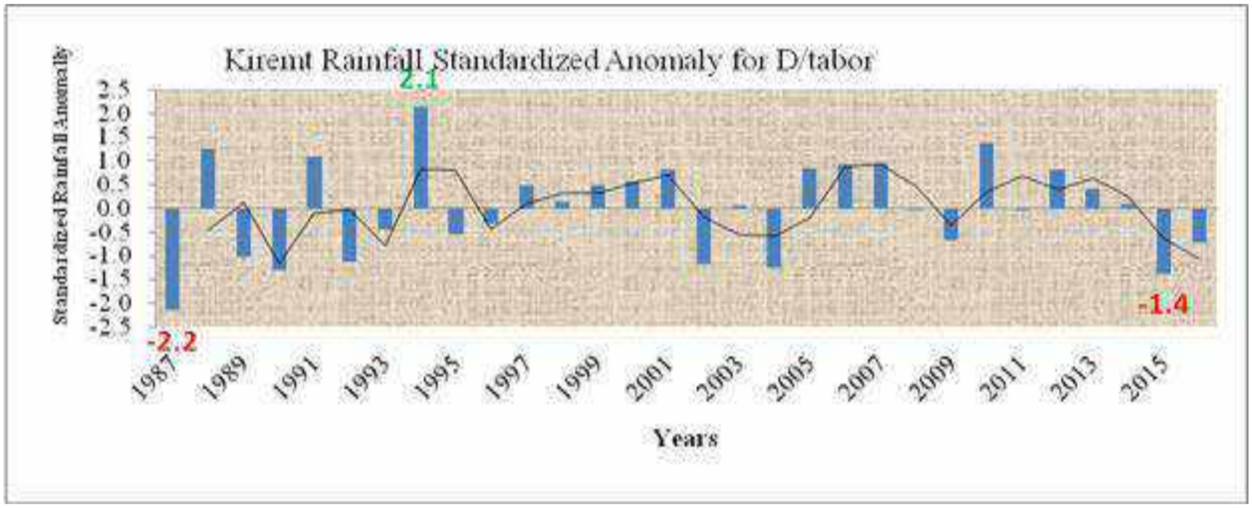


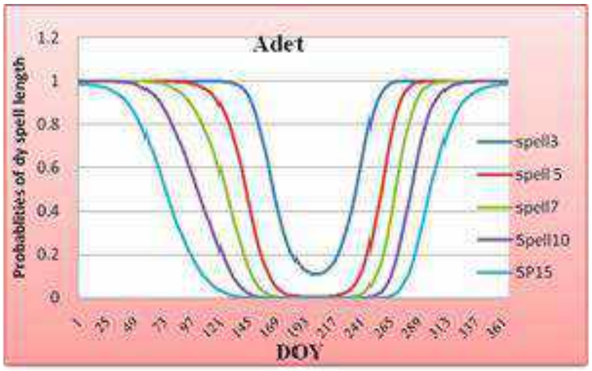
Figure 9: - Kiremt standardize rainfall anomaly for areal and Sample stations

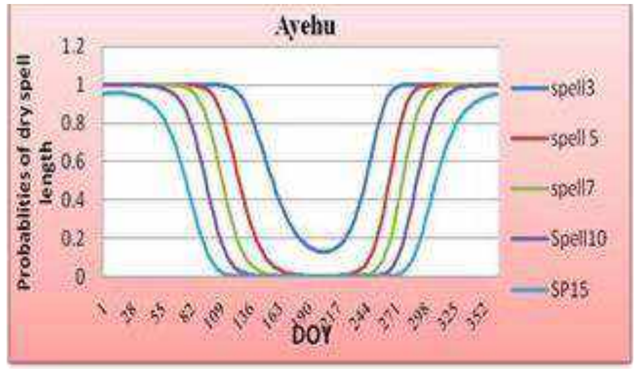
4.6. Length of dry spells

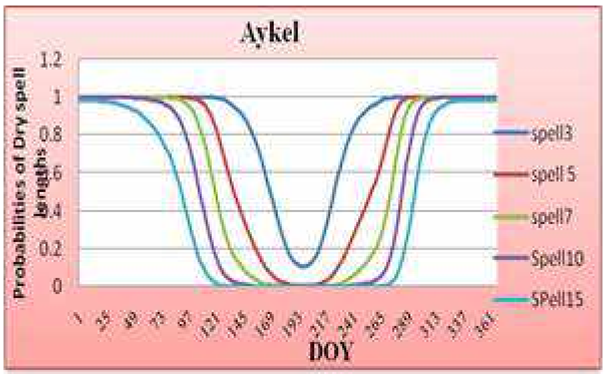
4.6.1. Probability of maximum dry in the region spell length

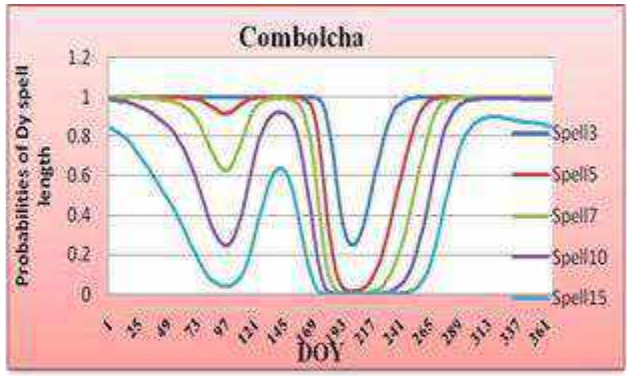
The results showed that the probability occurrence of dry-spells of various durations varied from month to month of the growing season (Figure 10). High probabilities of dry-spells were observed for most of *Belg* growing areas in spells 3, 5, 7 and 10 days from 61 to 152 DOY which is ranging (1-0.70) but, for spell 15 decreases to 0.043 (Figure 10). However, some stations like Combolcha, Haik, D/sina, D/birhan, Majete, Lalibela, wegeltena, M/meda, sirinka and Cheffathe spell lengths of 10, 15 days are lower than 0.35 in average.

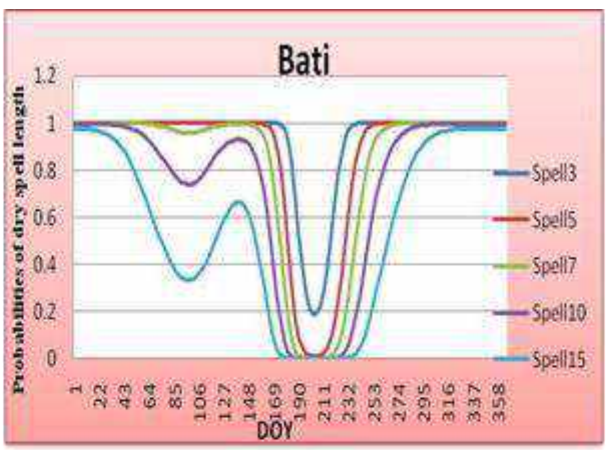
The probability of having a dry-spell increased with *Belg* benefiting areas (for instance, more chance of having a 10 or 15-day than 3, 5,7-daydry-spells). This study informed us the *Belg* season was difficult for crop production in the region for *Belg* benefiting areas. On the other hand, in the *Kiremt* season the probability of dry spell occurrence of 3, 5, 7, 10 and 15 day lengths from 181DOY-240DOY is lower than 0.4 in most stations. This indicates that the occurrence of dry spell lengths in Kiremt season is insignificant. To know the information on the length of dry spells could be used for deciding a particular crop or variety, supplementary irrigation water demand (Mathlouthi and Lebdi, 2008; Admasu*et al.*, 2014).

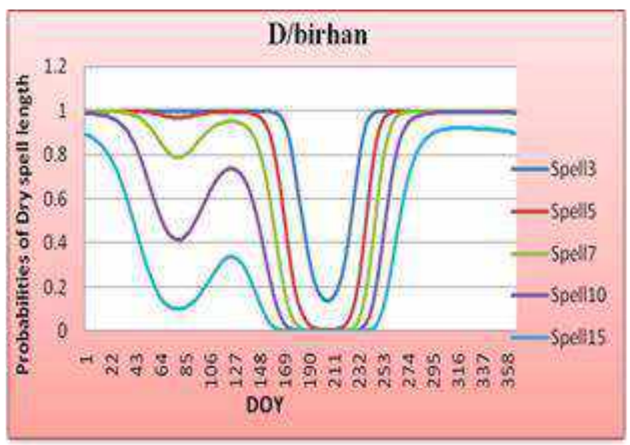

Adet
Probabilities of dy spell length
DOY
spell3
spell 5
spell7
Spell10
SP15

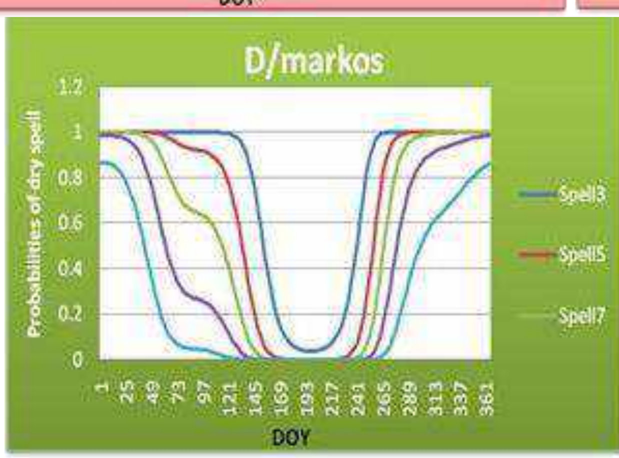

Ayehu
Probabilities of dry spell length
DOY
spell3
spell 5
spell7
Spell10
SP15

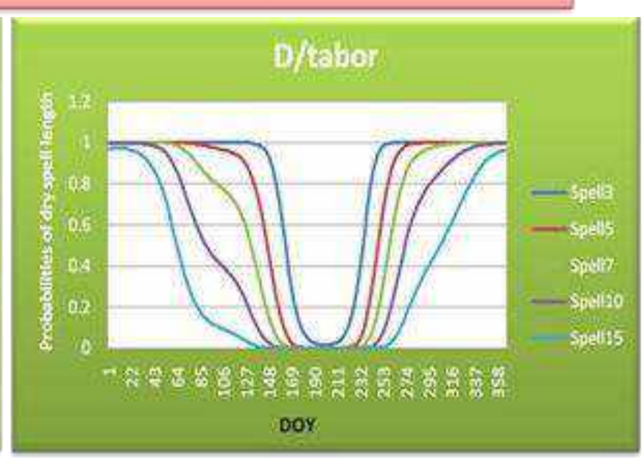

Aykel
Probabilities of Dry spell lengths
DOY
spell3
spell 5
spell7
Spell10
SPell15


Combolcha
Probabilities of Dy spell length
DOY
Spell3
Spell5
Spell7
Spell10
Spell15


Bati
Probabilities of dry spell length
DOY
Spell3
Spell5
Spell7
Spell10
Spell15


D/birhan
Probabilities of Dry spell length
DOY
Spell3
Spell5
Spell7
Spell10
Spell15


D/markos
Probabilities of dry spell
DOY
Spell3
Spell5
Spell7


D/tabor
Probabilities of dry spell length
DOY
Spell3
Spell5
Spell7
Spell10
Spell15

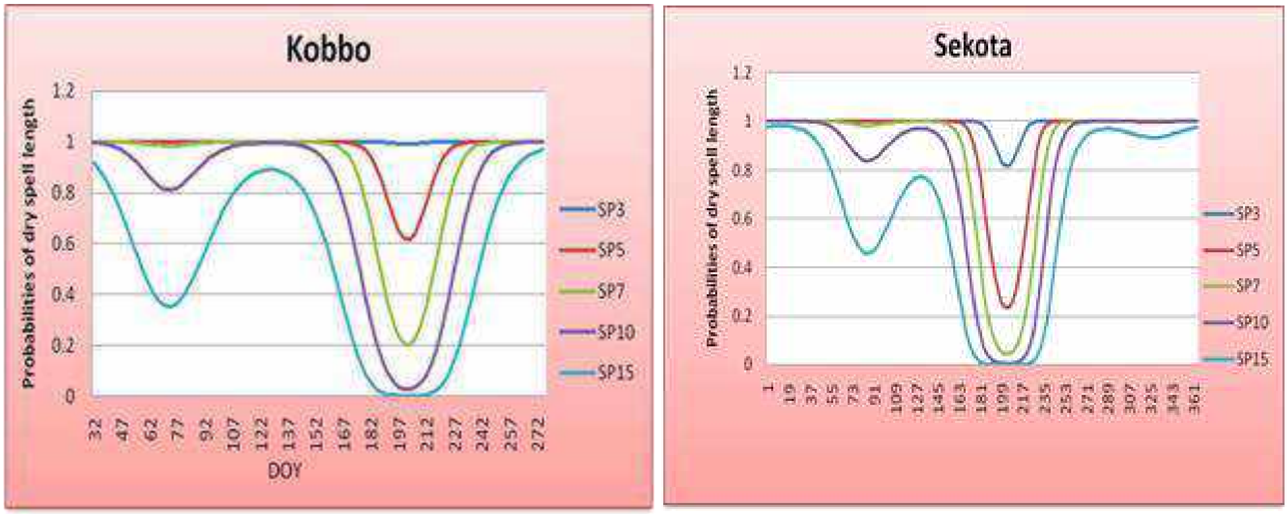
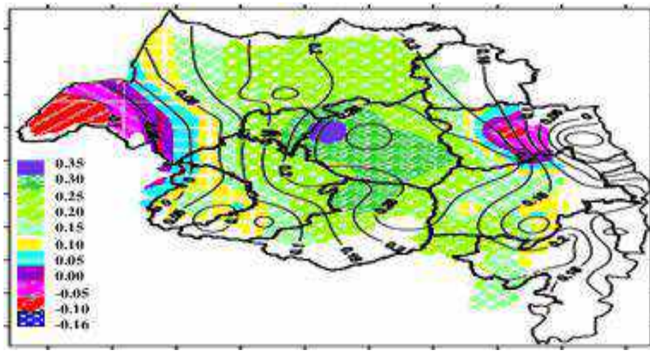


Figure 10: - Probability of occurrence of dry spell lengths for sample stations in the period (1987-2016)

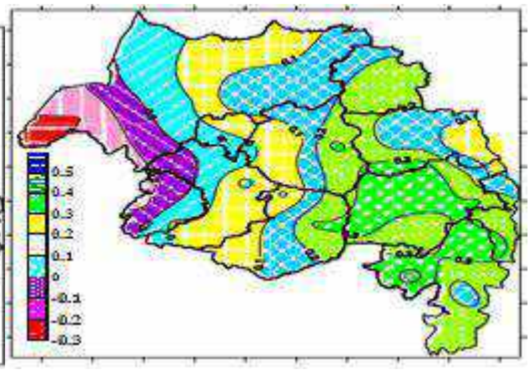
4.7. Influence of ENSO over the seasons

4.7.1. Correlation

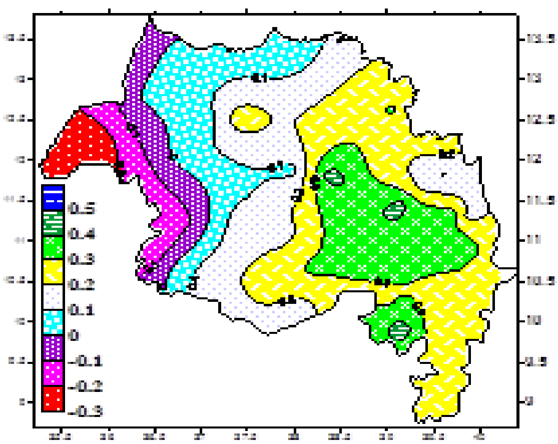
The relationship of Belg rainfall and ENSO (Nino 3.4) is positively weak correlated for most of the stations in the region that implies rainfall increases and SST increases (see figure 11). whereas, few stations like Enwary, Majete and Wegel Tena have been statistically significant positive correlated with Nino 3.4 region SST anomalies (at $P < 0.05$). Whereas, few stations like Chagni, Dangila and Quara have experienced moderate negatively correlated with Nino 3.4 region. Even though the correlation of Belg rainfall and Nino 3.4 region are moderate, the variation of Belg rainfall is varying at large. Figure 3c indicates that El Nino years associated with above normal rainfall and La Nina associated with below normal rainfall, especially for Belg benefiting areas. The years 1987, 1993 and 2016 were categorized as El Ninoyears with more than 2.4, 2.0 and 0.7 times standard deviation departure above from the mean for the Eastern parts while 2000 and 2008 are the corresponding La Ninayears.



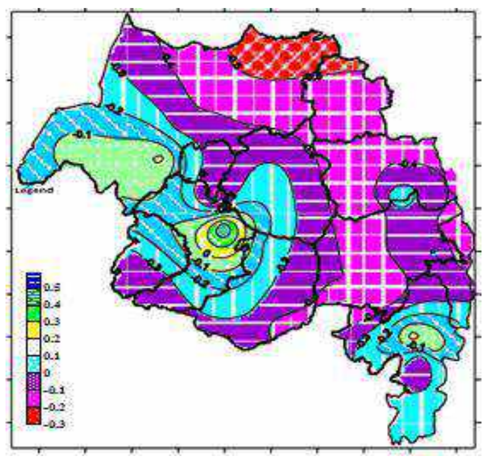
A) Belg Rainfall vs Nino 1+2



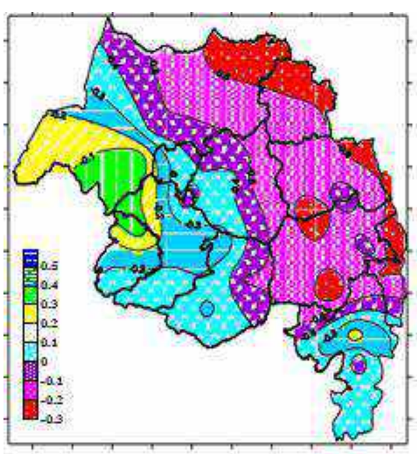
B) Belg rainfall vs Nino 3



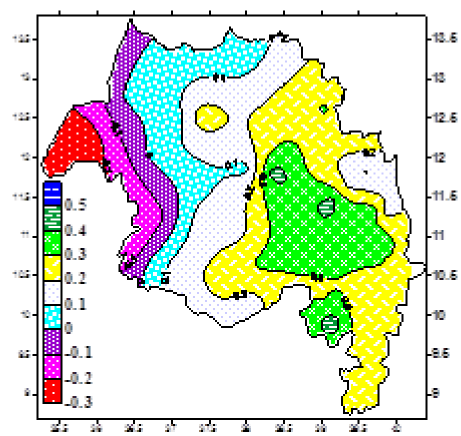
C) Belg rainfall vs Nino 3.4



D) Kiremt rainfall vs Nino 1+2



E) Kiremt rainfall vs Nino 3

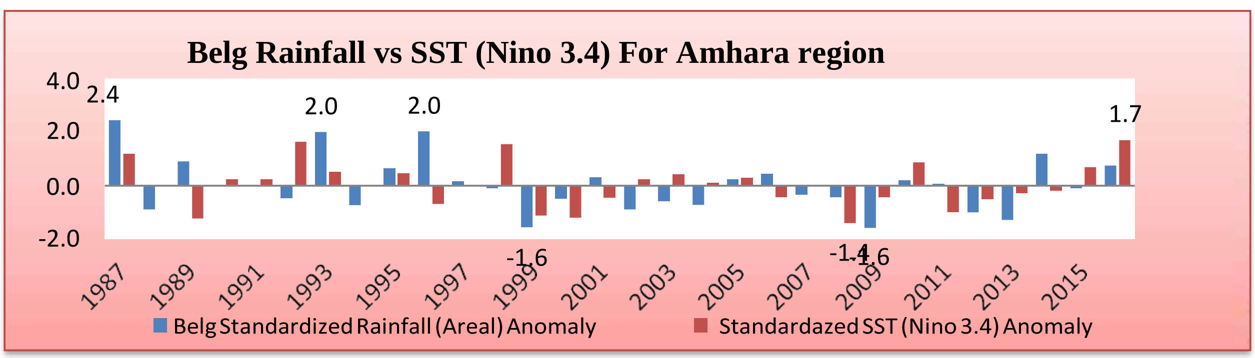


F) Kiremt rainfall vs Nino 3.4

Figure 11(A-F): - Correlations of ENSO vs. Belg and Kiremt Rainfall for Amhara region

The relationship of Kiremt rainfall and ENSO (Nino3.4) has been moderate to strong negatively correlated for most of the stations in the study region that implies rainfall increases and SST (Nino 3.4 region) decreases. Nefasmewucha, Debark, GundoMeskel, Haik, Chefa, Bati, Kemissie, Kobo, Sekota, WegelTena, Wereilu and Woldia have been statistically significant negative correlated with Nino 3.4 region (at P <0.01) sea surface temperature anomalies. Figure 12 indicated that El Nino years associated with below normal rainfall and La Nina associated with above normal rainfall, over most of the region. The years 1987, 1991, 1997, 2002, 2004, 2009 and 2015 were recognized as El Nino years with more than one standard deviation departure from the mean for the Eastern parts while 1988, 1999,2000, 2007 and 2010 are the corresponding La Nina years.

Among La Nina years, one year is deficit/dry rainfall observed which is 2011 year. Generally, the fluctuations of ENSO have weak linkage with “Belg” (spring) seasonal rainfall variability whereas, ENSO has significant linkage with “Kiremt” (summer) seasonal rainfall variability especially Eastern parts of the region. (Segele and Lamp et al. 2005; Gissila et al. 2004; Korecha, D. and A. Barnston et al., 2007).



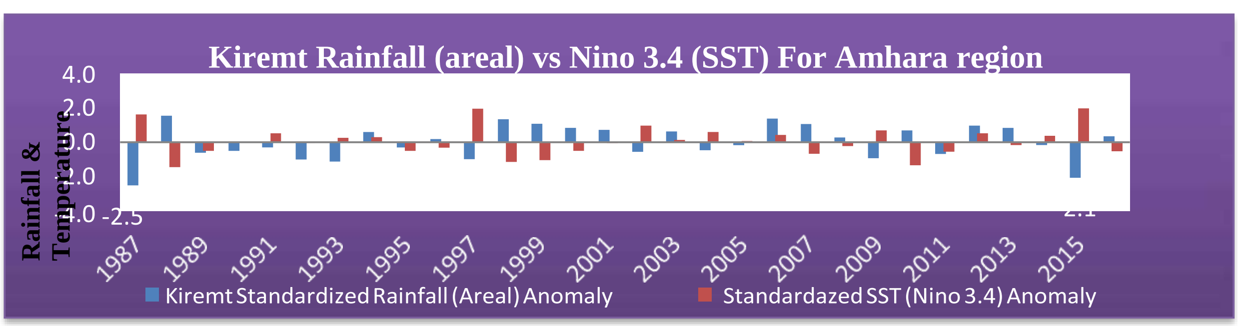
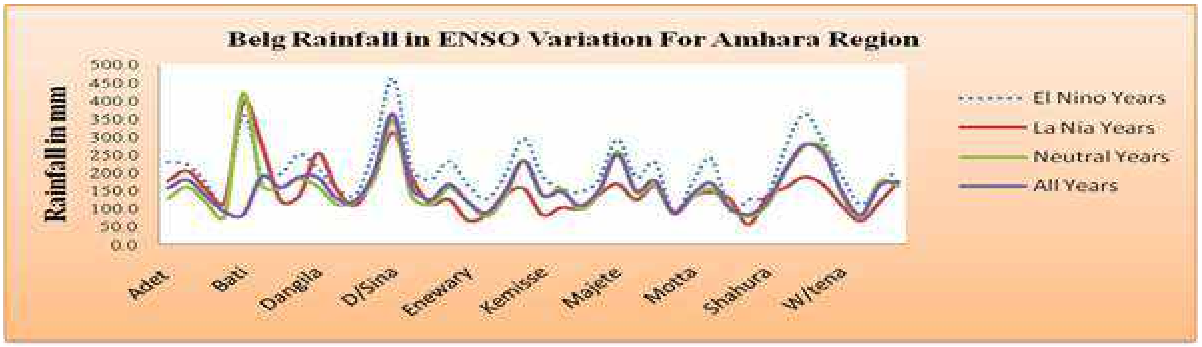


Figure 12:- Correlations of ENSO vs. Belg and Kiremt Rainfall for Amhara region



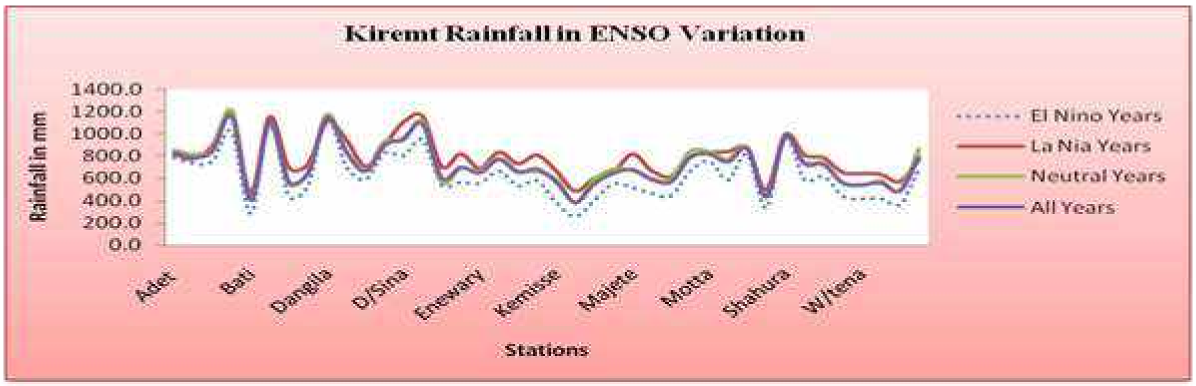


Figure 13:- Belg and Kiremt areal rainfall variation with in different phases of ENSO for Amhara region

5. Conclusion and Recommendation

This paper characterized and analyzed trends in seasonal, annual precipitation and ENSO influence in season over Amhara regionfor30-year study period (1987–2016). Mean date of Belg season in the region was undefined for all of stations while end dates of Belg season experienced in May 01 for all stations. Mean onset date of Kiremt season is ranged from May 19 to July 18 and the mean cessation date in Kiremt are ranged from September 21 to November 06 in the Eastern and Western parts of the region respectively. The variability of mean onset and end date of Kiremt season were less variable while the duration of rainfall was moderately variable in the region. The areal annual mean rainfall in the region was found to be 964.5 mm and it varied from 773.8 (lowest in 2015) to 1120.2 mm (highest in 2006) with standard deviation (SD) of 86.4mm and coefficient of variation (CV) 8.96%. The average areal annual rainy days were 94 which were between 78 days (1991) and 111 days (1997). In line with this, the average spatial and temporal rainfall is ranged from 520.4mm (Bati) to 1597.9mm (D/Sina) and the lowest and highest annual rainfall was recorded 206mm (2015) at Kobbo and 2968.0mm (1997) at D/sina in the region for the study period. The belg mean rainfall is ranging from 82.4mm (Wereilu) to 363.9 mm (D/sina) and with coefficient of variability and standard deviation be found to be 35.9% (D/birhan) to 82.9% (kemisie) and 41.7mm (Quara) to 174.3mm (Sh/gebiya) respectively. On the other hand, the Kiremt mean rainfall is between 383.3 (Kobbo) to 1157.3 mm (D/sina) and its variability is less variable. A mix of positive and negative trends was observed for some stations. The annual mean, “Belg” and “Kiremt” rainfall showed a few number of significant cases for some stations. Significant positive trends were detected in Kiremt and annually; negative trends were seen in belg season. D/Birhan and Motta stations exhibited significant positive trends in annual rainfall at $p<0.05$ and $p<0.01$ probability level; the remaining stations did not experience a statistically significant trend. To sum up, mean Belg, Kiremt, annual rainfall and rainy days were experienced insignificant trend in the region respectively. The variability of negative and positive trend for some stations point to the need for more detailed studies on the climate change of this region. Most stations of onset, cessation and duration of rainfall for Kiremt season have been decreasing trend but not significant. The fluctuations of ENSO have weak linkage with “Belg” (spring) seasonal rainfall variability. Whereas, ENSO has significant linkage with “Kiremt” (summer) seasonal rainfall variability especially Eastern parts of the region.

6. References

Ademe mekonnen, 1998.International Rainfall Variability over the Horn Africa. MSc Dissertation, University of Reading, Reading, UK.

Araya, A., Keesstra, S.D., Stroosnijder, L., 2010b.A new agro-climatic classification for crop Suitability zoning in northern semi-arid Ethiopia. Agric. For. Meteorol.150, 1047–1064.

Araya, A., Stroosnijder, L. 2011. Assessing drought risk and irrigation need in northern Ethiopia. Journal of Agricultural Meteorology151, 425-436.

Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp 695–738.

Bapna, M.; Mc Gray. H.; Mock, G.; and Whitheyl L. (2009). Enabling adaptation: Priorities for supporting thru rural poor in changing climate. WRI Issuse Brief WRI.

Barron, J., Rockstrom, J., Gichuki, F., Hatibu, N., 2003.Dry spell analysis and maize yields for two semi- arid locations in East Africa.AgricFor. Meteorology. 117, 23–37.

Bekele, F. 1992. Ethiopia Climate and Seasons. http://ccb.colorado.edu/ijas/ijasno2/bekele.html, Addis Ababa, Ethiopia.

Beltrando, G. and Camberlin, P. 1993. International variability of rainfall in the eastern horn of Africa and indicators of atmospheric circulation. International Journal of Climatology 13: 533-546.

Burton, I., Diringer, E. and Smith, J. (2006): Adaptation to climate change: international policy options; pew center climate change, Arlington, Virginia,

C. A. 2001. Climate change: Contribution of Working Group I to the Third41

C. A. 2001. Climate change: Contribution of Working Group I to the Third 41

Cheung, W.H., Senay, G.B. and Singh, A. 2008.Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. International Journal of Climatology28: 1723– 1734. (www.international sciencewiley.com). Accessed on October 10, 2014

Collins Armi, Harry F and Steven C A.1994.Statistic Concepts and Applications.PP 192, Cambridge university press.

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 E.L.F. Schipper.2011. Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. Global Environmental Change, 21(1), 227-237.

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.

Deressa T, R.M., Hassan, C., Ringler, TekieAlemu and Mahmud Yesuf, 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environmental Change, 19: 248-255.

Edwards-Jones, G.; Plassmann, K.; York, E. H.; Hounsome, B.; Jones, D. L. and Milà I Canals, L. (2009).'Vulnerability of Exporting Nations to the Development of a Carbon Label in the United Kingdom', Environmental Science and Policy (in press).

Eriksen, S., &Noess, L. O. (2003), Pro-Poor Climate Adaptation: Norwegian Development Cooperation and Climate Change Adaptation: Oslo. Norwegian Agency for Development Cooperation.

FeyeraLiben M., Charles Wortmann S. and KindieFantaye T. 2015. Risks associated with dry soil planting time in Ethiopia. International Journal of Agronomy and Agricultural Research, ISSN: 2223-7054 (Print) 2225-3610 (Online) http://www.innspub. Net Vol. 6, No. 4, p. 14-23, 2015

Funk, C., Senay, G., Asfaw, A., Verdin, J., Rowland J., Korecha, D., Eilerts, G., Michaelsen, J., Amer, S. and Choularton, R. 2005.Recent drought tendencies in Ethiopia and Equatorial Subtropical Eastern Africa. FEWSNET Report Number 01/2005.

Girma M. 2005. Using Climatic Outlook to Advice on Sorghum production in the Central Highland Rift Vally of Ethiopia. PhD dissertation submitted to the Department of Soil, Crop and Climates Sciences, University of Free State, South Africa.

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

Hadgu, KindieTesfaye, GirmaMamo and Belay Kassa4., 2012. Trend and variability of rainfall in Tigrai, Northern Ethiopia: Analysis of meteorological data and farmers' perception

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

HadguGebre, Testate, K. and Mamo, G., 2014. Analysis of climate change in Northern Ethiopia: implications for agricultural production. Theoretical and Applied Climatology ISSN 0177-798X.Vol.117: P 3-17.

Haile, Tesfaye. 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. M. (2010), Implications of Climate Change for Agricultural Sector Performance in Africa: Policy Challenges and Research Agenda, Journal of African Economies, Vol. 19, AERC Supplement: ii77- ii105

Houghton, J. T., Ding, Y. D. J. G., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., and Johnson,

Hulme, M. 1987. Secular changes in wet season structure in central Sudan. Journal of Arid Environment 13: 31-46.

IPCC. 2013. "Summary for Policy Makers: In: Working Group I Contribution to the IPCC Fifth Assessment Report - Climate Change 2013: The Physical Science Basis." IPCC WGI APR5, SPM-2.

Jaetzold, R., Kutsch, H. 1982. Agro-ecological zones of the tropics with a sample from Kenya.

Joachim, G. 2008. International Journal for rural development Rural 21 volume 43 the ultra-poor neglected resource, future potential. No.5/2008ISSN: 1866-8011.D20506F

Karim, Z., Mohamed, S.G. Hussain, and Kh. B. Rashid. (1994). "Impact of Climate Change in the Production of Modern Rice in Bangladesh." In Implications of Climate Change for International Agriculture: Crop Modeling Study, EPA 230-B-94-003.: Bangladesh 1-11. Washington D.C. USA.

Kasperson, R. E., Kasperson, J. X., and Dow, K. (2001). 'Vulnerability, equity, and global environmental change', in J. X. Kasperson and R. E. Kasperson (eds.), Global Environmental Risk, London: Earthscan.

Kipkorir, E.C., Raes, D., Bargerei, R.J., Mugalvai, E.M., 2007. Evaluation of two risk assessment methods for sowing maize in Kenya. Agric. For. Meteorol. 144,193–199.

Magadza, C.H.D., 2000: Climate change impacts and human settlements in Africa: prospects for adaptation.

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.

Mersha E. 1999. Annual rainfall and potential evapo-transpirtaion in Ethiopia.Ethiopian Journal of Natural Resources 1: 137– 154.

Mesay A. 2006. The Onset, Cessation and Dry Spells of the Small Rainy Season (Belg) of Ethiopia. National Meteorological Agency of Ethiopia, Addis Ababa.10-13P.

Meteorological Research Report Series.Vol.1, No. 1, Addis Ababa.

Meteorological Research Report Series.Vol.1, No. 1, Addis Ababa.

Meze-Hausken, E., 2004. Contrasting climate variability and meteorological drought with perceived drought and climate change in northern Ethiopia. Clim. Res. 27, 19–31.

MoA (Ministry of Agriculture), 1998.Agro ecological zones of Ethiopia.Ministry of agriculture. Addis Ababa, Ethiopia.

MoARD (Ministry of Agriculture and Rural Development), 2007. Ministry of agriculture and rural development crop development crop variety register. Addis Ababa, Ethiopia, 7: 104.

Mohan, M and Rob S. (2005). Primer on Climate Change and Sustainable Development: Fact, policy Analysis and application; Cambridge University Press, 445 pp.

Mugalavai, E.M., Emmanuel, C., Kipkorir, E.C., Raes, D., Rao, M.S., 2008. Analysis of rainfall onset, cessation and length of growing season for western Kenya. Agric. For. Meteorol. 148, 1123–1135

NMSA (National Meteorological Services Agency). 1996.Climate and Agro-climatic Resources of Ethiopia.

NMSA (National Meteorological Services Agency). 2001. Report submitted to initial national communication of Ethiopia to the United Nations Framework Convention on Climate Change, Addis Ababa, Ethiopia.

NMSA. 2005. Agro meteorological Bulletin Seasonal Agro Meteorological Bulletin Belg, 2005, Volume 15 No. 15, Addis Ababa, Ethiopia

Oxfam, (2006).Causing Hunger: An Overview of the Food Crisis in Africa.Briefing Paper.39 pp.http://www.oxfam.org/en/policy/briefingpapers/bp91_africa_food_crisis.

Philander, S. and G. H. 1990. El Niño, La Niña and the Southern Oscillation. Academic Press Inc.: San Diego, California. Pp293.

Raes, D., Sithole, A., Makarau, A., Milford, J., 2004. Evaluation of first planting dates recommended by criteria currently used in Zimbabwe. Agric. For. Meteorol.125, 177–18.

Reddy, S. J: Methodology: Agro-climatic Analogue Technique and Applications as relevant to 20 dry land agriculture, Agro climatology Series Eth 86/o21-WMO/UNDP NMSA, Addis Ababa, Ethiopia. 1990.

Romilly, T.G. and Gebremichael M. 2010. Evaluation of satellite rainfall estimate over Ethiopian river basins. Hydrology and earth Systems Science Discussion 7: 7669-7694.

S. V. and Kelkar, U. 2006. Mapping climate vulnerability and poverty in Africa: Report to the

Department for International Development. ILRI, Nirobi, Kenya, pp.171.

Segele Z. T. and Lamb.J. 2005.Characterization and variability of Kiremt rainy season over Ethiopia. National Meteorological Services Agency of Ethiopia, Addis Ababa, Ethiopia and Cooperative Institute for Mesoscale Meteorological Studies and School of Meteorology, Norman, OK, USA. Meteorology and Atmospheric Physics 89: 153–180.

Seleshi Y, Zanke U (2004). Recent changes in rainfall and rainy days in Ethiopia. Int. J. Climatol. 24:973- 983. http://dx.doi.org/10.1002/joc.1052.

Sinebo, W., Lakew, and AmanuelZenebel. 2010. "Bi plot analysis of grain yield in barley grown under differing management levels in years of contrasting season-end drought. Plant Breeding and Crop Science."152-164.

Sivakumar, M.V.K., 1992. Empirical analysis of dry spells for agricultural application in West Africa. J. Clim. 5, 532–539.

Sperling, D., & Cannon, J. (2007). Driving Climate Change: Cutting Carbon from Transportation. Boston: Academic Press.

Sreenivas, G., Devender, R. and Reddy, D.R. 2008. Prediction of phenology in aerobic rice using agro meteorological indices. Journal of Agro Meteorology (I): 111 – 114.

Stern, R., Dennett, M. and Dale, I. 1982.Analyzing daily rainfall measurements to give agronomically useful results. I. Direct methods. Experimental Agriculture 18:223-236.

Stern, R., Dennett, M. and Dale, I. 1982.Analyzing daily rainfall measurements to give ergonomically useful results. I. Direct methods. Experimental Agriculture 18:223-236.

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 Agriculture47, 241-266. Switzerland.

Tesfaye K and Walker S. 2004.Matching of crop and environment for optimal water use: the case of Ethiopia. Phys. Chem. Earth. 29 :(15-18):1061-1067.

Thornton, P. K., Jones, Owiyo, P.G., Kruska, T.M., Herrero, R.L., Kristjanson, M., Notenbaert, P., Bekele, A., Omolo, N., Orindi, A., Ochieng, V., Otiende, A., Bhadwal, B., Anantram, S., Nair, K., Kumar,

Tilahune K. 1999. Test of homogeneity, frequency analysis of rainfall data and estimate of drought probabilities in Dire Dawa, eastern Ethiopia. Ethiopian Journal of Natural Resources 1: 125-136.

Van Emden, H.F., S.L. Ball and M.R. Rao. 1988. Pest disease and weed problems in pea lentil and faba bean and chickpea. p. 519-534. In: R.J. Summerfield (ed.), World Crops: Cool Season Food

Legumes. ISBN 90-247-3641-2. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Viste E., Korecha D, and Sorteberg, A. 2012. "Recent Drought Precipitation Trends in Ethiopia." Theoretical and Applied Climatology, Springer-Verlag.Odi: 10.1007/s00704-012-0746.

Webb P. and Braun J. 1994. "Famine and Food Security in Ethiopia: lessons for Africa." John Willy and Sons. New York. Pp. 10-56.

Woldeamlak, B. 2009. Rainfall variability and crop production in Ethiopia Case study in the Amhara region In: Proceedings of the 16th International Conference of Ethiopian.

World Bank. 2010. Africa Development in a Changing Climate.Aschalew, A.2007. Climate change detection and attribution in tropical Africa.ResearchReport. Addis Ababa University. Addis Ababa.

Zeray, L.A., J. Roehrig, D.A. Chekol. 2007. Climate change impact on Lake Ziway watershed water availability, Ethiopia. Catchment and Lake Research, 1: 18-23

National archives and Library of Ethiopia

Verification of ISBN given by publisher

No	Author	Title	Publisher	Place of publisher	Given ISBN
1	NMA-EtMS	Ethiopian Meteorological Research series, First series	NMA-EtMS	Addis Ababa	978-99944-78-78-1

Note: this form will be filled in two copies one copy will be given to National archives and library of Ethiopia.

For office use only: ☑

Given ISBN is verified: ☑

Given ISBN must be corrected

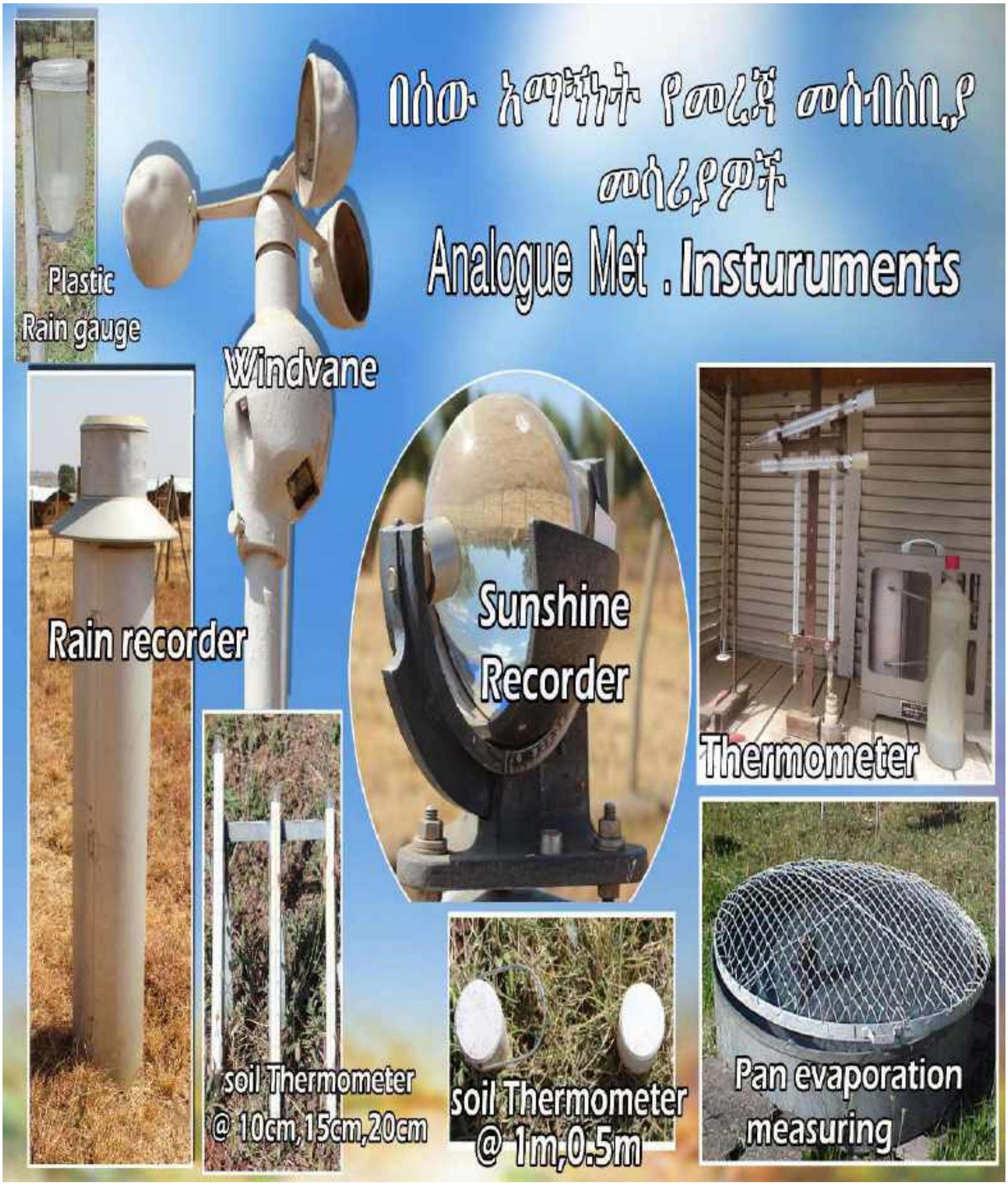
Head of personnel who verified

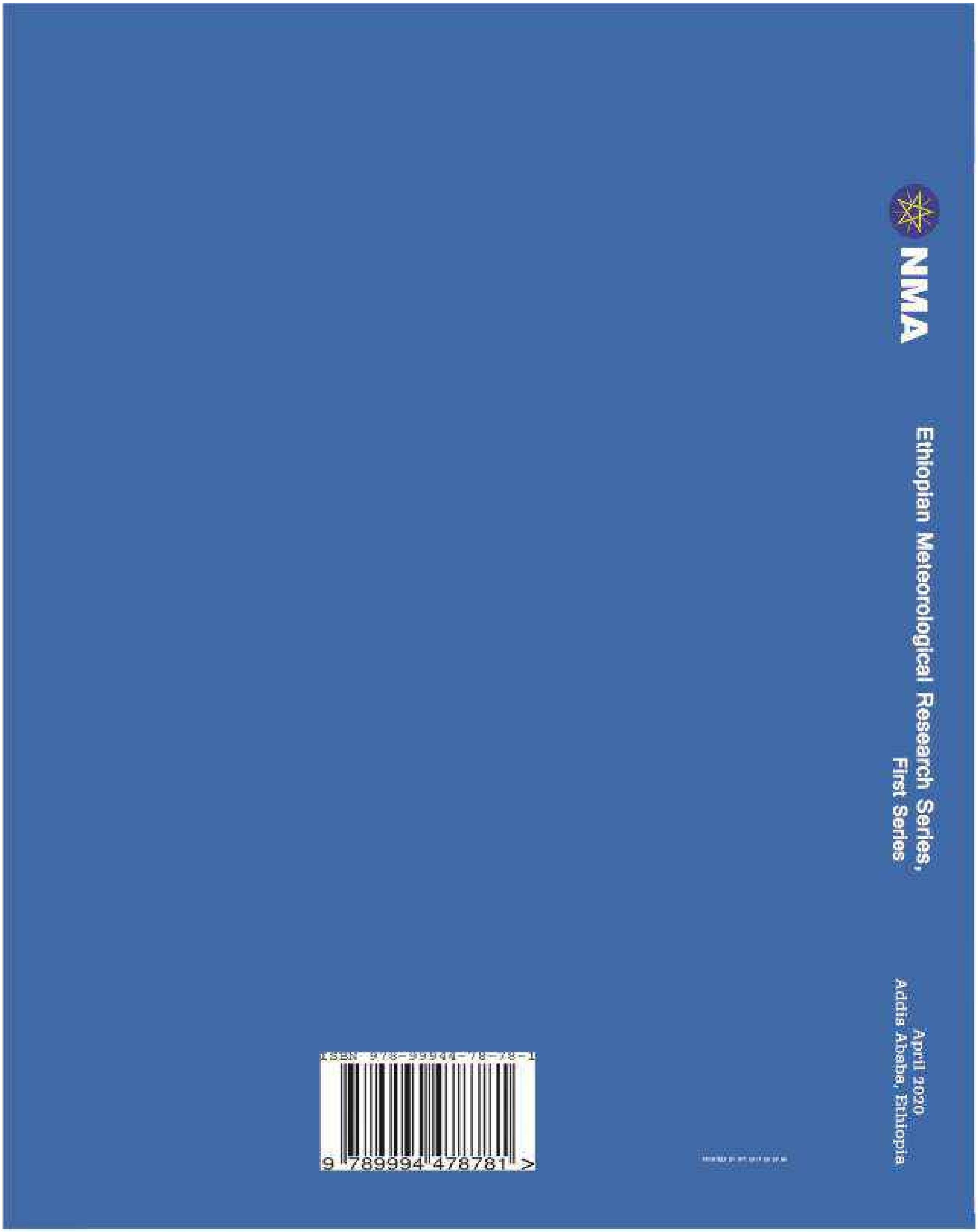
Name: Kidist

Position: Expert

Signature:


Digital Meterological Insturuments
Sateliite
Data Recivier
Radar
Ballon&Radiosonde
Station
Air Pollution
monitoring station
AWS
SAGIM
MP8


በሰው አማኻኝነት የመረጃ መሰብሰቢያ
መሳሪያዎች
Analogue Met . Insturuments
Plastic
Rain gauge
Windvane
Rain recorder
Sunshine
Recorder
Thermometer
soil Thermometer
@ 10cm,15cm,20cm
soil Thermometer
@ 1m,0.5m
Pan evaporation
measuring


NMA
Ethiopian Meteorological Research Series,
First Series
April 2020
Addis Ababa, Ethiopia
ISBN 978-99944-78-78-1
9 789994 478781 >