CHARACTERIZING CURRENT AND FUTURE RAINFALL VARIABILITY AND ITS EFFECT ON WHEAT AND BARLEY PRODUCTION IN SINANA DISTRICT, SOUTH EASTERN ETHIOPIA

MSc THESIS

Fitsum Bekele

OCTOBER 2015

HARAMAYA UNIVERSITY, HARAMAYA

CHARACTERIZING CURRENT AND FUTURE RAINFALL VARIABILITY AND ITS EFFECT ON WHEAT AND BARLEY PRODUCTION IN SINANA DISTRICT, SOUTH EASTERN ETHIOPIA

A Thesis Submitted to the Postgraduate Program Directorate

(School of Natural Resource Management and Environmental Sciences)

HARAMAYA UNIVERSITY

In Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN AGRO METEOROLOGY AND NATURAL RISK MANAGEMENT

By

Fitsum Bekele

October 2015

Haramaya University, Haramaya

APPROVAL SHEET

HARAMAYA UNIVERSITY

Postgraduate Program Directorate

We hereby certify that we have read and evaluated this Thesis entitled: Characterizing Current and Future Rainfall Variability and its Effect on Wheat and Barley Production in Sinana District, South Eastern Ethiopia prepared under my guidance by Fitsum Bekele. We recommend the thesis submitted as fulfilling the thesis requirement.

Diriba Korecha (PhD)	___________________	________________
Major Advisor	Signature	Date
Lisanework Nigatu (PhD, Assoc. Prof)	___________________	________________
Co-Advisor	Signature	Date

As a member of the Board of Examiners of the MSc Thesis Open Defense Examination, we certify that we have read and evaluated the Thesis prepared by Fitsum Bekele and examined the candidate. We recommend that this thesis been accepted as fulfilling the Thesis requirements for the degree of Master of Science in Agro meteorology and Natural Risk Management.

_____________________	___________________	_________________
Chairperson	Signature	Date
_____________________	___________________	_________________
Internal Examiner	Signature	Date
_____________________	___________________	_________________
External Examiner	Signature	Date

DEDICATION

This thesis manuscript is dedicated to my late brother Sebsibe Bekele.

STATEMENT OF THE AUTHOR

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

This thesis is submitted in partial fulfillment of the requirement for MSc degree at the Haramaya University. The thesis is deposited in the Haramaya University Library and is made available to borrowers under the rules of the library. I solemnly declare that this thesis has not been submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

Brief quotations from this thesis may be made without special permission provided that accurate and complete acknowledgement of the source is made. Requests for permission for extended quotations from, or reproduction of this thesis in whole or in part may be granted by the Head of the School or Department when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author of the thesis.

Name: Fitsum Bekele Signature: ______________________

Date: October, 2015

School/Department: Natural Resource Management and Environmental Sciences

BIOGRAPHICAL SKETCH

The author was born on May 31, 1985 in Goba town, Oromia Regional State to his Father Bekele Endeshaw and mother Amakelech Gurmu. He attended his elementary education at Micha, Delebetegel and Jemari Schools. After completion of elementary school he attended high school and preparatory class at Batu Terara Comprehensive Secondary and Preparatory School in Bale Goba from 2000-2003. After passing the Higher Education Entrance Certificate examination (HEECE), he joined Arbaminch University in 2004 and graduated with a BSc degree in Meteorology Science in 2006. Soon after graduation he was employed by the National Meteorological Agency of Ethiopia (NMA) at Bale-Robe Meteorological Branch Directorate. He served as a meteorologist and acting head of Branch Directorate. He joined the School of Graduate Studies of Haramaya University in October 2013 to pursue his MSc. study majoring in the field of Agro meteorology and Natural Risk Management.

ACKNOWLEDGEMENTS

I would like to express my heartfelt thanks to my major advisor, Dr.Diriba Korecha for his encouragement and advice during the course of the research and preparation of the manuscript. My grateful appreciation is extended to my Co-advisor Assoc.Prof Lisanework Nigatu, for his useful comments and boundless assistance throughout my study period.

I am greatly indebted to National Meteorological Agency of Ethiopia for giving me a study leave; and RUFORUM through Haramaya University for granting me the research fund. Special thanks goes to Dr Girma Mamo, Melese Lema and Zerihun for their inspiration and encouragement during study.

I am sincerely grateful to the staff of Bale Robe Meteorological Branch Directorate for their strong moral for the successful completion of this study. My sincere appreciation also goes to Mr. Nega Mosisa and Asegedew Gorfu for their invaluable support in arranging climate data.

I acknowledge the support I received from Sinana District Agricultural Office staff, namely w/ro Yenenesh in preparing long year crop yield data, Abdurazaq and Tadesse for their wonderful assistance.

Finally, special thanks goes to my family Amakelech (Emewedesh) my beloved mother and my sisters Marefia, Meresha and Hiwot who helped me gratefully to concentrate on my studies.

LIST OF ABBREVIATIONS

AR4	Assessment Report Four
AR5	Assessment Report Five
CMIP 5	Coupled Model Inter comparison Project Phase 5
CSA	Central Statistical Agency
CV	Coefficient of Variability
Das	Development Agents
DOY	Day of the Year
ENSO	El Niño- Southern Oscillation
DSSAT	Decision Support System for Agro-Technology Transfer
FDRE	Federal Democratic Republic of Ethiopia
GCMs	General Circulation Models
JJAS	June-July-August-September
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
LGP	Length of Growing Period
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
MoFED	Ministry of Finance and Economic Development
NAPA	National Adaptation Program of Action
NMA	National Meteorological Agency, Ethiopia
NMSA	National Meteorological Service Agency, Ethiopia
PAS	Peasant Association
RCP	Representative Concentration Pathways
RSCZ	Red Sea Convergence Zone
SST	Sea Surface Temperature
SDAO	Sinana District Agricultural Office
SPSS	Statistical Package for Social Science

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF TABLES IN THE APPENDIX

Appendix Table **Page**

LIST OF FIGURES IN THE APPENDIX

Appendix Figure **Page**

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Characterizing Current and Future Rainfall Variability and its Effect on Wheat and Barley Production in Sinana District, South Eastern Ethiopia

ABSTRACT

This study was undertaken in Sinana district to analyze current and future rainfall variability and its effect on wheat and barley production in Sinana district. Data on rainfall and crop yield were obtained from National Meteorological Agency and Sinana District Agricultural Offices, respectively. Following data quality checking, rainfall data (current and future), correlation and regression studies were analyzed using Statistical software like Instat V3.36 and SPSS V20. Downscaling the output of CSIRO-Mk3.6.0 GCM model (daily rainfall data) for RCP4.5 emission scenario using a web based software tool (Marksim GCM) for the period 2020-2049 were used to determine trends of annual and seasonal total rainfall and ascertain its impact on yield. Besides, a proportional size method was used to determine 161 sample respondents. Systematic random sampling method was employed to select respondents from Hora-Boqa kebelle for interview. This study used mean, coefficient of variation, correlation and regression analysis to ascertain the relation, cause and effect relationship between rainfall characteristics and wheat and barley yields. The results indicated that the mean onset date of the main rain season (JJAS) for Robe and Sinana station was 1st July. Furthermore, the results of Pearson Correlation Coefficients indicated that duration of kiremt rainy season and kiremt rain had moderate and strong positive relationship ($r = 0.488$ and $r = 0.702$) with wheat and barley, respectively in the study area. It was also observed that fifty percent of total variance of crop yield is explained jointly by kiremt rainfall total and rainy day (R^2 value are 51.2%). The results of the linear trend analysis indicated that annual rainfall will be increased by 0.16 mm and 0.86 mm every ten years for Robe and Sinana stations respectively. The result of projected wheat and barley yield indicated that there will be a slight decrease in both crops yield (qt/ha) by 2020, 2030 and 2049 years due to the impact of expected weakening of rainfall feature. The study revealed that Spider web, cold air, cloud movement and group of stars seen on the sky were the signs and signals identified by local communities which indicates whether the coming season will experience excessive or deficit rainfall. Taking in to account the above findings, it could be suggested that the farmers' community are encouraged to utilize timely climate information issued from National Meteorological Agency of Ethiopia (NMA) for farm level decision to enhance their crop yield under changing climate.

Key words: CSIRO-Mk3.6.0, Impact, Linear trend analysis, Perception, Rainfall Pattern

1. INTRODUCTION

Climate variability has always been identified as a challenge for African farmers. Specifically, it is a challenge to access climate information relevant to agricultural activities that enable the farmers to make prior decision about which crops to plant, where and when, will increase the ability of agricultural sector to make informed decision (Zermoglio, 2011). Studies in Ethiopia have shown that rainfall variability, unreliable occurrences in sufficient amount and delay in onset dates contribute to decline in crop yields with reasonable amount in almost all parts of the country (Godswill *et al.*, 2007). Agricultural yields are extremely sensitive to fluctuations in precipitation, and there is a fundamental concern that traditional farming practices may not be suited to produce sufficient crop yields under emerging climate contexts.

Rainfall variability has historically been found as a major cause of food insecurity and famine in the country (Beweket, 2009). This is clearly due to the fact that the agricultural sector is facing increased and continued risks of climate change. It is apparent that crop yield primarily depends on weather conditions, diseases and pests, planning of harvest operation etc. of the region. Due to this fact, effective management of these factors are necessary and used to estimate the probability of such unfavorable situation and to minimize the consequences (Raorane, 2012).

Agricultural sector is a pillar for the Economy of Ethiopian (MOA, 2010, MOFED, 2006). This sector, which is rain-fed by its nature, is highly sensitive to climate change and variability (NMA, 2007). According to World Bank (2006) report, close linkage between climate and Ethiopian economy is demonstrated by close pattern of rainfall variability and GDP growth. The trends in the contribution of agriculture to the countries total GDP clearly explain the presence of strong relationship between the performance of agriculture and climatic conditions. For instance, drought incidences that occurred during 1984/85, 1994/95 and 2000/01 years were strongly associated to nationwide famines. In contrast, good years in terms of climatic conditions of 1982/83 and 1990/91were associated with good agricultural year (CEEPA, 2006). Most of the study revealed that agricultural sectors of the country have been highly affected by climate related hazards (NMSA, 2001; Deressa, 2007). Annual as well as seasonal crop yield variations in Ethiopia can be partly explained by rainfall patterns.

Often rainfall is the only climatic indexes that have primarily been quoted for the purpose of rainfall-yield relationship analysis (Lemi, 2005). For example, previous studies have shown that (NMA-NAPA, 2007, Deressa, 2009) the major causes for low productivity of the agricultural sector are traditional farming practice, low adaptive capacity, lack of awareness and climate related risks management.

According to Besse (2010) and SDAO (2006), climate related risks such as drought (meteorological), water logging, and erratic rainfall were observed at different time in the study area, Sinana district which is the main causes for crop failure.

However, so far hardly any attempts have been made to investigate whether there exists any quantifiable relationship between some of the major crop of the region, mainly wheat and barley and rainfall. Besides, it is a paradox to demonstrate perception of farmers on the impact of rainfall variability and future change on their crop production.

This study was, therefore designed to investigate the effect of annual and inter-seasonal variation in rainfall on wheat and barley crop performance and quantify their relations, which enable to predict crop productivity trend for the future.

Taking in to account the severity of climate related problems in the study area, this study was conducted with the following objectives.

The general objective of this study is to analyze current and future rainfall variability and its effect on wheat and barley production in the study area

Specific objectives of this study are to:

- identify the rainfall characteristics and investigate its relationship with the crop of wheat and barley.
- predict the trend of future rainfall and analyze its impact based on sensitivity of the wheat and barley yields.
- assess the perception of local community on the rainfall characteristics, variability and future change

2. LITERATURE REVIEW

2.1. Ethiopian Rainfall Seasons and Associated Systems

2.1.1. Seasonal classification

Annual rainfall characteristics of Ethiopia are classified into three rainy seasons as documented by many authors (Gissila et al., 2004; Segele and Lamb, 2005; Korecha and Barnston, 2007). These distinct seasons are; the dry (October–January), the small rainy (February–May), and the main rainy (June–September) seasons. The seasons are locally defined as *Bega* (October–January), *Belg* (February–May), and *Kiremt* (June–September). A brief description of the mechanisms for rainfall formation for each season is given below:-

2.1.2. Meteorological systems associated with season

2.1.2.1. *Kiremt* season

During *kiremt season*, moist air flow is mainly dominated by zone of convergence in low-pressure systems, which is usually accompanied by north-south-north oscillatory of inter tropical convergence zone (ITCZ). Major Rain-producing systems during *kiremt* include the northward migration of the ITCZ, development and persistence of the Arabian and the Sudan thermal lows, development of quasi-permanent high-pressure systems over the South Atlantic and South Indian Oceans, development of tropical easterly jet (TEJ) and its persistence, and generation of low-level jet (Somali Jet). The Somali Jet is widely popular both for East African and Southeast Asia monsoon as it enhances low level southwesterly moisture flow towards the regions where JJAS is the main rainy season. It is to be noted that *Kiremt* rainfall covers most of the country with the exception of some part of south and southeast of Ethiopia (Kassahun, 1987; Camberlin, 1997; NMSA, 1996; Korecha and Barnston, 2007).

In the Sinana District of Bale Region the area is characterized by bimodal rainfall pattern *Kiremt* and *Belg*. The mean onset and cessation date of *Kiremt* season is July one and October twenty eight for Robe and surrounding respectively (Segele and lamb, 2005). Most farmers prefer to plant bread Wheat in the *Kiremt* season to minimize the problem of grain sprouting (i.e. Wheat matures during the dry December-January period) and also suitable for barley production (Alemayehu and Frazel, 1987).

2.1.2.2. *Bega* season

During *bega* season, the country predominantly falls under the influence of dry and cool northeasterly winds. These dry air masses originate either from the Saharan anticyclone and/or from the ridge of high pressure extending into Arabia from a large high pressure over Siberia, central Asia (Pedgley, 1966). However, very occasionally, northeasterly winds get interrupted when migratory low-pressure systems originating in the Mediterranean area move eastward and interact with the equatorial/tropical systems, resulting in rainfall over parts of central Ethiopia. In addition to this, occasional development of the Red Sea convergence zone (RSCZ) affects coastal areas (Kassahun, 1987). In *bega*, most of the country is generally dry; the exception is the south and southeast of Ethiopia, which receives its second important seasonal rainfall in this period (NMSA, 1996).

Crops which are planted on *Kiremt* season in Sinana district are collected in *Bega* season which is the dry period of the area. During this period feed shortage for livestock occurs (Alemayehu and Frazel, 1987).

2.1.2.3. *Belg* season

The *belg* season coincides with the domination of the Arabian high as it moves towards the north Arabian Sea. Major systems during the *belg* are the development of a thermal low (cyclone) over the south of Sudan, and winds from the Gulf of Aden and the Indian Ocean highs that are drawn towards this center and blow across central and southern Ethiopia (Kassahun, 1987; Camberlin and Philippon, 2002). These moist, easterly and southeasterly winds produce the main rains in Southern and Southeastern Ethiopia and the *belg* rains to the east-central part of the northwestern highlands.

This season is the second rainy season for Sinana district, which is suitable mainly for barley and field pea production (Alemayehu and Frazel, 1987).

2.2. Cause of Rainfall Variability in Ethiopia

The rainfall is highly variable both in amount and distribution across regions and seasons (Tilahun, 1999; Mersha, 1999). The seasonal and annual rainfall variations are results of the macro-scale pressure systems and moisture flows which are related to the changes in the pressure systems (Haile, 1986; Beltrando and Camberlin, 1993; NMSA, 1996). The most important weather systems that cause rain over Ethiopia include Sub-Tropical Jet (STJ), Inter

Tropical Convergence Zone (ITCZ), Read Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and Somalia Jet (NMSA, 1996).

The spatial variation of the rainfall is, thus, influenced by the changes in the intensity, position, and direction of movement of these rain-producing systems over the country (Taddesse, 2000). Moreover, the spatial distribution of rainfall in Ethiopia is significantly influenced by topography (NMSA, 1996), which also has many abrupt changes in the Rift Valley. However, the detail spatial and temporal variability of rainfall over the horn of Africa in general and Ethiopia in particular is highly complex and not well known yet. This variability of the rainfall and recurrent droughts in the country affects the lives of millions of people whose livelihood is mainly dependent on subsistence agriculture.

2.3. Correlation and Regression Analyses between Rainfall Characteristics and Crop Yield

In Ethiopia, Lemi (2005) found that crops are negatively affected by rain, based on the yield and rainfall data he analyzed for four provinces of Ethiopia. The results further showed strong negative correlation between *meher* season rainfall and crop yield. The converse is true for the case of *belg* season. For instance,

Meher (JJAS) rain (r = -0.161 and r = 0.479) had low to moderate negative and positive correlation with wheat yield in Harar and Gondor province in Ethiopia, respectively. On the other hand, *meher* rain (r=0.009 and r=-0.255) had low positive and negative correlation at both locations in the country**.** The regression result also shows *mehe*r rainfall has a negative effect on yield of wheat, whereas belg has positive impact on yield of all crops considered **(**appendix Table 2**)**.

Another study made by Beweket (2009) revealed that results of correlation analysis between monthly, seasonal and annual areal average rainfalls and cereal production. *Tef*, barley and wheat production, for example show considerably high correlations with the *kiremt* rainfall.

Similarly, a result revealed by Admassu (2004), using climate and crop data for the period 1994-2001 stated that, total annual rainfall doesn't show strong correlation with the production of cereals crops such as *teff*, barely, wheat and maize in the study areas except for annual rainfall with wheat production in the 2nd study area (South Wolo, Oromia and North Shoa Zones). Total *kiremt* rainfall also doesn't show strong correlation with production of cereals crops such as *Teff*, Barely, Wheat and Maize in the study areas except for *kiremt* rainfall with Barely Production in the third study site (South Wolo, Oromia and North Shoa Zones). Total *belg* rainfall doesn't also show significant correlation with production of cereals of *teff*, barely, wheat and maize in the study areas except for *belg* rainfall with barley and wheat production in the 3rd study area (West and East Welega).

2.4. Importance and Impact of Onset and Cessation of Seasonal Rainfall on Crop Production

Studies have shown that the number of rainy days serve as a marker that can be used to verify the distribution of rainfall. During the length of growing season of crops, farmers expect a balance between the distributions of rain days and moderation in rainfall amounts per rain days throughout the season. A fall in the number of rain days associated with an increase rainfall per rainy day signifies an increased in the intensity of rainfall (Fraser *et al.*, 1999). An increase in the intensity of rainfall may result in a potential serious risk of an increased flood frequency and severity for most region of the world (Gordon *et al.*, 1992; Flower *et al.*, 1995). High daily rainfall may be responsible for potentially destructive to agriculture in sensitive areas that are prone to flood. This situation could compound the problem of food shortages and led to unprecedented food price increases. The study of Fraser et al. (1999) also revealed that increase in the number of rain days does not depict high amount of rainfall. The onset of rains, which is defined as the first occasion after a selected date when the rain accumulated over three consecutive rainy days is at least 20mm and no dry spells of more than 7 days in the next 30 days was used as a successful planting data (Sivakumar, 1988).

The onset of rainy season is a very important event for farmers in Sub-Sahara Africa. The onset of rains mark the beginning of three main activities; planting, weeding and Harvesting (Omotosho, 1990). This enables to determine the socio-economic life and survival of the farming household. The importance of farming in the lives of these households also affect other activities (Omotosho *et al.*, 2000), Planting that depends and is influenced directly by the onset of the rainy season is the first activity, which the other two activities are based. Significant shifts in the onset of rains will therefore affect both agriculture and many other non-agricultural activities of small-scale farmers. Several researchers have reported how variability of the onset and cessation of the rainy season in tropical region pose a serious challenge in the process of determining when the rainy season/planting season begins (Oladipo *et al.*, 1993, Omotoshow *et al.*, 2000). The cessation of the rainy season, which is defined as a decadal rainfall amount is less than half of the corresponding reference evapotranspiration at the end of rainy season and length of growing, is the difference between cessation and onset of rainfall (FAO, 1978).

Studies in Ethiopia revealed that rainfall variability, unreliable occurrences in sufficient amount and delay in onset dates caused significant reduction in crop yield with reasonable amount almost all parts of the country (Godswill *et al.*, 2007). According to Feyissa (2009), in prolonged drought spell and *belg* rain failure over Siraro district in 2007/2008 were caused the loss of 862,400 quintals of yield and the household also suggested that erratic rainfall period has increased an opportunity for crop pest. Similarly, shortage of the *belg* rain was accounted for crop production reduction in 2003, 2004 and 2008 in Shashemene. Crop production was almost reached its minimum levels in Dodola during 1993,1997,1998,2001 and 2002.

2.5. Impact of Rainfall Variability on Agricultural Sector in Ethiopia

According to NMSA (1996), Nicholls and Katzk (1991)**,** most of the time agricultural planning in Ethiopia is difficult during small rainy season due to erratic nature of the rains. Moreover, in relation to ENSO phenomena, significant year to year variation in the performance of the rainy season has favored the agricultural activities of the country mainly due to the eastward moving mid latitude troughs facilitate the interaction between the mid latitude cold air with tropical warm and moist air so that unstable conditions often produce abundant rains during the small rainy season (February to May).

Studies in Ethiopia have shown that rainfall variability usually result in reduction of 20% production and 25% raise in poverty rates in Ethiopia (Hagose *et al.*, 2009; Osman and Sauerborn, 2002). Moreover, a 10% of decrease in seasonal rainfall from the long term average generally translates in to a 4.4% decrease in the countries food production (Von Braun, 1991).

Rainfall in much of the country is erratic and variable and the associated drought have historically been the major cause of food shortage and famine (Wood, 1997; Pankhart and Johnson, 1998). Economic dependence of agricultural sector in Ethiopia on natural rainfall makes the production projected to be widen variation of yields and spatially and temporary. In line with this, the recorded famine in Ethiopia in 1973 and 1984 mainly due to severe drought

(Wolde-Georgis, 1997) and hence caused crop damage and decline of food availability in the country (Degefe and Nega, 1999/2000).

2.6. Climate Models and Downscaling Technique

General Circulation Models (GCMs) describe the global climate system, representing the complex dynamics of the atmosphere, oceans, and land with mathematical equations that balance mass and energy (IPCC, 2007a). By simulating interactions among sea ice, land surface, atmospheric chemistry, vegetation, and the oceans, they predict future climates characterized by temperature, air pressure, and wind speed. Because these models are so computationally intensive, they can only be run on supercomputers at large research institutes. However, the results are made available to the general scientific community and have so far been used for studies of climate change and its impacts on natural, social, and economic systems (IPCC AR4, 2007; Ghost and Mujumdar, 2008; Jones and Thornton, 2013). GCMs results vary due to model attributes, including their components, resolution, flux-adjustment, and emission scenario forcing. Components refer to the individual processes modeled by smaller models with in a given GCM. Current GCMs are referred to as “coupled models” because they are comprised of linked components which model physical processes such as the atmosphere, oceans, land surfaces and sea ice. Atmospheric and ocean components are represented as grid cells in all GCMs while the representation of land surfaces and sea ice vary more. “Couplers” integrate these domains into one unified model by routing the flow of data between components (IPCC, 2007). A fundamental characteristic of any model is the scale at which it accurately depicts reality. Increasing model resolution often increases its computational demand exponentially. The level of detail for a general circulation model is defined by the number of layers it uses to model the atmosphere and the ocean and its spatial resolution, meaning the size of the cells in its discretization of those layers (IPCC, 1996).

In order to change large-scale GCM output to a finer spatial resolution downscaling techniques must be applied to establish empirical relationships between GCM-resolution climate variables and local climate (Fowler et al., 2007; Green et al., 2011). GCMs are the fundamental drivers of regional climate change projections. GCMs allow us to characterize changes in atmospheric circulation associated with human causes at global and continental scales (Cayan et al., 2013).

MarkSim is currently used to downscale outputs from GCMs and generate daily future climate data at a specific site (Jones and Thornton 2009, 2013). Unlike most statistical downscaling models, MarkSim does not depend on long term climate data records, which are lacking in most developing countries. Moreover, it has the capacity to generate climate variables (rainfall, solar radiation, and minimum and maximum temperatures), which are the minimum data required for most dynamic crop models such as the Decision Support System for Agro-technology Transfer (DSSAT). MarkSim can also generate synthetic climate variables that show patterns of variability which are important in agriculture (Lobell and Burke, 2010; Dixit et al., 2011).

2.7. Farmers Perception towards Variability of Rainfall and its Impact

According to Hadgu *et al.* (2013), trends of rainfall events such as onset date, cessation date, length of growing period, and dry spell length were changed significantly in most stations, which agreed with the farmers' perception. The perception of farmers on *kiremt* rainfall characteristic events such as onset date, cessation date and length of growing period has been supported with observed meteorological data of the stations. In this regard, perception of farmers' on increase in frequency of late onset of *kiremt* rainfall and subsequent reduction in length of growing period was agreed with observed data at Adigrat, Alamata and Mekelle. However, the perception of farmers' on early withdrawal of *kiremt* rainfall was agreed with observed data only at Mekelle. Belay (2012), Assessed farmers' perceptions of climate change and the extent to which these perceptions have influenced their current practices with respect to adapting with changes in temperature and precipitation. Most of the interviewed farmers for the studied kebelles perceived that they have observed the changing temperature and precipitation, such as reduced amount of rainfall (59.7%), increasing temperature (60%), shift in the timing of rainfall and shortened period of raining days. They also stated that these changes have been affecting their farming activities. Given this perception and depending on the farming system, farmers have practiced several adaptation mechanisms. At local level, some farmers experienced positive effects from increased precipitation while others experienced negative effects as results from interviewing farmers suggested. This is a reflection of the unclear impact of change in precipitation on crop activities in the area. It is also a reflection of the high degree of variability of the rainfall experienced in the recent past.

2.8. Climate Change Impacts in Agricultural Production

Agriculture is one of the most widely studied sectors with respect to the impacts of climate change as it is considered as one of the most vulnerable sectors (IPCC, 2007). Globally, agriculture is highly sensitive to climate variations and climate extremes (e.g. droughts, heavy precipitation, etc. Rosen Zweig, 1994) due to this, climate change is already affecting rainfall amounts, distribution, and intensity in many places. For instance, over 60% of Africans remain directly dependent on agriculture and natural resources for their well-being (FAO, 2003). In Africa, agriculture is still primarily rain-fed **(**World Bank, 2008) and this will become increasingly challenging as climate change is expected to lead to inconsistent in annual rainfalls, making droughts more frequent (Mwangombe, 2013;Uphoff, 2012). As a result, agriculture is one of the sectors most vulnerable to climate change impact in Africa (Ajibade, 2013).

In sub-Saharan Africa, there is a strong correlation between rainfall and overall GDP (Mwendera, 2013). As the results presented in Deressa (2006) indicate, climate change is expected to have generally negative effects on developing-country agriculture, with related implications for food security.

2.9. Rainfall Trend and Projected Climate Change over Ethiopia

According to the National Meteorological Agency, average countrywide annual rainfall trends remained more or less constant between 1951 and 2006. However, both seasonal and annual rainfall has exhibited high variability (NMA, 2007). However, some studies have indicated that rainfalls have been declining over some parts of the country. Considerable declining in March-September rainfall was observed in northeast, southeast, and southwestern portions of Ethiopia after 1997 (Oxfam, 2010). In particular, rainfall amounts have significantly decreased during the *belg* (February-May) season. *Belg* rainfall in the east and southeast exhibited the largest percent reductions. Declines in *belg* rains may impact long cycle crop production with crippling consequences for agricultural production. In much of Ethiopia, similar to the Sahelian countries to its west, rainfall from June to September contributes the majority of the annual total, and is crucial to Ethiopia’s water resource and agriculture operations (Korecha and Barnston, 2007).

In order to quantify the impact of oceanic events, it found that the sea-surface temperature (SST) over the tropical eastern Pacific Ocean is not significantly correlated with the main rainfall of the semi-arid lowland areas of eastern, southern, and southwestern Ethiopia, except at marginal zones in transition to the Ethiopian Highlands (Korecha and Barnston, 2007). Indeed, June–September rainfall over the Ethiopian Highlands is positively correlated to the equatorial east pacific sea level pressure and the southern oscillation index, and negatively correlated to SST over the tropical eastern pacific ocean as expected, confirming again that warm phase of ENSO episodes are associated with below-average June–September rainfall over the Ethiopian Highlands (Seleshi and Zanke, 2004).

According to the report launched from IPCC mid- range emission scenario a small increase in annual precipitation is expected over the country by 2030, 2050 and 2080 periods (IPCC, 2001). Furthermore, projected rainfall change over Sub-Saharan Africa in the mid- and late 21st Century is uncertain. In regions of high or complex topography such as the Ethiopian Highlands, downscaled projections indicate likely increases in rainfall and extreme rainfall by the end of the 21st Century (IPCC AR5, 2013).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study area covers Sinana District, which is small portions of Southern highlands of Bale zone in Ethiopia located at 6^0 50’ N-$7^0$17’ N and 40^0 06’ E-$40^0$24’ E (Figure 1). It extends from 1700 to 3100 mean above sea level (m.a.s.l). This District is under Indian Ocean influences as southerly fluxes generating rainfall when strong southerly moisture flow and easterly perturbation engulf. This can be also affected by heavy rainfall events coming from northward advancement and southward retreat of ITCZ. As a result it experiences an annual average temperature of 9^0C to 25^0C and annual rainfall totals of between 452.7 mm and 1129.5 mm, respectively.

This District is bordered by Goro District in the east Dinsho District in west, Agarfa and Gassera in the north and northeast and Goba District in the south (SDAO, 2006).

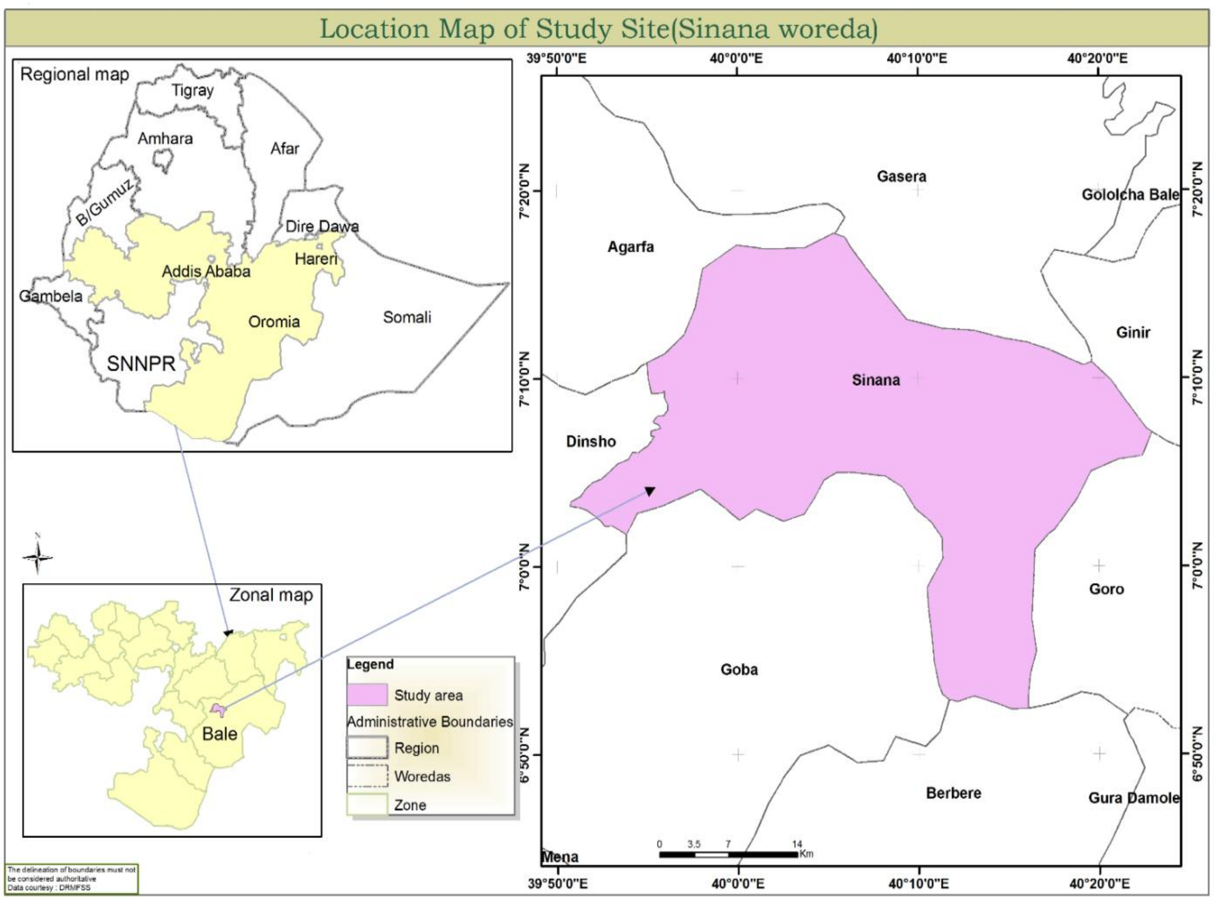

Figure 1. Map of the study area

Most part of Sinana District is found in SH2 (humid sub humid to cool mild highland) agro ecology (MoA, 2000). Rainfall climatologically patterns of the area also follow a bimodal distribution (NMSA, 1996; Bekele, 1997). Agriculture is the main economic practices in the district, from which the majority of dwellers earn their livelihood income mainly from crop cultivation. Major crops grow in the district include wheat, barley, oat, maize, bean and peas (Bogale *et al*., *2009).* Topographical delineation of Sinana district includes moderate, steep slope and plateaus. Out of total land area of the District serving for crop cultivation, which is 163,554 hectares, 99,992 hectares are currently used for farm. However, there are a number of climate related hazards that are recurrent in this part of Ethiopia. As a result, of this, crop productivity is always at risk (Besse, 2010; SDAO, 2006).

3.2. Data methodology

3.2.1. Rainfall and crop production data

Wheat and Barley yields data for the period 1987/88-2005/2006 were obtained from Sinana District Agricultural Offices (SDAO) for the *Meher* season. On the other hand, rainfall data were taken from Sinana Meteorological Stations, Sinana District and Robe meteorological station which is nearest to Sinana meteorological station for the period1995-2013 were obtained from National Meteorological Agency of Ethiopia.

3.2.2. Projected rainfall data

Future rainfall data (2020-2049) for Robe and Sinana Meteorological sites were downscaled from CSIRO-Mk 3.6.0 Atmosphere-Ocean GCM for RCP 4.5 emission scenarios of IPCC-AR5 using a web based software tool (http/:WWW.Marksim GCM Weather Generator.Com). Marksim is a spatially explicit daily weather generator that uses a third order Markov chain process to generate daily rainfall (Jones and Thornton, 2000). It requires geographical location to downscale and generate daily future data for a given site (Jones and Thornton, 2000).

According to Yang et al. (2014), out of 43 models of the Coupled Model Inter-comparison Project Phase5 (CMIP5) historical experiment involved in the study CSIRO MK 3.6.0 was the only model that captures both the East African precipitation climatology and the East African long rains-SST relationship in the observation. The study further revealed that fully coupled model had systematic errors in simulating the East African precipitation climatology and provided different sea surface temperature (SST) patterns associated with decadal variability of the East African long rains CSIRO-Mk 3.6.0 Atmosphere-Ocean GCM was selected among the 17 GCMs due to its better estimation of areal rainfall compared to station data (2010-2014) on annual and seasonal basis, in addition to seasonal contribution to the annual total by plotting values on bar graphs for visual inspection.

3.2.3. Sampling method and description of population

Hora-Boqa Kebelle among other Kebelles of Sinana district was selected because this area has been highly vulnerable to extreme climatic events such as droughts, waterlog which resulted in significant yield reduction on major crops (Besse, 2010).

Indigenous knowledge of local communities, particularly, farmers were interviewed based on pre-designed questionnaire in order to characterize social and economic implication of climate change or climate related hazard on their livelihood. Among the dwellers of Kebelle, some informants are selected using systematic random sampling technique.

Formula used for calculating a sample size is described as follows:-

$$\text{Sample size } (n) = \frac{N}{1 + N(e)^2} \qquad \text{(Equation 1)}$$

Where N is population size, n is the sample size and e is the level of precision (Belay, 2012; Getachew et *al.*, 2014; Yemane, 1967 and 2001).For the selected kebelle, N=771 at ±7% precision levels the sample size was computed as (Equation 2), with confidence level of 95% and p=.5 (maximum variability).

$$\text{Sample size } (n) = \frac{771}{1 + 771\,(0.07)^2}$$

Hence, an optimum sample size for this study is161 farmers.

Generally, 161 farmers were selected for interview (Household field survey) out of 771 using systematic random sampling method from the selected Hora-Boqa Peasant Association (kebelle). After offering one day training for data collectors, face to face interview were held with the farmers using semi structured questionnaire. In order to maintain the credibility and quality of data, the author of this thesis fully administered the data collection process.

3.3. Data Analysis

3.3.1. Analyses of crop yield and rainfall characteristics

In order to avoid potential problems during climate analysis, rainfall data were plotted for visual inspection and detection of outliers. Identification of outlier values should be done carefully to make sure that the outliers found is truly erroneous and is not naturally extreme values (Abbas et al., 2013). Simple statistical parameters noticeably; mean and standard deviations were computed according to their standard formula. A standard outlier threshold, which is defined using a parameter of inter-quartile range (IQR), was used for this study (Gonzalez-Rouco et al, 2001). Mathematically, it is defined by formula as:

$$\text{Threshold} = Q_3 + (3*IQR) \qquad \text{(Equation 3)}$$

Where Q_3 is third quartile and IQR is an inter-quartile range. The inter-quartile range method is known as a technique which is resistance to outliers but still keep the information of extremes (Gonzalez-Rouco et al., 2001). The detected outlier values were removed and substituted by outlier threshold (SUPARI, 2012).

In determining an onset date of the main rainy season, many different criteria exist for different crops exhibiting different maturity plus drought tolerance levels and soil types. In the present study, the one with 20 mm of total rainfall received over three consecutive days that were not followed by greater than 10 days of dry spell length within 30 days from planting was adopted (Raman, 1974). Sivakumar (1988) also used similar criteria, except that he used 7 day dry spell length. These criteria are useful particularly in mitigating the seedling establishment related rainfall risk. Ethiopian National Sorghum Improvement Program (ENSIP) also uses this criterion, especially the first part of the onset definition (cited by mamo, 2005). On the other hand, the end of the growing season is mainly dictated by stored soil water and its availability to the crop after the rain stops. In this study, the end of the rainy season was defined as any day after the first of September, when the soil water balance reaches zero (Stern *et al.*, 1982). In determining the end date, 3.4 mm/day evapotranspiration of the study site and 100 mm/m of the plant available soil water were considered. CROPWAT 8.0 was used to calculate evapotranspiration.

Onset and cessation of rainfall date is analyzed using an Instat version 3.6 package developed by the Statistical Services Centre of the University of Reading (Stern *et al*., 2006). Besides, duration of the rainy season was determined by counting the number of rainy days between the onset and the end date of the rainy season in a given time for the study area. Similarly, seasonal rainfall (*kiremt rain*) was decided by adding the amount of rainfall recorded for an entire season for the study area. Finally, in determining the number of rainy days, a number of different criteria are available for use. In this study however, a rainy day is defined as a period of 24 hours with at least 0.3 mm of recorded rainfall amount (Adamgbe, 2013**)**. In the context of Ethiopia, Segele and Lamb (2005) employed three rainfall thresholds to define a rainy day (0.1mm, 0.5mm and 1mm). In this study, the minimum rainfall threshold definition suggested by Segele and Lamb (2005), which is 0.1 mm per 24 hrs, was adopted.

3.3.2. Analysis of rainfall trend and Crop yield

Standard deviation, mean and coefficient of variation ware used in analyzing the variation in explanatory variables (rainfall characteristics) and wheat yield. Scientifically, it is computed using the following formula:

$$CV = \left(\frac{S}{\bar{x}}\right) 100 \qquad \text{(Equation 4)}$$

Where CV is Coefficient of variation, S is the standard deviation and $\bar{x}$ mean for rainfall.
To examine the nature of the trends, the Standardized Anomaly Index (SAI) is then used for both rainfall and perception of indigenous knowledge for select kebelle and Sinana District). It is determined as:

$$Z = \frac{x - \bar{x}}{s} \qquad \text{(Equation 5)}$$

Where, z is number of standard deviation of the observation deviated from the normal, x is an observed rainfall value and $\bar{x}$ is mean and S is the standard deviation. This statistics are enable us to determine the dry (-ve values) and wet (+ve values) years in the record.

To investigate the nature of the trends in the rainfall series, linear trend lines were also plotted for both annual and seasonal (June-September and February-May) using Microsoft Excel Statistical Tool (2007).

3.3.3. Correlation and regression analysis

Correlation and multiple linear regression methods were used to establish the relationship, cause and effect of rainfall characteristics on wheat and barley yields.

The regression equation for the study was in the form of:

$$Y=a+b_1x_1+b_2x_2+b_3x_3\ldots b_nx_n+e \qquad \text{(Equation 6)}$$

where; *Y* = the value of the dependent variable (wheat yield in qt or qt/ha); *a* = *Y* intercept and b1, *b*2, *b*3, *b*4, ⋯ *bn* = regression coefficients,x1, x2, x3, x4, ⋯ xn = The independent variables (rainfall characteristics such as rainfall onset, cessation, duration, seasonal rainfall total and number of rain days, respectively); and, *e* = the error of estimate or residuals of the regression.

Coefficients of multiple determinations (R^2) were used to determine the percentage of variation explained jointly by the rainfall characteristics.

Pearson Correlation coefficient (r) analyses were used to analyze the correlation between crop yields (Wheat and Barley yield expressed in qt/ha) with rainfall characteristics, value of r ranges between -1 to +1, a correlation coefficient close to +1 indicates a strong positive correlation, a correlation coefficient close to -1 indicates a strong negative correlation similarly a correlation coefficient of 0 indicates no correlation.
F-distribution test was employed for testing all the coefficients in a regression model.

If P-value of F exceeds 0.05 (confidence level) the explanatory variable does not predict response variable. Similarly, Student t-test in a multiple regression were employed to assess whether the independent variable adds unique and predictive value as a predictor for statistical significance (Armi Collins, *et al.*,1994; Agrawal *et al.*, 1986; Odekunle *et al.*, 2007) values were calculated using Instat package. To assess how serious the collinearity problem is the variance inflation factor (VIF) was employed. If the VIF is 1 there is collinearity at all, if the VIP is large such as 10 or more collinearity is the series problem.

3.3.4. Impacts of projected future rainfall on wheat and barley yields

To ascertain whether the impact of future rainfall variability is increased or decreased on wheat and barley yields, it was assessed by substituting analyzed rainfall characteristic variables on the developed regression model based on sensitivity of crops after obtaining it using statistical software like Instat (Stern *et al.*, 2006) and SPSS (version20)

4. RESULTS AND DISCUSSION

4.1. Correlation Analysis of Wheat and Barley Yields and Rainfall Characteristics

As it was presented in Table 1 and 2 , the correlation coefficients computed between wheat and barley yields and rainfall characteristics for Robe meteorological station showed that *kiremt* (JJAS) rainfall total (r = 0.460) and length of growing period (r = 0.032) had positive moderate and weak correlation with wheat yields, respectively. Whereas, onset date of the rainy season (r = -0.091), end date of the rainy season (r = -0.078) and *kiremt* rainy day (r = -0.227) had negatively weak correlation with wheat yield, respectively. Similarly, *kiremt* rain (r = 0.599), onset date of the rainy season (r = 0.057), end date of the rainy season (r = 0.158) and length of growing period (r = 0.064) had positive, moderate and weak correlation with barley yield, respectively. Likewise, *kiremt* rainy day (r = -0.043) had negative weak correlation with barley yield. In line with this result on national level Lemi (2005) reported that among the rainfall characteristics studied, *kiremt* rain had better with the value of low to moderate correlation with wheat yield.

Table 1. Pearson's upper triangular correlation matrix of rainfall characteristics and wheat yield for Robe meteorological station

	Wheat	Onset date	End date	Length of growing period (LGP)	Kiremt rainfall total	Kiremt rainy day
Number/Correlation	19	19	19	19	19	19
Wheat		-.091	-.078	.032	.460*	-.227
Onset date			.398	-.708**	-.123	-.207
End date				.367	.326	.079
LGP					.376	.271
Kiremt rainfall total						.500*
Kiremt rainy day						.029

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 2. Pearson's upper triangular correlation matrix of rainfall characteristics and barley yield for Robe meteorological station

	Barley	Onset date	End date	Length of growing period (LGP)	Kiremt rainfall total	Kiremt rainy day
Number/Correlation	19	19	19	19	19	19
Barley		.057	.158	.064	.599**	-.043
Onset date			.398	-.708**	-.136	-.207
End date				.367	.332	.079
LGP					.394	.271
Kiremt rainfall total						.495*
Kiremt rainy day						

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

In the case of Sinana meteorological station, *kiremt* rainfall total (r = 0.507), length of growing period (r = 0.085) and *kiremt* rainy day (r = 0.133) had moderate and weak positive correlation with wheat yield, respectively (Table 3). Whereas, onset date of the rainy season (r = -0.191) and end date of the rainy season (r = -0.087) had negative and very weak correlation with wheat yield, respectively **(**Table 3**)**. Similarly, *kiremt* rainfall total (r = 0.702), length of growing period (r = 0.488) and end date of the rainy season (r = 0.384) had strong and moderate positive correlation with barley yield, respectively in contrast, *kiremt* rainy day (r = 0.263) and onset date of the rainy season (r = -0.485) had weak positive and moderate negative correlation with barley yield, respectively **(**Table 4**)**.

Table 3. Pearson upper triangular correlation matrix of rainfall characteristics and wheat yield for Sinana meteorological station

	Wheat	Onset date	End date	Length of growing period (LGP)	Kiremt rainfall total	Kiremt rainy day
Number/Correlation	19	19	19	19	19	19
Wheat		-.191	-.087	.085	.507*	.133
Onset date			-.640**	-.938**	-.685**	-.515*
End date				.867**	.585**	.195
LGP					.709**	.422
Kiremt rainfall total						.452
Kiremt rainy day						

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4. Pearson's upper triangular correlation matrix of rainfall characteristics and barley yield for Sinana meteorological station

	Barley	Onset date	End date	Length of growing period (LGP)	Kiremt rainfall total	Kiremt rainy day
Number/Correlation	19	19	19	19	19	19
Barley		-.485*	.384	.488*	.702*	.263
Onset date			-.640**	-.938**	-.685**	-.515*
End date				.867**	.585**	.195
LGP					.709**	.422
Kiremt rainfall total						.452
Kiremt rainy day						

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.2. Descriptive Statistics for rainfall characteristics, Wheat and Barley Yields

4.2.1. Variation in rainfall features, wheat and barley yield

The descriptive statistics computed for rainfall characteristics are shown in Table 5**.** They provide valuable explanation on existing variability in the rainfall characteristics. The onset date for Robe and Sinana meteorological stations, the respective upper and lower quartiles falls between 155 DOY (3rd June) and 222 DOY (9th August) and between 155 DOY (3rd June) and 227 DOY (14th August), respectively **(**Figure 2 and 3**)**. Thus, at both sites planting earlier than 7 June (159 DOY) and 16 June (168 DOY) is possible only once in every four years' time. Furthermore at Robe this upper quartile (75th percentile) statistics extends up to 199 DOY (17th July) whilst it can extend up to 16th July (198 DOY) at Sinana. The earliest date of onset date of the rainy season at Robe was 155 DOY (3rd June of 2008) while the latest date was 222 DOY (9th August of 2000) and the mean date was 1st July (183 DOY). In fact, this result substantially agreed with the finding of Segele and Lamb (2005) that indicates the mean date for the onset of the main rainy season (*kiremt*) for Robe and the surrounding was 1stJuly. Similarly, the earliest onset date of the rainy season at Sinana was 3rd June in 2008 against the latest date 227 DOY, 14th August in 1998. The mean date was 1st July (183 DOY). At Robe, the main rainy season (*kiremt*) terminates during the second decade of November (11th November) once in four years and terminates earlier than 3rd decade of November (29th November) in three out of four years. The same statistics for Sinana was found, which is 306 DOY (3rd November) and the first day of December (336 DOY). Accordingly the main growing season may not extend beyond 3rd decade of November in the case of Robe and first day of December for Sinana. The earliest and latest date for the end of the rainy season was 21st October in 2005 and 11th December in the case of 2006, respectively In general, the mean date was 323 DOY (18th November) for Robe. We found that this result did not agree with the finding of Segele and Lamb (2005) who reported that the mean date of end of the main rainy season was October 28. This is due to the fact that after the end of the rainy season the soil is assumed to be a field capacity of 100 mm so for this study in determining the end date 3.4 mm evapotranspiration per day of the study area and 100 mm of the plant available soil water were considered which is used to state the end of the growing season (Stern *et al.*, 1982 and cited in Mamo, 2005). Similarly, for Sinana meteorological station the earliest and latest end date of the rainy season was 25th October in2004 and 11th December in 1997 respectively while the mean date was 324 DOY. A further note could also be made from Table 5 and Figure 2 that length of growing period is mainly dependent on the onset date. At robe length of growing period is lower than 128 days in only 25% of the years while it is lower than 161 days in 75% of the years. Similarly, the lower quartile for length of growing period at Sinana is below 101 and 172 days in 25% and 75% of the years. The longest length of growing period was 170 days both in 2007 and 2008 while the shortest length of growing period was 109 days in 2002 and the mean length of growing period was 140 days for Robe. Similarly, the longest length of growing period at Sinana was 189 day in 2011 while the shortest length of growing period was 89 and the mean length of growing period was 141 days. The highest *kiremt* (JJAS) rainfall total amount was 543.5 mm in 2012 while the lowest was 263.6mm in 2005 and the mean amount was 415.3 mm in the case of Robe. Similarly, the highest *kiremt* (JJAS) rainfall total amount was 854 mm in 2012 while the lowest was 217.4 mm in 2002 and the mean amount was 425.6 mm in the case of Sinana (Figure 4**)**. On the other hand, the highest wheat and barley yield per hectare for Sinana district was 43.94 qt/ha in 2010 and 32.59 qt/ha in 2012, respectively. Whereas, the lowest yield of 22.96 qt/ha and 14.79 qt/ha was recorded in 1997 and 2003 years, respectively. The mean yield was 31.14 qt/ha and 21.47 qt/ha, respectively **(**Table 6**)**.

Table 5. Descriptive statistics of rainfall characteristics for Robe and Sinana meteorological stations

Robe meteorological station					
Variables	Minimum	Maximum	Mean	SD	CV (%)
Onset date (DOY)	155	222	183.26	19.3	10.5
End date (DOY)	295	346	323.79	14.67	4.5
Length of growing period (Days)	109	170	140.53	19.05	13.6
Kiremt rainfall total (mm)	263.6	543.5	415.32	64.98	15.6
Kiremt Rainy day (Days	48	85	68.37	9.16	13.4
Sinana meteorological station					
Variables	Minimum	Maximum	Mean	SD	CV (%)
Onset date (DOY)	155	227	182.63	22.22	12.2
End date (DOY)	299	346	324.05	15.43	4.8
Length of growing period (Days)	89	187	141.42	34.22	24.2
Kiremt rainfall total (mm)	217.4	854	425.62	189.9	44.6
Kiremt Rainy day(Days)	37	94	64	15.77	24.6

Table 6. Descriptive statistics of wheat and barley yield in sinana district

Variables	Minimum	Year	Maximum	Year	Mean	SD	CV (%)
Wheat yield (qt/ha)	22.96	1997	43.94	2010	31.14	6.15	19.8
Barley yield (qt/ha)	14.79	2003	32.59	2012	21.47	5.74	26.7

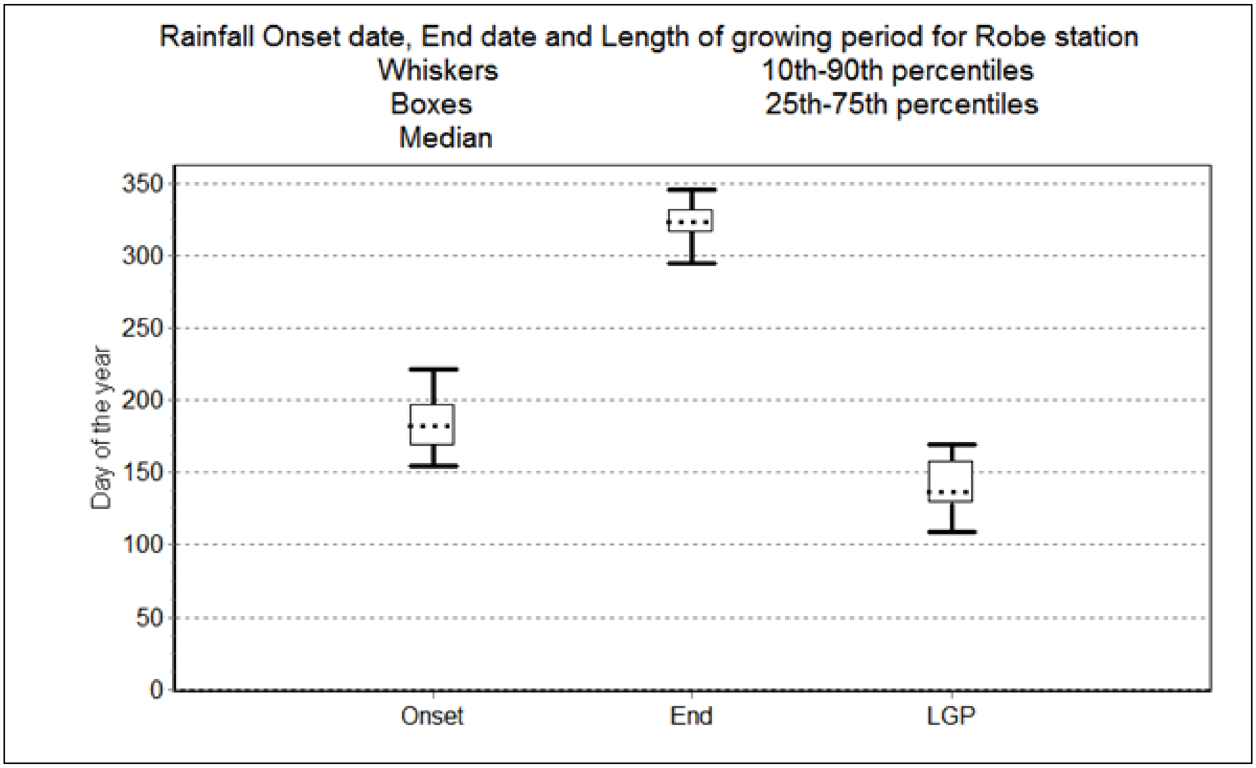

Figure 2. Box and whisker plots of onset date, end date and length of growing period for *kiremt* (June to September) season in Robe station.

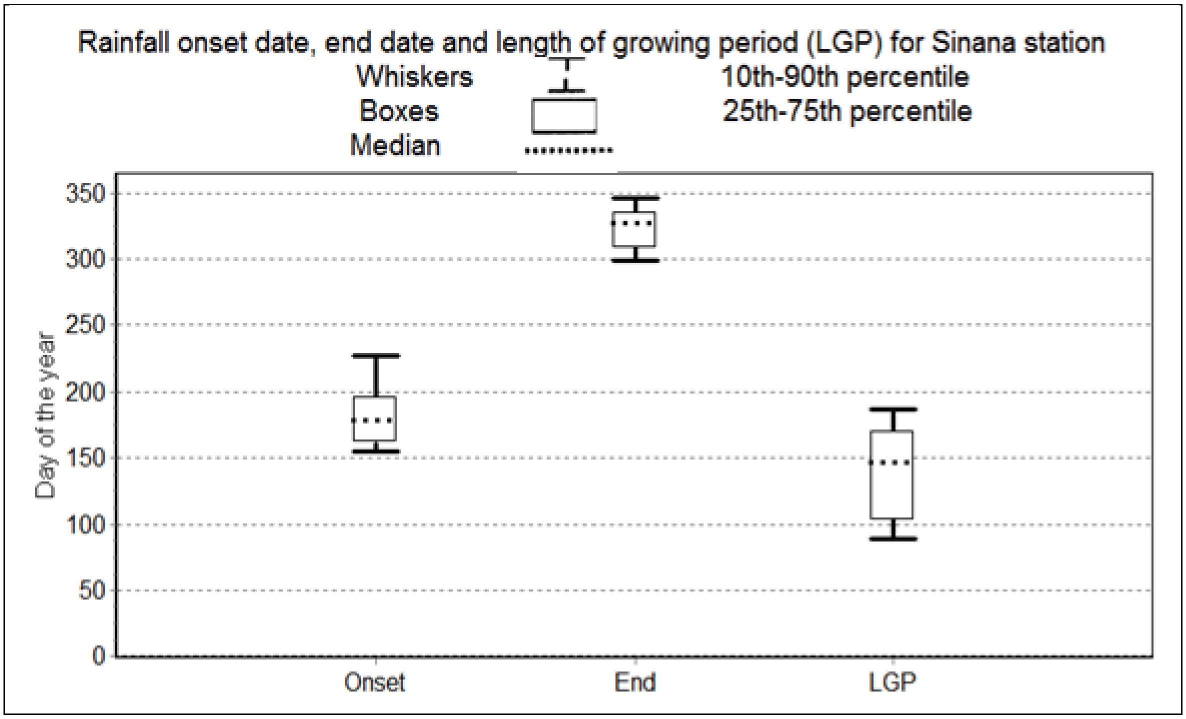

Figure 3. Box and whisker plots of onset date, end date and length of growing period for *kiremt* (June to September) season in Sinana station

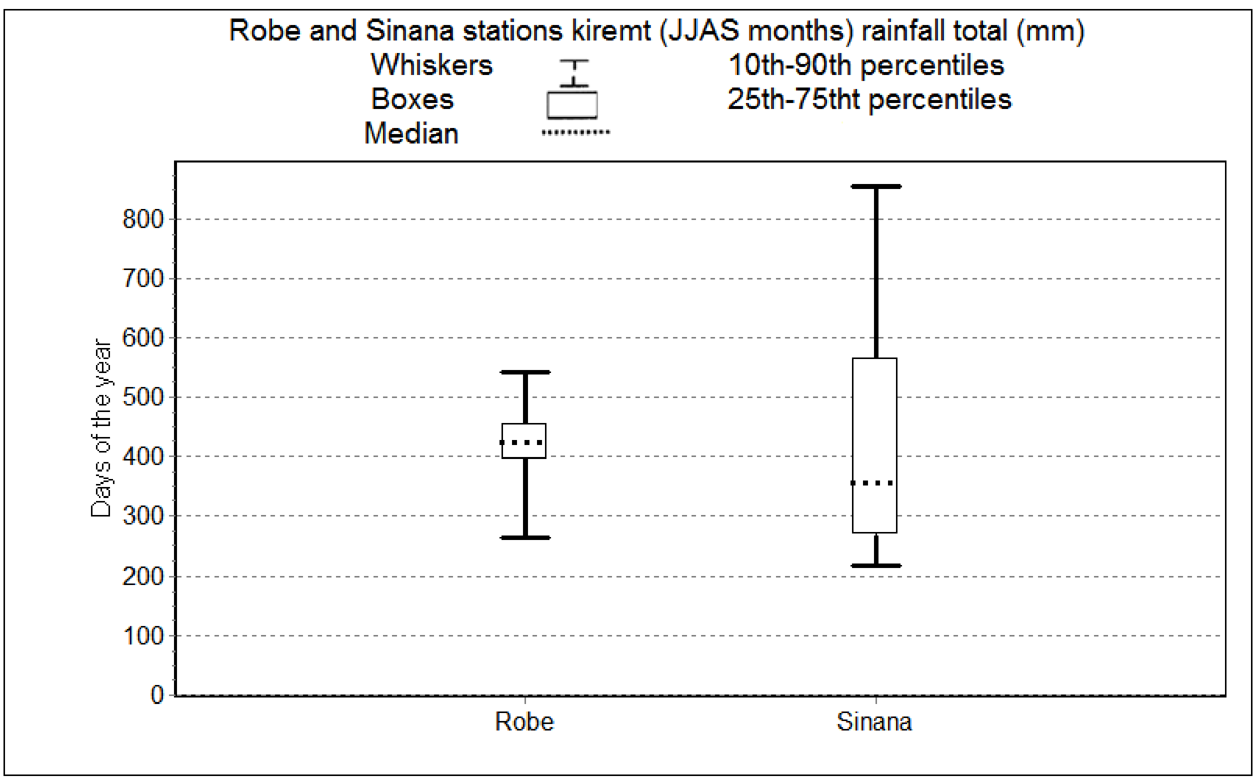

Figure 4. Box and whisker plots for *kiremt* (June to September) rainfall in Robe and Sinana meteorological station.

4.2.2. Coefficient of variation of rainfall characteristics, wheat and barley yield

Coefficient of variation of the rainfall characteristics for Robe meteorological station clearly demonstrates that *kiremt* (JJAS) rainfall total has the highest coefficient of variation (15.6%), followed by length of growing period (13.6%), *kiremt* rainy day (13.4%). An onset date of the rainy season (10.5%) and the lowest variability of 4.5% were found in the date of end of the rainy season. Much smaller box for end of the rainy season in Figure 2 and 3 indicated that the end dates of the rainy season vary over a short time span. Therefore, as less variability implies that patterns could be more understood, end of the rainy season were more reliable and predictable. Whereas the main rainy season followed by onset date of the rainy season were more unreliable and unpredictable in Robe station. This finding is in line with a study conducted by Gissila et al. (2004), who reported that the total June–September rainfall over the whole regions is difficult to predict due to seasonality variability. Similarly, among the rainfall characteristics in the study for Sinana, *kiremt* rainfall total has the highest coefficient of variability (44.6%), followed by *kiremt* rainy day (24.6%), length of growing period (24.2%), onset date of the rainy season (12.2%) and the lowest variability of 4.8% was found in the end date of rainy season(Table 5). As it can be inferred from Table 6, the highest coefficient of variability (26.7%), followed by 19.8% was recorded in barley and wheat yield per hectare, respectively. In contrary to this finding Beweket (2009) reported that the highest coefficient of variability that was recorded by wheat yield (14.2%) compared with barley yield (13.5%). This demonstrates that the highest coefficient of variation could be accounted for the joint effect by the variability in rainfall features. It should be noted that other climatic and non climatic factors were ignored in this study.

4.3. Regression Analysis of Rainfall Characteristics and Wheat and Barley Yield

In order to quantify physical relationship that exist between some of the major crops and climatic events, Some of these variables were identified as explanatory variables, namely; onset date, end date, length of growing period, *kiremt* (JJAS) rainfall total and *kiremt* rainy day. Wheat and barley yields were regressed separately on these variables by employing stepwise regression procedure in order to see the variation in yields and the result is shown in Tables7-14. The regression models in this case are solely developed for Robe and Sinana.

From Table7**,** the regression or prediction equation had been determined using the following equation by regressing yield (wheat yield) against selected climatic variables:

$$Y = 29.056+0.072X_1-0.409X_2$$

Where, Y = predicted yield of wheat in qt/ha

X_1 = *kiremt* (JJAS months) rainfall total in mm

X_2 = *kiremt* rainy day

The above regression model represents that given a unit change in any of the rainfall characteristics included in the study above while holding either of them constant, the highest variation in yield of wheat in the area will be experienced by *kiremt* rainfall total (0.072 qt/ha), followed by the least change in yield will be from *kiremt* rainy day (-0.409 qt/Ha). These result shows that among the rainfall characteristics included in the study, *kiremt* rainfall total (x_1) is the most important variable that has significant impact on wheat yield in the study area indicating that the yield of wheat is higher when *kiremt* rainfall total is getting higher. In contrast, *kiremt* rainy day has a negative impact on yield of wheat, meaning that there was higher yield of wheat under years with lower seasonal *kiremt* rainy days. Furthermore, statistical t-test analysis indicates that among the rainfall characteristics included in the study, only *kiremt* rainfall total (x_1) and *kiremt* rainy day (x_2) are statistically significant in influencing wheat yield positively and negatively at 0.05 confidence level, respectively. The computed value for coefficient of multiple determinations (R^2) is 0.489 (Table 8). This means that 48.9% of the variations on wheat yield per hectare for the past 19 years in Sinana district. That is, nearly fifty percent of total variance of crop yield is explained jointly by *kiremt* rainfall total and *kiremt* rainy day. The remaining 51.1% of the variation in wheat yield, however, could be explained by other climatic and non-climatic factors. Lemi (2005) also found similar result in 3 provinces of Ethiopia that Yield variability in Ethiopia agriculture can be partly explained by rainfall.

Table 7. Coefficients of regression analyses

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	29.056	8.936		3.252	.005
	Kiremt rainfall total	.072	.020	.764	3.704	.002
	Kiremt rainy day	-.409	.139	-.609	-2.952	.009

a. Dependent Variable: Wheat

Table 8. Regression values for predictors

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.700[a]	.489	.426	4.6640579

a. Predictors: (Constant), Kiremt rainy day, Kiremt rainfall total

Similarly, From Table9**,** the regression or prediction equation had been determined using the following equation by regressing yield (barley yield) against selected climatic variables:

$$Y = 10.98+0.072X_1-0.282X_2$$

Where, Y = barley in qt/ha

X_1 = *kiremt* (JJAS months) rainfall total in mm

X_2 = kiremt rainy day

From the estimated model above, given a unit change in any of the rainfall characteristics while holding either of the variables constant, the highest variation in yield of barley in the area will be accounted by *kiremt* rainfall total (0.072 qt/ha), followed by the least change in yield will be from *kiremt* rainy day (-0.282 qt/ha).These result show that among the rainfall characteristics included in the study *kiremt* rain (x_1) is the most important variable that has significant impact on barley yield in the study area indicating that the yield of barley is higher when *kiremt* rain is getting higher. In contrast, *Kiremt* rainy day has a negative impact on yield of barley, meaning that there was higher yield of barley under years with lower *kiremt* rainy days. Furthermore, statistical t-test analysis indicates that among the rainfall characteristics included in the study only *kiremt* rainfall total (x_1) and *kiremt* rainy day (x_2) are statistically significant in influencing barley yield positively and negatively at 0.05 confidence level, respectively. The calculated value for coefficient of multiple determinations (R^2) is 0.512 (Table 10). This means that 51.2% of the variations on barley yield per hectare for the past 19 years in Sinana district that is; more than fifty percent of total variance of crop yield is explained jointly by *kiremt* rainfall total and *kiremt* rainy day. The remaining 48.8% of the variation in wheat yield, however, could be explained by other climatic and non-climatic factors.

Table 9. Coefficients of regression analyses for *kiremt* rainfall total and *kiremt* rainy days

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	10.980	8.115		1.353	.195
	Kiremt rainfall total	.072	.017	.823	4.094	.001
	Kiremt Rainy day	-.282	.126	-.451	-2.242	.039

a. Dependent Variable: Barley

Table 10. Regression values for predictors

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.716[a]	.512	.452	4.2472639

a. Predictors: (Constant), Kiremt rainy day, Kiremt rainfall total

From Table11**,** the regression or prediction equation had been determined using the following equation by regressing yield (wheat yield) against selected climatic variables

$$Y = 94.827-0.233X_1+0.028X_2$$

Where, Y = predicted yield of wheat in qt/ha

X_1 = end date of the rainy season

X_2 = *kiremt* (JJAS) rainfall total in mm

The above prediction model represents that given a unit change in any of the rainfall characteristics included in the study while holding either constant, the highest variation in yield of barley in the area will be accounted by *kiremt* rainfall total (0.028 qt/ha), followed by the least change in yield will be from end date of the rainy season (-0.233 qt/ha). These result show that among the rainfall characteristics included in the study, *kiremt* rainfall total (x_2) is the most important variable that has significant impact on wheat yield in the study indicating that the yield of wheat is higher when *kiremt* rainfall total is getting higher. In contrast, end date of the rainy season has a negative impact on yield of wheat, meaning that there was higher yield of wheat under years with lower end of rainy season. Furthermore, statistical t-test analysis indicates that among the rainfall characteristics included in the study only end date of the rainy season (x_1) and *kiremt* rainfall total (x_2) are statistically significant in influencing wheat yield negatively and positively at 0.05 confidence level, respectively. The computed value for coefficient of multiple determinations (R^2) is 0.481 (Table 12). This means that 48.1% of the variations on wheat yield per hectare for the past 19 years in Sinana district, That is, nearly fifty percent of total variance of crop yield are explained jointly by *kiremt* rainfall total and end of *kiremt* rainy season. The remaining 51.9% of the variation in wheat yield, however, could be explained by other climatic and non-climatic factors.

Table 11. Coefficients of regression analyses for rainfall characteristics and wheat

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	94.827	27.045		3.506	.003
	End date	-.233	.089	-.583	-2.627	.018
	Kiremt rainfall total	.028	.007	.849	3.822	.002

Table 12. Regression values for predictors

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.694[a]	.481	.416	4.7012600

a. Predictors: (Constant), Kiremt rainfall total, End of the season

From Table13**,** the regression or prediction equation had been determined using the following equation by regressing yield (Barley yield) against selected climatic variables

$$Y= 12.45+0.021X_1$$

Where, Y = predicted yield of barley in qt/ha

X_1 = *kiremt* (JJAS months) rainfall total in mm

The above simple linear regression model represents that given a unit change in the *kiremt* rainfall total (X_1) the only variation in yield of barley will be accounted by *kiremt* rainfall total (0.021 qt/ha).These result shows that among the rainfall characteristics included in the study *kiremt* rainfall total is the only important variable that has significant impact on barley yield in the study area indicating that barley yield is higher when *kiremt* rain is getting higher. Furthermore, statistical t-test analysis indicates among the rainfall characteristics included in the study only *kiremt* rainfall total is statistically significant in influencing yield of barley positively at 0.05 confidence level. The computed value for the coefficient of determination (r^2) is 0.492 (Table 14). This means that 49.2% of the variation in the barley yields per hectare for the past 19 years in Sinana district that is; nearly fifty percent of total variance of crop yield is explained by *kiremt* rainfall total. The remaining 50.8% of the variation in barley yield, however, could be explained by other climatic and non-climatic factors.

Table 13. Coefficients of regression analyses for rainfall characteristics and barley yield

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	12.450	2.422		5.140	.000
	Kiremt rainfall total	.021	.005	.702	4.059	.001

a. Dependent Variable: Barley

Table 14. Regression values for predictors (*kiremt* rainfall total)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.702[a]	.492	.462	4.2052858

a. Predictors: (Constant), Kiremt rainfall total

4.4. Projected (2020-2049) Rainfall Variability and Trend

4.4.1. Robe annual rainfall projection and trend

Projected year to year variation of annual rainfall for Robe is expressed in terms of normalized rainfall anomaly (Figure 5**)**. As it can be seen from the figure, Robe and the surrounding region is expected to experience both unusual dry and wet years than the climatologically conditions between 2020 and 2049 years (Figure 5**)**. In line with this finding, studies made on national level have revealed that there is a close link between ENSO phenomena, which is identified as potential factor for alternative wet and dry years (Haile, T, 1988; Korecha and Barnston, 2007; Gissila *et al*., 2004).

The results of the linear trend lines for the study period (2020-2049) clearly demonstrate that there will be a slight increasing in rainfall trend. The result further revealed that an annual rainfall amount will be increased by about 0.02 mm and 0.16 mm per year and ten years, respectively (Figure 5**)**. This result resembled with the study conducted by NAPA (2007) and under IPCC mid-range emission scenario on regional time scale, IPCC (2013) concluded that The projection for rainfall is likely to increase over Ethiopian Highlands**.**

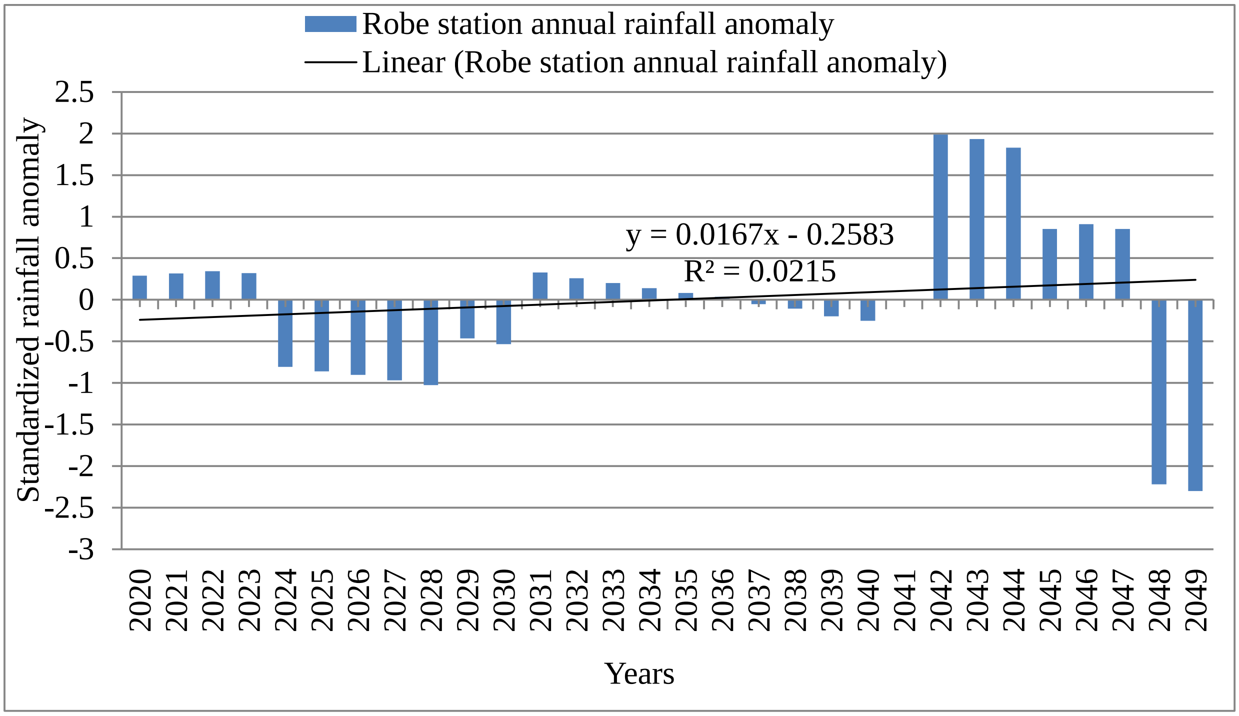

Figure 5. Robe meteorological station predicted (2020-2049) annual rainfall anomaly and trend

4.4.2. Robe *kiremt* rainfall projection and trend

Projected Year to year variation of *kiremt* (JJAS months) rainfall for Robe is expressed in terms of normalized rainfall anomaly (Figure 6). As it can be depicted in the figure, Robe and the surrounding region is expected to experience both unusual wet and dry years than the climatologically conditions years between 2020 and 2049 years (Figure 6).

From the trend lines of the *kiremt* (JJAS) rainfall, there will be a clear indication of a slight decrease in rainfall trend. The finding further revealed that *kiremt* rainfall amount will be decreased by about 0.1mm and 0.99 mm per year and ten years, respectively (Figure 6).

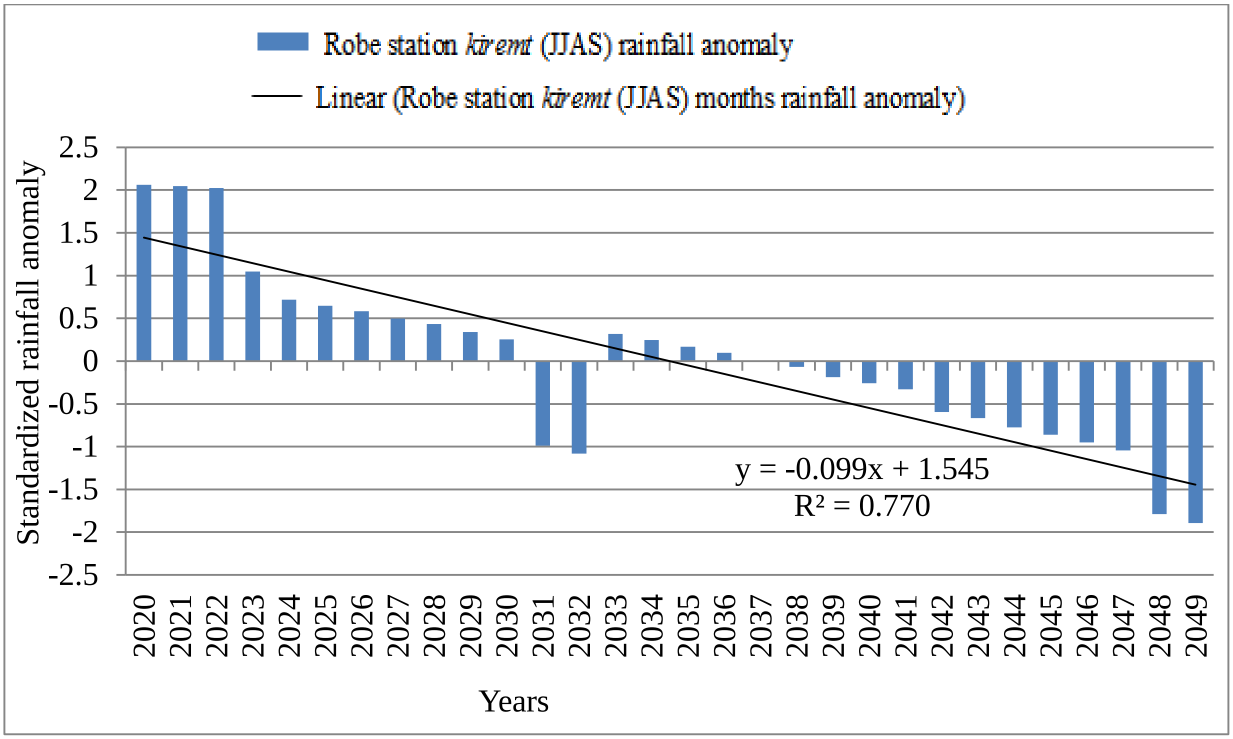

Figure 6. Robe meteorological station predicted (2020-2049) *kiremt* (JJAS month's) rainfall anomaly and trend

4.4.3. Robe *belg* rainfall projection and trend

Projected Year to Year variation of *belg* (Feb-May) rainfall for Robe is expressed in terms of normalized rainfall anomaly as shown in Figure 7. As it can be seen from the figure robe and the surrounding region is expected to experience both unusual wet and dry years than the climatologically condition between 2020 and 2049 years (Figure 7).

The trend analysis of *belg* season shows that rainfall trend will slightly increase. The result further revealed that *belg* rainfall amount will be increased by about 0.06 mm and 0.61 mm per year and ten years, respectively (Figure 7).

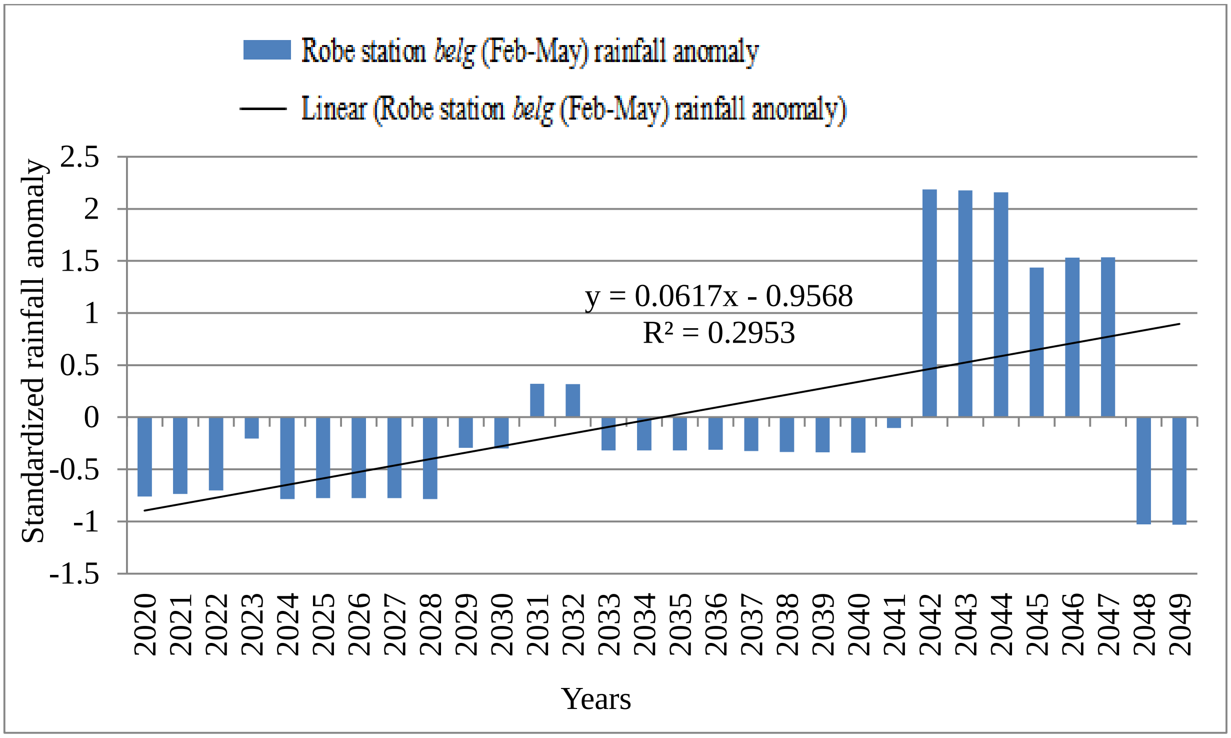

Figure 7. Robe meteorological station predicted (2020-2049) *belg* (feb-may) rainfall anomaly and trend

4.4.4. Sinana annual rainfall projection and trend

Projected Year to Year variation of annual rainfall for Sinana is expressed in terms of normalized rainfall anomaly (Figure 8). As it can be seen from the figure, Sinana and the surrounding region is expected to experience both unusual wet and dry years than the climatologically condition between 2020 and 2049 years **(**Figure 8).

The results of the linear trend lines for the study period (2020-2049) clearly demonstrates that there will be a slight increasing in rainfall trend. The finding further revealed that annual rainfall amount will be increased by about 0.02 mm and 0.19 mm per years and ten years, respectively **(**Figure 8).

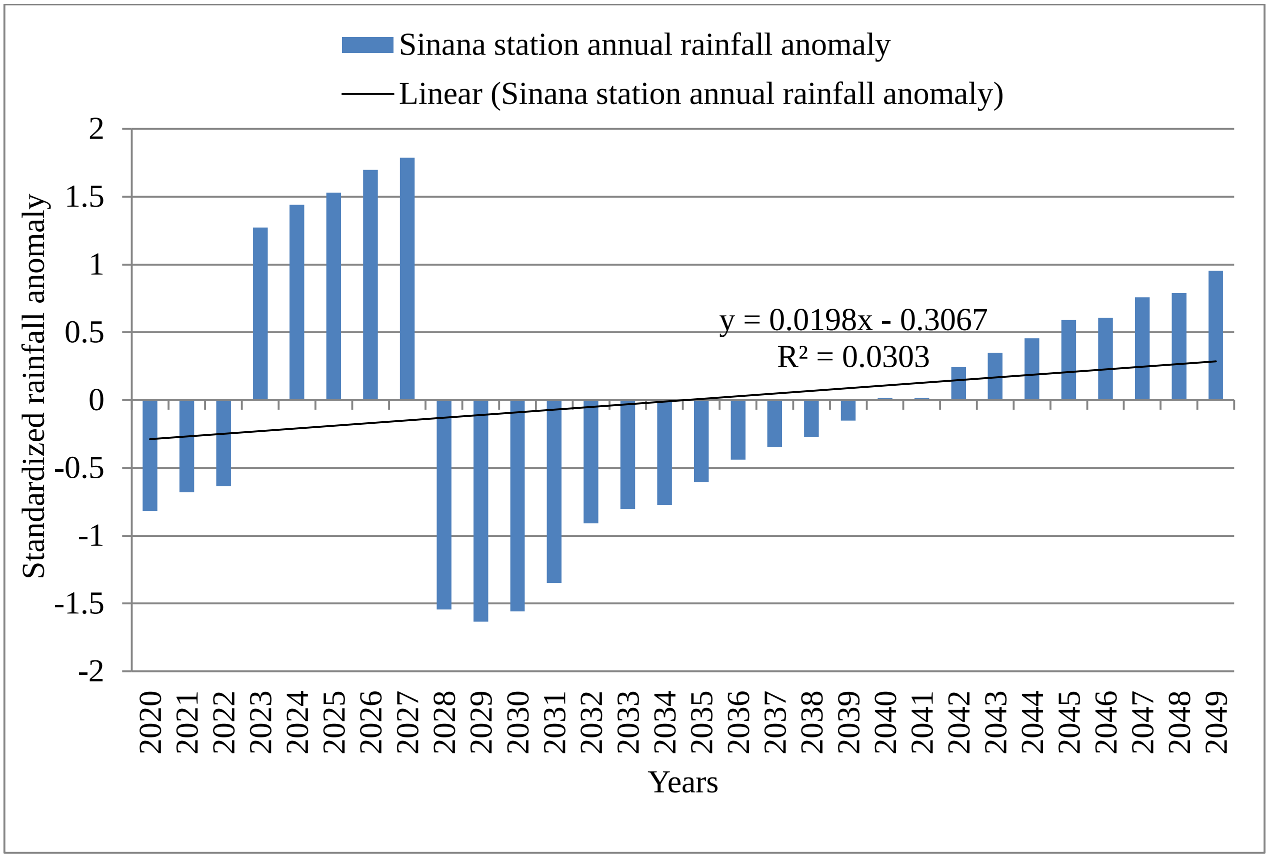

Figure 8. Sinana meteorological station predicted (2020-2049) annual rainfall anomaly and trend

4.4.5. Sinana *Kiremt* rainfall projection and trend

Projected Year to Year variation of *Kiremt* (JJAS months) rainfall for Sinana is expressed in terms of normalized rainfall anomaly (Figure 9). As it can be depicted in the figure, Sinana and the surrounding region is expected to experience both unusual dry and wet years than the climatologically conditions between 2020 and 2049 years (Figure 9).

The trend analysis of *Kiremt* rainfall for the study period (2020-2049) demonstrates that *Kiremt* rainfall will slightly decrease over time .The result further revealed that *Kiremt* rainfall will be decreased by about 0.09 mm and 0.86 mm per year and ten years, respectively (Figure 9).

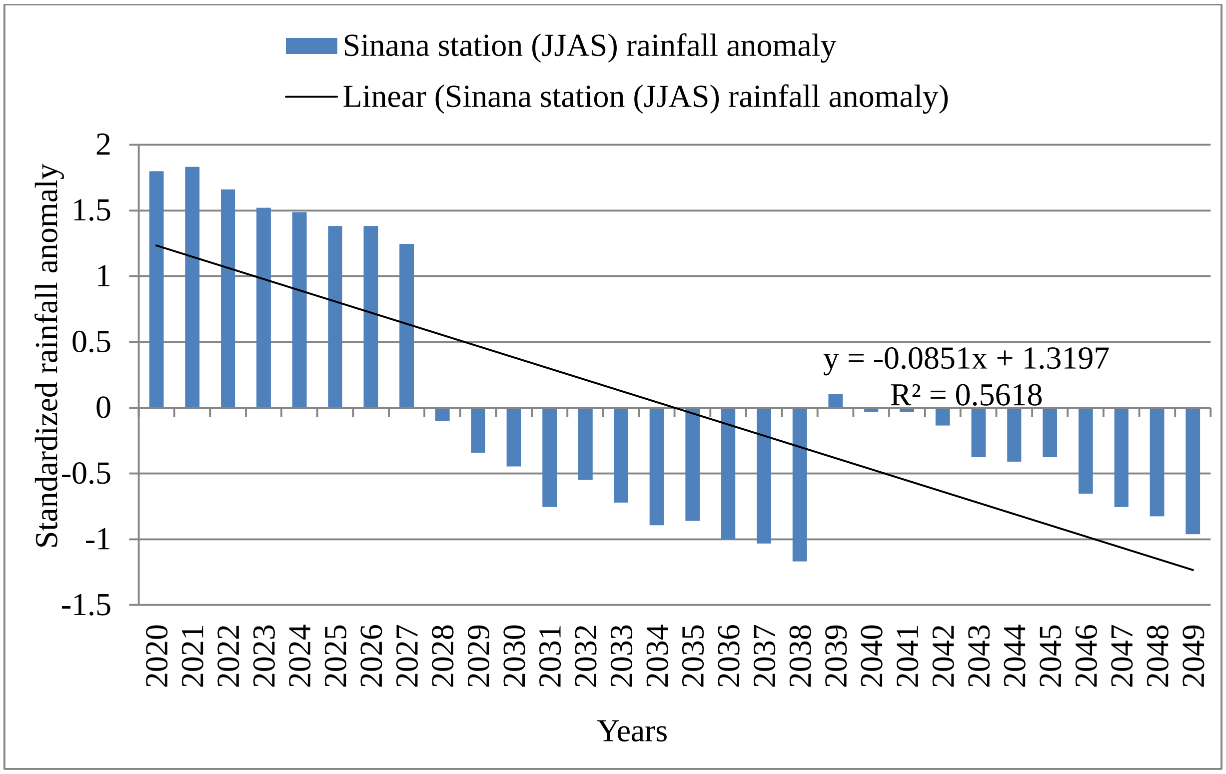

Figure 9. Sinana meteorological station predicted (2020-2049) *kiremt* (JJAS) rainfall anomaly and trend

4.4.6. Sinana *belg* rainfall projection and trend

Projected Year to Year variation of *belg* (Feb-May) rainfall for Sinana is expressed in terms of normalized rainfall anomaly as shown in figure 10. As it can be seen from the figure Sinana and the surrounding region is expected to experience both unusual wet and dry years than the climatologically conditions between 2020 and 2049 years.

The linear trend lines of the *belg* (Feb-May) rainfall for the study period (2020-2049) clearly demonstrate that there will be a clear indication of a slight decreased in rainfall trend. The result further revealed that *belg* rainfall will be decreased by about 0.04 mm and 0.44 mm per year and ten years, respectively (Figure 10**)**.

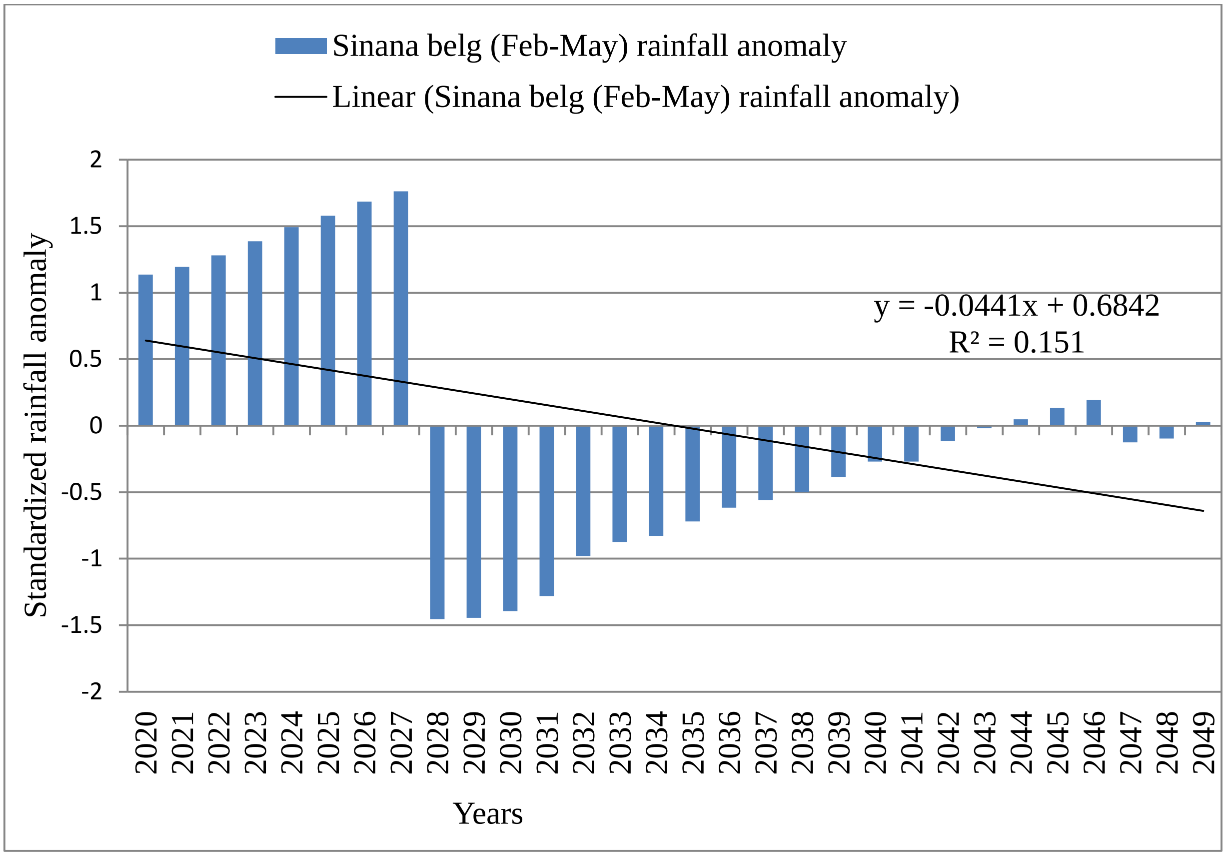

Figure 10. Sinana meteorological station predicted (2020-2049) *belg* (Feb-May) rainfall anomaly and trend

4.5. Projected impact of rainfall characteristics on wheat and barley yield

To ensure whether future rainfall change impact wheat and barley yields, the following regression model was developed based on sensitivity of crops for some potential climatic features (Table 15). X_1 (*Kiremt* rainfall total) in the first prediction model of table below will have a projected value of 425.2, 402.2 and 374.9 mm rainfall amount by the year 2020, 2030 and 2049 respectively. Similarly, X_2 (Number of rainy days during *kiremt* season) in the first prediction model of table below will have a projected value of 45, 44 and 45 days by 2020, 2030 and 2049 respectively. Substituting this value in the first prediction model the projected wheat yield in qt/ha will be 41.27 qt/ha, 40.02 qt/ha and 37.64 qt/ha by 2020, 2030 and 2049 years, respectively. Similarly, substituting X_1(*Kiremt* rainfall total) and X_2 (Number of rainy days during *kiremt* season) projected values in the second prediction model of table below the projected barley yield will be 28.9 qt/ha, 27.5 qt/ha and 25.28 qt/ha by 2020, 2030 and 2049 Years, respectively.

X_1 (end date of *kiremt* rainy season) will have a projected value of 306, 306 and 319 DOY by 2020, 2030 and 2049 Years, respectively. Similarly, X_2 (*Kiremt* rainfall total) will have a projected value of 458.4 mm, 451.9 mm and 450.4 mm rainfall amount by 2020, 2030 and 2049 Years, respectively. Substituting this value in the third predication model of Table 15, the predicted wheat yield in qt/ha will be 36.36 qt/ha, 36.18 qt/ha and 33.1 qt/ha by 2020, 2030, and 2049 years respectively. Likewise, X_1 (*Kiremt* rainfall total) will have a projected value of 458.4 mm, 451.9 mm and 450.4 mm rainfall amount by 2020, 2030 and 2049 Years, respectively. Substituting this value in the fourth predication model of Table 15 below, the predicted barley yield will be 22.07 qt/ha, 21.94 qt/ha and 21.91 qt/ha by 2020, 2030, and 2049 years, respectively.

Due to the impact of expected weakening of *kiremt* rainfall total, *kiremt* rainy days and end date of *kiremt* rainy season, the result of projected wheat and barley yield indicated that there will be a slight decrease in both crops yield (qt/ha) by 2020, 2030 and 2049 Years in the study area.

Similar results in yield reduction were reported in Oromia Regional State and national level (Zerihun, 2012). His finding dictated that percentage change in mean wheat yield over Oromia and Ethiopia will be-7.26 and -6.21 for the year 2050, respectively.

Table 15. Multiple regression models for the projected impact of rainfall features on wheat and barley yield at Sinana district

Name of stations	Input variables	Prediction model
Robe	*Kiremt* rainfall total (X_1) and Number of rainy days (X_2)	$Y=29.056+0.072X_1 0.409X_2$
	Kiremt rainfall total (X_1) and Number of rainy days (X_2)	$Y=10.98+0.072X_1-0.282X_2$
Sinana	End of *kiremt* season (X_1) and *Kiremt* rainfall total (X_2)	$Y=94.827-0.233X_1+0.028X_2$
	Kiremt rainfall total (X_1)	$Y=12.45+0.021X_1$

4.6. Perception of the local community on the variation of rainfall characteristics and climate related hazards

4.6.1. Overview of marital status and educational level of the respondents in the study area

Out of the 161 respondents, 94%, 5%, 1% were found as married, single and other (divorce), respectively (Figure11). Likewise, educational level of the respondents were identified as; illiterates (59%), primary school (35%), high-school (secondary school) (5%), and graduates (1%) (Figure 12).

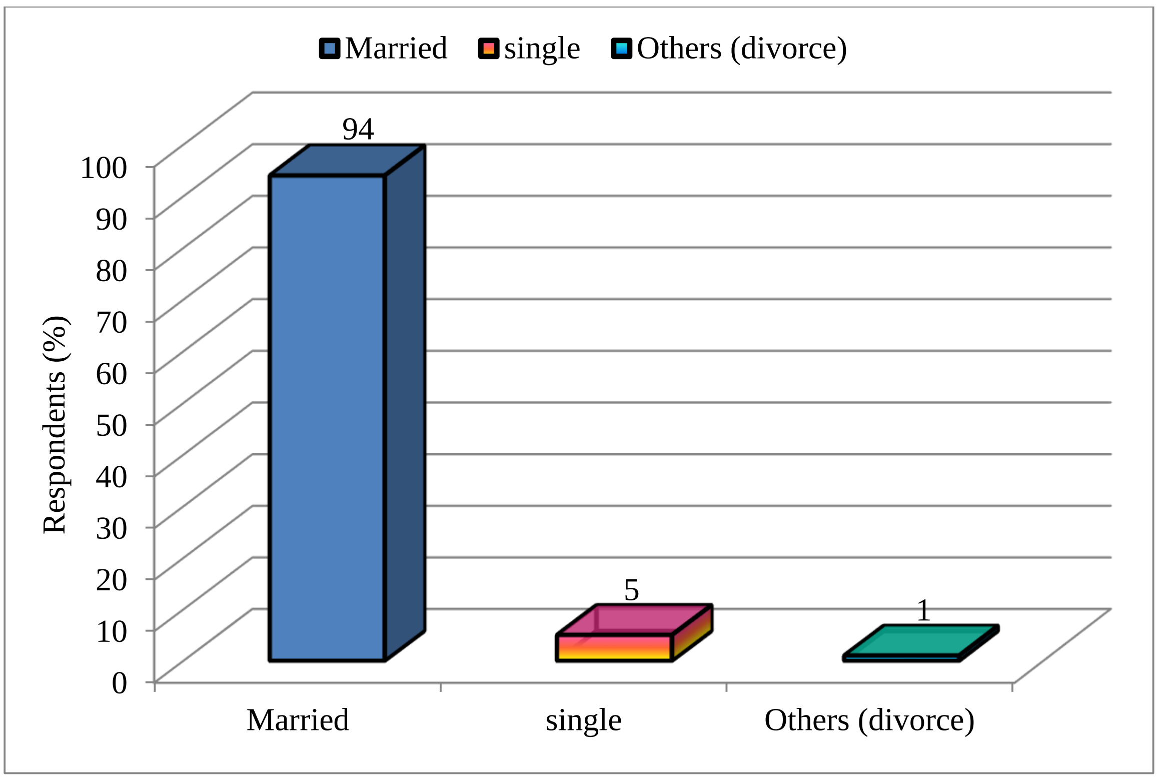

Figure 11. Marital status (in %) of farmers in Sinana district participated in the study

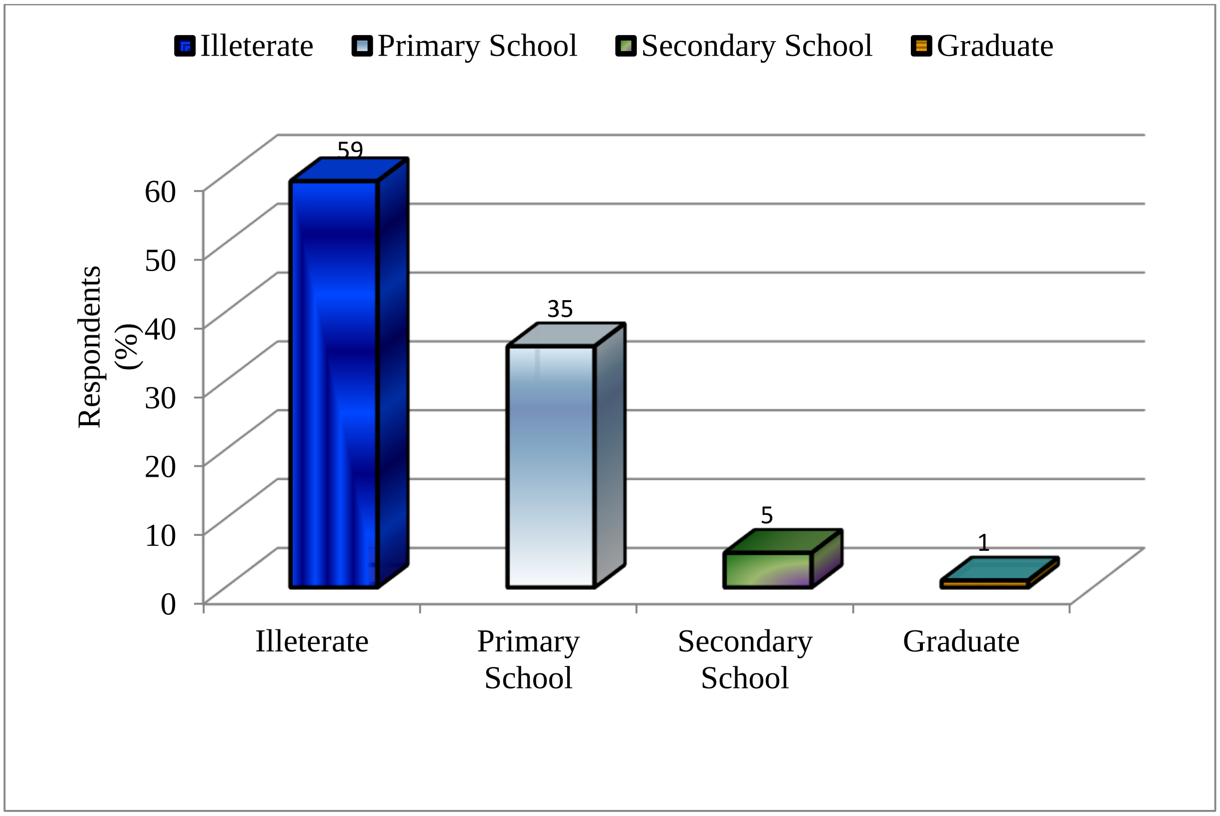

Figure 12. Educational level (in %) of farmers in Sinana district participated in the study

4.6.2. Perception of farmers on climate related hazard

From Hora-Boqa Kebelle, the farmers were asked about the major types of climate related hazard which altered their production and time of occurrence and the result is shown below.

As it was presented in Table 16**,** about 14%, 2%, 22% and 62% respondents stated that excess rainfall, drought, and erratic rainfall, respectively could be accounted for recurrent of the major types of climate related hazard, which affected crop production over different time period. Regarding the time of occurrence of climate related hazard, 8%, 39% and 53% of respondents have perceived that extreme climatic events mostly occurred during *belg*, *kiremt* and *bega* seasons, respectively.

Dejene (2011) for instance, documented that the majority of farmers in central Tigray ranked drought and untimely rainfall as first and second key climate related hazard as compared to others for the area. Furthermore Abate (2009) noted that heavy and unseasonal rain, delay in the onset of rain and prolonged drought were commonly observed in West Arsi Zone of Oromia Regional State.

Table 16. Farmers' perception for major climate related hazards

Types of hazard	Respondents (%)	Season	Respondents (%)
Excess rainfall	14	*Belg*	8
Drought	2	*Kiremt*	39
Erratic rainfall	22	*Bega*	53
All	62	All	-
Total	100	Total	100

4.6.3. Farmers perception on impacts of climate related hazard

As it can be seen from Figure 13**,** about 2%, 31%, 2% and 65% of respondents suggested that full crop damage, partial crop damage, increased crop disease and weeds were the consequence of climate related hazard occurred during different time period, respectively. This result has resembled with previous studies.

For instance, Belay (2012) and Tamiru et al. (2014) reported that farmers in Arsi-Negele district and Miesso-Assebot plain respectively perceived full crop damage, partial crop damage and increased crop disease and weed were among the identified consequence of climate change. Similarly, according to Deressa et al. (2008), crop yield was declined by 32.8% as result of shocks such as drought and flood etc.

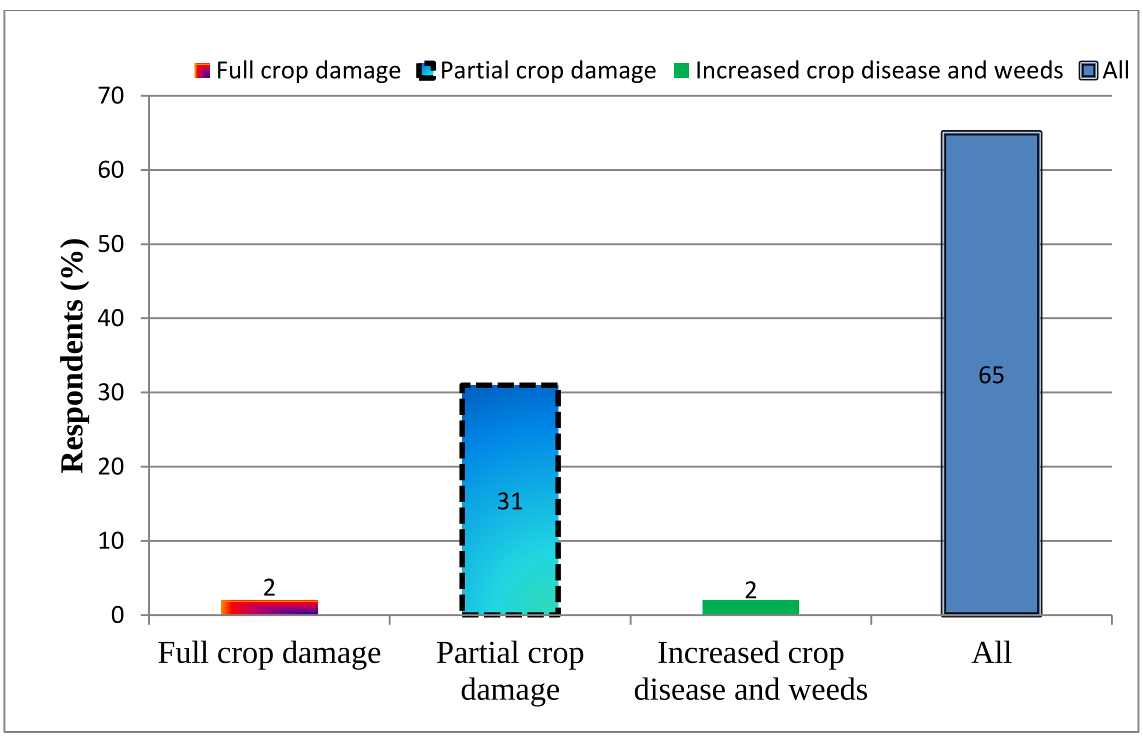

Figure 13. Farmer's perception on impacts of climate related hazard on crop production

4.6.4. Farmers observation on changing of rainfall characteristics

Farmers perception on changing of rainfall characteristics over the past19 years (1995-2013) were assessed (Figure 14) in comparison with measured climate records (Figure 15, 16 and 17). As configured in Figure 14, from 161 households interviewed about 3%, 2%, 22%, 5% and 68% of respondents have perceived that change of sowing date, change of harvesting time, increased rainfall trend, decreased rainfall trend and all, respectively were identified as good indicators for the change of rainfall characteristics. However, the record data on rainfall from1995 to2013 showed that there is a slight increasing trend in annual and seasonal (June-September and February-May) rainfall (Figure 15, 16 and 17). The result generated from current trend analysis somewhat agreed with farmers' perception (22%) in the study area.

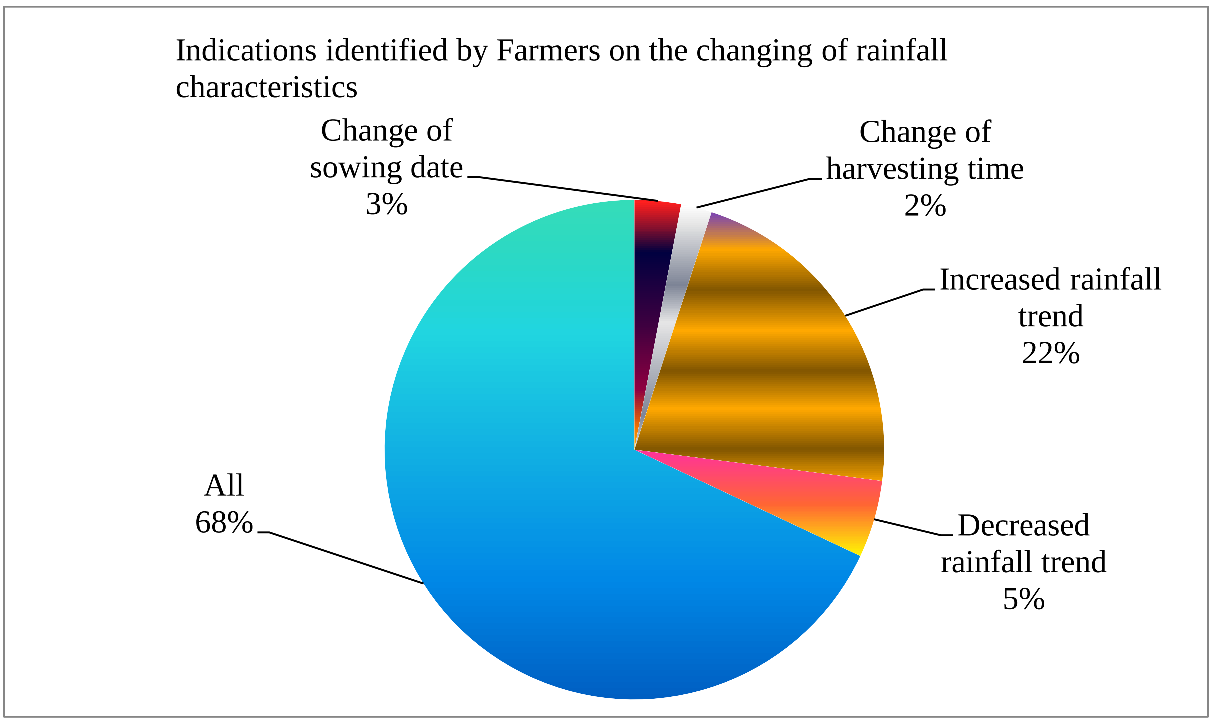

Figure 14. Indications identified by Farmers on the changing of rainfall characteristics for the past 19 years in the study area

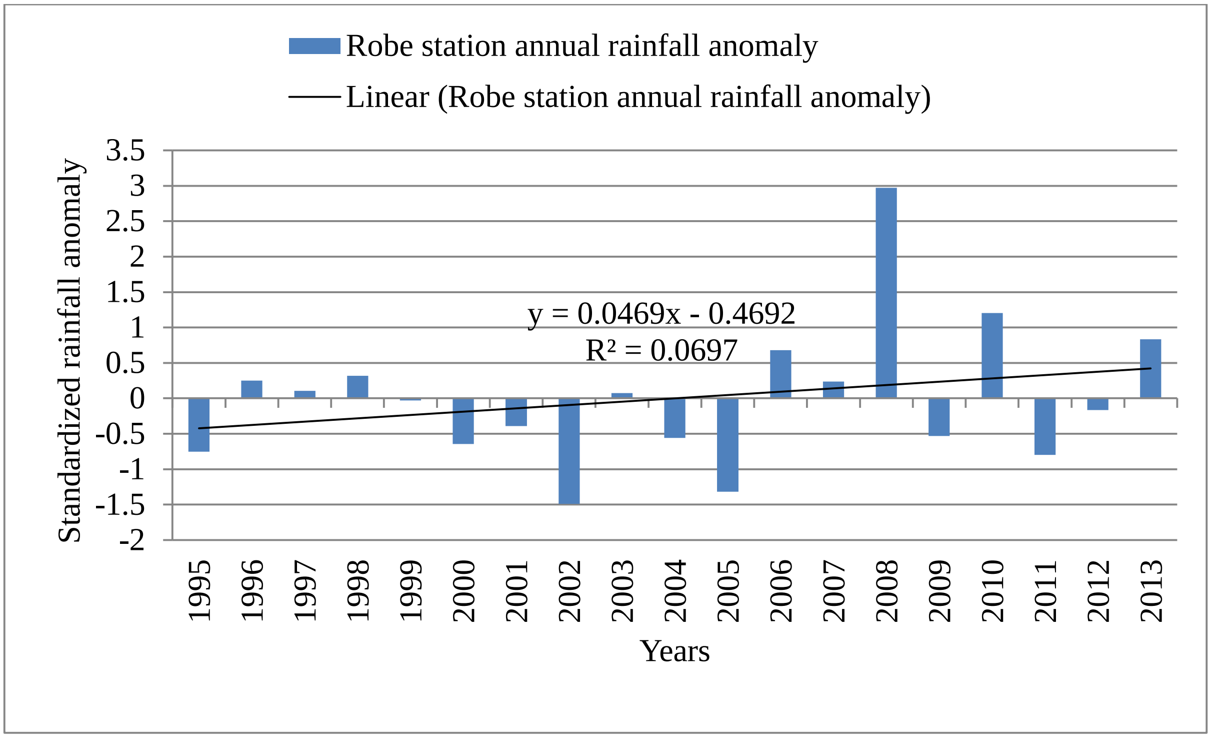

Figure 15. Time series showing annual rainfall over Robe meteorological station

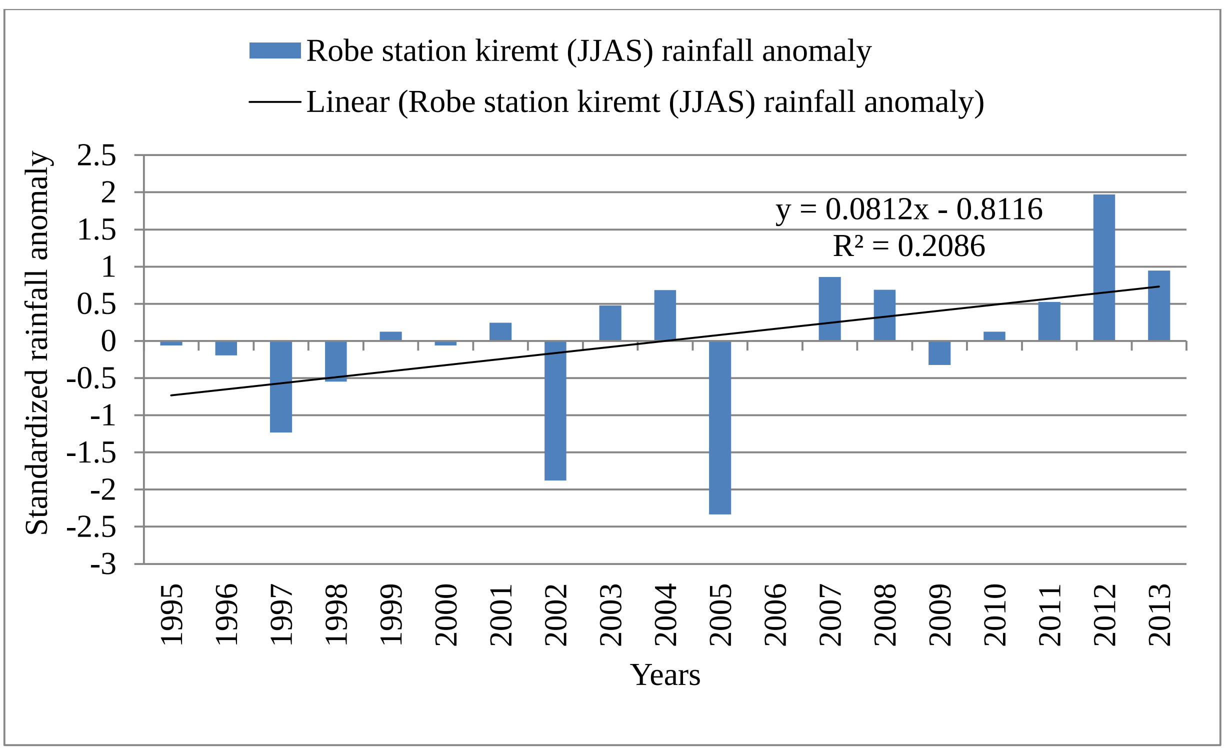

Figure 16. Time series showing *kiremt* rainfall over Robe meteorological station

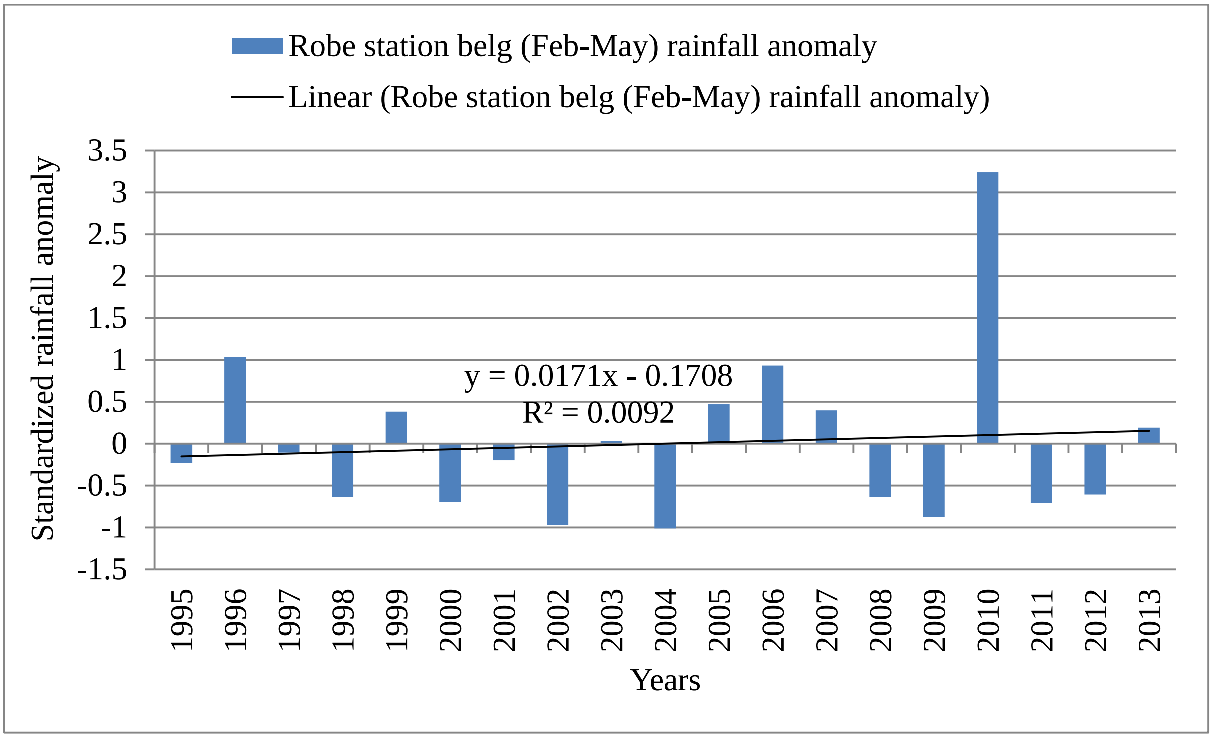

Figure 17. Time series showing *Belg* rainfall over Robe meteorological station

4.6.5. Indicators attribute for the change of agricultural activity

About 42%, 9%, 6% and 43% of respondents answered that change of sowing date in *Belg* and *Kiremt* seasons, change of growing period, change of harvesting time respectively were identified as a sign for the change of agricultural activity in the study area (Figure 18).

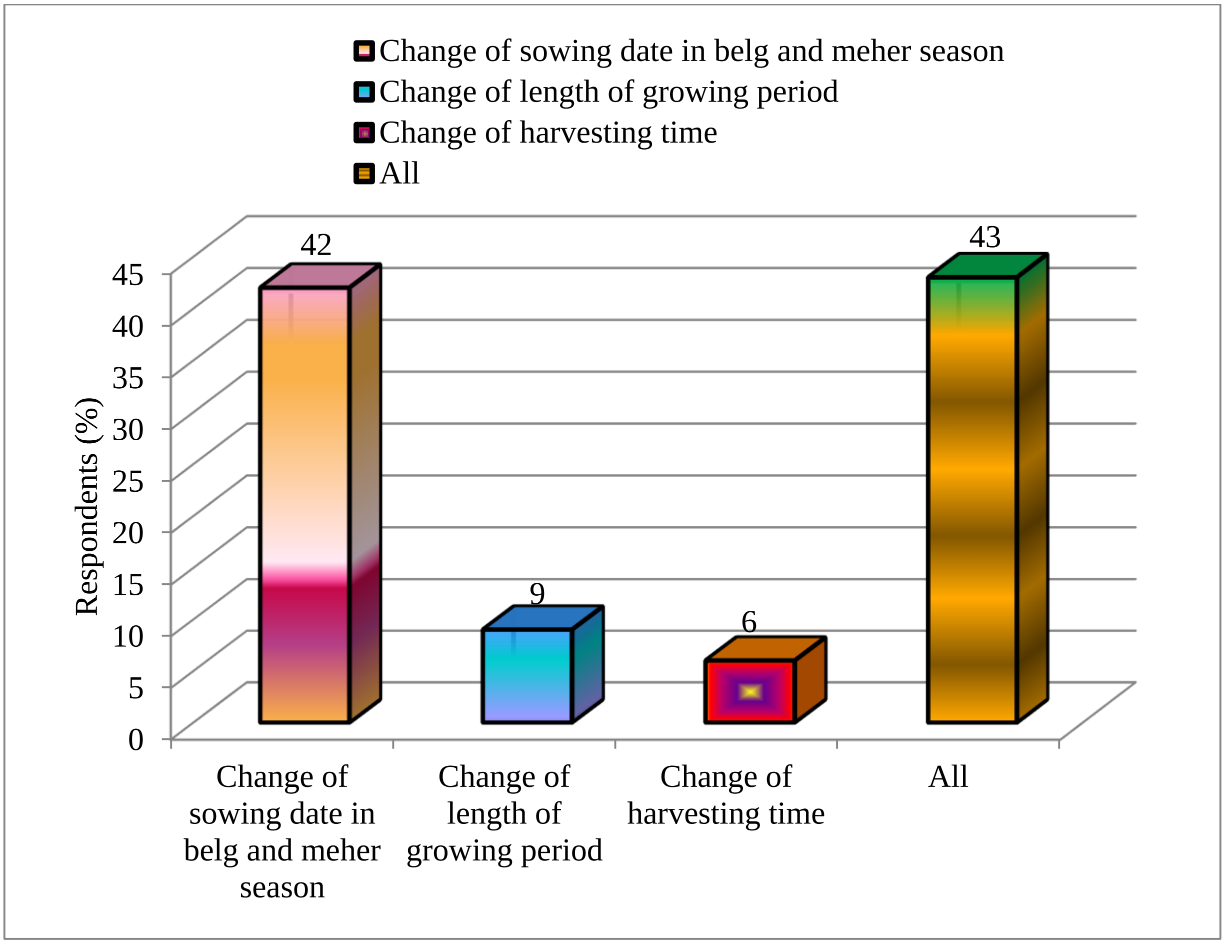

Figure 18. Indications identified by farmers on the changing of agricultural activity

4.6.6. Farmers perception on occurrence of climate related hazards

As indicated in Figure 19, about 3%, 34%, 60%, and 3% of the sample respondent were stated that most of the time climate related hazard in the area occurred during crop initial stage, vegetative stage, flowering stage and harvesting stages, respectively.

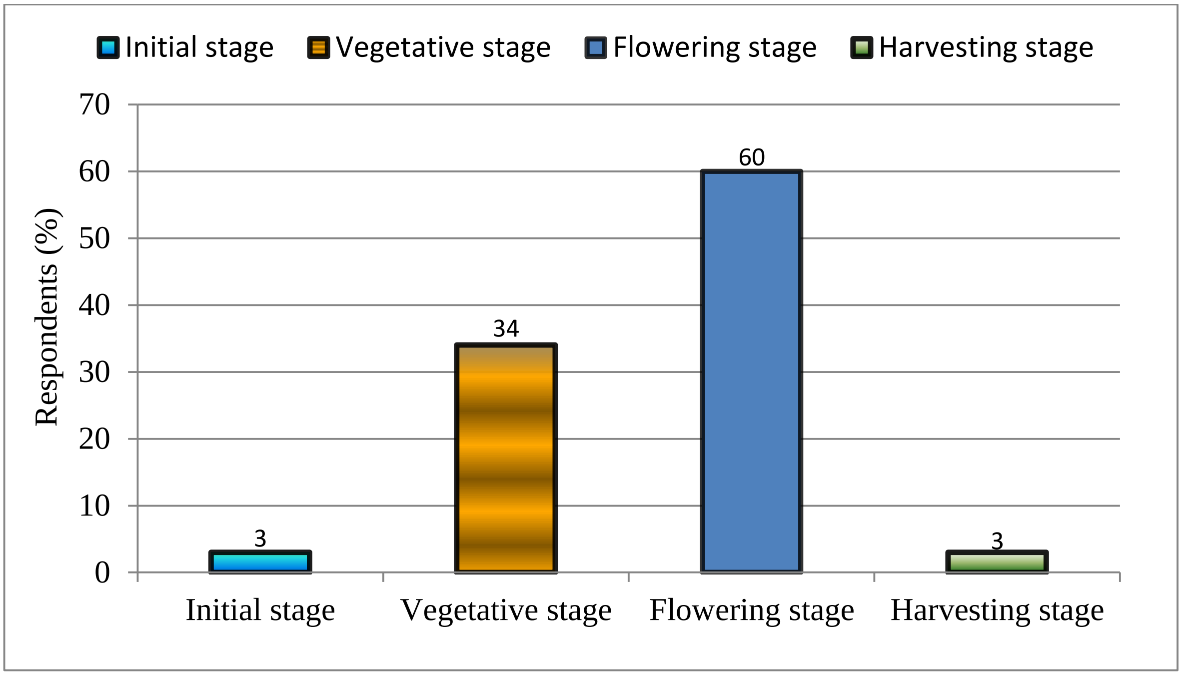

Figure 19. Farmer's perception on occurrence of climate related hazard during various crop growing stages

4.6.7. Farmers copying strategies and indigenous knowledge for climate predictions

As it can be deduced from unstructured questionnaire survey of Table 17, farmers in Hora-Boqa Kebelle adopted various copying strategies in response to climate related hazard. The most commonly adaptation strategies used includes early and late planting based on strength of hazard, soil conservation, crop rotation, fallowing and migration in search of fodder and water in the research site). Similar copying strategies were also reported by previous researchers for various parts of the country (Dejene, 2011; Belay, 2012; Tamiru et al., 2014). Other copying strategies currently practiced by farmers in the study area includes reduce animal size, planting short cycle and drought resistance crops and develop terrace (Table 17). This finding is in line with a study conducted by Abate (2009) in West Arsi zone, which indicated that farmers are accustomed to practicing planting short and drought resistance crops and saving money by selling animals in response to climate related hazard. On the other hand, farmer's indigenous knowledge to forecast the forthcoming climatic conditions using different signs and signals, indicators as documented in Table 17 below. The most common indicators in the study area believed to be clouds and their movement east to west and blowing wind. These natural phenomena are thought to indicate whether the coming season will have excess or deficit rainfall (Table 17). Study made by Dejene (2011) in central Tigray reported that among the common indicators gathered, cloud in the sky and wind direction are becoming very useful to indicate whether the coming season will be wet or dry. The other environmental indicators include spiders' web seen on the ground which indicates as dry season persists a long. Formation of fog also indicate whether a crop disease happened or not in the following season (Table 17).

Table 17. Copying strategies and traditional prediction system of farmers on rainfall and occurrence of upcoming climate related hazard

Copying strategies	Signs and Signals	Detailed description of the indicator	Measurement (action) taken
Reduce animal size	Spider web	Appearance of spiders web on grass indicates that long duration of dry season is coming	Fodder will be collected
Planting drought resistance crop	Clouds	Appearance of clouds on the sky and hill indicates probability of rain	Precautions on agricultural activity should be taken
Early and late planting based on strength of hazard	Cold air	Cold air that appears during morning indicates an extended/prolonged *Bega* season	Transfer of planting crops for other season specially for *Belg*
Crop rotation	Fog	Appearance of fog on adjacent hill in the month of September indicates occurrence of crop disease and it is highly likely to occur	
Migration in search of fodder and water	Drizzle	Appearance of drizzle at night indicates occurrence of rust	
Develop terrace	Cloud movement	Cloud movement east to west indicates for excess rainfall is coming	
Soil conservation	Red termite and earth worm	Appearance of red termite and earth worm on the ground indicates as excess *Kiremt* (*Meher*) is coming	transfer of planting crops for *Belg* season
	Wind direction and thunder	Wind direction and sound of thunderstorm are indicators of upcoming weather	
	Group of star	Group of stars on sky at night indicates extended Bega(dry) season	

4.6.8. Farmers perception on major constraints to copying mechanism

The final semi-structured questionnaire result indicate that lack of climate information (51%), lack of access to climate information (21%), lack of technology (20%), lack of money (7%) and lack of laboratory (1%) were the major constraints to climate related hazard in the study area (Figure 20). Similar constraints to climate related hazard were reported from various studies, particularly conducted in Arsi Negele district and Miesso-Assebot plain of Ethiopia (Belay, 2012; Tamiru et al., 2014).

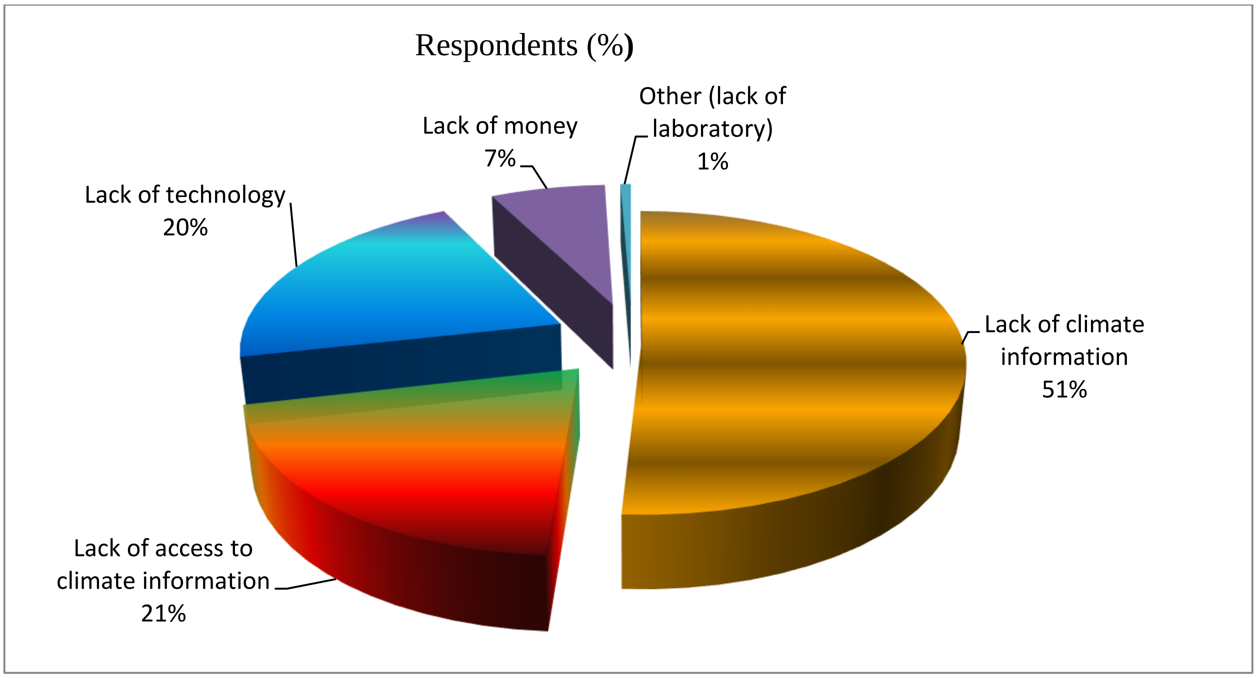

Figure 20. Farmers' perception on major constraints to copying mechanism for climate related hazard in Hora-Boqa kebelle

4.6.9. Local perception of government officials on rainfall features and climate patterns

Table 18 below illustrates perception of government officials on rainfall trend, consequence of climate related hazard and future plan. In general, the entire respondent believed that the rainfall trend over the past 19 years was changed, which can be described as erratic. Likewise crop failure, crop disease and decreased production were the major consequence of climate related risk while lack of awareness and technology were the main challenges in response to risk. Lastly, under the changing climate, use of improved variety, use of cured drugs, working in partnership, awareness creation and training were among the proposed plan for the coming seasons to flourish agricultural productivity of the area (Table 18).

Table 18. Perception of government officials on rainfall trend, consequence of hazard and future plan

	Response given by government officials		
Issues raised by respondents	SinanaWoreda Agricultural Head	Kebelle Leader	Development Agents
Direction of rainfall trend.	erratic	erratic	erratic
Consequences of climate related on crop production.	Crop disease and failure	Production declined Crop disease	Crop disease and failure
Challenges in response to risk.	No problem	Lack of awareness	Lack of technology
Future plan to increase production.	Use of improved variety Use of drugs working in collaboration with stakeholder	Use of new technology Providing different training for the community	Awareness creation in order to use new technology

4.7. Focus group discussion on rainfall and climate related hazard

As presented in Table 19 below, the focus groups have perceived that the rainfall over the past 19 years was declined on the area. Most of the time, climate related hazards were occurred during sowing and crop harvesting time in addition to changing agricultural activity. In response to climate related hazard, lack of climate information and use of improved variety were the constraints and measurement taken respectively in the past years (Table 19). It would be very suffice to note here that the present result did not agree with the trend analysis based on recorded meteorological data (Figure 6).

Table 19. Perception gained from focus group discussion on issues of rainfall and climate related hazard

Issues raised by respondents	Response given
Direction of rainfall trend	decreased
Time of occurrence of climate related hazard	At sowing and harvesting time
Consequence of climate related hazard	Agricultural activity were changed
Time of climate information conveyed	ahead of hazard occurred
Constraints in response to climate related hazard and measurement taken	Lack of climate information and use of different crop variety

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary and Conclusion

This study was undertaken to investigate the relationship of crop yield and rainfall characteristics, to predict future rainfall trend using global circulation model output and ascertain its impact on yield and to assess farmers' perception in characterizing rainfall conditions in Sinana district.

Analysis of rainfall characteristics (for Robe and Sinana meteorological stations) and crop yield (wheat and barley) were undertaken for the period 1995-2013. Correlation coefficient values revealed that among the rainfall characteristics studied *kiremt* (JJAS) rainfall total and Length of growing period had moderate to strong positive correlation with wheat and barley yield in the study area. On the other hand, the study developed regression model to account for the impact of rainfall characteristics on wheat and barley yield in the study site. Hence onset date of the rainy season, end date of the main rainy season, Length of growing period, *kiremt* rainfall total and *kiremt* rainy days were identified as potential predictors for variable includes wheat and barley yield.. The result showed that wheat and barley yields were influenced negatively and positively by the end of the rainy season, *kiremt* rainy days and *kiremt* rainfall total, respectively.

Output from single global circulation model, CSIRO for RCP4.5 scenario were used for this study to project annual and seasonal (June-September and Feb-May) rainfall and also to ascertain its impact based on sensitivity of crops to rainfall features. The result of projected annual rainfall trend indicated that there will be a slight increase in rainfall by 0.16 mm and 0.86 mm every ten years for both stations, respectively in amount under RCP 4.5 scenario during 2020-2049 periods. On the other hand, the result of linear trend analysis for *kiremt* rain over both Robe and Sinana meteorological stations showed that *kiremt* rain will be decreased in amount while *belg* rain for Robe will be increased by 0.61 mm every ten years under RCP 4.5 scenario during 2020-2049. Similarly, the projected year to year and seasonal (June-September and Feb-May) variation revealed that both wet and dry years will occur during 2020-2049 time period.

The descriptive statistics of rainfall characteristics revealed that the mean onset date of the main rainy season (*kiremt*) was 1stJuly for Robe while the end date was 18th and 19th

November for Robe and Sinana meteorological stations, respectively. Hence it was concluded that at both locations planting earlier than 7th June and 16th June is possible only once in every four years, respectively while the main growing season would not extend beyond last decade of November and 1st of December for Robe and Sinana districts, respectively. Furthermore, coefficient of variation of the rainfall characteristics showed that among the five rainfall characteristics studied, *kiremt* rain had the highest coefficient of variability while end date of the main rainy season exhibited the least coefficient of variability. Due to this fact, it can be concluded that *kiremt* rain is not easily predicted while the patterns of end date of the rainy season can be easily understood.

The result of projected wheat and barley yield indicated that there will be a slight decrease in both crops yield (qt/ha) by 2020, 2030 and 2049 years due to the impact of expected weakening of *kiremt* rain, *kiremt* rainy days and end date of the main rain season.

To assess perception of farmers on local climatic systems and their impacts farmers' livelihood systematic random sampling techniques was employed to select the respondents for interview from climate related hazard vulnerable peasant association. Hence the analysis of perception of farmers on climate related hazard indicated that excess rainfall, drought and erratic rainfall were the major identified risks for full and partial crop failure in addition to increased crop disease and weed infestation in the study area. From this study climate relate risks mostly occurred during crop flowering stages and in response to this risks lack of climate information was the key constraints in the study area.

Traditionally, some physical elements were identified as pre-indicators for local communities in performing indigenous climate forecasting systems. These indicators include spider web, cold air, cloud movement and group of stars seen on the sky. They were listed by respondents among the signs and signals, which indicates whether the coming season will experience excessive or deficit rainfall. Moreover, use of improved variety, new technology and awareness creation were the proposed future plan by the government officials in order to flourish agricultural productivity in the study site.

5.2. Recommendation

This study only considered how wheat and barley yields would respond to rainfall characteristics. Hence inclusion of other climatic (temperature, climate information and access to climate information etc) and non-climatic (planting date, application of fertilizer, seed variety and farming methods etc) factors might enhance the visibility of boundaries up to what levels other non-climatic factors can influence crop performance.

By using seasonal climate information issued from National Meteorological Agency of Ethiopia (NMA) on the likelihood performance of upcoming season in terms of rainfall characteristics namely; onset, end date and kiremt rains, farmers are kindly encouraged to benefit from these services and apply such information for farm level decision so that they can ultimately enhance their crop yield under changing climate.

We found that indigenous knowledge on local climate have enormous advantage where farmers are in accessible for modern climatic information. In order to sustain information flow as well as better usage, however, district agricultural office would be advised to supplement indigenous knowledge with modern scientific climate information in collaboration with NMA so that the farmers can get up to date climate information Assessing the impacts of rainfall features on crop yield (wheat and barley) by using different and a number of global circulation model outputs, downscaling techniques and RCP GHG emission scenarios is crucial. This would enable local policy makers and service providing institutions in order to design adaptation strategies, setting agenda for development policy and further studies under the remaining emission scenarios.

Climate related hazard is a key factor which frequently quoted as the main cause for crop failure over the study area. Hence the use of reliable, local-specific and timely climate information occasionally produced on daily, weekly, decadal, monthly, seasonally and beyond can be utilized by the farmers community. NMA and agricultural sectors should avails all valuable climate related and agronomic information for the farmers so that it can enable the farmers to plan earlier for cropping season undertake improved land management, soil conservation, flood control method and improve farmers knowledge about proper use of weather information etc that apparently to minimize risks of climate related hazard or seasonal rainfall variability.

6. REFERENCE

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

Abate, F.2009. Climate Change Impact on Livelihood, Vulnerability and Coping Mechanisms: A Case Study of West-Arsi Zone, Ethiopia. MSc.Thesis, LUCSUS, Lund University SE-22644, Lund, Sweden.

Admassu, S. 2004. Rainfall Variation and its Effect on Crop Production in Ethiopia, A thesis submitted to School of Graduate Studies, Addis Ababa University.

Agrawal, A . 2008. The Role of Local Institutions in Adaptation to Climate Change. Washington, D.C.: The World Bank.

Agrawal, Jain, R.C. and Jha, M.P .1986. Models for studying rice crop-weather relationship, *Mausam*, **37(1)**: 67-70.

Ajibade, I. 2013. Climate Change and Human Rights: a Case Study of Vulnerability and Adaptation in Coastal Communities in Lagos, Nigeria. Ontario, Canada: PhD dissertation, University of Western Ontario London.

Alemayehu Mamo and S.Franzel.1987.Initial Results of Informal Survey: Sinana Mixed Farming System Zone .Working Paper No.1/87.IAR,Addis Ababa, Ethiopia. pp52.

Armi Collin S, Harry F and Steven C A.1994.Statistic Concepts and Applications.PP 192, Cambridge university press.

Bekele, F. 1997. Ethiopian use of ENSO information in its seasonal forecast.Internet Journal for African Studies (IJAS), Vol.1, No.2.Case studies.

Belay, A. 2012. Analysis of climate variability and its economic impact on agricultural crops: the case of Arsi negele district, central rift valley of Ethiopia M.Sc. thesis, Hawassa University.

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.

Bessie, S.2010.Input Supply and Output Marketing Role of Multipurpose Cooperatives in Increasing Cereal Production in Bale Zone (Oromia Regional State), Ethiopia, MSc thesis, Addis-Ababa University.

Beweket, W.2009. Rainfall variability and crop production in Ethiopia Case study in the Amhara region. Department of Geography & Environmental Studies, Addis Ababa University.

Bogale S, Solomon, M. and Yami, A.2009.The interdependence of crop-livestock production sectors. The case study of Sinana Dinsho District in Bale Highlands of Ethiopia, vol.42 (2).

Camberlin P., 1997: Rainfall anomalies in the source region of the Nile and their connection with the Indian summer monsoon. J. Climate, 10, 1380–1392.

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

Dejene, K .2011. Farmers' perception and knowledge of climate change and their coping strategies to the related hazards: Case study from *Adiha*, central Tigray, Ethiopia. Vol.2, No.2, 138-145.

De la Rosa, D., Cardona, F. and Almorza, J. 1981.Crop Yield Prediction Based on Properties of Soils in Sellilla, Spain.*Geoderma,* 25 (3-4), 267-274.

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.

Deressa, T.T. 2006. Measuring the Economic Impact of Climate Change on Ethiopian Agriculture: Ricardian approach" CEEPA DP25, University of Pretoria, South Africa.

Deressa, T.T .2007. Measuring the Economic Impact of Climate Change on Ethiopian Agriculture: Ricardian Approach.World Bank Policy Research Working Paper No. 4342.World Bank, Washington, DC.

Dixit PN, Cooper PJM, Dimes J, Rao KP .2011. Adding value to field based agronomic research through climate risk assessment: a case study of maize production in kitale, Kenya. ExpAgric 47(02):317–338. Doi: 10.1017/S0014479710000773

F.D.R.E.MoFED .2006. A Plan for Accelerated and Sustained Development to End Poverty (PASDEP).Vol I. Addis Ababa.

FAO. 2003. The digital soil map of the world: Version 3.6 (January), Rome, Italy.

FAO.1978. Report on the Agro-Ecological zone project vol.1 Methodology and Result of Africa. Rome.

Feyissa, A. 2009. Climate Change Impact on Livelihood, Vulnerability and Coping Mechanisms: A Case Study of West-Arsi Zone, Ethiopia. MSc. Thesis, Lund, Sweden.

Fowler, A.M and Hennesy KJ .1995. Potential impacts of global warming on the frequency and magnitude of heavy precipitation natural hazards.

Fowler HJ, Blenkinsop S, Tebaldi C .2007. Linking climate change modeling to impacts studies: recent advances in downscaling techniques for hydrological modeling. Rev Int J Climatol 27:1547–1578

Fraser A.I, Hazard T.R., Harrad,T.R. and Haygarth P.M.1999. The effect of rainfall intensity on soil erosion and particulate phosphorus transfer from Arable Soils. *Water science and technology,* 39:12, 41-45.

Getachew S; Tilahun T; Teshager M.2014.Determinants of agro-pastoralist climate change adaptation strategies: research Journal of Environmental Sciences 8(6):300-317.

Ghosh S, Mujumdar PP .2008. Statistical downscaling of GCM simulations to stream flow using relevance vector machine. Adv Water Resource 31:132–146

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

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

Gommez, R.2003. Non parametric crop yield forecasting, Rome Environment and Natural Resources Service, SDRN Food and Agriculture Organization of the United Nations, FAO Rome.

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

Gordon, H.B, Whetton, P.H, Pittock A.B, Fowler, A.M, and Haylock, M.R.1992. Simulated changes in daily rainfall intensity due to the enhanced greenhouse effect: *implications for extreme rainfall events Climate Dynamics*, 8:83-102

Green TR, Taniguchi M, Kooi H, Gurdak JJ, Allen DM, Hiscock KM, Treidel H, Aureli A .2011. Beneath the surface of global change: impacts of climate change on groundwater. J Hydrol 405:532–560

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

Hagos F, Makombe G, Namara RE, Awulachew SB. 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. (IWMI Research Report 128)

HaileT. 1986. Climatic Variability and Support Feedback Mechanisms in Relation to the Sahel-Ethiopian Droughts. Master of Science thesis in Meteorology. Reading University, UK.

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

IPCC (Intergovernmental Panel on Climate Change). Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., and Johnson, C.A. 1996. Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, 572 pp.

IPCC. 2001. The Scientific Basis. Contribution of Working Group I to the Third Assessment

IPCC, 2007a. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report 1 of the Intergovernmental Panel on Climate Change, T. F.Stocker et al. (Eds.), Cambridge University Press, Cambridge and New York, 1535pp.

Jones PG, Thornton PK (2000) MarkSim: software to generate daily weather data for Latin America and Africa. Agron J 9:445–453

Jones PG, Thornton PK (2009) Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. Environ Sci Pol12:427–437

Jones PG, Thornton PK (2013) Generating downscaled weather data from a suite of climate models for agricultural modeling applications. AgricSyst 114:1–5

Kassahun, B. (1987). Weather systems over Ethiopia. Proc. First Tech. Conf. on Meteorological Research in Eastern and Southern Africa, Nairobi, Kenya, UCAR, 53–57.

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

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

Lobell DB, Burke MB .2010. On the use of statistical models to predict crop yield responses to climate change. Agric For Meteorol. doi:10.1016/j.agrformet.2010.07.008

Malaylay, R.A., Munoz, M.J., Paglinawan, K.L. 2011. Proposed Crop Decision Planning Model for Yellow Corn Production in Quezon Province for the Years 2011 – 2015.

Mamo, G. 2005. Using seasonal climate outlook to advice on sorghum production in the central rift valley of Ethiopia.PhD Thesis. Faculty of Natural and Agricultural Sciences, Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein, South Africa.171 p.

Mersha, E. 1999. Annual rainfall and potential evapotranspiration in Ethiopia. *Ethiopian Journal of Natural Resources* 1: 137–154.

MoA (Ministry of Agriculture) .2000. Agro-ecological zonations of Ethiopia. Addis Ababa, Ethiopia.

MoA .2010. Ethiopia's agriculture sector policy and investment framework: Ten Years Road Map (2010-2020).

MoFED. 2010a. The Federal Democratic Republic of Ethiopia: Growth and Transformation Plan (GTP) 2010/11-2014/15.

Mwendera, E. 2013. Climate Change Impacts on Water, Agriculture and Food Security. CAAST Net Plus workshop, Addis Ababa, June 2013.
www.caast-net-plus.org/attach/Climate_Change_Impacts_-_E_Mwendera.pdf. Accessed on September 23-2014.

NMA-NAPA. 2007. Climate change National Adaptation Program of Action (NAPA) of Ethiopia. Ministry of Water Resources, Addis Ababa.

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

Odekunle, T. O., Orinmoogunje I. O. and Ayalande A., .2007. Application of GIS to Assess Rainfall Variability impact on Crop Yield in Guinea Savanna Part of Nigeria, *Journal of Biotechnology*, Vol. 6, No. 18, pp. 2100- 2113.

Oladipo,E.O and Kyari K.D.1993. Fluctuations in the onset, termination and length of the growing season in Northern Nigeria *.theory and Application of climatology* 47:4,241-250.

Omotosho J.Bayo, Balogun, A.A and Ogunjobi, K.O .2000. Predicting monthly and seasonal rainfall, onset and cessation of the raining season in West Africa using only surface data. *International journal of climatology* 20:865-880.

Omotosho, J.1990. Onset of thunderstorms and precipitation over Northern Nigeria. *International Journal of Climatology* 10:849:860.

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

Othman,M, Thomas M. 2007. Comparison of Different Classification Techniques Using WEKA for Breast Cancer. *IFMBE Proceedings* 15, pp. 520-523.

Oxfam.2010. Poverty, Vulnerability and Climate Variability in Ethiopia. International Research report. Addis Ababa, Ethiopia.

Pedgley, D.E. 1966. The Red Sea Convergence Zone: Weather 21, 350-358 and 394-406

Raman, C.V.R. (1974). Analyses of commencement of Monsoon rains over Maharashtra State for agricultural planning. Scientific report 216, India Meteorological Department, Poona, India.

Raorane, A.A. and Kulkarni, R.V. 2012. Data Mining: An Effective Tool for Yield Estimation in the Agricultural Sector. Report of the Intergovernmental Panel on Climate change Cambridge: Cambridge University Press.

Segele, Z. T. and P. J. Lamb .2005.Characterization and variability of Kiremt rainy season over Ethiopia. *Meteorology and Atmospheric Physics* **89**(1): 153–180.

Seleshi Yand Zanke U. 2004. Recent changes in rainfall and rainy days in Ethiopia. *International journal of climatology* 24(8):973–983.

Sivakumar, M. V. K. 1988. Predicting rainy season potential from the onset of rains in southern Sahelian and Sudanian climatic zones of West Africa. Agric. For. *Meteorology*. 42, 295-305.

Stern, R.D. & R, Coe .1982. The use of rainfall models in agricultural planning. *Agric. Meteorol*.**26**: 35-50.

Stern, R., Rijks, D., Dale, I. and Knoch, J. 2006. Instat climatic guide. Statistical services center, Reading University, UK.

SUPARI .2012. Spatiotemporal Characteristics of Extreme Rainfall Events over Java Island. Submitted to M.Sc program. Faculty of Geo-Information and Earth Observation, University of Twente.

SDAO .2006. Sinana District Agricultural Office Annual physical year report. Documented File. Bale-Robe.

Tamiru,S;Tesfaye,K and Mamo,G .2014. Assessing the Farmers Perception of Climate Variability and Change:A case study of Miesso-Assebot Plain, Eastern Ethiopia. African Journal of Environmental Science and Technology.Vol.8 (10):pp.539-549.

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

Tilahun, K. 1999. Test of homogeneity, frequency analysis of rainfall data and estimate of drought probabilities in Dire Dawa, eastern Ethiopia. *Ethiopian journal of Natural Resources 1: 125-136.*

Tunde, A. M. 2011. Perception of Climate Variability on Agriculture and Food Security by Men and Women Farmers in Idanre L.G.A, Ondo State. Nigeria. *Ethiopian Journal of Environmental Studies and Management* Vol. 4 No.2 2011

Uphoff, N. 2012. A Forward Look: Water Governance for Agriculture and Food in ACP Countries. Synthesis Report of the 2012 ACP-EU Think Tank on S&T for ACP Agricultural and Rural Development, Commissioned by CTA.

Walker, G.K .1989. Model for Operational Forecasting of Western Canada Wheat Yield. *Agricultural and Forest Meteorology*, 44(3-4), 339-351.

Wolde-Georgis T. (1997). The Use of El Nino Information as Drought Early Warning in Ethiopia. IJAS, Vol.1, No.2. Case studies.

World Bank .2006. Managing Water Resources to Maximize Sustainable Growth: A World Bank Water Resources Assistance Strategy for Ethiopia.A Country Water Resources Assistance Strategy. World Bank, Washington, DC.

Yamane, T. 1967. Statistics, an Introductory Analysis, 2nd Ed., New York: Harper and Row.

Yamane, T.2001. Basic Sampling Methods. Literature Publishing, Istanbul, Turkey.

Yang, W; Seager, R; and A. Cane, M .2014. The East African Long Rains in Observations and Models.Journal of Climate, Volume 27. New York

Zerihun G. Kelbore .2012. Analysis of impacts of climate change on crop yield and yield variability: the Ethiopian case, university of Trento, Philippines.

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.

7. APPENDICES

Introduction

My Name is Fitsum Bekele. I am a student at Haramaya University doing my MSC. Degree in Agro Meteorology and Natural Risk Management. I am conducting my master's thesis on' Characterizing Current and Future Rainfall Variability and its Effect on Wheat and Barley Production in Sinana District, South Eastern Ethiopia in this area. Your information will be a big input for my research. Thanks for your cooperation and your precious time.

So your feedback will help me to get good information which will be the input and make more fruitful of my study. Thanks in advance for your cooperation to offer me your precious time.

I. Interview Question: Local Selected Households

1. Name--- Sex---------------Age----------------
2. Marital status Married ☐ Single ☐ Other specify ---------------------------
3. What is your educational level? Illiterate ☐ Primary school ☐ Secondary School ☐ Graduate ☐
4. Have you ever faced any climate related hazard related to rainfall variability in your locality which altered your production? Yes ☐ /No ☐ If yes, what type of climate related hazard? A) Excess Rainfall B) Drought C) Erratic Rainfall D) all E) Others--When did you observe? A) Belg season B) Meher season C) Bega season
5. If the answer to Q4 is yes, did it affect your crop? Yes ☐ / No ☐ if yes to what extent? A) Full crop damage B) partial crop damage C) Increased Crop disease and weeds D) all E) Others---
----
----

6. Have you observed any change on rainfall characteristics like onset, cessation and length of growing period over the past 19 years? Yes ☐ /No ☐ If yes how did you know? A) Due to change of sowing date B) due to change of harvesting time C) due to increased rainfall trend D) due to decreased rainfall trend E) all F) others----------------------------------
----

7. Has your agricultural activity changed due to rainfall variability or climate related hazard? Such as sowing date, length of growing period, harvesting time changing due to climate related hazard? Yes ☐ / No ☐ If yes verify the indication a) sowing date changed in Belg and Meher season B) length of growing periods changed C) Harvested time changed D) all E) others ---

8. At which growing stage is more hazards happened? A) Initial stage B) vegetative stage C) flowering stage D) harvesting stage

9. What were the agricultural indigenous skills you have taken during climate related hazard had been occurred? Any traditional prediction system if you have?

10. What are the major constraints you have that hinders your coping mechanisms?

A) Lack of climate information

B) Lack of access to climate information

C) Lack of technology

D) Lack of money

E) Others---

II. Checklist for focus group discussion

1. Have you ever faced any climate related hazard in this locality related to rainfall characteristic? Yes ☐ / No ☐ If yes what was the trend in the past 19 years? Increasing ☐ decreasing ☐ as usual ☐
2. If yes did it affect crop production? Yes ☐ / No ☐ How much is its extent?--- Did you remember the time?--
3. Is your Agricultural activity affected by climate related hazard? Yes ☐ / No ☐
4. Have you heard weather information ahead of the coming hazard? Yes ☐ / No ☐

5. What are the major constraints you have that hinder your coping mechanism? and the measurement taken?

A. Lack of climate information

B. Lack of access to climate information

C. Lack of technology

D. Lack of money

E. Others---
-- --

and the measurement taken? --

II. Interview with government officials, expert's, kebele leader and woreda agricultural head

1. Name------------------profession/position ---
2. Have you observed any change in rainfall trend over the past 19 years?--------------------
   ----

   ----
3. Have you ever noticed any kind of climate related hazard which affect the locality on agricultural sector? Yes ☐ / No ☐If yes explain briefly its extent on crop production?...
   ....
   ....
   ....
   ....

4. What are the challenges to combat the existed problem?...
   ....
   ....
   ....

5. What is your plan to flourish agricultural productivity under changing climate or variable rainfall?...
   ....
   ....

....
....

III. Sinana district disaster and preparedness office

1. Name……………………………….Profession/ Position ……………………………
2. What are the impacts of climate related hazard or rainfall fall variability exerted on agriculture specifically crop production?

   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………
3. What is the role of your office to combat the hazard?
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   …any
   constraints?...
   ....
   ....
4. Do you use climate information? Yes ☐ / No ☐ If yes for what purpose?...
   ....
   ....
   ....
   ....

5. What is your future plan in increasing agricultural productivity under changing climate?..
   ....
   ....
   ....

LIST OF TABLES IN THE APPENDIX

1. Quartiles of rainfall characteristics for Robe and Sinana meteorological stations

Variables	Quartile1 (25%ile)	Quartile2(50%ile)	Quartile3 (75%ile)
	Robe Meteorological Station		
Onset date (DOY)	168	182	199
End date (DOY)	316	324	334
Length of growing period (Days)	128	137	161
Kiremt rainfall total (mm)	394.3	423.3	459.3
Kiremt rainy day (Days)	63	69	73
	Sinana Meteorological Station		
Onset date (DOY)	159	179	198
End date(DOY)	308	327	336
Length of growing period(Days)	101	147	172
Kiremt rainfall total (mm)	266.3	355.9	583
Kiremt rainy day(Days)	54	62	67

2. Correlation between rainfall and crop yield (Source: Lemi, 2005)

Gojjam	.	Kiremt (Meher) rainfall	Belg rainfall
Cereal	0.105	-0.083	0.286
Teff	-0.001	0.277	-0.283
Wheat	0.249	0.053	0.048
Barley	-0.013	0.055	-0.012
Maize	-0.131	-0.191	0.034
Sorghum	0.061	-0.218	0.658
Gonder			
Cereal	0.176	0.202	-0.286
Teff	0.013	0.034	-0.083
Wheat	0.401	0.479	-0.420
Barley	0.037	0.009	-0.219
Maize	0.115	0.160	-0.187
Sorghum	-0.329	-0.359	0.156
Harar			
Cereal	0.033	-0.009	-0.129
Teff	0.006	0.044	-0.173
Wheat	0.020	-0.161	0.055
Barley	0.056	-0.255	0.096

3. Crop data used in the study area (Sinana District)

Year	Cereals	Wheat	Barley
1995	Area Cultivated (ha)	9997	12125
	Production (qt)	229931	299970
	Yield (qt/ha)	23	24.78
1996	Area Cultivated (ha)	17391	11046
	Production (qt)	406926	168984
	Yield (qt/ha)	23.4	15.3
1997	Area Cultivated (ha)	17391	11846
	Production (qt)	399255	194433
	Yield (qt/ha)	22.96	16.41
1998	Area Cultivated (ha)	17391	10938
	Production (qt)	431157	183001
	Yield (qt/ha)	24.79	16.73
1999	Area Cultivated (ha)	17932	9684
	Production (qt)	469584	184953
	Yield (qt/ha)	26.19	19.19
2000	Area Cultivated (ha)	11982	10393
	Production (qt)	341127.5	183514
	Yield (qt/ha)	28.47	17.66
2001	Area Cultivated (ha)	14089	10186
	Production (qt)	422670	170183
	Yield (qt/ha)	30	16.71
2002	Area Cultivated (ha)	19714	8661
	Production (qt)	536220.8	158583
	Yield (qt/ha)	27.2	18.31
2003	Area Cultivated (ha)	22564	12500
	Production (qt)	679678.9	184906
	Yield (qt/ha)	30.12	14.79
2004	Area Cultivated (ha)	22564	11879
	Production (qt)	932013.3	234781
	Yield (qt/ha)	41.31	19.76
2005	Area Cultivated (ha)	30190	13305
	Production (qt)	975570	203593
	Yield (qt/ha)	32.31	15.3
2006	Area Cultivated (ha)	31470	9598
	Production (qt)	949994	193593
	Yield (qt/ha)	30.19	20.17
2007	Area Cultivated (ha)	37295	12457
	Production (qt)	1156145	264557
	Yield (qt/ha)	31	21.24
2008	Area Cultivated (ha)	38028	12627
	Production (qt)	1214234	341179
	Yield (qt/ha)	31.93	27.02
	Area Cultivated (ha)	37169	12541
Appendix Table 3			

(Continued)

Year	Cereals	Wheat	Barley
2009	Area Cultivated	37169	12541
	Production (qt)	1189408	312158
	Yield (qt/ha)	32	24.89
2010	Area Cultivated (ha)	37176	12341
	Production (qt)	1633523	316371
	Yield (qt/ha)	43.94	25.64
2011	Area Cultivated (ha)	38076	17779
	Production (qt)	1384170	558923
	Yield (qt/ha)	36.35	31.44
2012	Area Cultivated (ha)	37269	12464
	Production (qt)	1416569	406159.5
	Yield (qt/ha)	38.01	32.59
2013	Area Cultivated (ha)	36843	11942
	Production (qt)	1416560	357907
	Yield (qt/ha)	38.4	29.97

4. Analysis of variance (ANOVA) table for kiremt rainfall total and rainy day under Robe Station

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	333.543	2	166.771	7.666	.005[b]
	Residual	348.055	16	21.753		
	Total	681.598	18			

a. Dependent Variable: Wheat

b. Predictors: (Constant), Kiremt rainfall, Kiremt rainy day

5. Analysis of variance (ANOVA) table for kiremt rain and rainy day under Robe station

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	303.377	2	151.689	8.409	.003[b]
1	Residual	288.628	16	18.039		
	Total	592.005	18			

a. Dependent Variable: Barley

b. Predictors: (Constant), Kiremt rain, Kiremt day

6. Analysis of variance (ANOVA) table for *kiremt* rainfall and end date under Sinana station

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	327.968	2	163.984	7.419	.005[c]
1	Residual	353.630	16	22.102		
	Total	681.598	18			

a. Dependent Variable: wheat

b. Predictors: (Constant), Kiremt rainfall, End date

7. Analysis of variance (ANOVA) table for *kiremt* rainfall under Sinana station

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	291.370	1	291.370	16.476	.001[b]
1	Residual	300.635	17	17.684		
	Total	592.005	18			

a. Dependent Variable: Barley

b. Predictors: (Constant), Kiremt rainfall

LIST OF FIGURES IN THE APPENDIX

1. Focus group participant photo taken during discussion

2. Focus group participant photo with researcher taken during discussion