Investigating Climate Variability in Spatio-Temporal Domains and Its Impact on Crop Production Using GIS and Statistical Techniques: The Case of North and South Wello Zones, Northern Ethiopian Highlands

By

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A Thesis Submitted to

The department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's of Science in Geodesy and Geomatics Engineering

Office of Graduate Studies

Adama Science and Technology University

Adama

December, 2017

APPROVAL SHEET

This undersigned hear by certify that they have read and recommend to Adama Science and Technology University, School of Civil Engineering and Architecture for acceptance a thesis entitled: "**Investigating Climate Variability in Spatio-Temporal Domains and Its Impact on Crop Production Using GIS and Statistical Techniques: The Case of North and South Wello Zones, Northern Ethiopian Highlands** " by Getie Gebrie Eshetie in the partial fulfillment of the requirement for the degree of Master of Science in Geodesy and Geomatics Engineering.

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DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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

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Date of submission: ____

ACKNOWLEDGMENTS

Almighty God deserves the first word of thanks for all the achievements which I have attained in my entire life. I would like to express my sincere thanks and deep gratitude to my advisor Dr. Daniel Alemayehu for his tireless commitment and dedication to bring my thesis to this end, moreover, profound thanks to Mr. Yossief Abebe, Department Head of Geomatics, for his help and suggestions.

Big thanks to my best friend Getachew Bayable for his continuous technical and scientific guidance and encouragement. I would like to extend my deep thanks to Mr.Wubetu Anley for his encouragement and valuable support by giving different materials like computer.

I am most deeply grateful to my beloved wife Yalemtsehay Birhie for helping me strive towards the realization of my potentials, initiation, encouragement, and handling all burdens and managing the family. I very much thank my daughter, Lidia Getie, for tolerating my absence. I would also like to show gratitude to my sister, Amelework Gebrie, for her support and taking care of my family. Finally, many thanks to my heroes father, Gebrie Eshetie, and mother, Shashe Ayzuachihu who are the reason of my success.

" Glory to the Almighty God "

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ACRONYMS

ANRS-BFE	Amhara National Regional State Bureau of Finance and Economics Development
CFSR	Climate Forecast System Reanalysis
CSA	Central Statistical Agency
CV	Coefficient of Variation
DEM	Digital Elevation Model
EEP	Eastern Equatorial Pacific
ENSO	El Niño-Southern Oscillation
ESRI	Environmental System Research Institute
FAO	Food and Agriculture Organization
FEWS NET	Famine and Early Warning System Network
GDP	Growth domestic products
GIS	Geographical Information System
GW	Global weather
IDW	Inverse Distance Weighted
IPCC	Intergovernmental Panel on Climate Change
JJAS	June, July, August, September
MK	Mann Kendall
mm	
NCEP's	National Centers for Environmental Prediction's
NMA	National Meteorological Agency
NMSA	National Metrological Services Agency
NOAA	National Oceanic and Atmospheric Administration
ONI	Oceanic Niño Index
RF	Rainfall
SSTA	Sea Surface Temperature Anomaly
SST	Sea Surface Temperature

Tmax	Maximum temperature
Tmin	Minimum temperature
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Metrological Organization

LIST OF SYMBOLS AND UNITS

Symbol	**Description**	**Dimension**
mm	Millimeter	to measure rainfall
qt/ha	Quintal per hectare	to measure amount of yield
r	Pearson correlation coefficient	an index to measure association
R^2	Coefficient of determination	an index to measure effect/variance

ABSTRACT

Climate variability is the most complex and serious environmental problem facing the world today. Ethiopia has historically suffered from climate variability and extremes. Climate variability and change likely are significant contributing factors in food security challenges, Ethiopia currently experiences. The problem of climate change is broadly studied from various angles that emanates from seriousness of the problem. In this regard, the application of GIS and statistical techniques in analyzing climatic data and its impact on crop production is crucial. The study aimed at investigating climate variability and its impact on crop production in North and South Wello Zones, Northern Ethiopian Highlands. In this study, time series data of rainfall and temperature from NCEP's CFSR and NMA, SST from NOAA and crop data from CSA were used. Mann-Kendall and Sen's Slope methods have been used for the trend analysis and quantification. The result showed that total Kiremt RF decreased by 9.076mm per Kiremt season and the trend was statistically significant at 95% confidence interval. Similarly, total annual RF showed a decreasing trend by 9.632mm per year. On the contrary, Tmax, Tmin and SST showed an increasing trend both seasonally and annually during the last 33 years (1984-2016) in the study area. With regard to spatial and temporal distribution, the highest amount of mean total Kiremt and annual RF were 993.71mm and 1715.95mm, respectively. The highest values of mean annual Tmax and Tmin were 30.13°C and 11.1°C, correspondingly, while the lowest values of mean annual Tmax and Tmin were 19.94°C and 5.76°C, respectively. Furthermore, RF, Tmax and Tmin data of the study area were analyzed for the magnitude of temporal and spatial variations using percentage of coefficient of variations (CV). CV of Mean total Kiremt and annual RF were ranging from 24.8% to 62% and from 23.13% to 57.86%, respectively. The correlation between total Kiremt and Belg RF with mean SST were negative (r = -0.457) and positive (r = 0.385), respectively and statically significant at alpha 0.05 level.From the regression analysis, it was observed that the variation of crop production was explained by the variation of rainfall and temperature. For instance, the impact of mean Kiremt Tmax accounted for 21.8% (R^2 = 0.218) of teff yield changes, whereas 47.5% (R^2 = 0.475) of variations in Sorghum was explained by the variations in total Kiremt RF. From the study, it has been observed that current rainfall and temperature variability has a significant influence on crop production in the area and any unfavorable change in the local climate in the future will have serious implications for household level food security, unless efforts to adapt to the ongoing climate change should begin from tackling the current climate variability and take a climate risk management approach for adapting to the ongoing climate change.

Keywords: GIS, RF, Tmax, Tmin, SST, Spatio-Temporal Variability, Climate Variability.

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Climate variability plays a great role in agricultural activities having a direct influence from the beginning of land preparation to the final harvest (Akinseye *et al*., 2013; Mesike and Esekhade, 2014). Rainfall and temperature in particular are critical climatic elements. While non-climatic factors like availability and access to farm inputs, land quality, tenure security, infrastructure, market and policy can be managed by farmers or the government in the short- or long-term, little could actually be done to drastically change the influence of climate, particularly rainfall. Mesike and Esekhade (2014) note that rainfall has always dictated how land is used and plays a dominant role in agriculture exerting a direct impact on production and spatial distribution of crops.

Among the climate parameters that have exhibited a change in both short and long-term trends are rainfall and temperatures. Previous assessments (Hulme *et al.,* 2001) concluded that over dependence on rain-fed agriculture and unpredictable temperatures are among the contributing influences to food insecurity. Already, in the Sub-Saharan Africa, climate change has drastically reduced agricultural production through extreme weather events, such as recurrent droughts and floods (Nhemachena and Hassan, 2007).

Today, climate change is increasingly recognized as a critical challenge to ecological health, human well-being and future development (IPCC, 2007). Even though Climate change is global in nature, potential changes are not expected to be globally uniform; rather, there may be dramatic regional differences (Mullugojjam and Ferede, 2012). Climate change is real and happening now. In the present time, seasonal climate variability is often observed (Conway *et al*., 2005). The basic climatic elements such as rainfall and temperature show seasonal and annual variation different from normally expected climatic conditions.

Because of the lack of economic development and institutional capacity, African countries are among the most exposed to the risk of climate change (IPCC, 2001). In addition, IPCC (2007) in its report declared that the region will be hard-hit by changing climate because of lack of economic development and institutional capacity to deal with it. As the region strives to achieve sustainable development, national governments are immensely grappling with difficult trade-off and opportunity costs with regard to climate change (Muller *et al*., 2010). Climate change impacts have the potential to undermine and even, undo progress made in improving the socio-economic well-being of East Africans (Ayalew *et al.*, 2012).

Climate variability and change likely are significant contributing factors in food security challenges, Ethiopia currently experiences. The Intergovernmental Panel for Climate Change (IPCC, 2001) has expressed that as a result of climate change; least developed countries including Ethiopia will experience a range of unfavorable impacts. Diminished resource exacerbates due to desertification, increased transmission of vector disease, and there are also predictions of increased incidence extreme event and gradual change that could jeopardize national efforts in poverty reduction, economic growth and sustainable development. Climate change could affect poverty reduction strategies of developing countries. Of all the regions affected by climate change, Ethiopia, is characterized by widely varied microclimates (NMSA, 1989) and is very sensitive to climatic changes in particular to rainfall variation.

Different studies have shown the importance of climate variability in explaining crop production fluctuations at different spatial scales. At the global level, estimates are that climate variability accounts for roughly a third of observed crop yield variability (*Ray et al*., 2015). At the continental level, climate variability is widely recognized to be a major driver of crop production fluctuations particularly in Africa, where agriculture is predominantly small scale and rain-fed (Jones and Thornton, 2003; IPCC, 2014). For instance, Rowhani (2011) and Afifi *et al*. (2014) reported that annual variability of rainfall and temperature had significant impacts on crop production and thereby food security of communities in Tanzania. In Nigeria, rainfall variability was found to have a significant influence on crop production (Adamgbe and Ujoh, 2013; Akinseye *et al*., 2013; Yamusa *et al*., 2015). In Uganda, variations in rainfall and temperature had significant effects on crop production (Mwaura and Okoboi, 2014).

Ethiopia‘s climate is influenced by general atmospheric and oceanic factors that affect the weather condition and the time of inception and intensity of the rains (Bekele, 1997). The summer rainfall contributes about 74% of the annual rainfall in the country. Therefore, the failure of the summer rainfall has disastrous consequences upon the country and the rest of East Africa (Robel, 2012). The failure of seasonal rainfall adversely affects the country‘s socioeconomy, in particular food production (Babu, 1999). To alleviate this problem different research works have been carried out and result indicated that the major cause of frequent drought in Ethiopia is climate variations across the country especially rainfall variation (Babu, 1999).

Variability of rainfall and temperature is believed due to variations of tropical oceanic and atmosphere interaction, especially El Niño-Southern Oscillation (ENSO) (Haile, 1988). As climate change as if ENSO leads to decrease in yields, in developing countries, it will further severe food security (Jaochin, 2008).

The National Meteorological Service Agency (NMSA) of Ethiopia assured that, ENSO is strongly related to rainfall distribution in the country (Babu, 1999). Researchers at NMSA and policy makers in Ethiopia stated that the state of sea surface temperatures (SST) in the tropical Pacific Ocean affect Ethiopian climate through teleconnections (Haile, 1988). NMSA (2004) also explained that the Atlantic and the Indian oceans' SST anomalies (SSTA) affect Ethiopian climate (Robel, 2012). Quinn (1992) also reported that the variability between high and low flood levels of the Nile River, whose major water source is highlands of Ethiopia, is related to the ENSO.

In countries like Ethiopia where agriculture is dependent on rainfall, the influence of climate variability on crop production is generally large. Previous studies have shown that variability in Ethiopia's agricultural GDP is clearly correlated with rainfall variability (World Bank, 2006; Bewket, 2009). Segele and Lamb (2005) also note that the characteristics of the main rainy season (June – September, known as *Kiremt*) rainfall are the most important determinants for agricultural activity from the perspective of its amount and geographical coverage

Therefore, as an attempt of showing the necessity of GIS and statistical tools in analyzing and portraying critical facts pertinent to climate variability, and in doing so, to contribute to the effort of mitigating the negative impact of climate variation, this study was focused on climate variability impacts on crop yields of North and South Wello Zones due to the prevalence and largeness of the problem.

1.2. Statement of the Problem

Climate variability is the most serious challenges that humanity may ever face. Hence, it has recently become a pressing issue in various development, environment, and political forums at national, regional and international levels (Mikias, 2014). There is a substantial concern over the global problem of climate variability and it is described as the most universal and irreversible environmental problem facing the Earth (IPCC, 2001). It threatens the achievement of Millennium Development Goals aimed at poverty and hunger reduction, health improvement and environmental sustainability (UNDP, 2010).

Due attention is given to this issue because of the occurrences of damage it might bring to the world following the change. For the world as a whole, the issue of climate variability has been studied from different views using various types of evidence in the last 30 years. It has become clear that not only have there been worldwide climate changes occurring in the last 100,000 years, which have unquestionably affected the distribution of crop, and livestock, but also that recent short term climate change may be affecting agricultural distribution (Getnet, 2010).

Arguably, one of the most widespread and highly devastating influences of climate change in East Africa had been changes in the frequency, intensity, and predictability of precipitation and temperature (Mullugojjam and Ferede, 2012). The same source further explained that changes in regional precipitation will ultimately affect water availability and may lead to decreased agricultural production and potentially widespread food shortages. Supporting this idea, Hulme *et al*., (2001) point out that changes in rainfall pattern will ultimately affect crop production and potentially widespread food shortages.

Many researchers now pointed out that several droughts in Africa, especially in Southern Africa and the Horn, are caused by the physical processes related to the occurrence of ENSO events thousands of miles away, along with sea surface temperature anomalies (SSTA) in the Southern Atlantic and Indian oceans combined with anthropogenic activities (Wolde-Georgis, 1997). In Ethiopia, El Niño has been the cause of crop failure, livestock death and food insecurity for many years (Getachew, 2017). Analyzing El Niño/La Niña Southern Oscillation episodes together with other climatic parameters would be helpful for many sectors.

In Ethiopia climate variability is the main factors for the failure of crop production. In relation with this, Bishaw *et al*., (2013) argued that Ethiopia is especially exposed to the risk of climate variability and change because large of the population are poor and depend on agricultural income, which is highly sensitive to rainfall variability. Its diverse agro-ecological zones are characterized by very impressive variety of microclimates and corresponding weather patterns.

Many studies had been conducted to assess the spatial and temporal pattern of climate variables in various parts of the country. A recent study was drawn by *Taye et al*., (2013) focusing on spatiao-temporal variability and trend of rainfall and temperature in western Amhara Region from GIS and remote sensing perspective. The study announced that the contribution of *Kirem*t rainfall to the annual total rainfall was very high in all study stations and variations of minimum and maximum temperatures were found in every month. Similarly, another research carried out by Ayalew *et al.,* (2012) examines variability of rainfall and its current trend in the same region. The study has discovered that long-term movements of rainfall in a time series did not show any increasing or decreasing trend of rainfall.

Ethiopia is one of the poorest nations of the world, which has been vulnerable to the impacts of climate variability and change. The limited economic, institutional and logistic capacity to mitigate and adapt to climate change exacerbated the vulnerability of many peoples and communities to climate change induced-hazards that are occurring through global climatic change and land use transformation. The problem is more serious on communities who heavily depend on climate sensitive livelihoods, agriculture. This situation has retarded the country's development program and creating multi-faceted challenges. The challenge limits the country's primary agenda, poverty reduction. Though climate change stands as a major obstacle to eradicate poverty and protect the environment; its direct and indirect impacts were not well studied in the country. Facing climate change-induced hazards may not be new for the Ethiopian peoples. The challenges, however, are both diversified and frequent hazards in the current climate system. This shows that the need to review disaster-response mechanism. This is however, impossible without research-generated knowledge.

It is important that scientific studies be undertaken so as to provide the society with accurate information on the real and potential impacts of extreme climatic variability, as well as, the mitigation and adaptation options available. At this time when the world is grappling with diverse environmental problems including global warming, ozone depletion, acid rain, killer hurricanes, destructive thunderstorms, droughts and major flood episodes, efforts at finding explanations to these problems should be of great importance, since the environmental, social and economic cost of managing extreme climatic variability is bound to be enormous from the standpoint of society and policy makers (Ekpoh, 2011 cited in Elodie, 2011).

As to the knowledge of the researcher, studies relating to ENSO impact on rainfall and temperature have not been still conducted. The study made by Woldamlak and Conway (2007) focusing on temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia and another study carried out by Mikias (2014) emphasizing on the effect of climate change and variability on the livelihoods of local communities the case of central rift valley region of Ethiopia. Basically, the investigator was necessitated to conduct this research primarily to fill the gap that had not discussed by previous researchers and provide a cumulative knowledge in the area by incorporating the issue of GIS and statistical techniques

1.3. Objectives of the Study

The main objective of this study was to investigate climate variability in spatio-temporal domain and its impact on crop production, and the following specific objectives were addressed under this objective:

(1) To elucidate the spatial and temporal variability of rainfall and temperature in the study area;
(2) To characterize the relationship between rainfall, temperature and ENSO;
(3) To evaluate the influence of rainfall and temperature variability on crop yields.

1.4. Significance of the Study

The impact of the climate brings serious damages on agricultural activities especially in developing countries like Ethiopia, even though the degree of the climate variability and its impact on agriculture is not clearly characterized and studied in the study area. Hence analyzing the impact of climate variability (Sea Surface Temperature, rainfall and temperature) on agricultural yields, and the impact of ENSO on rainfall and temperature variability are providing useful information for pertinent decision-makers in order to make more effective management in agriculture, water, natural resources and environment. Furthermore, the study will be helpful as a reference for future research undertakings particularly in the study area and cross-reference in general.

1.5. Scope and Delimitation of the Study

The project was mainly designed to analyze climate variability impacts on crop production. Geographically, the scope of the study was confined to North and South Wello found in Amhara National Regional State, Ethiopia where both the distribution of rainfall and temperature are highly erratic in nature. More specifically, among the various climate variables in this study particularly rainfall, ENSO and temperature were thoroughly analyzed using GIS and statistical tools.

1.6. Organization of the Study

The study is organized in to six chapters. The first chapter contains introduction and statement of the problem. In addition, it briefs the objectives, significance of the study, scope of the study, organization of the paper. The second chapter deals with review of related literature. This part addresses the relevant literature that is very much associated with the research topic. Hence, it is the background of the study, which is used as a springboard to sketch the direction of the study. The third chapter deals about the description of the study area. The fourth chapter explains the materials and methods. It clearly indicates the data type and sources, techniques of data analysis and a conceptual framework that helps to understand the flow of the analysis. The fifth chapter vastly concerned with analysis and discussion of the result. Finally, the sixth chapter covers conclusion and recommendations.

CHAPTER TWO

2. LITERATURE RIVIEW

2.1. Overview

Today, climate variability is increasingly recognized as a critical challenge to ecological health, human well-being and future development (IPCC, 2007). It is one of the greatest challenges of humanity, affecting current generations. Agricultural activities are the most economic sectors in Ethiopia. This sector is always affected by climate variability. The impact of agriculture as a result of climate variability is largely occurred in dry land semi arid areas (Gizachew, 2010). Ethiopia's climate is influenced by general atmospheric and oceanic factors that affect the weather system (Bekele, 1997). The El Niño-Southern Oscillation (ENSO) is one of the most important contributors to global inter- annual climate variability, but the relationship between seasonal climate and crop yield variations associated with ENSO remains inconclusive.

In line of the above induction, the aim of this chapter is to review literatures on climate variability, its cause and impact on agricultural products. Accordingly, the review of literature help to highlight previous studies on climate change with their underlying concepts so as to identify gaps in the literature and forward research questions for the study.

2.2. Concept of Climate Change and Variability

The concept of climate change has been around for quite a while. The earliest mention of climate change dates back to the nineteenth century. Svante Archenius, a Swedish scientist, was the first to study the effect of the CO_2 climate (Rodhe *et al*. 1997). The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in mean and/or the variability of its properties and that persists for an extended period, typically, decades or longer. Climate change may be due to natural internal processes or external forcing, or anthropogenic changes in the composition of the atmosphere or in land use" (IPCC, 2001).

The United Nations Framework Convention on Climate Change (UNFCCC) also defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods of time" (UNFCCC, 2010).

The terms “Climate Change” and “Climate Variability” are often used interchangeably; the IPCC, however, defines climate variability as “variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events”. Variability may be due to natural internal processes within the climate system – internal variability – or to variations in natural or anthropogenic external forcing – external variability (IPCC, 2001).

As stated in Keely (2009) climate variability is the way climate fluctuates yearly above or below a long-term average value and climate change is long term continuous change (increase or decrease) to average weather conditions or the range of weather. As drawn in the work of Yitea (2012) climate is described in terms of the variability of relevant atmospheric variables such as temperature, precipitation, wind, snowfall, humidity, clouds, including extreme or occasional ones over a long period in a particular region. The classical period for performing the statistics used to define climate correspond to at least 3 decades, and it is designated by “climate normal period”, as defined by the World Meteorological organization (WMO). As a result, the 30-years period proposed by the WMO should be considered more as an indicator than a norm that must be followed in all cases but other periods may be used depending on the purpose.

This definition of the climate as representative of conditions over several decades should of course not mask the fact that climate can change rapidly. Climate can thus be viewed as a synthesis or aggregate of weather in a particular area for a long time (Esubalew, 2014).

2.3. Causes of Climate Change and Variability

Climate variability generally refers to the « natural » fluctuations of the climate system. They are generated by (1) internal causes —by the climate system itself— like the ocean-atmosphere coupling at play during the various El Niño/La Niña oscillations and (2) external causes usually called natural forcing since they are related to the presence of natural radioactively active gases and aerosols in the atmosphere that perturb the radioactive energy budget of the Earth. Climate Change, on the other hand, rather refers to the long-term anthropogenically mediated modifications of the Earth climate. Both climate variability and climate change are contributing to the modern climate. Consequently, climate variability is "superimposed" on the climate change long-term evolution and makes the detection of its impacts over a short time period difficult (IPCC, 2013). The most well understood occurrence of climate variability is the naturally occurring phenomenon known as the El Niño-Southern Oscillation (ENSO), which results from an interaction between the ocean and the atmosphere over the tropical Pacific Ocean that has important consequence for weather around the globe, particularly in the tropics (NOAA, 2010). The ENSO cycle is characterized by coherent and strong variations in sea-surface temperatures, rainfall, air pressure, and atmospheric circulation across the equatorial Pacific. The El Nino-southern oscillation (ENSO) phenomenon, resulting from the interaction between the surface of the ocean and the atmosphere in the tropical Pacific. ENSO profoundly affects climatic variability in parts of sub-Saharan Africa, including the Sahel, Ethiopia, equatorial eastern Africa and southern Africa, where strong and persistent ENSO events create unique and persistent anomaly patterns in rainfall (Ogutu *et al*., 2008). The impacts of El Niño on eastern and southern African rainfall exhibit specific spatial-temporal patterns depending on the space-time evolution of each individual event.

The El Niño-Southern Oscillation (ENSO), which refers to fluctuations in both sea-surface temperature (SST) in the tropical Pacific and sea-level pressure in the southern Pacific (the Southern Oscillation Index), is one of the most important contributors to global inter-annual climate variability (Rasmusson & Carpenter, 1983).

El Niño Southern-Oscillation (ENSO) refers to the cycle of coherent and sometimes very strong variations in the sea surface temperature (SST), convective rainfall, surface pressure and atmospheric circulation across the equatorial Pacific Ocean (Salau *et al*, 2012). The pattern generally fluctuates between two states called La Niña (cold phase) and El Niño (warm phase). The warm phase is associated with reduced rainfall in the Western Equatorial Pacific and prolonged warming with higher precipitation in the Eastern Equatorial Pacific (EEP) when compared with neutral condition, while the patterns are reverse during La Niña event (Collins *et al.*, 2010). ENSO episodes are usually identified with changes in the Niño 3 (150° W–90° W, 5° S–5° N) (or Niño 3.4 (170° W–120° W, 5° S–5° N)) anomalies, which correspond to the departure in the monthly SST from its long-term mean over the Niño 3 (or Niño 3.4) region of the EEP (Latif *et al*, 2009).

Rainfall and temperature are the two most prominent variable influences the climate of a region. Precipitation is the general term for rainfall, snowfall and other forms of frozen or liquid water falling from clouds. A changing climate can directly influence precipitation amount, intensity, frequency and type. Large natural variability and strong geographic variations in these parameters are evident, substantially affected by atmospheric circulation patterns such as the El Niño Southern Oscillation (Esubalew, 2014). Increased warming accelerates evaporation and increases the amount of water vapor in the atmosphere, resulting in certain areas getting wetter and others getting drier. Widespread increases in heavy precipitation events have occurred even in places where total amounts have decreased (Kedir *et al*., 2013). Temperature is a measure of the intensity of heat energy produced by solar radiation. Temperature influences plant growth as it affects physiological processes such as photosynthesis, transpiration, respiration, germination, and flowering (Elodie, 2011).

Human activity is the main cause of the variations seen in climate during recent decades (Carolin, 2012). FAO (2009) has stated that climate change, which is mainly caused by human activities, is considered as the major cause of climate events. Rising fossil fuel burning and vegetation cover changes have emitted, and are continuing to emit, increasing quantities of greenhouse gases into the Earth's atmosphere. These greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrogen dioxide (N_2O), and an increase in these gases has caused raise in the amount of heat from the sun with held in the earth's atmosphere, heat that would normally be back into space(UNFCCC, 2007). Greenhouse gases and aerosols affect climate by altering incoming solar radiation and out-going infrared (thermal) radiation that are part of Earth's energy balance. Changing the atmospheric abundance or properties of these gases and particles can lead to a warming or cooling of the climate system. Since the start of the industrial era (about 1750), the overall effect of human activities on climate has been a warming influence. The human impact on climate during this era greatly exceeds due to known changes in natural processes, such as solar changes and volcanic eruptions (IPCC, 2007).

2.4. Climate Change, Variability and Agriculture

Climate change is arguably one of the most important challenges facing African countries, largely due to their geographic exposure, low income, greater reliance on climate-sensitive sectors such as agriculture, and weak capacity to adapt to the changing climate (Belloumi, 2014). Although climate change and climate variability affect all economic sectors, agricultural activities are most vulnerable to climate fluctuations (Salinger *et al*., 2005; Anwar and Liu, 2012). These are reflected in changes in temperature and precipitation, which affect the land and water regimes and eventually affect agricultural production (Anwar *et al*., 2012). A small increase in temperature decreases agricultural production (IPCC, 2007). According to Li *et al*., (2013) climate change and climate variability affect the productivity of agricultural ecosystems.

Many studies have shown the importance of climate variability in explaining crop production fluctuations at different spatial scales. At the global level, estimates are that climate variability accounts for roughly a third of observed crop yield variability (Ray *et al*., 2015). At the continental level, climate variability is widely recognized to be a major driver of crop production fluctuations particularly in Africa, where agriculture is predominantly small scale and rain-fed (Jones and Thornton, 2003; IPCC, 2014). For instance, Rowhani (2011) and Afifi *et al*. (2014) reported that intra-annual and inter-annual variability of rainfall and temperature had significant impacts on crop production and thereby food security of communities in Tanzania. In Nigeria, rainfall variability was found to have a significant influence on crop production (Adamgbe and Ujoh, 2013; Akinseye *et al*., 2013; Yamusa *et al*., 2015). In Uganda, variations in rainfall. According to the United Nations, climate variability will affect Africa more than anywhere else with will in the world due to extreme poverty levels, high rates of population growth, over-reliance on rain-fed agriculture and over-dependence on natural resource-based livelihoods (UNEP, 2006). Currently, climate change and variability have imposing significant challenges to Ethiopia by affecting food security, water and energy supply, health, poverty reduction and sustainable development efforts (Abebe, 2007). Furthermore, extreme weather events, such as droughts, floods, or landslides, may cause death to domestic animals.

As indicated in IPCC (2007) report, climate variability impacts on water demand are predicted to be highly significant in Africa, this is likely to have severe impacts on crop yields, as the majority of the African population (over 85 percent in the case of Ethiopia) depends on rain-fed agriculture (IPCC, 2007). Climate variability will aggravate the water stress currently faced by some countries, while some countries that currently do not experience water stress will become at risk of water stress (IPCC, 2007).

2.5. The role of GIS and Statistical Techniques for the assessment of Climate Variability and its Impact on Crop Production

The issue of climate change is currently an important concept that attracts the attention of several scholars. The problem of climate change is broadly studied from various angles that emanate due to the seriousness of the problem. Among those, the application of GIS and statistical techniques to analyze climate variability in spatio-temporal domain as well as to investigate climate variability impact on crop yields.

Reducing the risks caused by climate change is an immense challenge. Scientists, policy makers, developers, engineers, and many others have used GIS and statistical technology to better understand a complex situation and offer some tangible solutions. GIS users represent a vast reservoir of knowledge, expertise, and best practices in applying this cornerstone technology to the science of climate change and understanding its impact on natural and human systems (ESRI, 2008).

The same source further explained that the key to understanding our dynamic climate is creating a framework to take many different pieces of past and future data from a variety of sources and merge them together in a single system. GIS creates a new framework for studying global climate change by allowing users to inventory and display large, complex spatial data sets. They can also analyze the potential interplay between various factors, getting us closer to a true understanding of how our dynamic climate may change in the coming decades and centuries (ESRI, 2008).

CHAPTER THREE

3. SITE DESCRIPTION

3.1. Location

This study was conducted in the North and South Wello Zones in the Amhara National Regional State, Ethiopia. The zones are located in the eastern part of the region. The capitals of the South and North Wello zones are Dessie and Weldia, respectively. Dessie and Weldia are about 410 km and 521 km north of the Ethiopian capital, Addis Ababa, respectively. The two zones are located between 10°12' to 12°22' N latitude and 38°30' to 40°14' E longitude and cover about 30,000km^2.

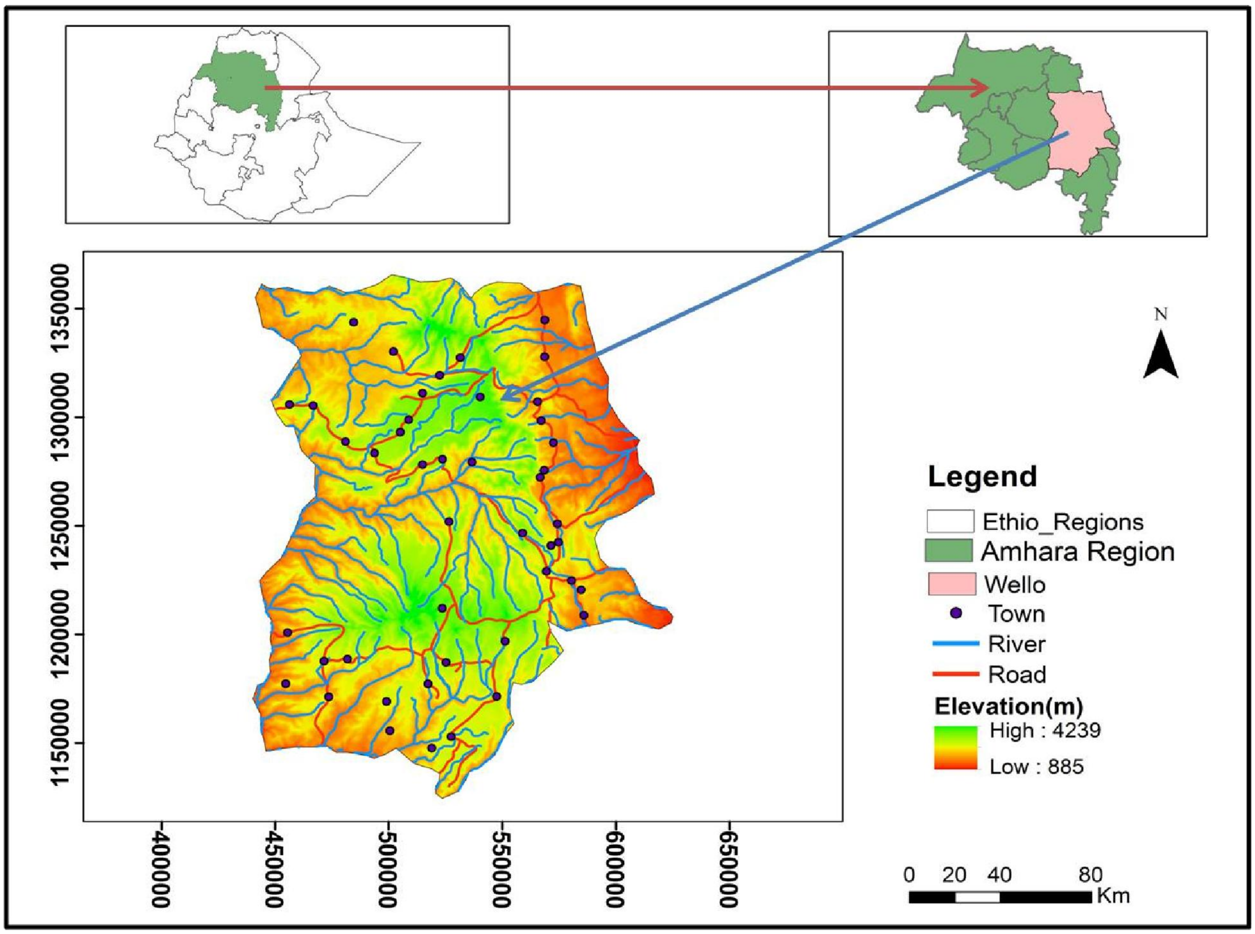


Figure 3. 1: Location Map of the Study Area

3.2. Bio-Physical Characteristics

Climate

According to the local system, the country is classified into 5 agro-ecological zones: Wurch, Dega, Weyna-Dega, Kolla and Berha (NMSA 1996; Hurni 1998). In the study area, the Kolla, Weyna-Dega, Dega and Wurch zones cover 8.5%, 44.8%, 38.5% and 8.2% of the area, respectively (Shimeles, 2012). The Wello area is classified in three climatic regions: cool highland climate, tropical climate with dry summer, and tropical climate with distinct dry winter (Shimeles, 2012). Wello also has three distinct seasons namely *Beg*a, *Belg* and *Kiremt*. *Bega* is a dry season from October to January (NMSA 1996). *Belg* is the small rainy season that occurs between mid February and mid May, while *Kiremt* is the main rainy season that extends from mid June to mid September (NMSA, 1996). The mean annual temperature and mean annual rainfall ranges from 11°C to 30°C and from 140mm to 1700mm, respectively. Based on the moisture index, the climate of Wello is classified as dry with arid to dry sub-humid conditions (Shimeles, 2012). According to the climatic characteristics, the region is further subdivided into an eastern and western part. Eastern Wello has a relatively dry climate with a moisture index of minus 60 to 0, and most areas receive sufficient moisture during the rainy seasons with some surplus water. In contrast, western Wello has a moderate to large amount of water surplus in the rainy seasons, which results in high run-off, soil erosion and water-logging depending on the soil type and topography (Gonfa 1996).

Topography

The Digital Elevation Model (DEM) reveals that larger parts of Wello are characterized by rugged topography that consist very high mountains, deeply incised canyons and gorges, valleys and plateaus (Figure 3.3).The rugged topographic condition of the area was also reported in other studies (e.g. FAO 1984; Tefera *et al*., 1996; Coltorti *et al*., 2007). Due to the strong relief differences, anthropogenic activities have led to extensive degradation. The highest (4220 m) and lowest (900 m) elevations are in the South Wello zone. The lowest areas are in the Rift Valley, which is part of the East African rift system.

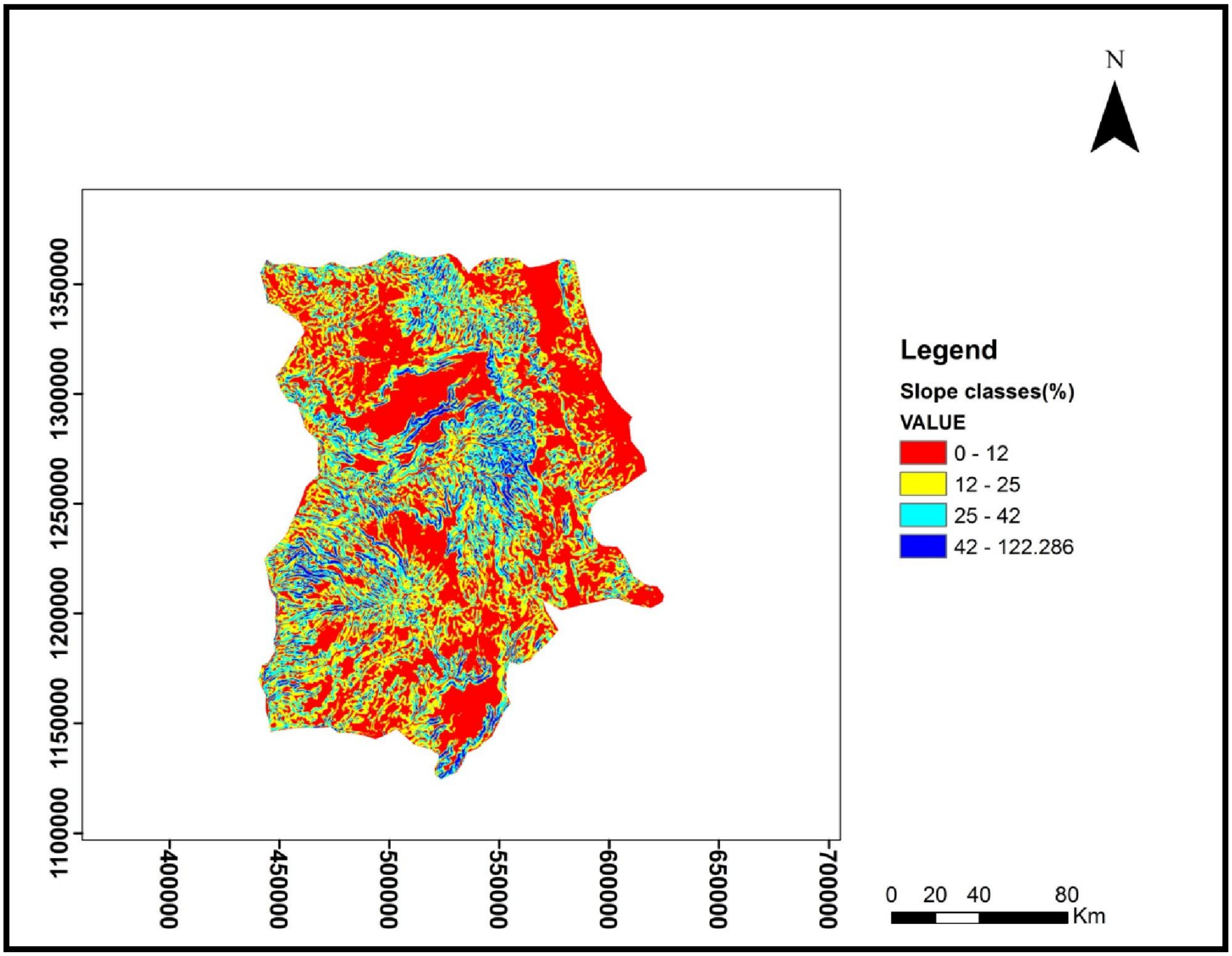


Figure 3. 2: Slope map of the study area

Geology

Cenozoic volcanic rocks with some sedimentary rocks cover Wello. The Cenozoic volcanic rocks have developed from tertiary flood basalt sequences with intercalation of felsic lava and pyroclastic rocks up to 3 km thick (Shimeles, 2012). The Cenozoic volcanic rocks and the associated sedimentary rocks are further subdivided in various formations. The major formations are Ashangi, Tarmaber-Megezez, Alajae, Aiba basalts and Amba-Aradom formations covering 49%, 18%, 14%, 12% and 3%, respectively (Tefera *et al*., 1996).

Soils

Wello has various soil types, the major soils bein Leptosols, Cambisols,Vertisols, Andosols and Luvisols (FAO, 1984). Leptosols are the dominant soil types, which cover over 35% of the study area and followed by Cambisols,Vertisols, Andosols and Luvisols (FAO, 1984). Leptosols are shallow, mostly brown or yellowish brown and clay to clay loam. Leptosol are characterized by common to abundant surface stoniness, few to common rock outcropping and many coarse fragments throughout the profiles. At the second level, the Leptosols are further classified into Eutric, Dystric and Lithic. Cambisols are further classified as Vertic and Dystric.Cambisols have wide physical,chemical and morphological characteristics and are shallow to moderately deep. Vertisols in the study area are moderately deep to very deep on flat to almost flat lands. They are characterized by dark to dark gray color, clayey texture, poor drainage and workability, and develop wide and deep cracks upon drying and swell upon wetting. The Vertisols of Wello are further classified into Euthric and Calcic. Luvisols occur in cooler areas in very small parts and on gently sloping lands. They are well drained, brownish in color, clayey textured, have high CEC (>24 cmol/kg clay) and higher base saturation, mostly >50%. Andosols cover small parts of the study area in the Rift Valley and the escarpments towards the valley. They are shallow to very deep, clayey textured and have a high pH (pH >7) (FAO, 1984).

Hydrology

The study area drains to three major river basins of the country and to a river that sinks within the study area. The rivers are Abay (Blue Nile), Tekeze, Awash and Golina. Tekeze River joins the Blue Nile at Atbara in Sudan. The Tekeze and Golina drain the northwest and northeast parts, respectively, while the other parts are drained by the Abay and Awash rivers. The Abay, Tekeze, Awash and Golina rivers drain 17550 km^2, 5265km^2, 4385 km^2 and 2770 km^2, respectively. The concentrated drainage network and the closely spaced watershed divides indicate dissected topographic characteristics and possibility of intensified differential erosion. The intense drainage systems and steep slopes also indicate vulnerability of the area to erosion and degradation, if there is improper anthropogenic intervention (Shimeles, 2012).

3.3. Agriculture and Farming System

The main livelihood base and economy of the Ethiopians is agriculture. Like other parts of the Ethiopian highlands, the major farming system of Wello is mixed cereal-livestock (Haileslassie et al.2005). The farming system is diversified and determined by agro- ecology. Cereals are the dominant crop accounting for over 73%, followed by pulses (24%) and the remaining 3% is oilseed (ANRS-BFED 2008). Among the cereal crops teff, sorghum, wheat and barley are dominant, accounting for 25%, 18%, 16% and 11% of the total, respectively (ANRS-BFED 2008). Horse bean, lentil, chickpea and field bean are the major legume crops accounting for16% of the total crop production (ANRS-BFED 2008). Farmers rotate cereals with legumes to maintain soil fertility and crop yield. Like in other parts of the country, the farming system and farm implements are traditional and inherited from indigenous knowledge (Ehret 1979). The traditional tillage implement known as Maresha is an ox-drawn plough, which has been used for more than two thousand years (Ehret, 1979; McCann, 1995). Traditional re-tillage practices, known as Shilshalo, are usually performed about six weeks after maize and sorghum sowing. Shilshalo has various purposes such as harrowing, which improves soil air, water and nutrient circulation, root development, and uproots and kills weed and optimizes plant density. The traditional up and down cultivation across the slope of the land practiced for centuries has led to severe soil erosion and land degradation.

The components of the mixed cereal-livestock farming system support each other (Haileslassie *et al*., 2005). Ehret (1979) reported that domestication of grasses was accompanied or even preceded by small ruminants (sheep and goat) husbandry, which indicate long standing history of the two sectors in Ethiopia. Livestock husbandry supports crop production mainly through providing traction power, while crop residue is used as a major livestock feed. Consequently, farmers keep wide variety and high livestock population. The livestock include cattle, small ruminants, equines, poultry and bees (ANRS-BFED, 2008). Small ruminants and cattle are the dominant animals accounting for 40% and 32% of the total population, respectively (ANRS-BFED, 2006/2007).

3.4. Demography

Wello is characterized by high population. The population density of Wello (134 persons km^{-2}) is higher than the national average (84 persons km^{-2}) (CSA, 2008).The population of the Amhara region grew at an annual rate of 1.7% between 1994 and 2007, which is a lower rate than in the previous censuses. It was also almost 50% lower than the national growth rate. On the other hand, Wello has limitation of agriculturally suitable lands. Agricultural potential (≤ 15% slope) and marginally suitable land (15-30% slope) accounts for about 60%. Considering the area that can be used for most agricultural activities in relation to the population, the density is higher than the overall Ethiopian density and is estimated to be about 235 people km^{-2} (Shimeles, 2012)

CHAPTER FOUR

4. MATERIALS AND METHODS

4.1. Data Type and Sources

The data used for this study were rainfall and temperature (maximum and minimum) found from the National Centers for Environmental Prediction's Climate Forecast System Reanalysis (CFSR) and Ethiopian National Meteorological Agency (NMA). In addition, Central Statistical Agency (CSA) time series data on production of five major crops: barley (*Hordium vulgare*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), tef (*Eragrostis tef*) and wheat (*Triticum* aestivum) grown in the area for the main cropping season, locally known as *Meher* (any temporary crop harvested between September and February) have been employed. Therefore, weather data sources used were observed weather data from climatic stations in the study area (hereafter called "ground meteorological stations") and weather data from the NCEP's CFSR (hereafter called "CFSR weather") (Saha *et al*., 2010). Another variable used in this research was sea surface temperature (SST) obtained from National Oceanic and Atmospheric Administration (NOAA) satellite mission.

The ground meteorological stations has monthly rainfall and temperature (both maximum and minimum) from five climatic stations. It spans the period from 2000 to 2016 inclusive. However, spatial location of these stations that record rainfall and temperature data were distributed unevenly and there were data gaps in the study area. In addition to this, the numbers of ground meteorological stations found in the study area are unsatisfactory and the period of record does not include adequate historical coverage to analyze climatic variability and trends. Therefore, the present study used CFSR weather data instead of using in-situ rainfall and temperature data from NMA.

Many studies have explored ways to improve the quality of climatic data in data-scarce regions. Barrett (1994); Tsintikidis *et al*. (1999) and Ymeti (2007) have applied satellite as weather data inputs. Others have employed various statistical methods to fill data gaps. Tesemma *et al*. (2009) and Uhlenbrook *et al*. (2010) used regression and spatial interpolation to fill data gaps. While these are some of the various efforts exerted to improve climatic data quality in data limited regions, CFSR data sources are becoming very promising options in representing observed weather data (Zhang *et al*., 2012).

It is not always easy to find weather data from ground meteorological stations at a given spatial and temporal resolution, especially in this study area. Moreover, when the data exist, they may be unreliable because of gaps and other problems, such as random errors. In such cases, it may be better to use global data sources such as CFSR. CFSR weather has an advantage over ground meteorological stations weather data in that it provides complete sets of climatic data (Dile *et al*., 2014).

The CFSR weather is an open global reanalysis dataset for each hour at 38km resolution (Fuka *et al*., 2013). For this research CFSR weather data were obtained by bounding box of latitude 8.6896ºS, Longitude 36.0956ºW, Latitude13.3148ºN and Longitude 40.2045ºE (the Texas A&M University spatial sciences website, globalweather.tamu.edu) (Globalweather,2017). It includes daily rainfall, maximum and minimum temperature, wind speed, relative humidity, and solar radiation from 1/1/1979 to 31/7/2014 for 195 locations. The CFSR weather is produced using cutting-edge data-assimilation techniques (both data from ground meteorological stations and satellite irradiances) as well as highly advanced (and coupled) atmospheric, oceanic, and surface-modeling components at ~38 km resolution (Saha *et al*., 2010). The production of CFSR data involves various spatial and temporal interpolations of ground meteorological stations of weather data found on the study area, other nearby data of ground meteorological stations, and satellite products (Dile *et al*., 2014).

From 195 locations, 19 CFSR weather data stations were used in this study since they have appropriate distribution and long-term rainfall and temperature data from 1984 to 2013 in the study area. Mean sea surface temperature (SST) of NINO3.4, NINO3 and NINO4 region from National Oceanic and Atmospheric Administration (NOAA) satellite mission were used for the analysis to characterize the relationship between SST and temperature as well as SST and rainfall in the study area. Since NINO 3.4 has characteristics of both NINO3 and NINO4 (Zaroug, 2010), NINO3.4 SST was considered in this study. To be classified as a full-fledged El Niño and La Niña episode the Oceanic Niño Index (ONI), sea surface temperature anomaly (SSTA) must exceed +0.5 [El Niño] or -0.5 [La Niña] for at least five consecutive months (Yitea, 2012).

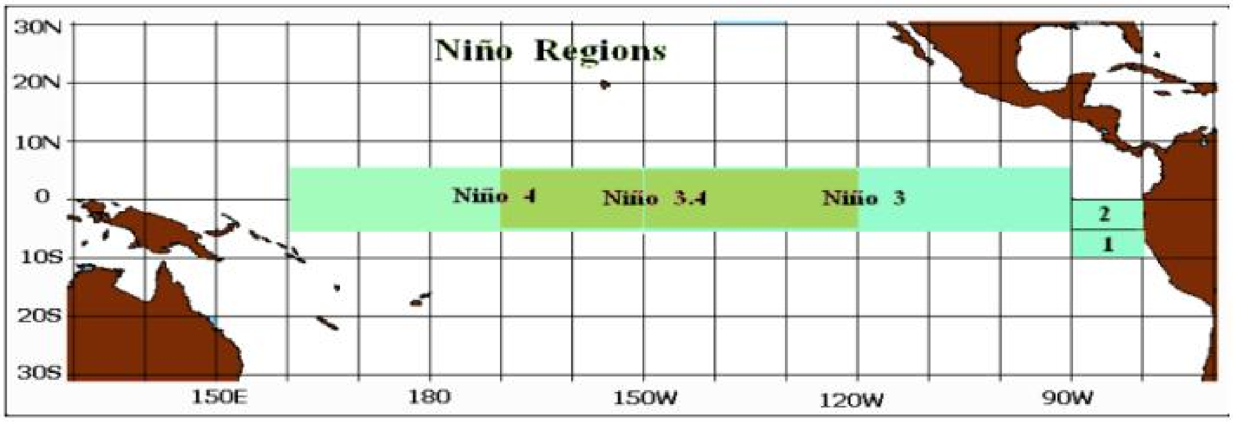


Figure 4. 1: Geographical extent of the currently defined El Niño regions

Source: http://www.cgd.ucar.edu/cas/catalog/climind/TNI_N34/index.html

Zonal level data on crop production were collected from the Central Statistical Agency for the period 2004-2015 inclusive, for which relatively good quality data were available. The short rainy season, *Belg* season, production was not included in this study for two reasons: its contribution to the annual total is not significant; it is much less than its national average contribution (Alemayehu and Bewket, 2016); and the *Belg* season crop production data were not available on consecutive year in the study area.

4.2. Estimating Missing Values Using Simple Linear Regression Model

Time Series is a sequential set of data measured over time. Thus, a set of data depending on time is called a time series; in this study, temperature and rainfall from 1984 to 2013 represent the time series. The analysis of time series data constitutes an important area of statistics (Fung, 2006; Afsar *et al*., 2013). Since, the data records are taken through time, missing observations in time series data are very common. This occurs because an observation may not be made at a particular time owing to faulty equipment, lost records, or a mistake, which cannot be rectified until later. When one or more observations are missing, it is necessary to estimate the missing values from past-observed values by applying simple linear regression. By including estimated missing values, a better understanding of the nature of the data is possible with more accurate result of the analysis to achieve the stated objectives in this study.

Simple linear regression analysis describes the estimation of the unknown (missing) value of one variable from the known value of the other variable. There are two types of variables in simple linear regression analysis first tell us that the variable whose value is influenced or is to be predicted is called the dependent variable and the variable which influences the values or is used for prediction is called independent variable. Therefore, simple linear regression is the measure of the average relationship between two or more variables in terms of the original units of the data (Afsar *et al.,* 2013)**.**

As described in the previous section CFSR weather data includes daily rainfall and temperature from 1/1/1979 to 31/7/2014. Daily data were converted to monthly data using excel spreadsheet since monthly data were required to achieve the study objectives. However, there were missing values from 2014 to 2016 inclusive. Therefore, in this thesis work simple linear regression equation from 1984 to 2013 was employed as a model to estimate missing values of rainfall and temperature (maximum and minimum) for all months from 2014 to 2016. Simple linear regression model is expressed as:

$$Y = a + bX \qquad (1)$$

Where

*Y is the response/ estimated value (rainfall, maximum and minimum temperature), X is explanatory variable (observation period), a is the intercept (the point where the line meets the Y-axis, where X = 0) and b is the slope (gradient) of the line also called the regression coefficient. If b positive means, an increase in X leads to an expected increase in response variable Y and negative in X means, an expected decrease in response variable Y(*Afsar *et al.,* 2013).

Table 4. 1: Regression equations of each station to estimate missing values of RF, Tmax and Tmin

CFSR Stations	Equations		
	RF	Tmax	Tmin
GW1	Y = 152.86- 0.22X	Y = 22.01+0.007X	Y = 8.52+0.001X
GW2	Y = 97.29+ 0.045X	Y = 21.24+0.0007X	Y = 7.84-0.0015X
GW3	Y = 28.63- 0.005X	Y = 25.77+0.002X	Y = 11.42-0.001X
GW4	Y = 48.55-072X	Y = 25.42+0.009X	Y = 9.77-0.0003X
GW5	Y = 100.88-0.141X	Y= 22.38+0.009X	Y = 8.13+0.0006X
GW6	Y = 78.93-0.033X	Y = 20.76+0.003X	Y = 7.00-0.0014X
GW7	Y = 35.26-0.0168X	Y = 24.73+0.002X	Y = 9.70+0.0005X
GW8	Y = 72.36-0.12X	Y = 22.65+0.017X	Y = 8.11+0.001X
GW9	Y = 48.92-0.074X	Y = 23.35+0.005X	Y = 9.44+0.001X
GW10	Y = 19.52-0.023X	Y = 26.89+0.006X	Y = 7.33+0.0006X
GW11	Y = 91.52-0.065X	Y = 27.26-0.014X	Y = 5.63-0.001X
GW12	Y = 137.31-0.14X	Y = 18.65+0.005X	Y = 5.63-0.0014X
GW13	Y = 73.41-0.064X	Y = 22.59+0.0008X	Y = 6.52-0.0002X
GW14	Y = 16.40+0.021X	Y = 26.70+0.005X	Y = 9.11+0.0012X
GW15	Y = 76.21+0.094X	Y = 21.74+0.002X	Y = 7.37+0.0018X
GW16	Y = 172.62-0.128X	Y = 18.24+0.006X	Y = 5.911+0.0023X
GW17	Y = 22.49-0.053X	Y = 28.56+0.009X	Y = 9.91+0.0027X
GW18	Y = 24.39-0.020X	Y = 23.73+0.01X	Y = 8.81+0.0049X
GW19	Y = 110.92-0.025X	Y = 19.71+0.015X	Y = 7.045+0.009X

4.3. Evaluation of CFSR Climate Data

As described in the previous section, the CFSR weather is produced using cutting-edge data-assimilation techniques (both data of ground meteorological stations and satellite irradiances) as well as highly advanced (and coupled) atmospheric, oceanic, and surface-modeling components at ~38 km resolution (Saha *et al.,* 2010). This indicates that the production of CFSR data involves various spatial and temporal interpolations of ground meteorological stations of weather data presented on the study area, other nearby ground meteorological stations weather data and satellite products. It is uncertain whether this process would yield similar climatic results to the ground meteorological stations weather data, which is one reason for this evaluating assessment using meteorological gauge stations. Comparison of climate data (rainfall and temperature) from CFSR is done usually with ground meteorological stations data because it measures climate data directly.

The relationship of mean annual CFSR data (rainfall and temperature) with mean annual ground meteorological stations data (rainfall and temperature) could be studied by applying statistical analysis, correlation, to see how well the two data sets were associated for the stations. Correlation is commonly used in research and measurement studies, including studies conducted to obtain validity and reliability evidence (Goodwin and Leech, 2006). For comparison of CFSR data with the gauge data, four ground meteorological stations for temperature and five ground meteorological stations for rainfall, which have less number of missing value and continuous record compared to the other stations for the period of 2000-2013, were used in this study. The spatial coverage of gauge and CFSR stations used for this thesis work are distributed as shown in Figure 4.2. Stations of the two data sets which have higher proximity to each other were correlated to evaluate the relationship between the CFSR and ground meteorological stations data set.

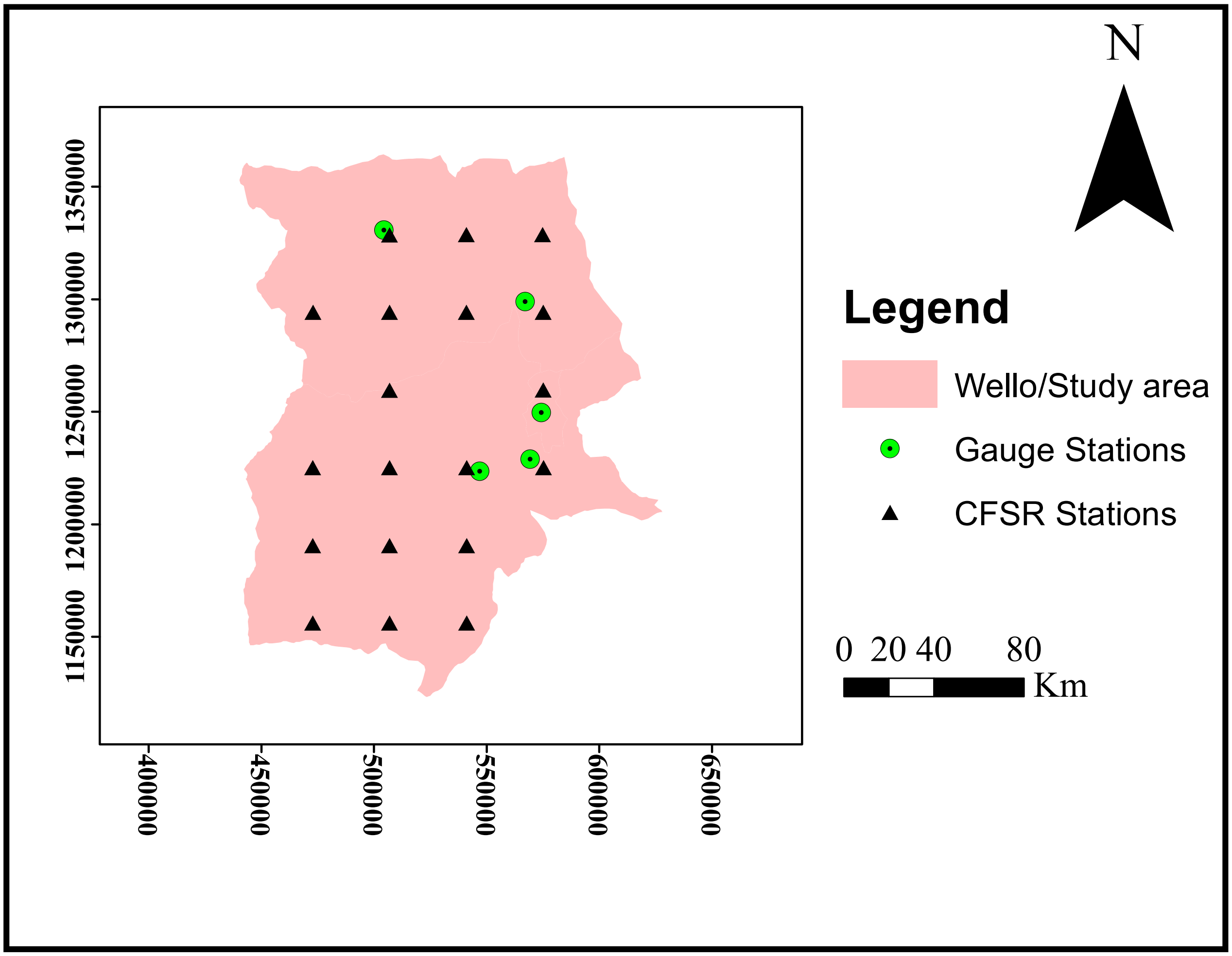


Figure 4. 2: Ground meteorological/Gauge and CRSR stations

The average value for annual CFSR rainfall and temperature (maximum and minimum) and the corresponding gauged average annual rainfall and temperature (maximum and minimum) were taken to test the reliability of the CFSR climate data. The results of correlation of CFSR rainfall and temperature (maximum and minimum) with ground meteorological stations of rainfall and temperature (maximum and minimum) observations for the period of 14 years from 2000 to 2013 inclusive is shown in table 4.2. It shows the correlation coefficient (r) and p-value for testing the statistical significance of correlation between the two weather data sets. From correlation analysis, it was observed that the correlation of mean annual rainfall and temperature (both maximum and minimum) between the two weather data sources were positive, high and statistically significant at p-value 0.01 level in all stations, indicating that CFSR weather data were of good quality to analyses climatic variability and trends in the study area. As to this analysis, similar results were reported in the study made by Admasu (2004) who made a comparison between satellite and gauge estimate rainfall and Dile *et al*. (2014) who evaluated the performance of CFSR climate data using ground meteorological stations gauge data. This implied that CFSR weather could be a valuable option to use in this study area where ground meteorological stations gauges are not available.

Table 4. 2: Correlation coefficient (r) and p-value of rainfall, maximum and minimum temperature from correlation analysis between CFSR and ground meteorological stations gauge stations

Stations		**Rainfall**	
Gauge Stations	CFSR Stations	r	P-value
Lalibela	GW1	0.955	0.0001
Sirinka	GW2	0.872	0.0005
Haik	GW3	0.793	0.0007
Dessie	GW4	0.878	0.0004
Kombolcha	WG5	0.977	0.0002
Stations		**Maximum Temperature**	
Gauge Stations	CFSR Stations	r	P-value
Lalibela	GW1	0.773	0.0012
Sirinka	GW2	0.769	0.0013
Haik	WG3	0.826	0.0003
Kombolcha	GW5	0.787	0.0008
Stations		**Minimum Temperature**	
Gauge Stations	CFSR Stations	r	P-value
Lalibela	GW1	0.787	0.0008
Sirinka	GW2	0.744	0.0023
Haik	WG3	0.800	0.0006
Kombolcha	GW5	0.732	0.003

4.4. Techniques of Data Analysis

4.4.1. Spatial Interpolation by Ordinary Kriging

Sample data can provide valuable information, but due to many constraints, it is difficult to get the whole region sample data. Therefore, geo-statistical models predict the value in un-sampled location and quantify the uncertainty of prediction.

Geo-statistical interpolation method, ordinary kriging, was employed in this study to generate surface maps for rainfall and temperature of the study area and to examine specific sample points to obtain a value for spatial autocorrelation that is only used for estimating around that particular point; rather than weighting nearby data points by some power of their inverted distance (IDW) which depends solely on distance to the prediction location. Ordinary kriging is one of the best estimation approaches of weather conditions at un-sampled location in which the region is large and limited low density of base stations where the distribution of the station is unrepresentative of topographic variability and geographic features (Hunter and Meentemeyer, 2005). Ordinary kriging is an effective spatial interpolation and mapping tool, because it honors data locations provides unbiased estimates at un-sampled locations, and provides for minimum estimation variance, i.e. a best linear unbiased estimator (Jantakat and Ongsomwang, 2011 cited in Getahun and Shefne, 2015). With the ordinary kriging method, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points.

$$\acute{Z}(So) = \sum_{i=1}^{N} (\lambda i Z(Si) \qquad (2)$$

Where

$Z(Si)$ *is the measured or computed value (in this case rainfall and temperature) at* i^{th} *location* λi *is an unknown weight for the measured value at the* i^{th} *location* So *is the prediction location and N is the number of locations where rainfall and temperature values were measured.*

4.4.2 Correlation Analysis

Correlation and regressions techniques are important in showing the relationship between climatic parameters and crop production, and to identify the most predictor variable. Lemi (2005); Bewket (2009); Tunde *et al*. (2011); Rowhani (2011); Adamgbe and Ujoh (2013) and Akinseye *et al*. (2013) used the same methodology in their study of the relationship between climate variables and crop production.

To determine the effect of climatic variables, namely rainfall (monthly, seasonal and annual rainfall totals) and temperature (maximum and minimum) on crop production in the study area, coefficient of determination (R^2) from simple linear regression analysis was used. In addition to estimating missing values, regression analysis was also employed to quantify the influence of temperature and rainfall on crop yields per hectare.

To test the association between seasonal and annual rainfall and temperature with seasonal and annual SST, Pearson correlation was employed in this study area. The Pearson correlation coefficient (r) is a measure of the linear relationship between two variables X and Y, giving a value between +1 and -1 inclusive, where 1 is total positive correlation, 0 is no correlation, and -1 is negative correlation. The strength of the correlation is not dependent on the direction or the sign. A positive correlation coefficient indicates that an increase in the first variable would correspond to an increase in the second, implying a direct relationship. A negative correlation indicates an inverse relationship (Abigail, 2015). It is widely used in the science field as a measure of the degree of linear relationship between two variables (Guo *et al*., 2014). The absolute value of the correlation coefficients (r) was into a weak correlation ($0 < |r| \leqslant 0.3$), a low correlation ($0.3 < |r| \leqslant 0.5$), a moderate correlation ($0.5 < |r| \leqslant 0.8$), and a strong correlation ($0.8 < |r| \leqslant 1$) (Changbin *et al*., 2014). The mathematical formulation of Pearson correlation is presented as follows;

$$r_{xy} = \frac{\left[\sum xy - \frac{\sum x \sum y}{n}\right]}{\sqrt{\left(\sum x^2 - \frac{(\sum x)^2}{n}\right)\left(\sum y^2 - \frac{(\sum y)^2}{n}\right)}} \qquad (3)$$

Where

r_{xy} is correlation coefficient, x and y are correlated variables i.e in this case x is SST whereas y is temperature and rainfall, which were individually correlated with SST.

4.4.3. Trend Analysis

In all region of Ethiopia, the majority of population relies largely on agricultural sector. All food crop production in the country depends on rainfall and temperature. Rainfall and temperature shows systematic and irregular variation over time. These variations play significant role in adopting farming systems, agricultural planning, crop selection and thus productivity. Characterization of these systematic variations is very helpful in rain-fed agriculture.

Detection of such abrupt or gradual changes in hydrologic records is of considerable scientific and practical importance, being fundamental for planning of water resource and related issues. The change in quantity and distribution of annual and seasonal rainfall and temperature directly affect the availability of water and crop production in a region. It is important to know whether there is significant change in rainfall quantity so that this information may be useful for practitioner to improve water resources and agricultural planning.

Analysis of rainfall for agricultural purpose must include information concerning the gradual change (trend), the start, end and length of rainy season, the distribution of rainfall amounts through the year, etc (Admasu, 2004). However, the objective in this thesis work is to identify whether total annual and seasonal rainfall, mean annual and seasonal temperature (maximum and minimum) and mean annual and seasonal SST data show significant changes recently in Wello during the observation period (from 1984 to 2016, inclusive).

This study used non-parametric statistical tests, the Mann-Kendall (MK) trend test to evaluate the statistical significance of trends (Ndiritu, 2005; Burns *et al*., 2007; He *et al*., 2012; Changbin et al., 2014) using XLSTAT 2017. MK test is non-parametric test, which tests for a trend in a time series without specifying whether the trend is linear or non-linear. The null hypothesis Ho is that a sample data Yi, i = 1,2…n doesn't change as a function of time (Yue *et al*., 2002). Unlike ordinary least squares regression, the Mann-Kendall trend test is less affected by missing values and uneven data distribution, and are robust towards extreme values (Udelhoven, 2011). To identify the magnitude of trend, Sen's slope has been calculated (Changbin *et al*., 2014; Nayak *et* *al*., 2010; Yin *et al*., 2011) which is a form of robust linear regression and less affected by gross data errors or outliers compared to linear regression analysis (Bouza *et al*., 2008).

The Mann-Kendall test analyzes the sign of the difference between later-measured data and earlier-measured data. Each later-measured value is compared to all values measured earlier; resulting in a total of n (n-1)/2 possible pairs of data, where n is the total number of observations. The Mann-Kendall test assumes that a value can always be declared less than, greater than, or equal to another value; that data are independent (Donald *et al*.,2011).

To perform a Mann-Kendall test, compute the difference between the later-measured value and all earlier-measured values, $(X_j - X_i)$where j>i, and assign the integer value of 1, 0, or –1 to positive differences, no differences, and negative differences, respectively. The test statistic, S, is then computed as the sum of the integers:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(X_j - X_i) \qquad (4)$$

Where

$\text{sign}(X_j - X_i)$*, is equal to +1, 0, or -1 as indicated above (Donald et al., 2011*).

When S is a large positive number, later-measured values tend to be larger than earlier values and an upward trend is indicated. When S is a large negative number, later values tend to be smaller than earlier values and a downward trend is indicated. When the absolute value of S is small, no trend is indicated.

The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend (Worku, 2016). If the value is less than the significance level α (alpha) = 0.05, H0 (null hypothesis) is rejected. Rejecting H0 indicates that there is a trend in the time series, while accepting H0 indicates no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant.

Similarly, the trend was quantified using Sen’s slope method. Sen’s slope is another index to quantify the trend using the nonparametric procedure developed by Sen (Mishra, 2010).

$$Q_i = \frac{X_j - X_k}{j-k} \text{ For i} = 1, 2, 3, \ldots, N \quad (5)$$

Where

X_j and X_k are data values at time j and k (j > k), respectively. The median of these N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by Qmed = Q (N + 1)/2, and if N is even, the Sen's estimator is computed by Qmed = [QN/2+ Q (N + 2)/2]/2.

4.4.4. Analysis of Variations in Rainfall and Temperature

Coefficient of variation is a widely applied method of variability analysis of rainfall and temperature (Beyene, 2016). Coefficient of variation (CV) provides a measure of year-to-year variation in the data series (Admasu, 2004). According to Cherkos (2001), NMSA (1996) and Hare (1983) CV is used to classify the degree of variability of rainfall events as less (CV < 20), moderate (20 < CV < 30), high (CV > 30), very high CV>40% and CV>70% indicate extremely high inter-annual variability of rainfall. Similarly, in this study coefficient of variation (CV) (standard deviation divided by the mean) was used in analyzing the variations in rainfall and temperature. Scientifically, it is computed using the following formula:

$$CV = \left(\frac{S}{X}\right) 100 \quad (6)$$

Where

CV is Coefficient of variation, S is the standard deviation and X mean for annual and seasonal rainfall totals and temperature of 33 years from 1984 to 2016 inclusive.

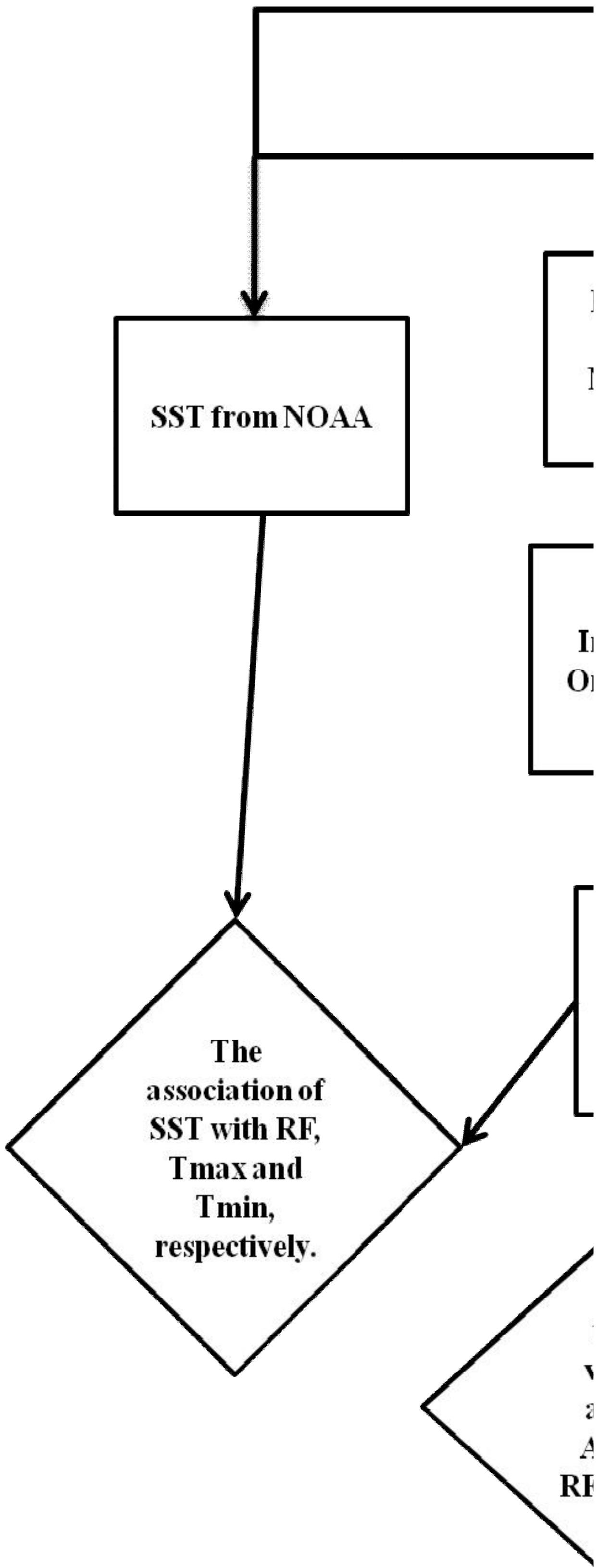


Figure 4. 3: Schematic flow chart that describes the methodology of the study

CHAPTER FIVE

5. RESULTS AND DESCUSSION

This chapter provides the results of the analysis of climate variability as a determinant factor for agricultural activities in the study area.

5.1. The Spatial Distribution and Temporal Fluctuations of Total Seasonal and Annual Rainfall (RF), Mean Seasonal and Annual SST, Tmax and Tmin

5.1.1. Temporal Fluctuations of Total Seasonal RF and Mean Seasonal SST in Wello

The long-term (from 1984 to 2016) total *Kiremt* RF reached highest and lowest values of 801.22mm and 182.7mm in 1994 and 1984, respectively. Whereas, the long-term mean value of the SST for the *Kiremt* season has highest and lowest values of $28.92°C$ and $25.59°C$ in 2015 and 1988, respectively over the study period. Long-term total *Belg* RF would have experienced the highest value of 519.72mm in 1987 and the lowest value of 37.10mm in 2008. Moreover, in the analysis of mean *Belg* SST, the highest value of $28.9°C$ and the lowest value of $26.23°C$ were observed in 1992 and 2008, respectively across the study area. Change curves of total *Kirem*t RF and mean *Kiremt* SST were fluctuating in an opposite direction from 1984 to 2015. However, from 2015 to 2016 the variation is slightly in the same direction (Figure 5.1). On the other hand, the variation of total *Belg* RF and mean *Belg* SST was in the same direction from 1985 to 1990, from 1997 to 2001 and from 2005 to 2011, while from 1990 to 1992 and from 1995 to 1996 the observed variation was in opposite direction (Figure 5.2). From this, it was observed that the variations of total *Belg* RF and mean *Belg* SST were almost in the same direction during the last 33 years across the study area. Throughout the study period, the highest and the lowest values of total *Bega* RF were 197.32mm in 2014 and 8.18mm in 1994, respectively, while the maximum and minimum Mean *Bega* SST recorded were $28.81°C$ in 2015 and $25.13°C$ in 1988, respectively (Figure 5.3). From the figure it was pointed out that the direction of variations of both total *Bega* RF and mean *Bega* SST was the same in most years of the study period undertaken. Likewise, the highest and the lowest values of long-term total annual RF were 1098.19mm in 1998 and 359.77mm in 1984, respectively. The highest value of mean annual SST was $28.62°C$ in 2015, while the lowest value was $25.96°C$ in 1999 (Figure 5.4).

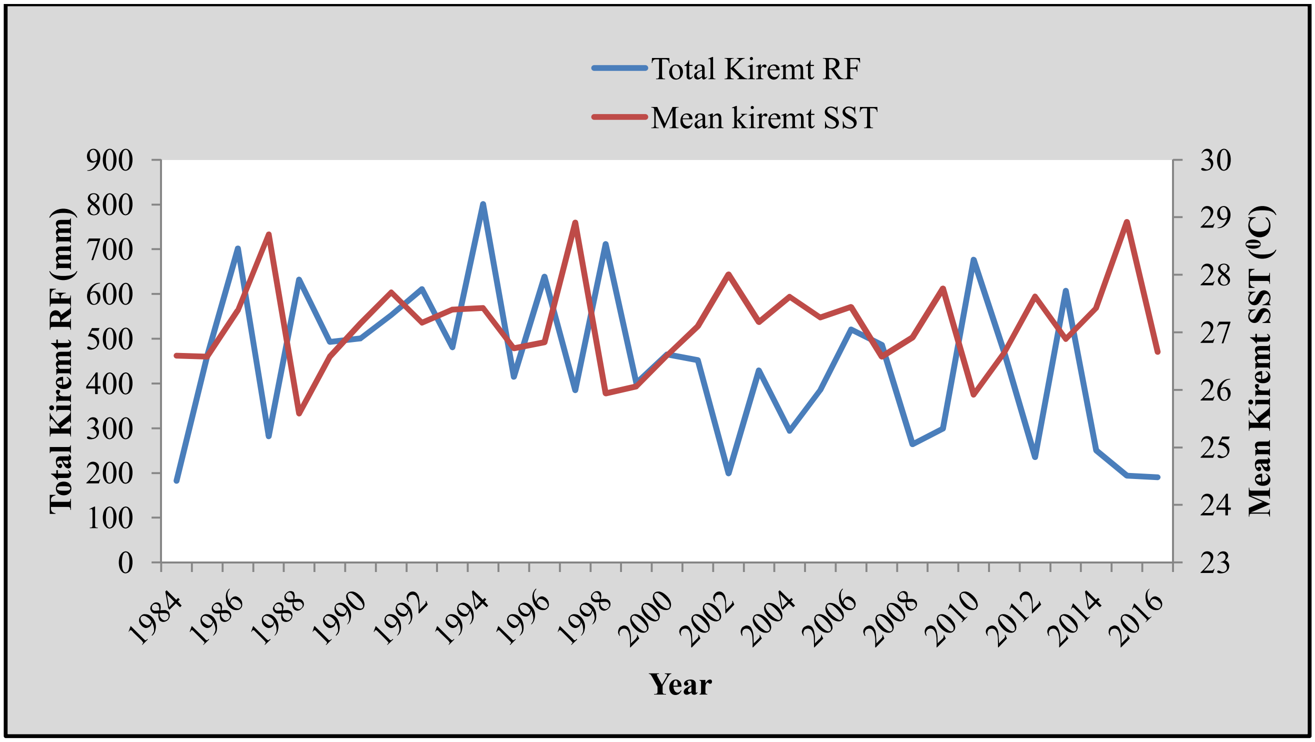


Figure 5. 1: Fluctuations of total *Kiremt* RF and Mean *Kirem*t SST of the study area from 1984 to 2016

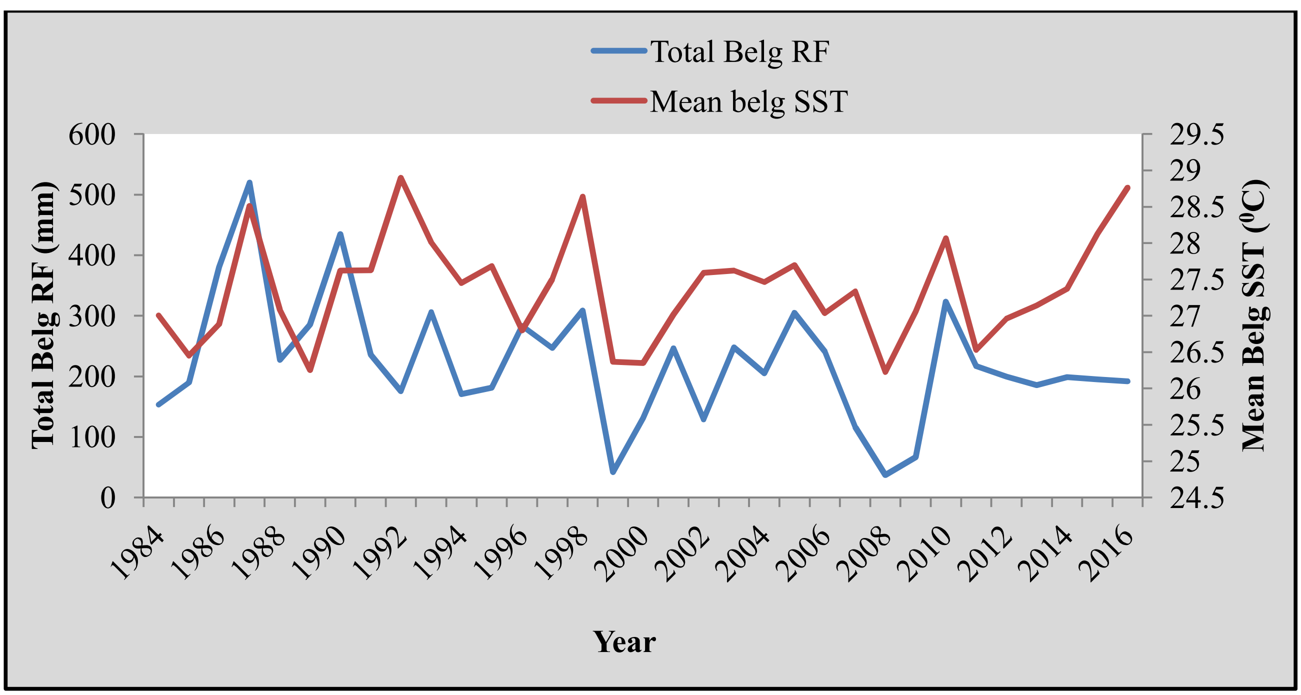


Figure 5. 2: Fluctuations of total *Belg* RF and Mean *Belg* SST of the study area from 1984 to 2016

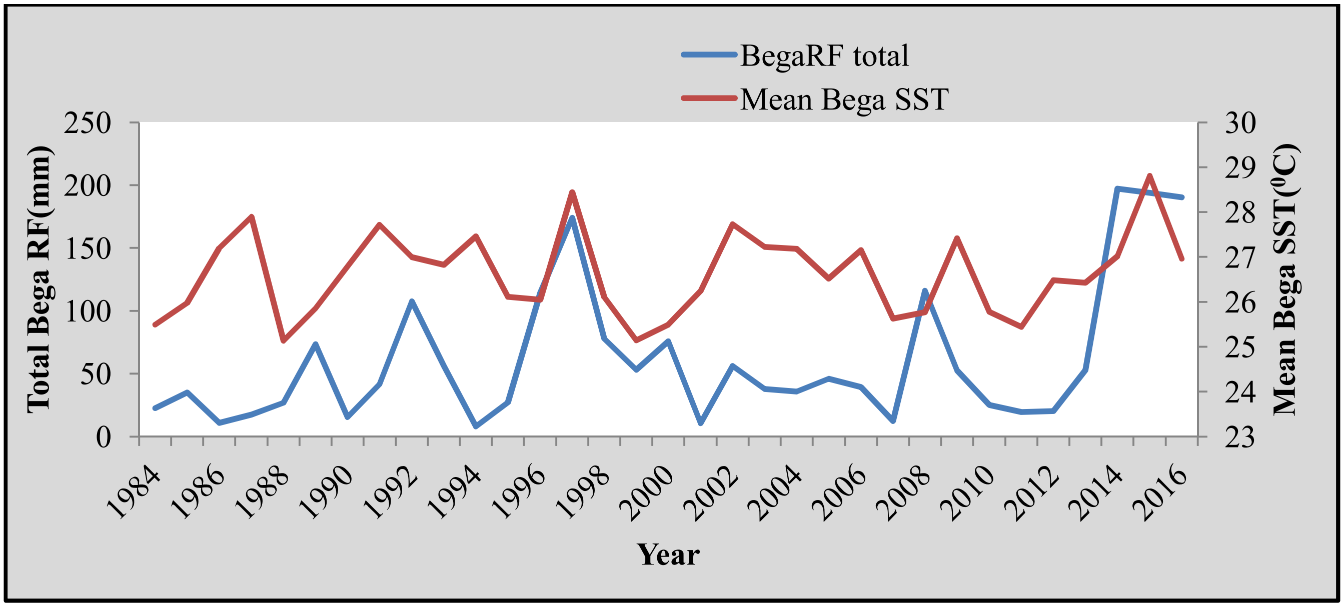


Figure 5. 3: Fluctuations of total *Bega* RF and Mean *Bega* SST of the study area from 1984 to 2016.

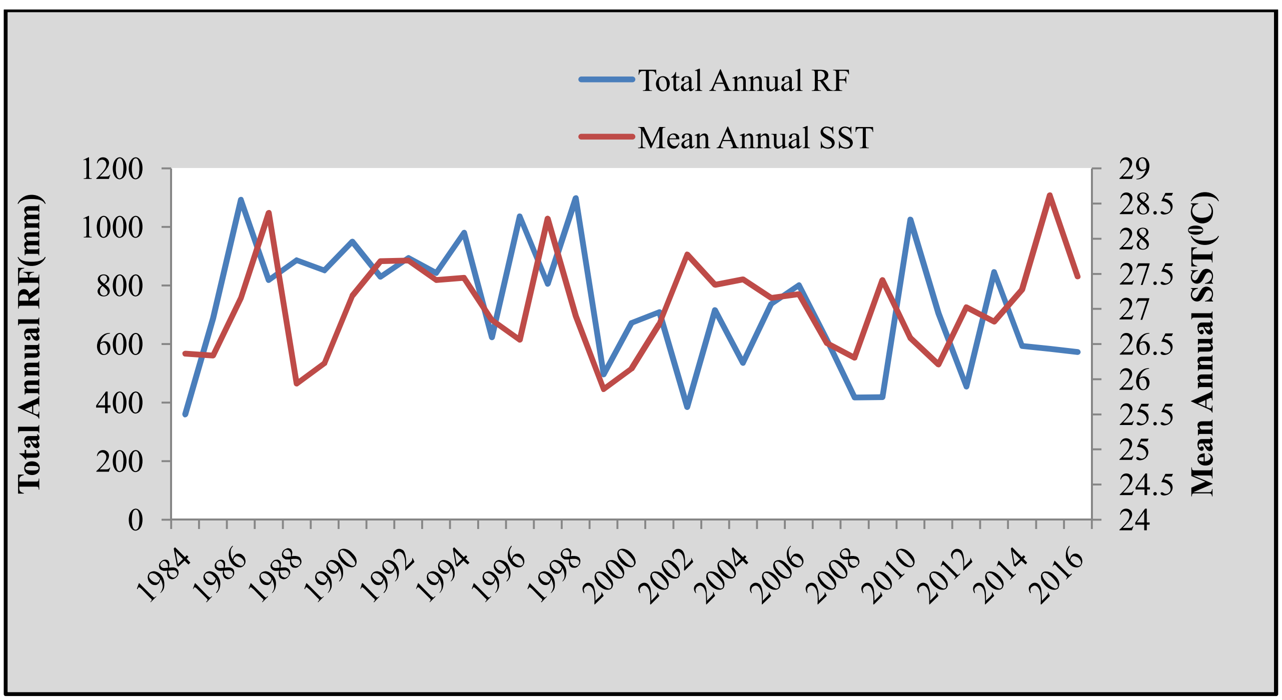


Figure 5. 4: Fluctuations of total Annual and Mean Annual SST of the study area from 1984 to 2016.

5.1.2. Temporal Fluctuations of Mean Seasonal and Annual Temperature (Tmax and Tmin)

The results of temporal analyses revealed that the highest mean *Kirem*t Tmax was 25.16°C in 2004 and the lowest mean *Kiremt* Tmax was 20.25°C in 1986. Here, the variety between the highest and the lowest Tmax value is low, which implied that the fluctuation (fall/rise movement) of mean *Kiremt* Tmax was less as compared to mean *Kiremt* SST throughout the study years. Change curves of mean *Kiremt* Tmax and mean *Kirem*t SST were fluctuates almost in the same direction of most years i.e. as the change curve of Tmax increases, SST curve also increases and vice versa(Figure 5.5). In *Belg* season, the highest and the lowest values of Tmax were 38.77°C in 1991 and 23.55 in 2014, respectively. The direction of variations of both mean *Belg* Tmax and SST was almost opposite in most years of the study period. In the present study, the increment of mean *Belg* SST implied that the decrement of mean *Belg* Tmax over all the study period and the inverse was true (Figure 5.6).

The long-term analysis of mean *Bega* Tmax revealed a variation with values ranging from 22.49°C in 1996 to 24.86 in 2004 and the change curves f both mean *Bega* Tmax and SST were varied almost in the same direction (Figure5.7). The study also pointed out that fluctuation of the mean annual Tmax in the study area was slight throughout the years except 1991 in which the highest value (27.98°C) of mean annual Tmax was observed (Figure 5.8).

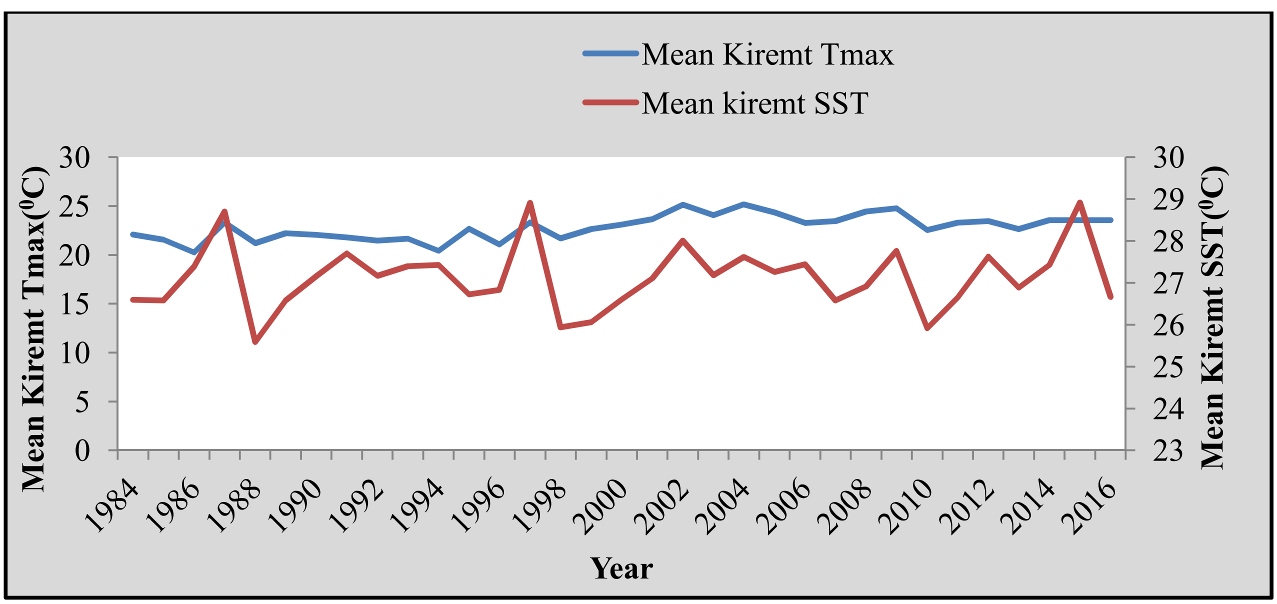


Figure 5. 5: Fluctuations of Mean *Kiremt* Tmax and SST of the study area from 1984 to 2016

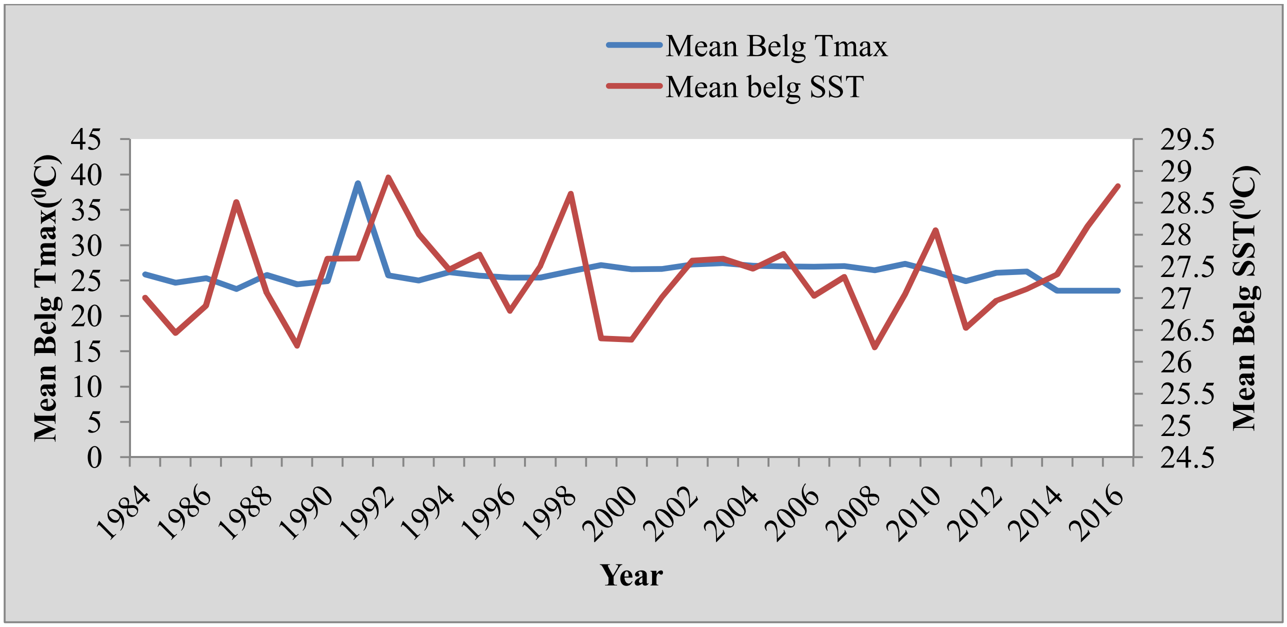


Figure 5. 6: Fluctuations of Mean *Belg* Tmax and SST of the study area from 1984 to 2016

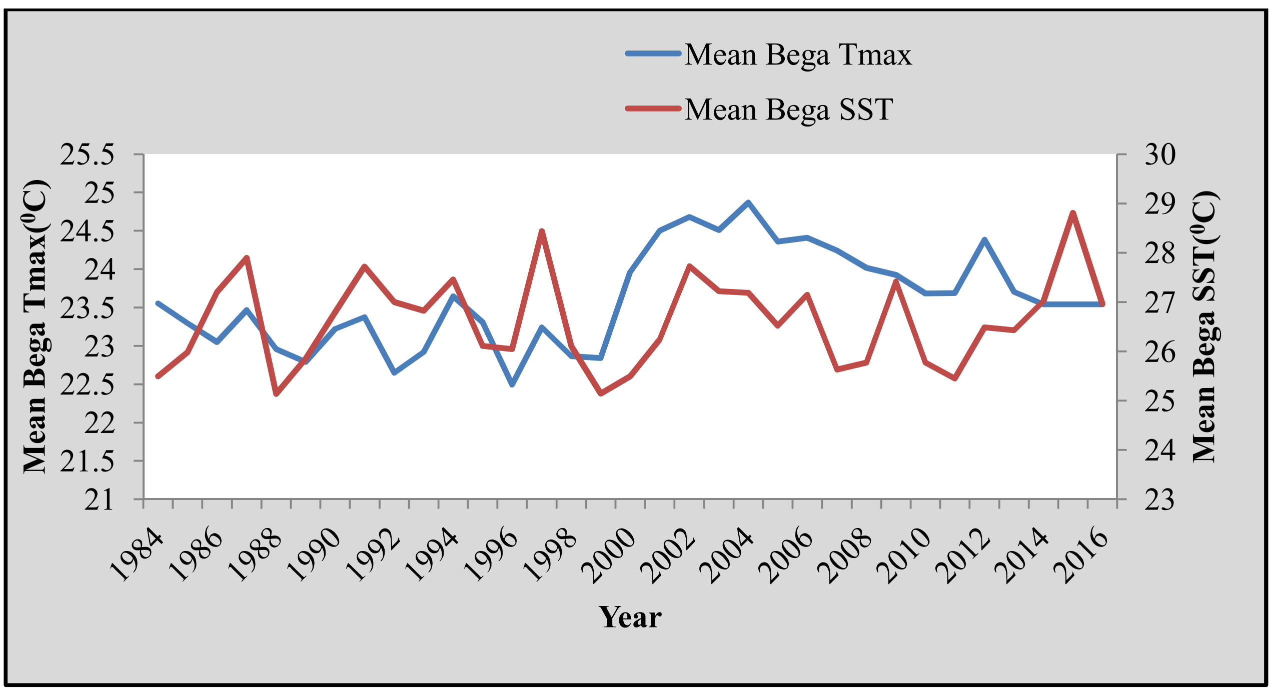


Figure 5. 7: Fluctuations of Mean *Bega* Tmax and SST of the study area from 1984 to 2016

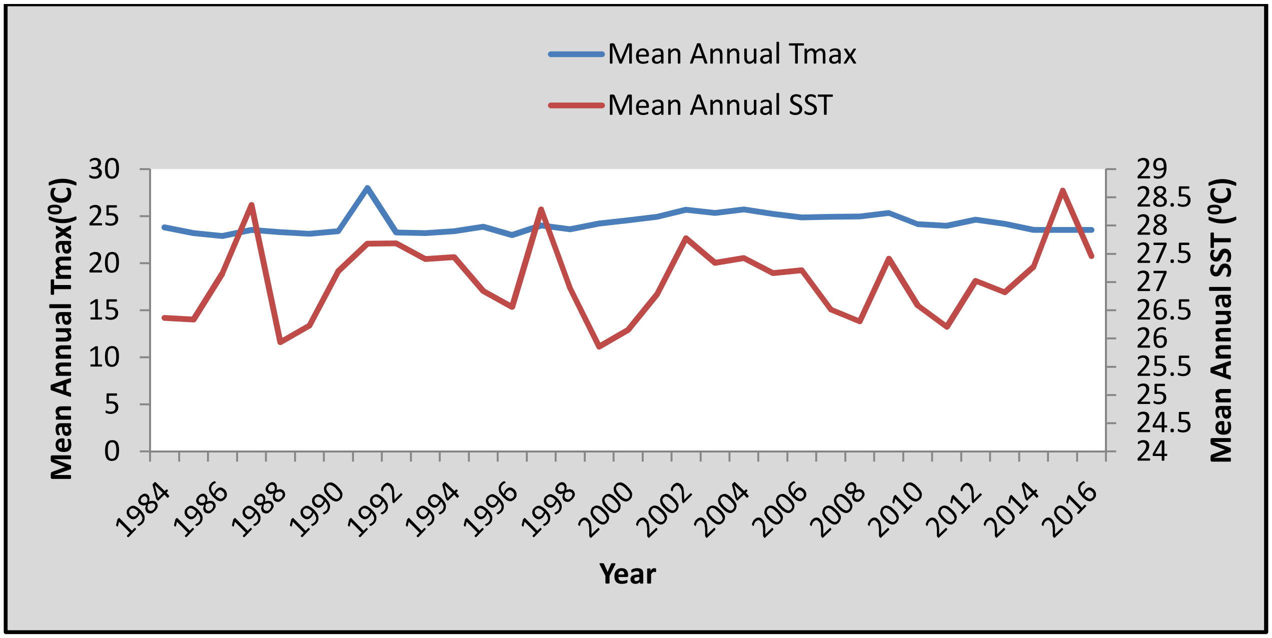


Figure 5. 8: Fluctuations of Mean Annual Tmax and SST of the study area from 1984 to 2016

Moreover, the change curves of 33 years seasonal and annual minimum temperature (Tmin) were presented as below. It was observed that the change curves of mean Seasonal and annual Tmin, and the corresponding SST were fluctuated almost in the same direction except the change curves of mean *Kiremt* Tmin and Mean *Kiremt* SST, which were fluctuated nearly in the opposite direction (Figure 5.9, 5.10, 5.11 and 5.12)

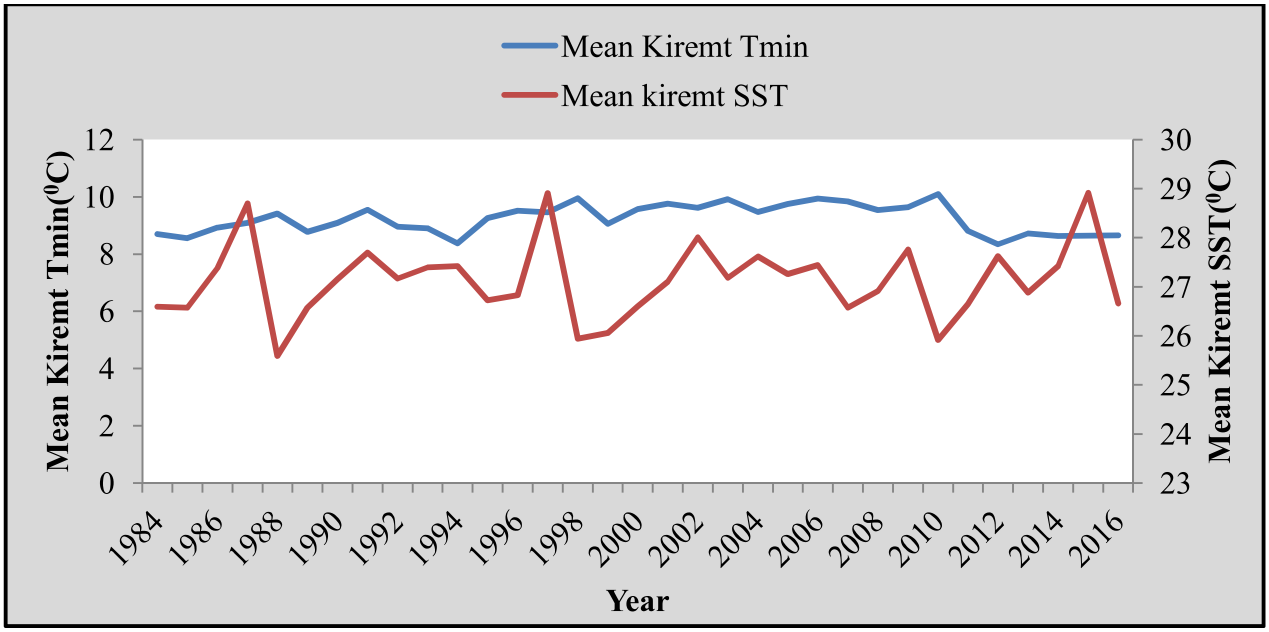


Figure 5. 9: Fluctuations of Mean *Kiremt* Tmin and SST of the study area from 1984 to 2016

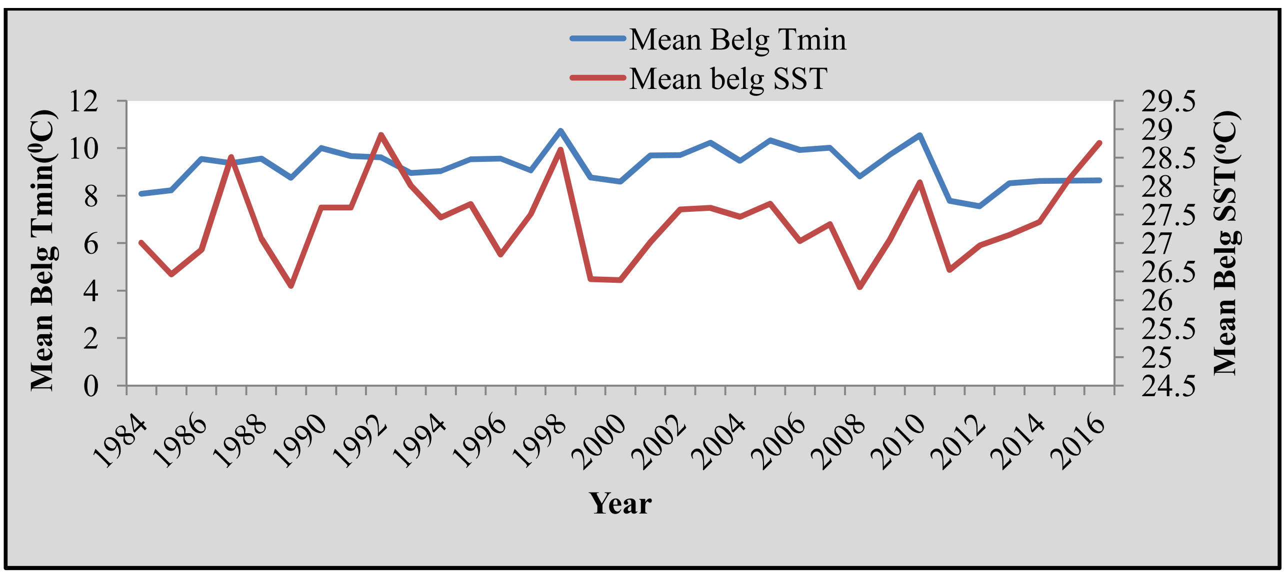


Figure 5. 10: Fluctuations of Mean *Belg* Tmin and SST of the study area from 1984 to 2016

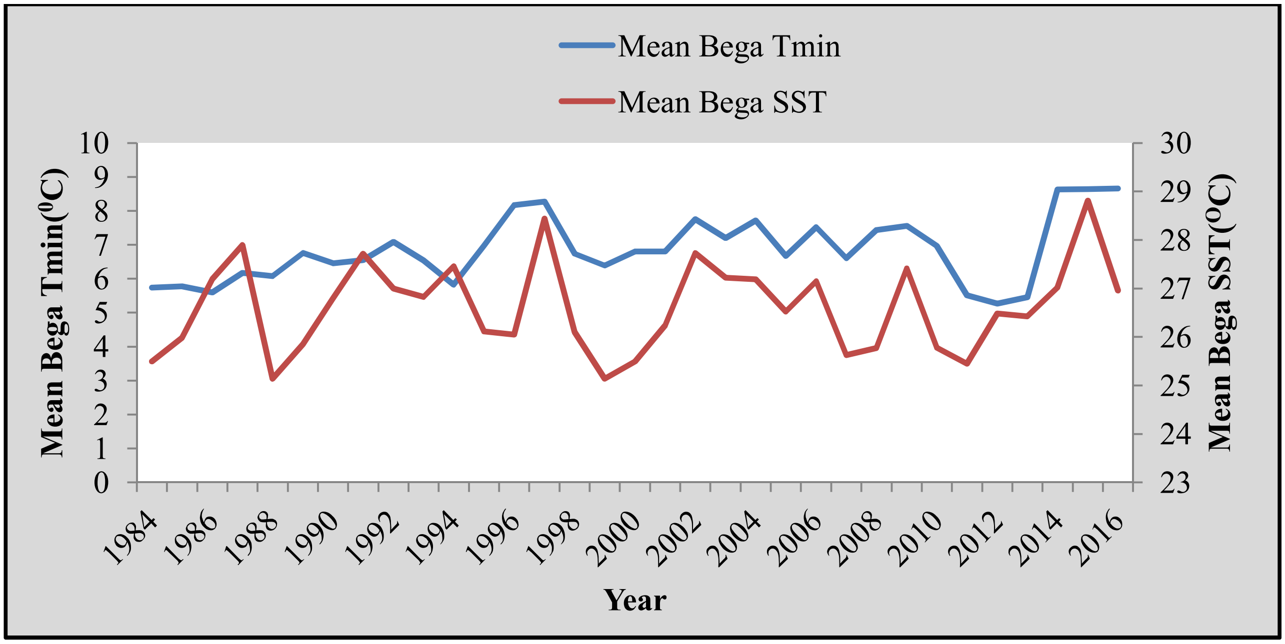


Figure 5. 11: Fluctuations of Mean *Bega* Tmin and SST of the study area from 1984 to 2016

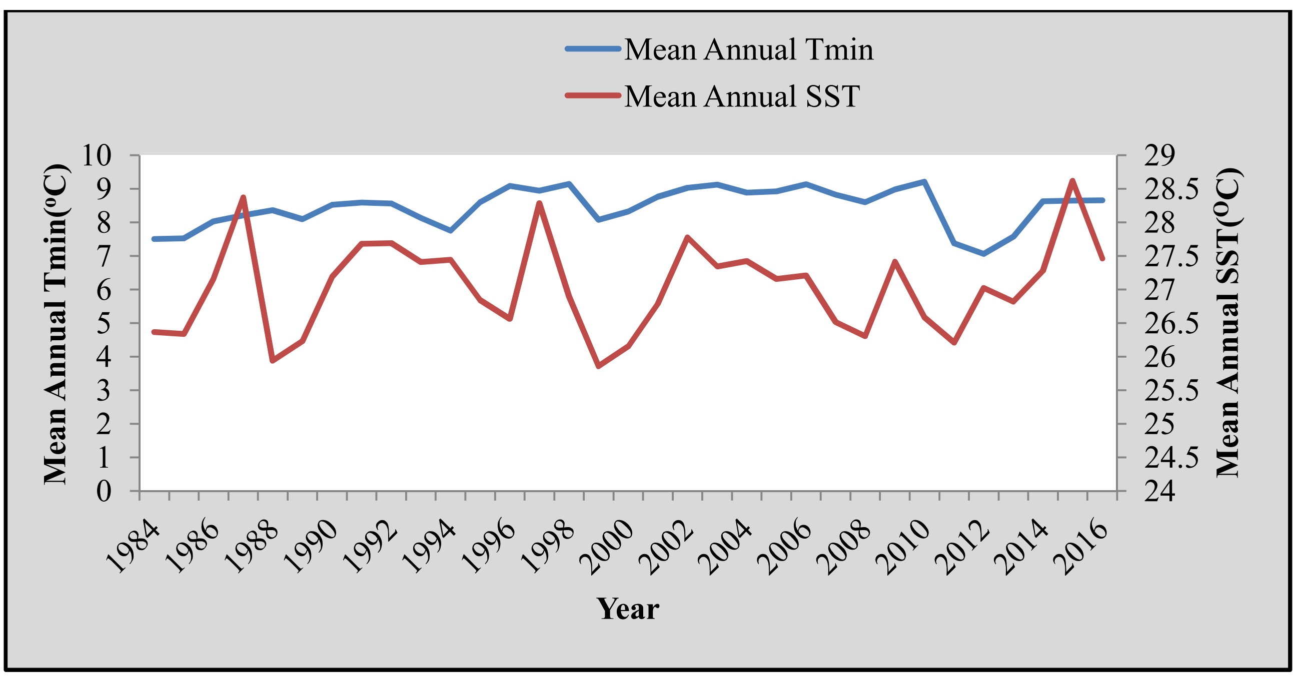


Figure 5. 12: Fluctuations of Mean Annual Tmin and SST of the study area from 1984 to 2016

Furthermore, to describe a trend of time series for both seasonal and annual RF, SST, Tmax and Tmin, Mann–Kendall trend test was used to see whether there is a decreasing or increasing trend, and it was quantified using Sen's slope across the study area for the last 33 years. Mann–Kendall statistics (S) is one of the non-parametric statistical tests used for detecting trends of climatic elements. Mann–Kendall trend test is also the most widely used methods since it is less sensitive to outliers (extraordinary high values within time series data) and it is the most robust as well as suitable for detecting trends in rainfall (Keredin *et al*., 2013). The MK test is based on the calculation of Kendall's tau (measures of connection between two successive seasonal and annual RF, Tmax, Tmin and SST).

The results of MK test analysis as shown in table 5.1 below revealed that during main rainy season locally known as *Kirem*t (JJAS) season, total RF was decreased by 9.076mm per *Kiremt* season and the trend was statistically significant, as the p-calculated is less than the significant level alpha 0.05, reflecting the changes in the total *Kiremt* RF across the study area for the observation period (1984-2016). In *Kiremt* season, the computed slope value of total RF was found to be negative, implying that the total RF amount declined from time to time across the study period in the study area. It is, therefore, clear that the rain-fed dependent population of Wello has suffering from surface and ground water shortage for their crop, livestock and for household consumptions. Unless measures should be taken, the adverse impacts of climate change will be more severe on the rural livelihoods since they are the direct victim among the society. In line with this, Zanke and Seleshi (2004) reported comparable result that number of Kiremt rainy days and number of *Kiremt* dry days showed decreasing and increasing change, respectively, over Ethiopia. An increasing change in number of *Kiremt* dry days indicates that rain fed crop production in the study area was at risk of soil moisture stress which resulted in crop failure (Zanke and Seleshi, 2004).

On the other hand, mean *Kirem*t Tmax, Tmin and SST were increased by 0.08℃, 0.014℃ and 0.007℃, respcetively and the trend was statistically insignificant except Mean Tmax at significant level alpha 0.05. In agreement with this finding, the study made by Addisu *et.al*., (2015) on time series trend analysis of temperature and rainfall in lake Tana Sub-basin, Ethiopia reported that the mean, maximum and minimum temperature had a general increasing trend; whereas, rainfall amount showed a general decreasing trend. In similar fashion, a recent report from Famine Early Warning System Network (FEWS NET) showed that there has been an increase in seasonal mean temperature in many areas of Ethiopia, Kenya, South Sudan and Uganda over the last 50 years Funk *et al*.(2012). In addition a study made by Getachew (2017) reported the increment trend of mean *Kiremt* of SST anomaly, which was comparable to the finding of this research. It is, therefore clear that development planners should design strategies and plans by taking into account a declining *Kiremt* rainfall and increasing temperature impacts on rural livelihood.

Moreover, it has been pointed out that MK trend rest showed a positive trend for mean Tmax, Tmin, SST and total RF per *Bega* Season and Tmax and Tmin were statistically significant, whereas RF and SST revealed insignificant trend at alpha level 0.05. For small rainy season, Belg, trend test showed a decreasing pattern by 3.46mm per *Belg* season, though it was not statistically significant at alpha level 0.05. Similar to the present study result, Muluken (2015) found the result that number of *Belg* rainy days showed decreasing and non-significant change in stations (Kobo, Lalibela and Kombolcha) in the nearby areas of northern Ethiopia. IPCC (2014) justified that this is due to rapid warming of Indian Ocean causing less rainfall over eastern Africa between March and May-June in the last 30 years. Overall, the magnitude and direction of small rainy season was not uniform due to its high inter-annual variability (42.45%≤CV≥87.69%) (Figure 5.23).

Moreover, to assess the presence of statistically significant trend on annual mean Tmax, Tmin, SST and total RF, non-parametric Mann–Kendall (MK) trend test was employed. Overall, the total annual RF was declined by 9.632mm per year. It was found to be statistically significant total annual RF irregularities across the whole recorded years in the study area (Wello) at the 5% level of significance. Similarly Seleshi and Zanke (2004), NMSA (2001), NMA (2007), Cheung *et al*. (2008), McSweeney *et al*. (2008), and Viste *et al*. (2012) also reported a declining tendency in annual rainfall across Ethiopia from 1960 to 2006. On the contrary, mean annual Tmax, Tmin and SST revealed a positive trend and statistically significance at alpha level 0.05 except mean annual SST. This implied that the mean of annual temperature change indicates significant variations of temperature observations increased for the last 33 years across the study area (Table 5.1). IPCC (2014) Fifth Assessment Report also presents strong evidence of warming over the lands of Africa in the last 50-100 years.

This implies that agricultural activities are highly vulnerable to such changes. Since agriculture is the backbone of the country's economy, productivity fluctuation directly influences the growth domestic products (GDP). This should be aggravated because of the low adaptive capacity of the rural poor and their full dependency on rain-fed agriculture for their livelihoods. Therefore, it is clear from the analysis that climate change is clearly happening in Ethiopia as well as in Wello and appropriate adaptation strategies should be properly designed and implemented.

Table 5. 1: Results of the Mann-Kendall trend test for Seasonal and Annual mean Tmax, Tmin, SST and total RF value for the study area.

Kiremt Season					
	Kendall's tau	S	p-value (Two-tailed)	Sen's slope	alpha
Total RF	-0.303	-160.000	0.013	-9.076	0.05
Mean Tmax	0.451	238.000	0.000	0.08	0.05
Mean Tmin	0.129	68.000	0.302	0.014	0.05
Mean SST	0.119	63.000	0.337	0.007	0.050
Bega Season					
	Kendall's tau	S	p-value (Two-tailed)	Sen's slope	alpha
Total RF	0.208	110.000	0.092	1.107	0.05
Mean Tmax	0.261	138.000	0.033	0.026	0.05
Mean Tmin	0.333	176.000	0.006	0.058	0.05
Mean SST	0.047	25.000	0.710	0.01	0.050
Belg Season					
	Kendall's tau	S	p-value (Two-tailed)	Sen's slope	alpha
Total RF	-0.212	-112.000	0.086	-3.46	0.05
Mean Tmax	0.114	60.000	0.364	0.028	0.05
Mean Tmin	0.19	528.000	0.001	0.9	0.05
Mean SST	0.061	32.000	0.634	0.006	0.050
Annual					
	Kendall's tau	S	p-value (Two-tailed)	Sen's slope	alpha
Total RF	-0.292	-154.000	0.017	-9.632	0.05
Mean Tmax	0.299	158.000	0.014	0.04	0.05
Mean Tmin	0.273	144.000	0.026	0.022	0.05
Mean SST	0.064	34.000	0.612	0.007	0.050

5. 1.3 Spatial Distribution of Mean Total *Kiremt* RF, Mean *Kiremt* Tmax and Tmin

Results of the analysis showed that the values of mean total RF, mean Tmax and Tmin were 473.26 mm, 22.76°C and 9.30°C, respectively in *Kiremt* season for the last 33 years. In *Kiremt* season, the amount of mean total RF, mean Tmax and mean Tmin revealed a spatial variation with values ranging from the lowest to the highest across the study area. The 33 years mean total RF was varied from 123.46 mm to 993.71 mm, mean Tmax was ranged from 18.48°C to 27.61°C and mean Tmin was between 6.91°C to 13.32°C across the study area in *Kiremt* season (Figure 5.13 and 5.14). Highest RF value was found in the Northern and Southeastern part of the study area, specifically in Lalibela, Dessie and Kombolcha (Figure 5.13). Also the Southeastern and some part of southern area were characterized by high Tmax, as well as Northeastern part of the study area experienced by high Tmin in *Kiremt* season (figure 5.14 (a) and (b)), respectively.

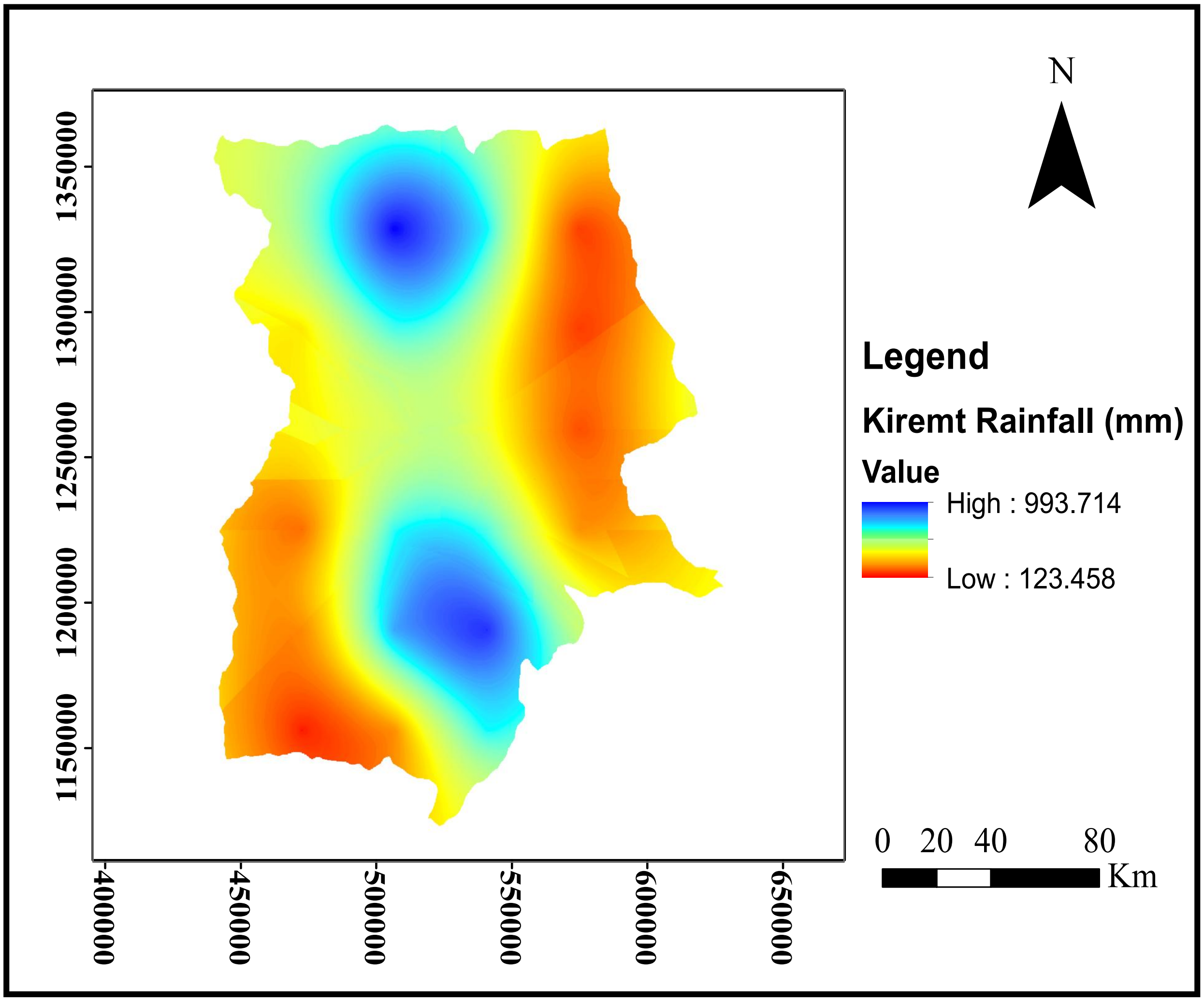
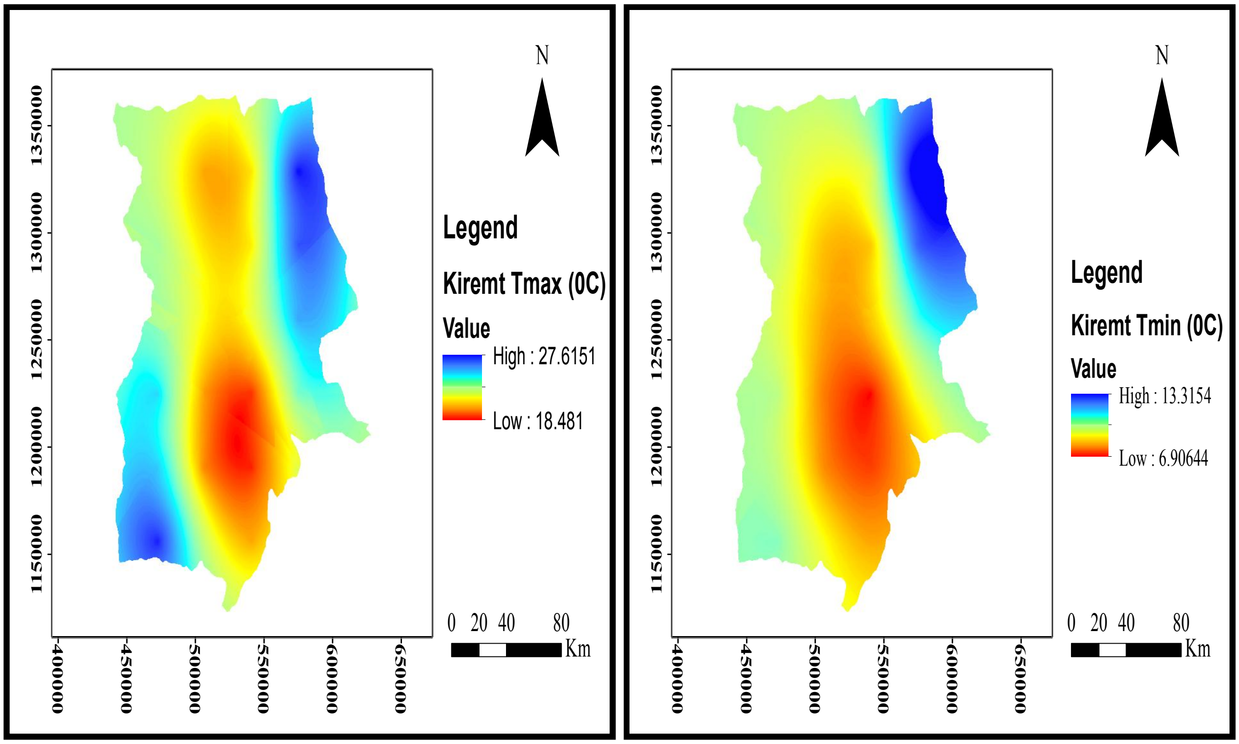


Figure 5. 13: Spatial distribution of mean total *Kirem*t RF of the study area from 1984 to 2016

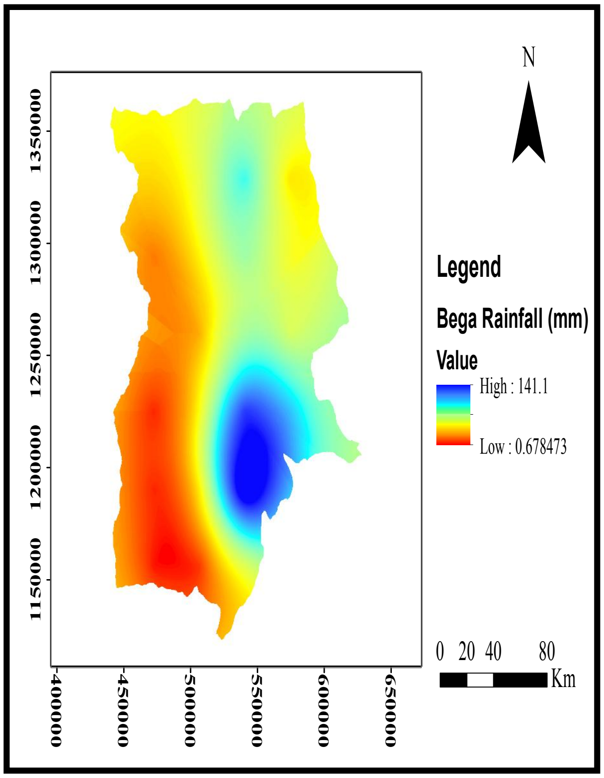


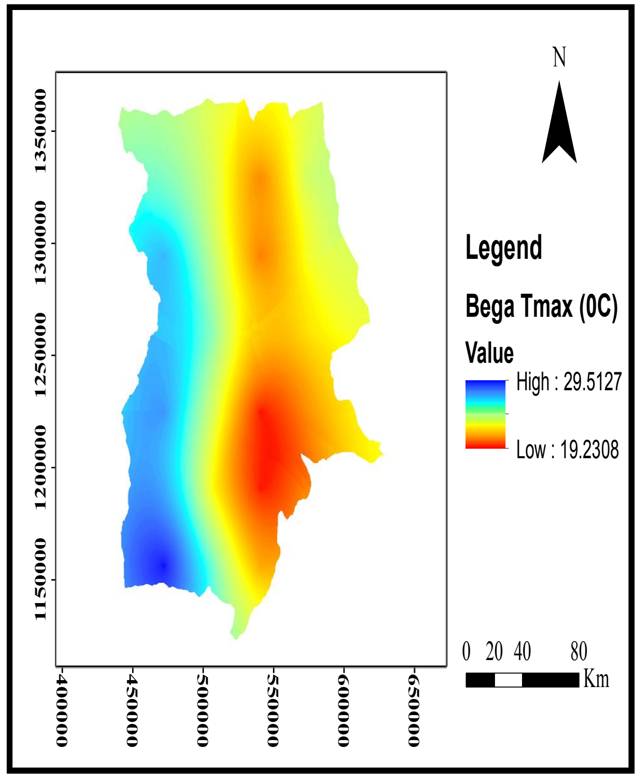
(a) (b)

Figure 5. 14: Spatial distribution of mean *Kiremt* Tmax (a) and mean *Kiremt* Tmin of (b) of the study area from 1984 to 2016

5.1.4. Spatial Distribution of Mean Total *Bega* RF, Mean *Bega* Tmax and Tmin

Similarly, the 33 years values of mean total RF, mean Tmax and Tmin were 48.48 mm, 23.61°C and 6.82°C, respectively in *Bega* season of the study area. Mean total *Bega* RF varied from 0.678 mm to 141.1 mm where the highest value was observed in Southeastern part and the lowest one in Southern and Southwestern part of the Study area (Figure 5.15(a)). The mean *Bega* Tmax and Tmin ranged respectively from 19.23°C to 29.51°C and 3.1°C to 9.04°C. The highest value of mean Tmax was observed in Southwestern and Tmin in Southwestern, Northwestern and Northeastern part, whereas the lowest value of Tmax revealed in Southeastern and Tmin Southeastern region (Figure 5.15 (b) and (Figure 5.16)), respectively.





(a) (b)

Figure 5. 15: Spatial distribution of mean total *Bega* RF (a) and mean *Bega* Tmax (b) of the study area from 1984 to 2016

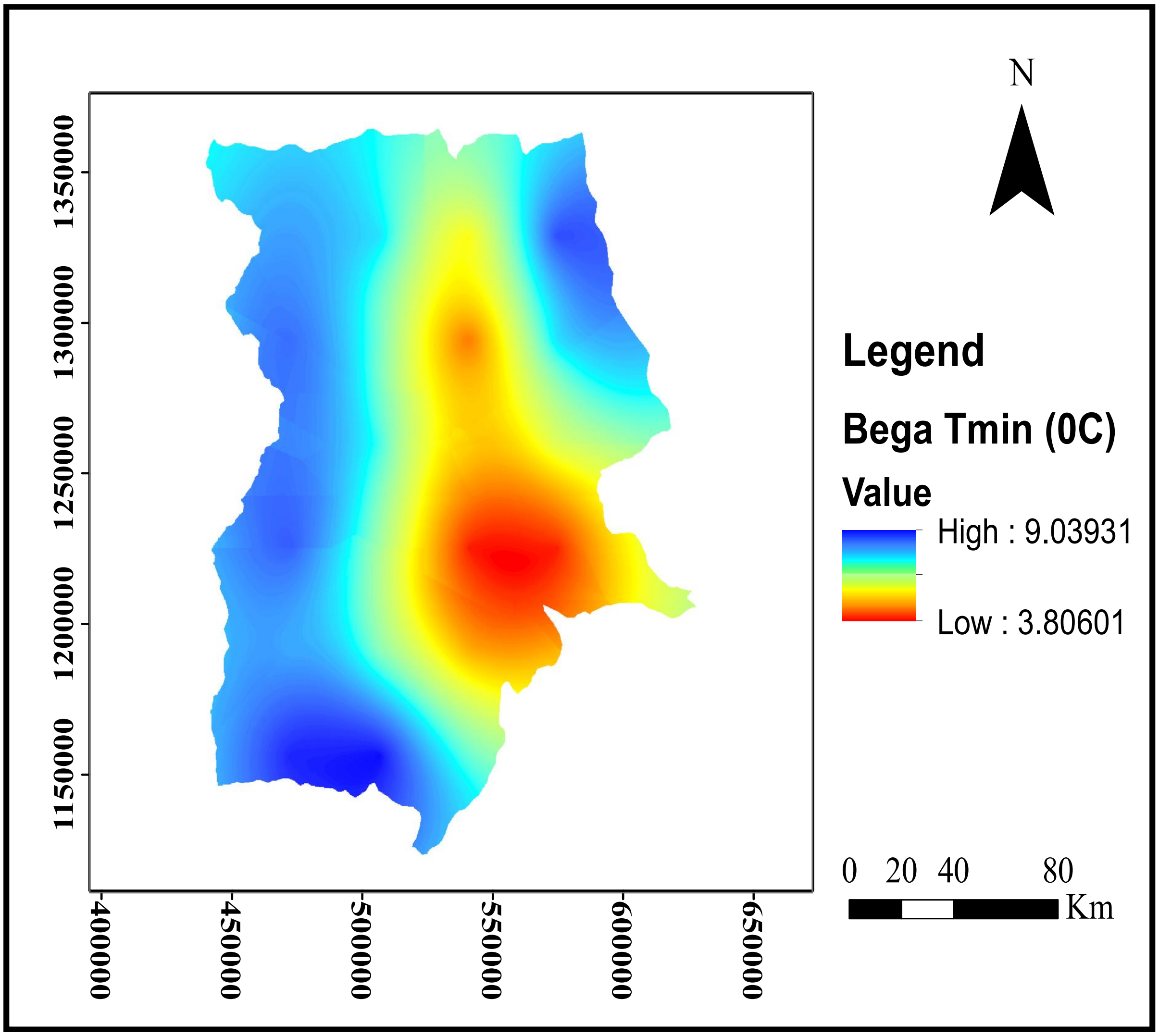
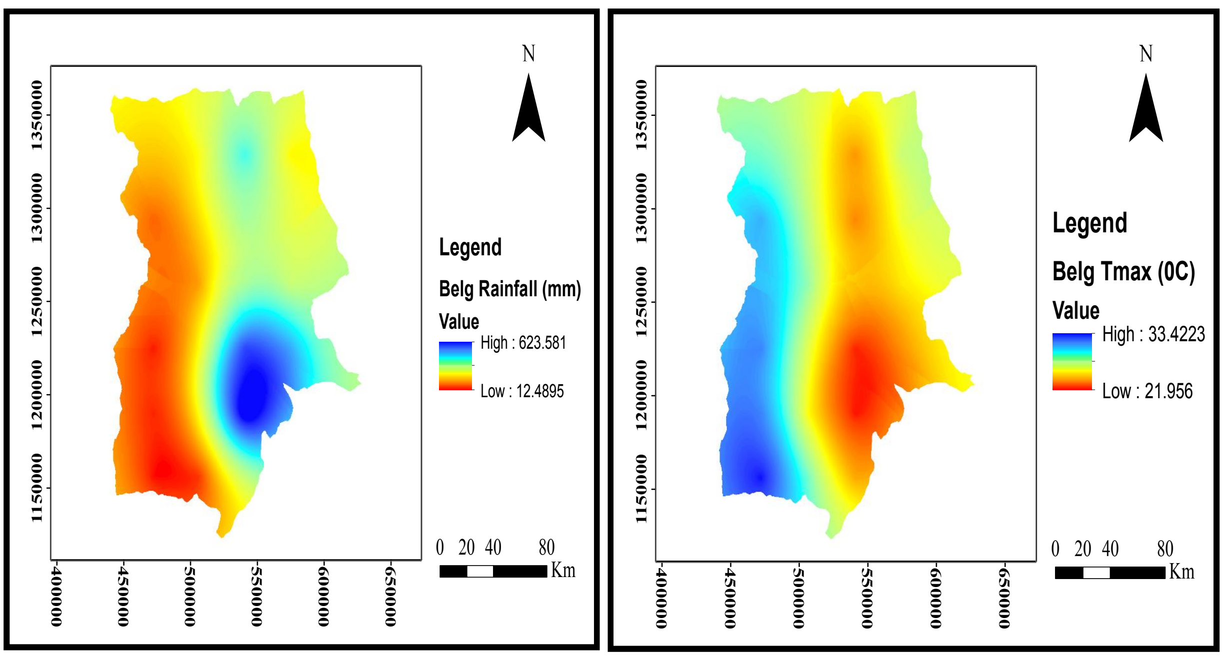


Figure 5. 16: Spatial distribution of mean *Bega* Tmin of the study area from 1984 to 2016

5.1.5. Spatial Distribution of Mean Total *Belg* RF, Mean *Belg* Tmax and Tmin

The average total *Belg* RF, mean *Belg* Tmax and Tmin between 1984 and 2016 were 230.91 mm, 26.94°C and 9.32°C, respectively, According to the spatial distribution for the observation time in the study area, the highest values of mean total *Belg* RF, mean *Belg* Tmax and Tmin were 623.58 mm, 33.42°C and 12°C, respectively. Whereas the lowest values of mean total *Belg* RF, mean *Belg* Tmax and Tmin were 12.49 mm, 21.96°C and 6.43°C, correspondingly. In *Belg* Season, the highest amount of RF was revealed in Southeastern part of the study area, while southwestern and Western region recieved less amount of RF throughout the observation time (Figure 5.17(a)). From this, it is possible to note that *Belg* RF showed high deviation across the study area. Similarly, high Tmax was observed in Southwestern and Western region, and low Tmax was indicated in Southeastern part, whereas high Tmin was shown in Southern, Southwestern, Northwestern and Northeastern part, but low Tmin occurred in Southeastern region for the observation time (Figure 5.17 (b) and (Figure 5.18)), respectively.



(a) (b)

Figure 5. 17: Spatial distribution of mean total *Belg* RF (a) and mean *Belg* Tmax (b) of the study area from 1984 to 2016

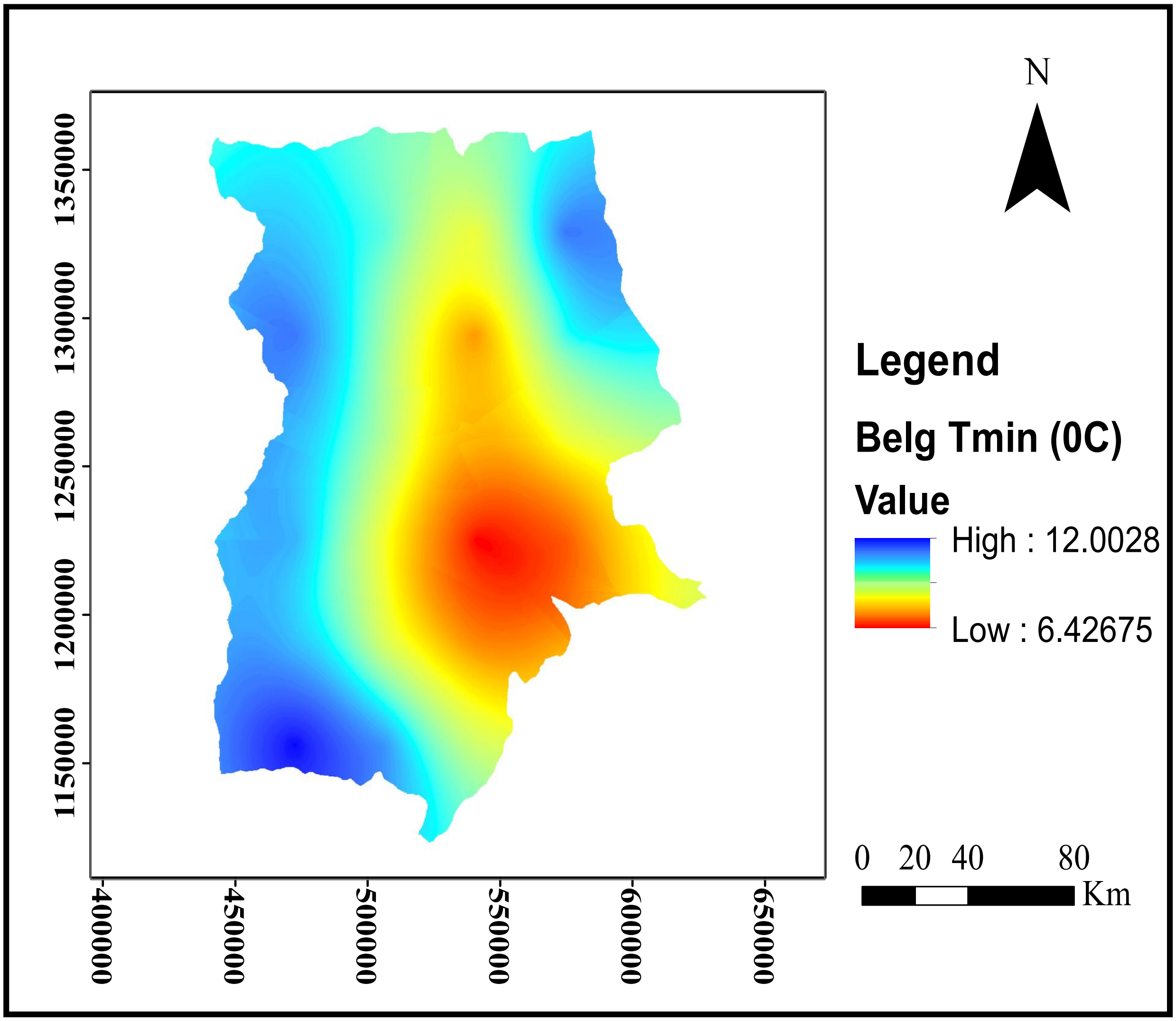


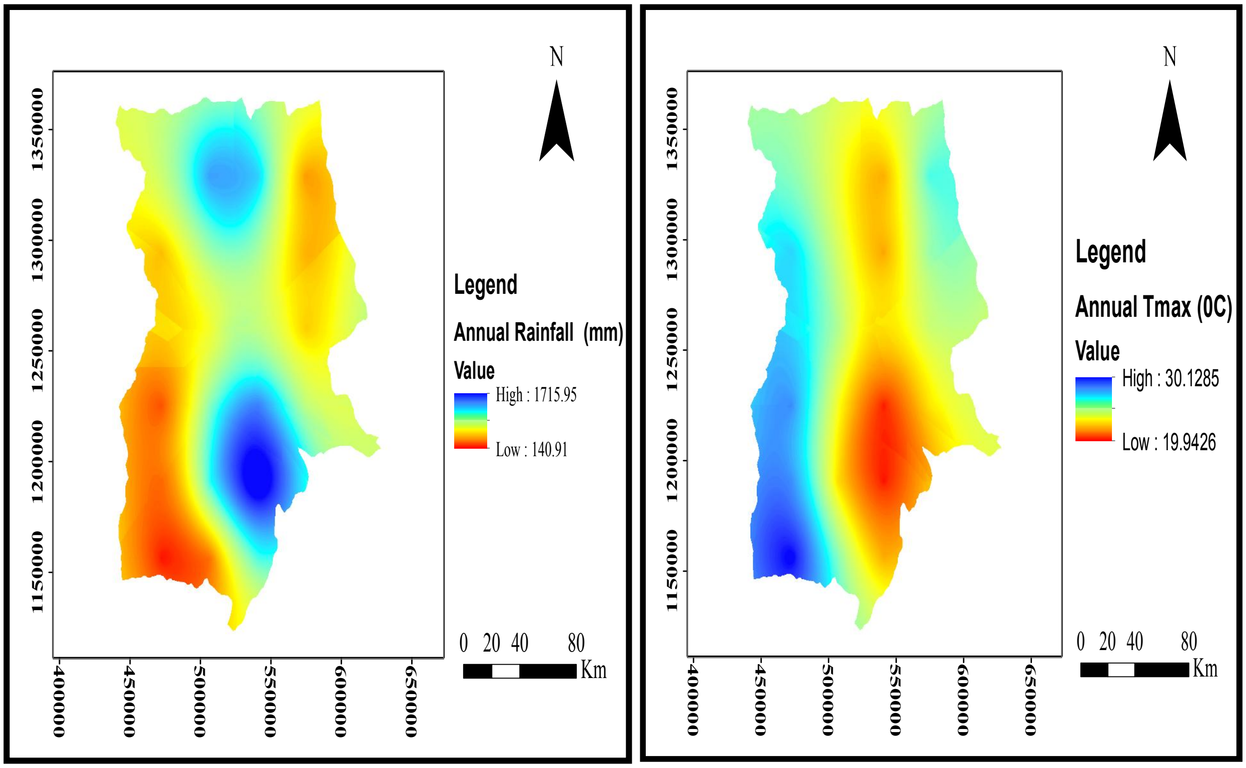
Figure 5. 18: Spatial distribution of mean total *Belg* Tmin of the study area from 1984 to 2016

5.1.6. Spatial Distribution of Mean total Annual RF, Mean Annual Tmax and Tmin

The mean total annual RF, mean annual Tmax and Tmin of the study area varies temporally and spatially. From the analysis of present study, the amount of mean total annual RF, mean annual Tmax and Tmin were 753.63mm, 24.43°C and 8.53°C, respectively over 33 years of the study area. With regard to spatial distribution, some parts of the study area were characterized by high amount of annual RF, Tmax and Tmin, while the remain regions of the study area were experienced by low amount of RF, Tmax and Tmin for the last 33 years. It was observed that the highest value of mean total annual RF for the observation period of the study area was 1715.95mm, whereas the lowest amount of mean total annual RF was 140.91 mm. From the study area, the highest RF was found in Southeastern region and some part of Northern area (Figure 5.19 (a)). Generally, the result showed that the mean total annual RF distribution varies both in space and in time.

Temperature is the most widely reported direct observation of changes in climate (Kadir *et al*., 2013). It is a key indicator amongst whole climatic elements to show whether the terrestrial or water surfaces are getting hot or cool. It is due to observable changes recognized in mean temperature in the world that significant emphasis is given to the issue of climate change. Annual temperatures can be examined for the occurrence of average, low or high temperature extremes. Further characterizing and quantifying temperature data has various advantages: such as, to help make decisions about how crop are grown and managed, to estimate yields to help government and incorporate decision about buying and selling products and to improve understanding and suggest new or improved management methods (Mulugojam and Ferede, 2012).

The analysis of this study revealed that the mean Tmax and Tmin of the study area over 33 years period varies both in time and in space. The highest values of mean annual Tmax and Tmin were 30.13°C and 11.1°C, respectively, while the lowest values of mean annual Tmax and Tmin were 19.94°C and 5.76°C, respectively (Figure 5.19 (b) and (Figure 5.20)), respectively. The Southwestern part was characterized by the highest amount of temperature, whereas the Southeastern region found the lowest temperature over the last 33 years of the study area.



(a) (b)

Figure 5. 19: Spatial distribution of mean total Annual (a) and mean Annual Tmax (b) of the study area from 1984 to 2016

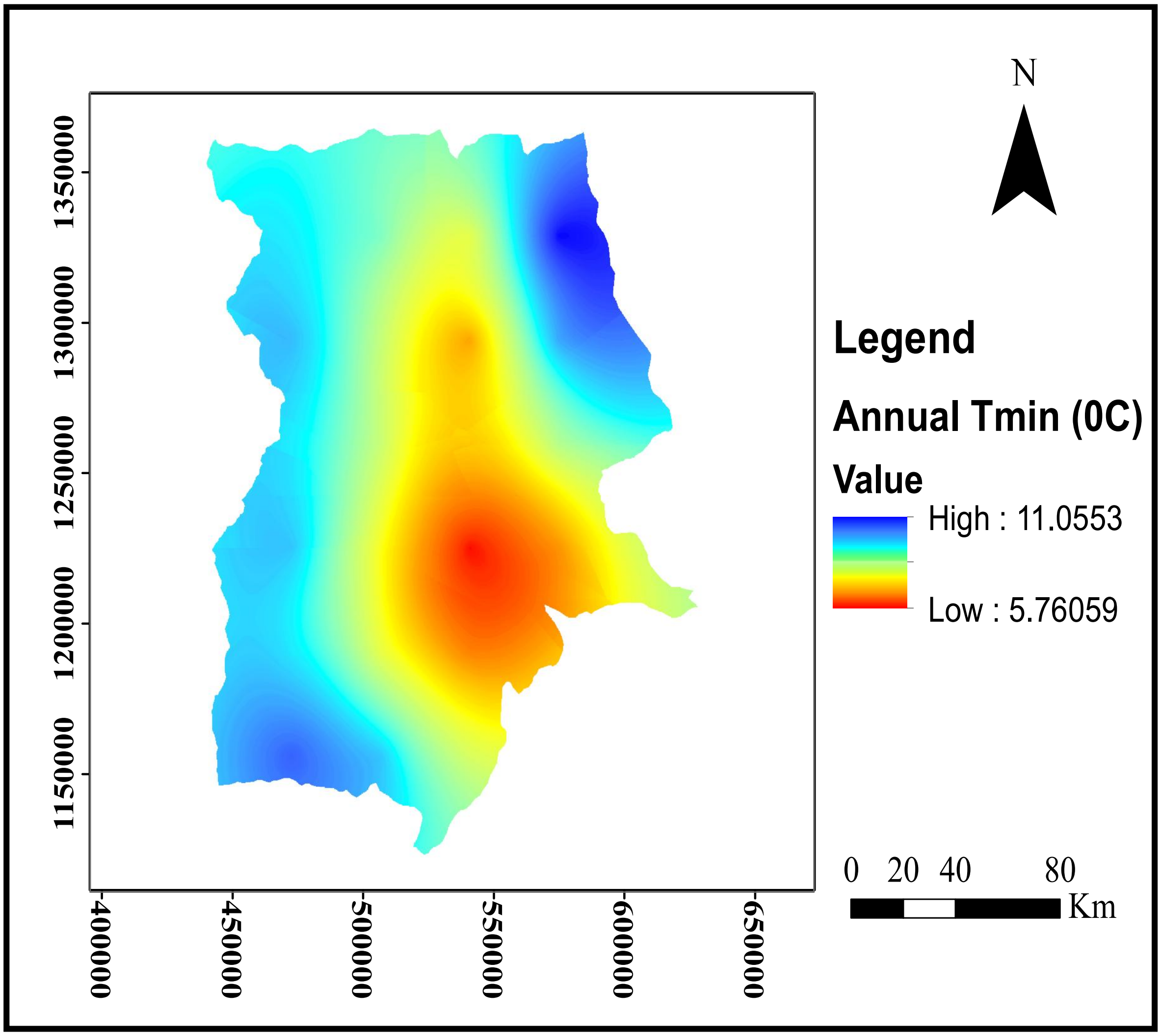


Figure 5. 20: Spatial distribution of mean Annual Tmin of the study area from 1984 to 2016

5.2. Temporal and Spatial Variability of RF and Temperature (Tmax and Tmin)

The amount of mean total(both seasonal and annual) rainfall and mean seasonal and annual temperature (Tmax and Tmin) of the study area were varied spatially and temporarlly over the last 33 years. This climate variability was the main cause for crop failure and water scarcity in the region due to late onset of rainfall, short dry spells and multi-annual droughts. In this study, RF, Tmax and Tmin data of the study area were analyzed for the magnitude of temporal and spatial variation using percentage of coefficient of variation (CV).

5.2.1. Temporal and Spatial Variabilty of Mean Total *Kiremt* Season RF (Main RF from June to September)

Kiremt rain has great significance over life of Ethiopian farmers. Since the economic activity is based on *Kiremt* rain, the variations occurred in each moment which later lead to climate change can affect the maturity and development of crop.

The results of the temporal variability analysis of *Kiremt* RF across the study area are presented in Figure 5.21. Coefficients of variation (CV) which corresponds to the ratio of the standard deviation to the mean total *Kiremt* RF indicated that the variation of *Kiremt* RF was ranged from 22.8% to 62% across the study area over the last 33 years. The highest value of CV was observed in Southern and Eastern regions, whereas the lowest value of CV was found in the Northern and Southeastern regions of the study area. The complex spatial pattern illustrated the spatial heterogeneity of RF and indicated that topography factor may be responsible of this variability.

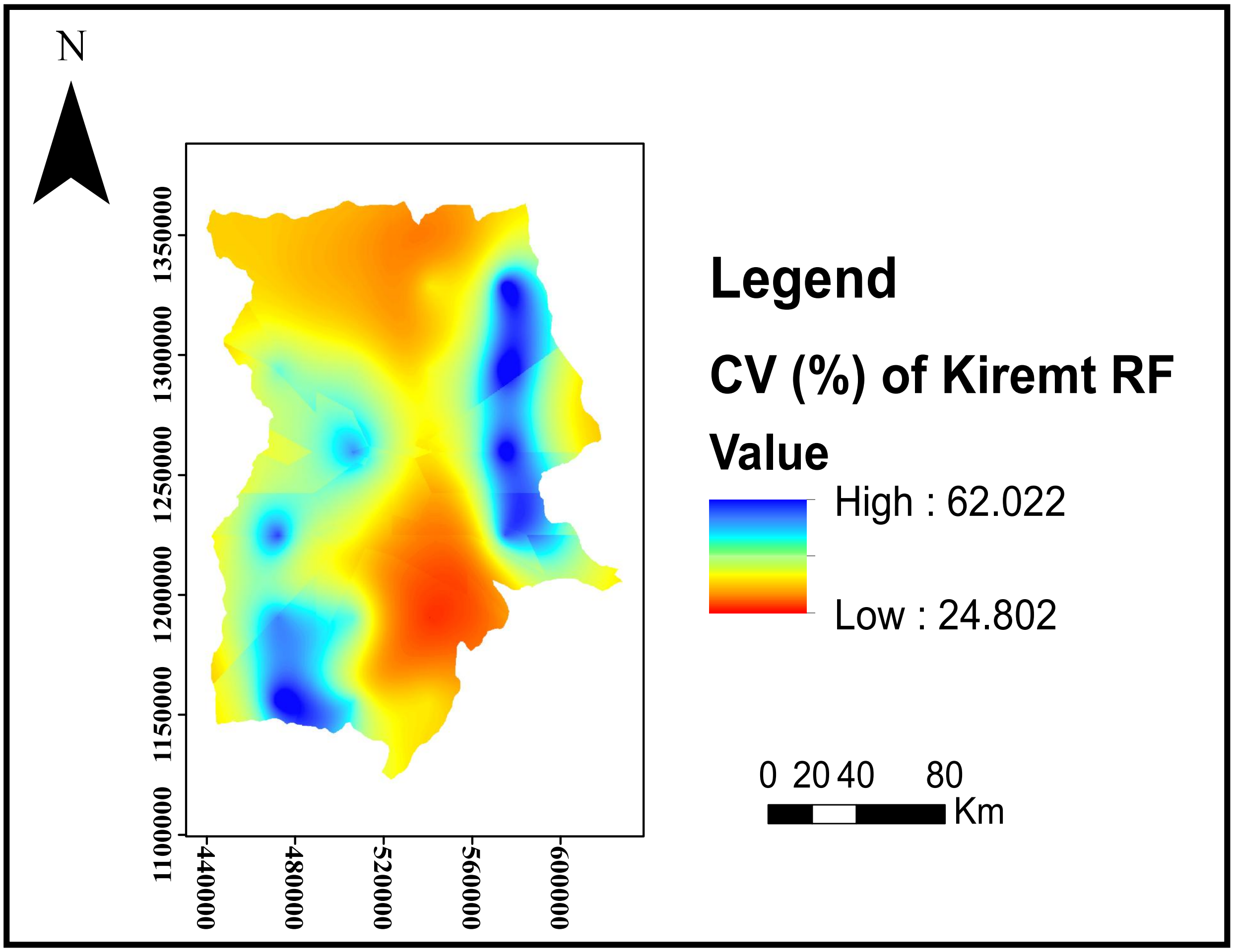


Figure 5. 21: Temporal and spatial and variability (CV) of mean total *Kiremt* RF of the study area from 1984 to 2016

5.2.2. Temporal and Spatial Variabilty of Mean Total *Bega* Season RF

The results of the spatial and temporal variability of *Bega* RF across the study area are presented in Figure 5.22 below. For the observation time, *Bega* RF has CV ranged from 65.98% to 92.96%, which indicated that the variation of *Bega* RF was very high in most parts of the study area and extremely very high in some Southern region (Figure 5.18). From this, it was observed that *Bega* RF was more variable than *Kiremt* RF across the study area for the last 33 years. Woldeamlak and Conway (2007) arrived at a similar conclusion that *Belg* and *Bega* rainfalls are more variable than *Kiremt* rainfall in their study that analyzed rainfall data from 12 stations in drought-prone areas of Amhara Region, Ethiopia.

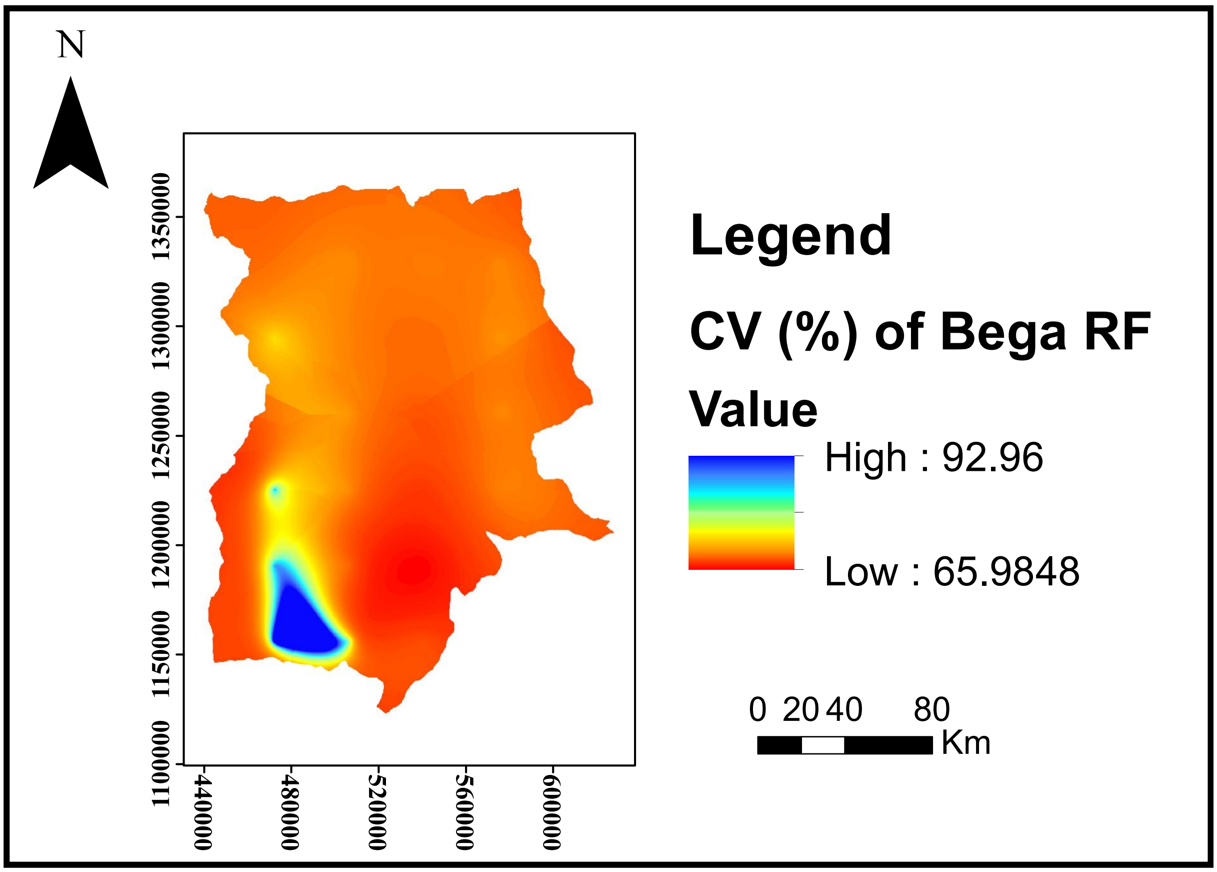


Figure 5. 22: Temporal and spatial and variability (CV) of mean total *Beg*a RF of the study area from 1984 to 2016

5.2.3. Temporal and Spatial Variabilty of Mean total *Belg* Season RF(small rainfall in February to May)

In Ethiopia, there are seasonal rainfall patterns that vary in number, intensity, duration, and timing, depending on location. The *Belg* season is particularly important for the production of fast growing crops. According to NMSA (2001), the *Belg* season lasts February through May, which is a short rainy season. The result of the analysis across the observation (1984-2016) demonstrated that the variation of mean total *Belg* RF ranged from 42.45% to 87.69% across the study area (Figure 5.23). Similar to mean total *Bega* RF, the variation of mean total *Belg* was very high in most regions and extremely very high in some Southern regions (Figure 5.23). From this, it is possible to note that the variation of *Bega* and *Belg* season RF were very high almost all parts of the study area during the last 33 years. Supporting this idea, Woldeamlak and Conway (2007) arrived at a similar conclusion that *Belg* and *Bega* rainfalls are more variable than *Kiremt* rainfall in their study that analyzed rainfall data from 12 stations in drought-prone areas of Amhara Region, Ethiopia.

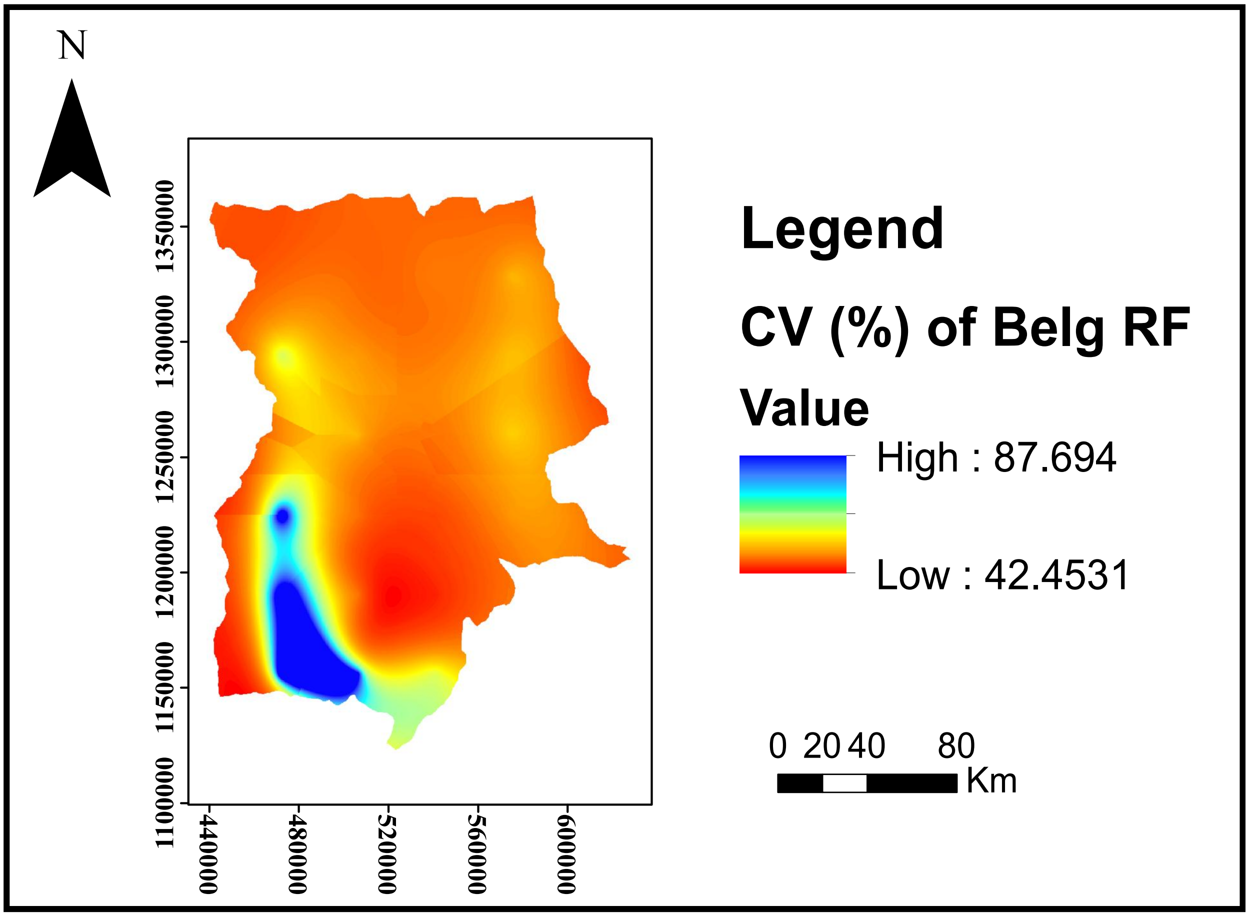


Figure 5. 23: Temporal and spatial variability (CV) of mean total *Belg* RF of the study area from 1984 to 2016

5.2.4. Temporal and Spatial Variabilty of Mean total Annual RF

The annual mean total rainfall of the study area varied temporally and spatially. The results of spatio-temporal variability analysis revealed the lowest and the highest variation (CV), which were 23.13% (moderate) in Southeastern region, and 57.86% (very high) in Southern part, respectively across the study area for the last 33 years (Figure 5.20). Generally, the result showed that the mean total annual RF distribution across all the observation period varied in both space and time.

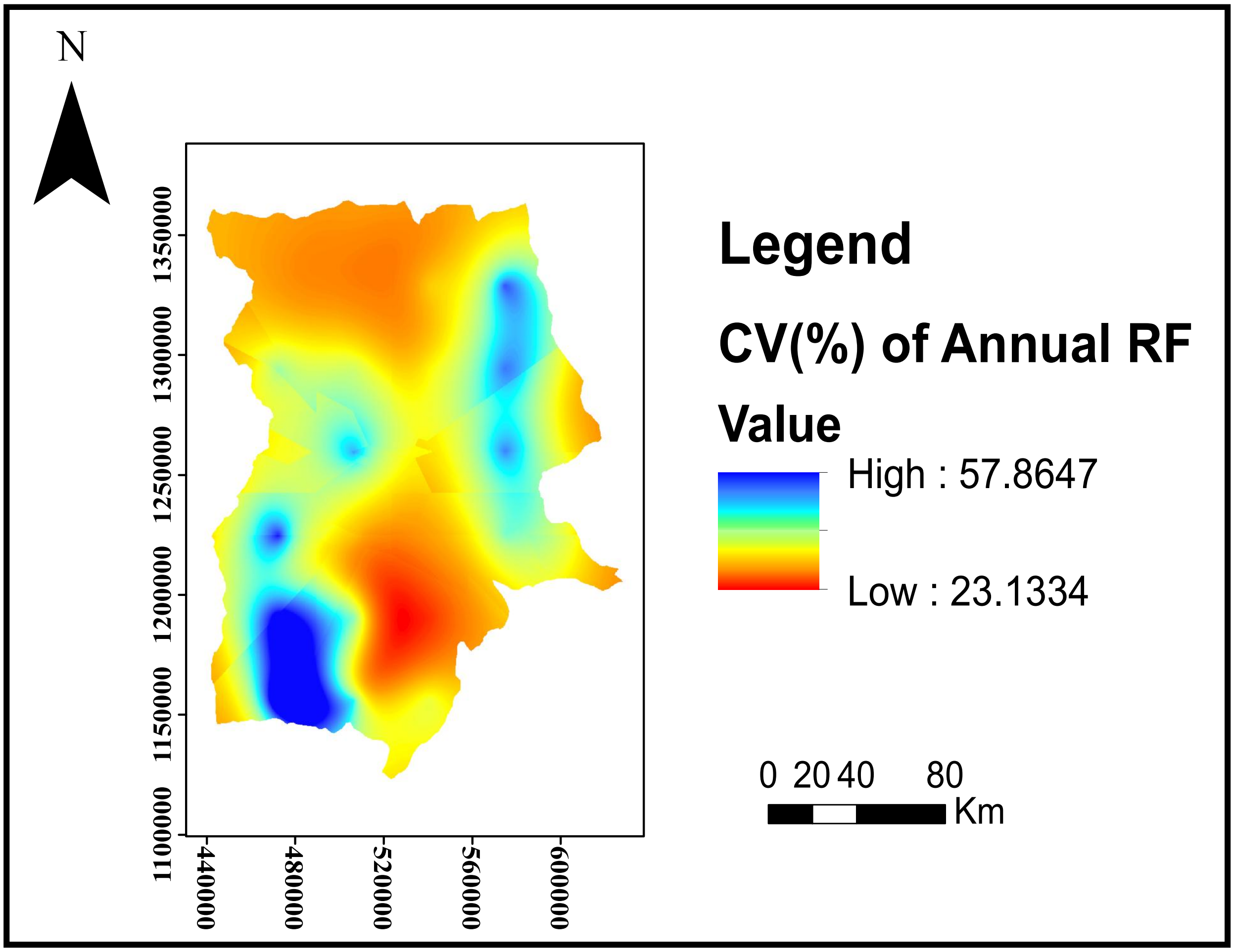
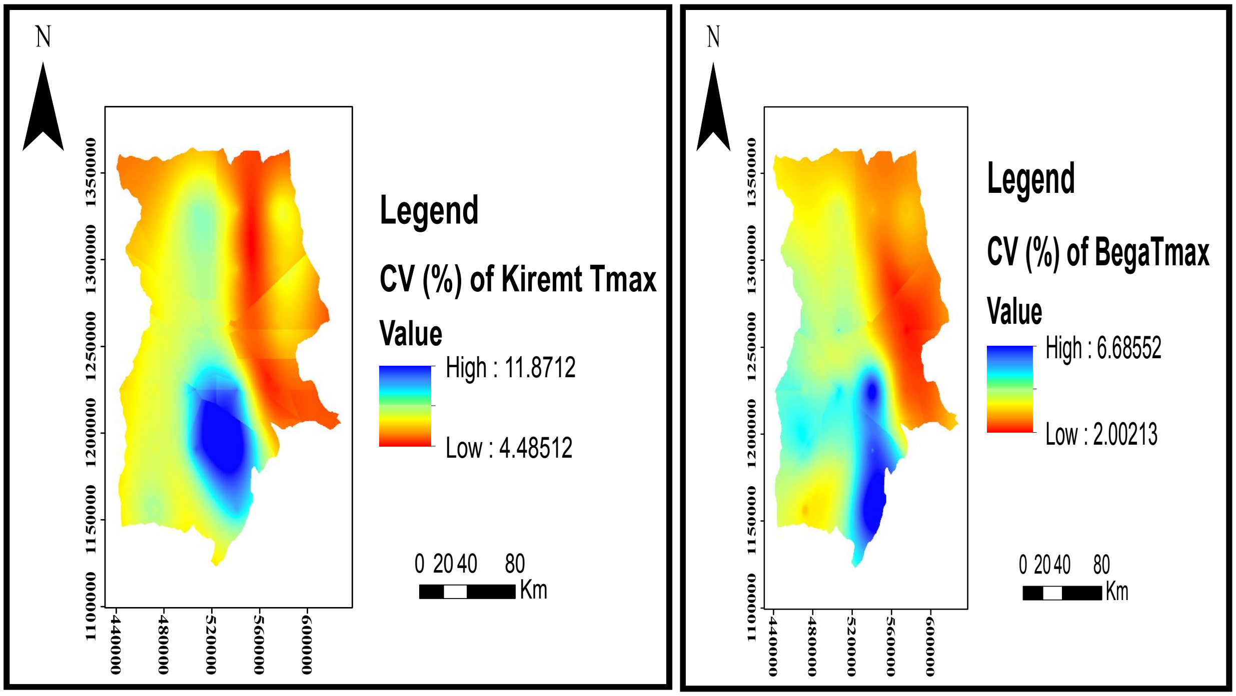


Figure 5. 24: Temporal and spatial and variability (CV) of mean total annual *RF* of the study area from 1984 to 2016

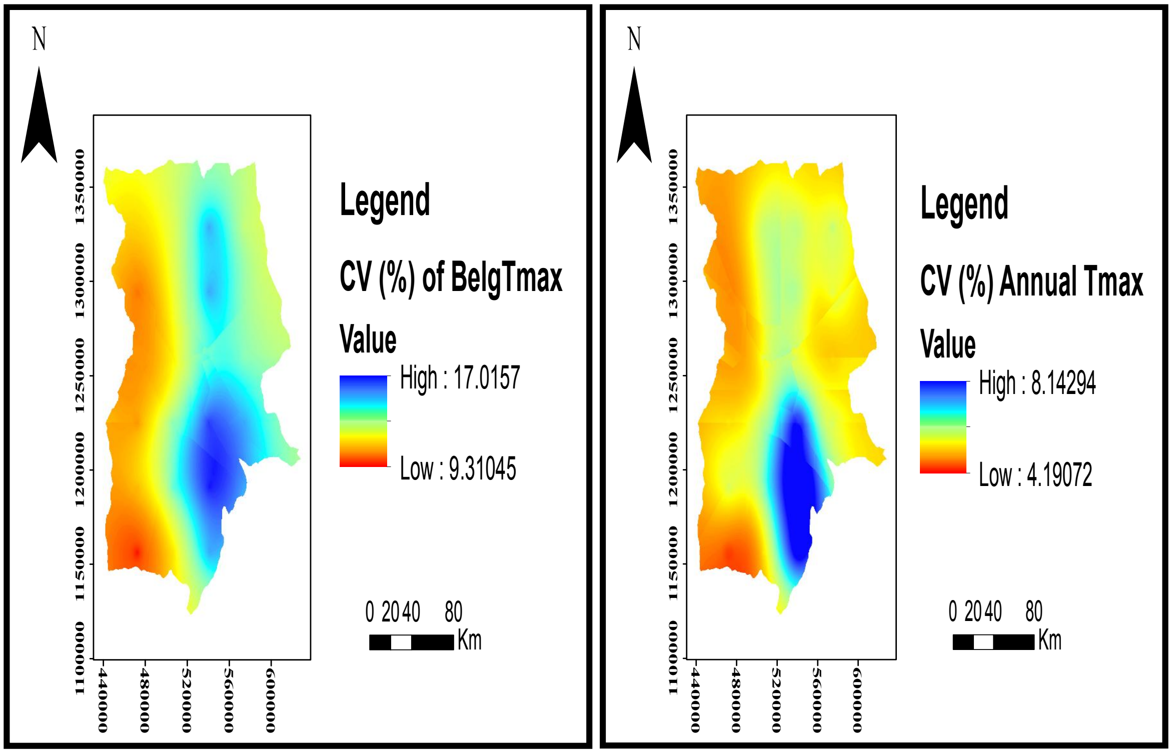
5.2.5. Temporal and Spatial variability of Mean Seasonal and Annual Tmax

To show mean seasonal and annual Tmax variability, the analysis of coefficient of variation (CV) was employed. The result of the analysis revealed that the mean maximum temperature of the study area over 33 years period varies both in time and in place. However, the variation was less as compare to the variation of rainfall. Figure 5.25 and 5.26 below show the range of mean seasonal and annual Tmax variation, respectively across the study area over the last 33 years.



(a) (b)

Figure 5. 25: Temporal and spatial variability (CV) of mean *Kiremt* (a) *Bega* (b) Tmax from 1984 to 2016

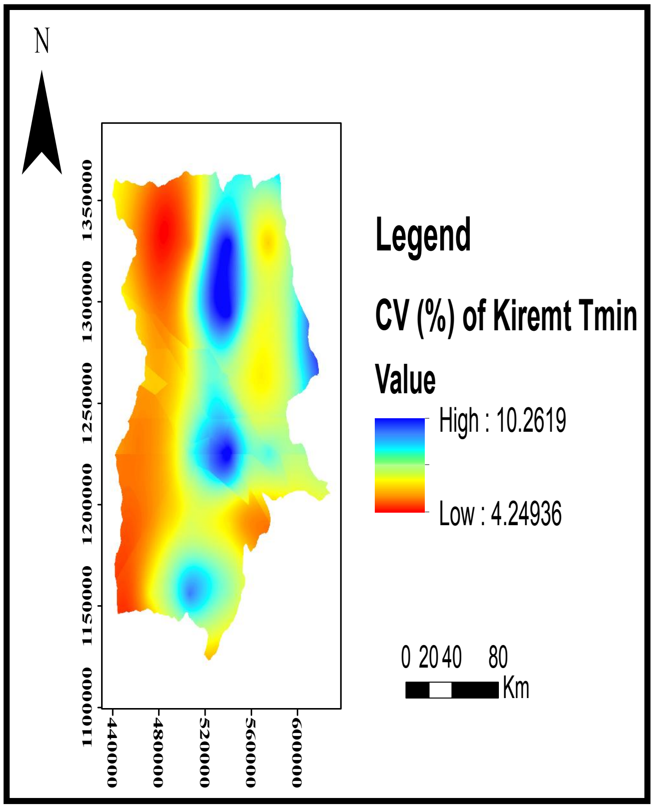


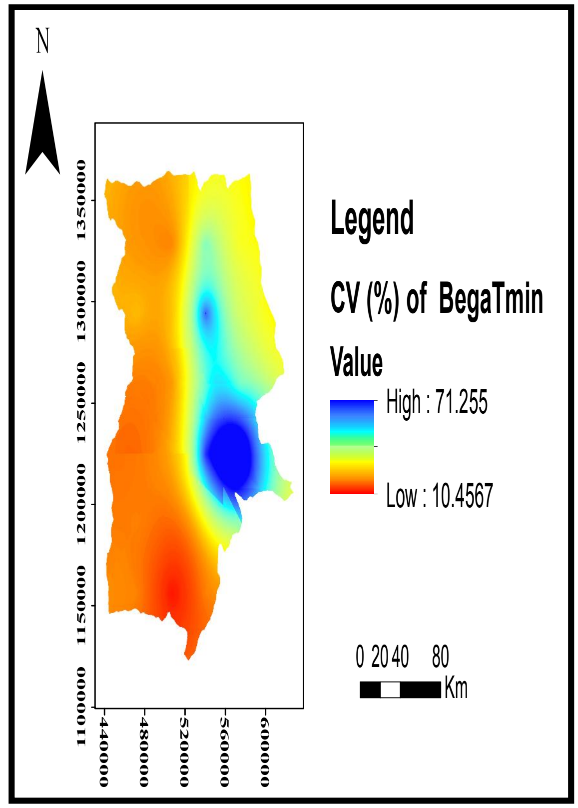
(a) (b)

Figure 5. 26: Temporal and spatial and variability (CV) of mean *Belg* (a) annual (b) Tmax from 1984 to 2016

5.2.6. Temporal and Spatial and variability of Mean Seasonal and Annual Tmin

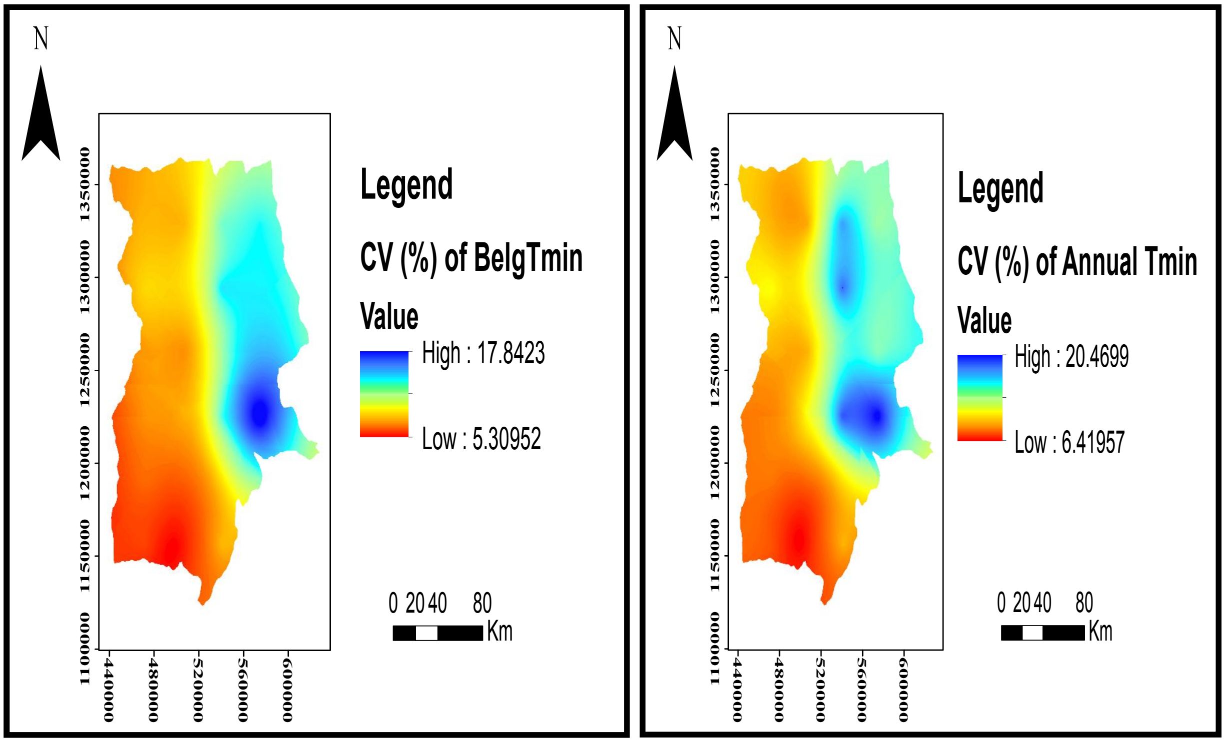
Similarly, the spatial and temporal variability of mean seasonal and annual Tmin was also observed by applying the coefficient of variation (CV) analysis. As shown in the Figure 5.27 and 5.27 below, mean seasonal and annual Tmin varied spatially and annually. The variation of mean *Bega* Tmin was extremely high in Eastern region of the study area (Figure 5.27(b)); the coefficient variation was much higher for minimum temperature than maximum temperature.





(a) (b)

Figure 5. 27: Temporal and spatial variability (CV) of mean *Kirem*t (a) *Bega* (b) Tmin from 1984 to 2016



(a) (b)

Figure 5. 28: Temporal and spatial variability (CV) of mean *Belg* (a) annual (b) Tmin from 1984 to 2016

5.3. The Association of SST with RF and Tmax both Seasonally and Annually

The correlation between *Kiremt* rainfall total and mean SST was negative (r = -0.457) and statistically significant at alpha level 0.05. *Belg* rainfall total, on the other hand portrayed the opposite, means *Belg* rainfall total has positive correlation (r=0.385) and statically significant at alpha 0.05 level. This implies that SST decreased the amount of rainfall in *Kiremt* season and the opposite was true for *Belg* rainfall across the study area over the last 33 years. This is supported by Bekele(1993) and Woldegiorgis (1997) who both identified similar inter seasonal correspondence. Another study made by Sintayehu *et al*., (2017) reported that during *Belg* season rainfall anomaly and related Nino regions was positively correlated, while during *Kiremt* season rainfall anomaly and SST anomaly was negatively correlated. Similarly, the correlation between *Bega* rainfall total and mean *Bega* SST as well as annual rainfall total with mean annual SST were positive in the study area. Contrary to this finding, another study made by Getachew (2017) reported the negative association between mean annual rainfall and mean annual SSTA in Upper Awash Basin.

As described by Rajashree and Yashwant (2014), the amount of rainfall in La Niña years was higher than El Niño years. Similar result was obtained in this study, and the amount of annual rainfall total was higher in La Niña years (886.13mm in 1988 and 704.84mm in 2011) than El Niño years (384.66mm in 2002 and 583.24 in 2015). *Kiremt* rainfall total (632.31mm in 1988 and 464.84 in 2011) during La Niña was also higher than *Kirem*t rainfall total (199.18mm in 2002 and 194.12mm in 2015) in El Niño years. Similarly, the amount of *belg* rainfall total was higher in La Niña years (227.04mm in 1988 and 216.53mm in 2011) than El Niño years (129.26mm in 2002 and 195.28mm in 2015). On the contrary, *Bega* rainfall total was less in La Niña years (26.78mm in 1988 and 19.46mm in 2011) than El Niño years (56.22mm in 2002 and 193.83mm in 2015). As to the finding of this research, similar results were reported in the study made by Getahun and Shefine (2015) in Gojjam and Getachew (2017) in Upper Awash Basin.

In Ethiopia, El Niño reduces the amount of rainfall in summer. This study also showed the same phenomenon for Wello. La Nina works in contrast to the effect of El Niño, resulting in excessive rainfall during the Ethiopian summer (Bekele, 1997; Wolde-Georgis, 2000; Korecha and Barnston, 2007; Babu, 2009).

Table 5. 2: Correlation coefficients between seasonal rainfall totals and SST as well as between mean Tmax and SST in the study area

	Totals RF vs. Mean SST		Mean Tmax vs. Mean SST		Mean Tmin vs. Mean SST	
	r	P-value	r	P-value	r	P-value
Kiremt	-0.457	0.008	0.341	0.052	-0.146	0.416
belg	0.385	0.027	-0.055	0.763	0.432	0.012
bega	0.349	0.047	0.161	0.370	0.435	0.011
annual	0.034	0.973	0.135	0.454	0.295	0.096

5.4. Relationship between RF and Cereal Production

To determine the relationship and effect of climatic variables, namely rainfall (monthly, seasonal and annual rainfall totals) and temperature (maximum and minimum) on crop production in the study area, linear regression analysis was employed. The result of correlation coefficient(r) and coefficient of determination (R^2) from linear regression between rainfalls totals (monthly, *Kirem*t and annual) and cereal Meher production on the study area are given in Table5 .3.

At the monthly time scale, correlations between rainfalls during May to September and cereal productions were all positive in this study. May to September covers the period from preparation of fields and sowing to maturity stage of crops. Similar to the finding of this research, another study made by Beweket (2009) revealed that the correlation between monthly, seasonal and annual rainfall totals and cereal production are positive. The correlation between Meher teff production (qt/ha) with May, June, July, September and August rainfalls were (r=0.141), (r=0.244), (r=0.336), (r=0.646) significant at alpha 0.05 level and (r=0.346), respectively and it has been observed that as there was moderately strong relationship between teff production and August rainfall. The coefficient of determination (R^2=0.417) from linear regression between August rainfall and teff production indicated that 41.7% of the variation in teff production in the study area was explained by the variations in August rainfall. This finding is in line with a study conducted by Alemayehu and Bewket and (20016) focused on Local Climate Variability and Crop Production in the Central Highlands of Ethiopia and reported that August rainfall shows statistically significant strong positive correlation with production of teff. The correlation between Meher barley production (qt/ha) with May, June, July, September and August rainfalls are (r=0.304) significant at alpha 0.05 level, (r=0.267), (r=0.135), (r=0.059) and (r=0.152) respectively. The association between Meher wheat production (qt/ha) with May, June, July, September and August rainfalls are (r=0.695) significant at alpha 0.05 level, (r=0.466), (r=0.706) significant at alpha 0.01 level, (r=0.527) significant at alpha 0.1 level and (r=0.656) significant at alpha 0.05 level respectively. This implied that the correlation of wheat production with monthly rainfall was moderately strong and significant except June rainfall. The coefficient of determination (R^2=0. 0.498) from linear regression between July rainfall and wheat production showed that 49.8% of the variation in wheat production in the study area was explained by the variations in July rainfall that indicated as July rainfall increases, wheat production increases as compare to the other monthly rainfalls.

The correlation between Meher maize production (qt/ha) with May, June, July, September and August rainfalls were (r=0.568) significant at alpha 0.1 level, (r=0.619) significant at alpha 0.05 level, (r=0.614) significant at alpha 0.05 level, (r=0.599) significant at alpha 0.05 level and (r=0.254) respectively. Here, maize production is correlated moderately strong with June and July rainfall and is associated moderately with May and August rainfall, but weakly related with September rainfall. This explains how much rainfall variation explains the variation of maize production in the study area. Example, The linear regression analysis between Meher maize production (qt/ha) and June rainfall indicates that coefficient of determination (R^2=0.384), implying that the impact of June rainfall accounts for 38.4% of maize yield changes, while 61.6% of variation in maize yield was explained by other factors, such as the use of fertilizers, better crop management practices, etc. The correlation of Meher sorghum production (qt/ha) with May, June, July, September and August rainfalls are (r=0.546) significant at alpha 0.1 level, (r=0.593) significant at alpha 0.05, (r=0.527) significant at alpha 0.1 level, (r=0. 0.630) significant at alpha 0.05 level and (r=0. 0.494) significant at alpha 0.1 respectively. August rainfall was the most important determinant factors for the variation in sorghum production. Similar to the finding to this study, previous studies reported positive correlation between rainfall and crop production in Nigeria, Ethiopia, Uganda and Tanzania (Bewket, 2009; Rowhani, 2011; Adamgbe and Ujoh, 2013; Akinseye *et al*., 2013; Mwaura and Okoboi, 2014; Yamusa *et al*., 2015).

The correlation coefficients computed between Meher crop yield (teff, barely, wheat, maize and sorghum) and Kiremt rainfall totals in this study area showed from low to moderately strong and positive relationship. Alemayehu and Beweket (2016) also reported the existence of positive correlation between *Kirem*t rainfall totals and crop yields. The correlation of *Kiremt* rainfall totals with teff, barely, wheat, maize and sorghum were (r=0.341), (r=0.343), (r=0.659), (0.736) and (r=0.689), respectively. Here, it has been observed that total *Kiremt* rainfall has statistically significant correlation with the production of barely, wheat, maize and sorghum. The linear regression analysis indicates that coefficient of determination (R^2) describes the proportion of the total variance in the observed crop data explained by *Kiremt* rainfall totals. For example, in this study, the regression analysis between Meher maize production (qt/ha) and *Kiremt* rainfall indicates that coefficient of determination (R^2=0.541), implying that the impact of *Kiremt* rainfall totals account for 54.1% of maize yield changes, while 45.9% of variation in maize yield was explained by other factors. Annual rainfall totals have statically significant at significant level alpha 0.1, positive and moderately strong correlation with Meher maize and Sorghum yields (qt/ha), but week and statically non-significant correlation with teff, barley and wheat production. The finding of this study has similar connotations with the study done by Admasu (2004) on Rainfall Variation and its Effect on Crop production in Ethiopia.

Even though the correlation between annual rainfall totals and crop productions taken understudy were positive, most are not significant in statistical terms. This can be due to short length of the production data used and consideration of rainfall isolating from all other agronomic factors such as growing period, radiation, temperature, pests, diseases, etc. However, the result may imply that the total annual rainfall amount may not be indicative for the failure of production but the distribution of amount of rainfall during crop growing period is important. The yield response to water deficiency during part of total growing period varies depending on how sensitive the crop at that growing period. However, crops are generally more sensitive to water deficient during emergence, flowering and early yield formation (David, 1993 cite in Admmasu, 2004). Therefore, it would be preferable to see how rainfall distribution looks like during these crops growing period. Generally, rainfall has very important contribution to get the required amount of crop yields.

Table 5. 3: Regression Analysis for crops and rainfall

	Teff		Barely		Wheat		Maize		Sorghum	
	r	R^2	r	R^2	r	R^2	r	R^2	r	R^2
May	0.141	0.020	0.304*	0.092	0.695**	0.483	0.568*	0.323	0.546*	0.298
Jun	0.244	0.059	0.267	0.072	0.466	0.217	0.619**	0.384	0.593**	0.351
July	0.336	0.113	0.135	0.018	0.706***	0.498	0.614**	0.377	0.527*	0.277
August	0.646**	0.417	0.059	0.003	0.527*	0.278	0.599**	0.359	0.630**	0.397
September	0.346	0.120	0.152	0.152	0.656**	0.430	0.254	0.065	0.494*	0.244
Kiremt	0.341	0.116	0.343**	0.118	0.659**	0.434	0.736***	0.541	0.689**	0.475
Annual	0.338	0.114	0.254	0.064	0.256	0.066	0.503*	0.253	0.572*	0.328

* Significant at 0.1 level, ** significant at 0.05 level and *** significant at 0.01 level

Similarly, the association of major crop yields (qt/ha) with mean *Kiremt* and annual Tmax and Tmin was anaysed. The results revealed that the association of all crops with that of mean *Kirem*t and annual temperature (Tmx and Tmin) were positive. The linear regression analysis results are shown in Table 5.2 for teff, barely, wheat maize and sorghum. The results suggested that the coefficient of determination (R^2) describes the proportion of the total variance in the observed crop data explained by mean *Kiremt* and annual temperature. In this study, the regression analysis between Meher teff production (qt/ha) and mean *Kiremt* Tmax indicated that coefficient of determination (R^2=0.218), implying the impact of mean *Kirem*t Tmax accounted for 21.8% of teff yield changes, while 78.2% of variation in teff yield was explained by other factors, such as better seeds, better crop management practices, introduction of new agro-technology and other unexplained factors. In addition, about 6%, 4.8%, 20.2% and 27.9% of the variation in barely, wheat, maize and sorghum production in the study area could be, respectively explained by the variations in mean *Kirem*t Tmax.

Similarly, mean annual Tmax explained 53.1%, 2.5%, 42.6%, 77.3% and 5.8% of variations in teff, barely, wheat, maize and sorghum production, respectively in the study area. The remaining percentage of the variations can be, respectively, explained by other factors not considered in this study.

The regression analysis between mean Tmin (*Kiremt* and anuual) and crop production showed positive and no significant relationship except the association of maize yield with mean *Kiremt* Tmin, statistically significant at 0.1 levels. As a result, about 48.5% (R^2=0.485 of variation in maize yield (qt/ha) was explained by the variation of mean *Kiremt* Tmin in this study area. As reported by Alemayehu and Bewket and (20016), the minimum temperature has a positive impact on the growth and development of crops by minimizing the effect of frost. Likely as a result of this, positive correlation was observed between the minimum temperature and crop production.

Table 5. 4: Regression Analysis for crops and temperature

	Teff		Barely		Wheat		Maize		Sorghum	
	r	R^2	r	R^2	r	R^2	r	R^2	r	R^2
Mean Kiremt Tmax	0.467	0.218	0.245	0.060	0.219	0.048	0.450	0.202	0.528***	0.279
Mean Annual Tmax	0.729*	0.531	0.159	0.025	0.653**	0.426	0.879*	0.773	0.240	0.058
Mean Kiremt Tmin	0.446	0.199	0.094	0.009	0.359	0.129	0.696***	0.485	0.056	0.003
Mean Annual Tmin	0.153	0.023	0.375	0.141	0.191	0.036	0.351	0.123	0.316	0.100

* Significant at 0.01 level ** Significant at 0.05 level *** Significant at 0.1 level

CHPTER SIX

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

Ethiopia is susceptible to climate variability and change. The effects of climate change may exacerbate existing social and economic encounters across the country, mainly where people are reliant on resources that are sensitive to climate variability and *Kiremt* rain-fed agriculture. In this study an attempt has been made to analyze climate variability and its impact on crop production by applying GIS and statistical analysis in the study area, where agricultural activities have been highly influenced by climate variability. In light of the evidences that were obtained from the study the following conclusions could be drawn;

With regard to spatial and temporal distribution, the finding of this study revealed that the amount of seasonal and annual rainfall and temperature varies temporally and spatially across the study area during the last 33 years. It was observed that the Southeastern and Northern regions (Lalibela, Dessie, Kombolcha) received the highest amount of mean total *Kiremt* RF (993.71mm) and mean total annual RF (1715.95mm). The highest values of mean annual Tmax and Tmin were 30.13°C and 11.1°C, respectively, while the lowest values of mean annual Tmax and Tmin were 19.94°C and 5.76°C, respectively. The Southwestern part was characterized by the highest amount of temperature, whereas the Southeastern region found the lowest temperature during the observation period of the study area. Regarding to the Mann-Kendall trend analysis test, Tmax, Tmin and SST examination bring about mean seasonal and annual Tmax, Tmin and SST had a general increasing trend; whereas RF amount showed a general decreasing trend. Furthermore, RF, Tmax and Tmin data of the study area were analyzed for the magnitude of temporal and spatial variations using percentage of coefficient of variations (CV). CV of Mean total Kiremt and annual RF were ranging from 24.8% to 62% and from 23.13% to 57.86%, respectively. The variation was high in Southern and Southeastern part of the study area. In *Bega* season the variation was very high (65.98% to 92.96%), which implied that some part of the study area received unseasonal RF. The variation of temperature was less as compare to the variation of rainfall. Generally, the variations of rainfall and temperature were the main cause for crop failure and water scarcity in the region, particularly, due to late onset of rainfall, short dry spells and multi-annual droughts.

The associations between total *Kiremt* and *Belg* RF with mean SST were negative (r = -0.457) and positive (r = 0.385), respectively and statically significant at alpha 0.05 level. This implies that SST decreased the amount of rainfall in *Kiremt* season and the opposite was true for *Belg* rainfall across the study area over the last 33 years. The results of regression analysis of crops with total *Kiremt* RF revealed that Mehere crop yield (qt/ha) (teff, barely, wheat, maize and sorghum) have coefficient of determination (R^2) 0.116, 0.118, 0.434, 0.542 and 0.475, respectively, indicating that 11.6%, 11.8%, 43.4%, 54.2% and 47.5% of variations in teff, barely, wheat, maize and sorghum production in this study area could be, respectively, explained by the variations in total *Kiremt* RF. In addition, the variation of crop production was explained by the variation of temperature. For instance, the impact of mean *Kirem*t Tmax accounted for 21.8% of teff yield changes, while 78.2% of variation in teff yield was explained by other factors, such as better seeds, better crop management practices, introduction of new agro-technology and other unexplained factors.

6.2. Recommendation

Based on the findings of the study, the following recommendations have been drawn.

- The results emphasize the negative impact of current climate variability on crop production in the study area. To reduce vulnerability to the effects of climate variability and ensure household level food security, context specific local level climate risk management approach should be implemented. Example, expanding irrigation and water management practices, strengthening awareness of farmers and early warning responses, shift to early maturing and drought resistant crops, diversifying livelihood opportunities, promoting perennial trees like fruits in the highlands and fast maturing cash crops in the lowlands, intensive use of inputs and better land management practices are some of the strategies.
- This study strongly recommends to the other potential related researchers to include other climatic elements like wind speed, solar radiation, and soil moisture data in addition to rainfall and temperature.
- It is better to compare available rainfall with the water requirement of crops during their growing period in the study areas to understand rainfall effect on crop production. However, this was not studied here due to the difficulty of obtaining crop water requirement during their growing period.
- It will be also good to integrate population dataset for in-depth analysis of the role of population dynamics and pressure as driving force of climate variability.

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