IMPACT OF CLIMATE CHANGE ON AGRICULTURAL WATER DEMAND: THE CASE OF BILATE RIVER CATCHMENT

MASTER OF SCIENCE THESIS

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HAWASSA UNIVERSITY

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ADVISORS’ APPROVAL

This is to certify that the Thesis entitled “**Impact of Climate Change on Agricultural Water Demand: The Case of Bilate River Catchment**” as MSc thesis in Hydraulic Engineering submitted to **Faculty of Civil and Built Environment** and has been carried out by **Zekiwos Kebede**_Id. No **PGHY 045/08** under my supervision. Therefore I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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DECLARATION

I 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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EXAMINERS’ APPROVAL

We, the undersigned, members of the Board of Examiners of MSc Final thesis defense by **Zekiwos Kebede_**have read and evaluated his MSc Final thesis entitled “ **Impact of Climate Change on Agricultural Water Demand: The Case of Bilate River Catchment**” and examined the candidate. This is, therefore, to certify that the MSc Final thesis has been accepted.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the Department of Graduate Council (DGC) of the candidate's major department.

I hereby certify that I have read this thesis prepared under my direction and recommend that it accepted as fulfilling the thesis requirement.

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Name of Thesis Advisor Signature Date

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Dedication

I dedicate this thesis manuscript to the Almighty Lord, Which is and was, and is to come above all who has given me extreme counsel.

MARANATA!!

Abbreviations

APF ……………………………African Partnership Forum

AWD…………………………...Agricultural Water Demand

COORDEX …………………....Coordinated Regional Downscaling Experiment

UNFCCC………………………United Nations Framework Convention on Climate Change

IPCC……………………………Intergovernmental panel on climate change

IFAD……………………………International Fund for Agricultural Development

FAO…………………………….Food and Agricultural Organization of United Nations

WMO…………………………...World Meteorological Organization

NMAE…………………………..National Meteorology Agency of Ethiopia

GCM ……………………………Global Climate Model

RCP………………………………Representative Concentration Pathways

GHG…………………………….Greenhouse gases

MOA…………………………….Minister of agriculture

SNNPR…………………………..South Nation Nationality peoples Republic

NAPA…………………………….National Adaptation Programme of Action

IWMI…………………………….International Water Management Institute

CMIP5……………………………Fifth Phase of the Coupled Model Inter Comparison Project

WGCM…………………………..Working Group on Coupled Modelling

AIMES…………………………. Analysis, Integration and modelling of the Earth System

SRES……………………………. Special Report on Emissions Scenarios

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Abstract

Climate change has impact on agricultural water demand by affecting the different climate variables such as temperature and rainfall. This study was carried out to detect the impact of the climate change on agricultural water demand under different time horizon to prevent vulnerability to climate change at Lower Bilate River sub-basin. The data used in this study were collected from National Meteorology Agency of Ethiopia, Ministry of Water, Irrigation and Electricity. Simulated climate data were obtained with using single climate model ICHEC-EC-EARTH, Precipitation and temperature time series of historical and projected time period. The scenarios used were from the Eth_CORDEX_Grids archive based on RCP4.5 and RCP8.5 Scenarios. The trend analysis for the last 32 years, indicated that the impact of the climate change to changes in long-term maximum and minimum temperature is increased by 0.0395^{o}c and 0.138^{0}c respectively and changes in precipitation is by the factor of the -0.83, the prediction analysis indicates that precipitation at the study area will be -35.71% and -40.18% for the year 2048 and 2080 respectively from RCP4.5 Scenarios. Whereas, based on RCP8.5 Scenarios the change in the same order will be -48.90% and -60.11%. As a result the change is expected in agricultural water demand for the selected crops at specific study area. The average irrigated agriculture water demand of selected crops Tobacco and cotton are found to be 19.01Mm3. However, this value is not kept constant as a result of the change in climate that for future time period (2017-2048) and (2049-2080) found to be $24.01Mm^{3}$ and $25.01Mm^{3}$ respectively for RCP4.5, and in case of RCP8.5 is found to be $25.33Mm^{3}$ and $28.36Mm^{3}$ respectively. Whereas, the Rain fed agriculture water demand for the crops maize and haricot bean are estimated 87.98Mm3 at the study area. As a result, the change in climate computed as 86.65Mm3 and 104.28Mm3 for the period of 2048 and 2080 respectively for RCP4.5 Scenarios, whereas based on RCP8.5 Scenarios the change will be 100.39Mm3 and 125.42Mm3 respectively.

Key Words: Climate change, Agricultural Water Demand, RCP4.5 and RCP8.5 Scenarios

1. INTRODUCTION

1.1 Background

Climate system is a complex, interactive system consisting five major components, such as atmosphere, land surface, snow and ice, Oceans and other bodies of water, Biosphere/Living Environment. The atmospheric component most obviously characterizes climate; often defined as ‘average weather’. It can be regarded as a machine that converts sun radiation to heat & motion of the lower atmosphere & ocean. Major elements that add/subtract energy inputs into this machine are called forcing. Major changes in our climate system have been observed since 1950 while future changes are highly likely. Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to likely exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (high confidence). There will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases (IPCC, 2014).

Agricultural Water demand is defined as the volume of water required by crops either irrigated or rain fed to satisfy their needs. Demand is the theoretical while consumption is the actual. Climate is defined as long-term averages and variations in weather measured over a period of decades that the change in climate could disturb consumption rate. An important global challenge for the 21st century is adaptation to climate change. It refers to 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 time periods (Gebre et al. 2014).

According to IPCC (2014), climate variability and change present complex challenges to people’s livelihoods in Africa. An anticipated increase in the frequencies of extreme events such as droughts and floods under climate change, agriculture will suffer greatly. Below et al. (2010), concluded that like any Sub-Saharan African countries, Ethiopia faced climate variability and change which cause negative impacts upon agriculture. Because of the size and sensitivity of the agricultural sector, the impact is relatively high in developing countries and they are the most adversely affected by the negative effects of climate-induced events because of their low level of adaptation (IFAD, 2014). Conway et.al, (2011) revealed that the nature of Ethiopia’s agriculture is primarily rain-fed, and hence, the production is sensitive to fluctuations in rainfall.

The fact that climate has changed in the past and will continue to change in the future underlines, the need for developing a well thought early warning and adaptation interventions.

Climate change is real and it’s first effects existing poverty and is expected to have serious environmental, social impacts and economic of Ethiopia particularly rural farmers, whose livelihood depends on the use of natural resources.

Water requirements and availability are critical factors that determine the extent of climate change impacts on agriculture. Thus, it is the key importance to investigate how climate change could affect agricultural water use, especially irrigation requirements, given that irrigated land produces about 40% of the global harvest (FAO, 2011). While the increasing precipitation and changing intra-annual precipitation distribution in many areas can lead to more effective rainfall for crop growth, the declining diurnal temperature range will play a key role in offsetting the warming effect at the global scale. Regionally, Africa and China are likely to benefit from lower water requirements (Zhang, 2013).

Human activities affect hydrological extremes of river basin directly and indirectly. The factors which cause climate change are industrial development and Greenhouse effect. These all result global warming due to climate change. The release of greenhouse gases in the atmosphere in recent years is thought to be the cause of changing climatic patterns. Increases in global surface temperatures and significant inter-annual climate variability were observed in many regions of the world during the latter half of the twentieth century. The WMO (1998) has reported on warming trends, with proof of climate change and its continuation observed from many parts of the world. Hydrological scenarios for Central America show that a significant limitation of the potential water resources will occur due to an increase in evapotranspiration and changes in precipitation. Studies on vulnerability of hydrologic regions in Mexico and all Central American countries to future changes in climate suggest that potential changes in temperature and precipitation may have a dramatic impact on the pattern and magnitude of runoff, on soil moisture, and on evaporation (Arnell, 2000).

Ethiopia is also one of the affected countries by global warming and frost of Pacific Ocean in interval of years, which abrupt extreme events as a result and is consequence of EL-Nina and La-Nina due to change in global weather condition. The spatial distribution of rainfall in Ethiopia is significantly influenced by topography, which also has many abrupt changes in the Rift Valley (NMAE,2010) Depending on the type of product being grown, croplands tend to have a percentage of bare ground even during the peak of the growing season, and may be completely bare prior to being planted. In both instances, most of the precipitation that lands on these denuded areas will be discharged directly into the stream channel rather than infiltrating into the soil or evaporating/transpiring from the plant surfaces. As a result, conversion to cropland tends to increase water yield compared to native vegetation (Fisher et al. 2004). According to Abayneh (2011), quantify the possible impact of climate change on extreme hydrological events and the water availability around the Addis Ababa and surrounding catchment by applying GCM model output. Since the consequence of global climate change are not limited at global level but also effects are extends up to national and regional or local level.

1.2 Statement of problem

According to the Jiri et al. (2015) climate change and variability is one of the biggest global problems to agricultural production for the current and future generations. There is some evidence that climate change has greatly modified the hydrological cycles, rainfall and temperature patterns in many parts of the world. The effects of climate change and variability vary across regions, farming systems, households and individuals.

Conway et al. (2011) indicated that the nature of Ethiopia’s agriculture is primarily Rain-fed, and hence, the production is sensitive to fluctuations in Rainfall. Since, most of the study area is Rain fed dependent, but fluctuation of rainfall creates confusion to Rain fed agricultural based society due temporal variation of Rainfall due to abrupt change of climate. Specifically, at the study area mean annual anomaly of Rainfall and Temperature differs from year to year. This results in shortage of food, animal fodder, less economy and food insecurity are problem at hand and the consequence has increasing from period to period. These all needs extensive strategy, evaluation and planning on Agricultural water demand development. However, due to climate variability and change, the crop water requirement fluctuates. On the other hand, water demand is also expected in different periods of the year in the sub-basins. Hence, this study will have a paramount importance in giving an insight on the vulnerability of the Bilate sub basins to climate change. According to Gintamo (2009) and Tekle et al. (2014) the Bilate catchment has high mean temperature (22.950C) and low mean annual rainfall (733.95mm), which makes it vulnerable to any climate change. Since, objective of this study is to increase agricultural production through the introduction of impacts of climate change on agriculture water demand and will view the direction for the problem, thereby attain food self-sufficiency and food security for specific study area.

1.3 Objectives of the study

General:

- To evaluate the impact of the climate change on agricultural water demand of the study area

Specific objectives:

- To estimate current agricultural water demand based on historical records of meteorological data to check the balance on availability and demand.
- To project the climate change using RCP4.5 and RCP8.5 scenarios
- To compute future agricultural water demands based on the above scenarios
- To estimate the seasonal shift and abrupt change with main climate variables and the trend overtime

1.4 Research Questions

- What is the current experience of Agricultural water demand?
- What looks like the impact of the climate change on Agricultural water demand if project climate change for the future?
- Is there a seasonal shift and abrupt change with main climate variables and the trend overtime due to climate change?

1.5 Scope of the study

Bilate River Catchment is frequently influenced by different factors such as land use/cover, water use and climatic change. But this study limited to evaluate the effects of climate change on Agricultural water demand.

1.6 Research Frame Work

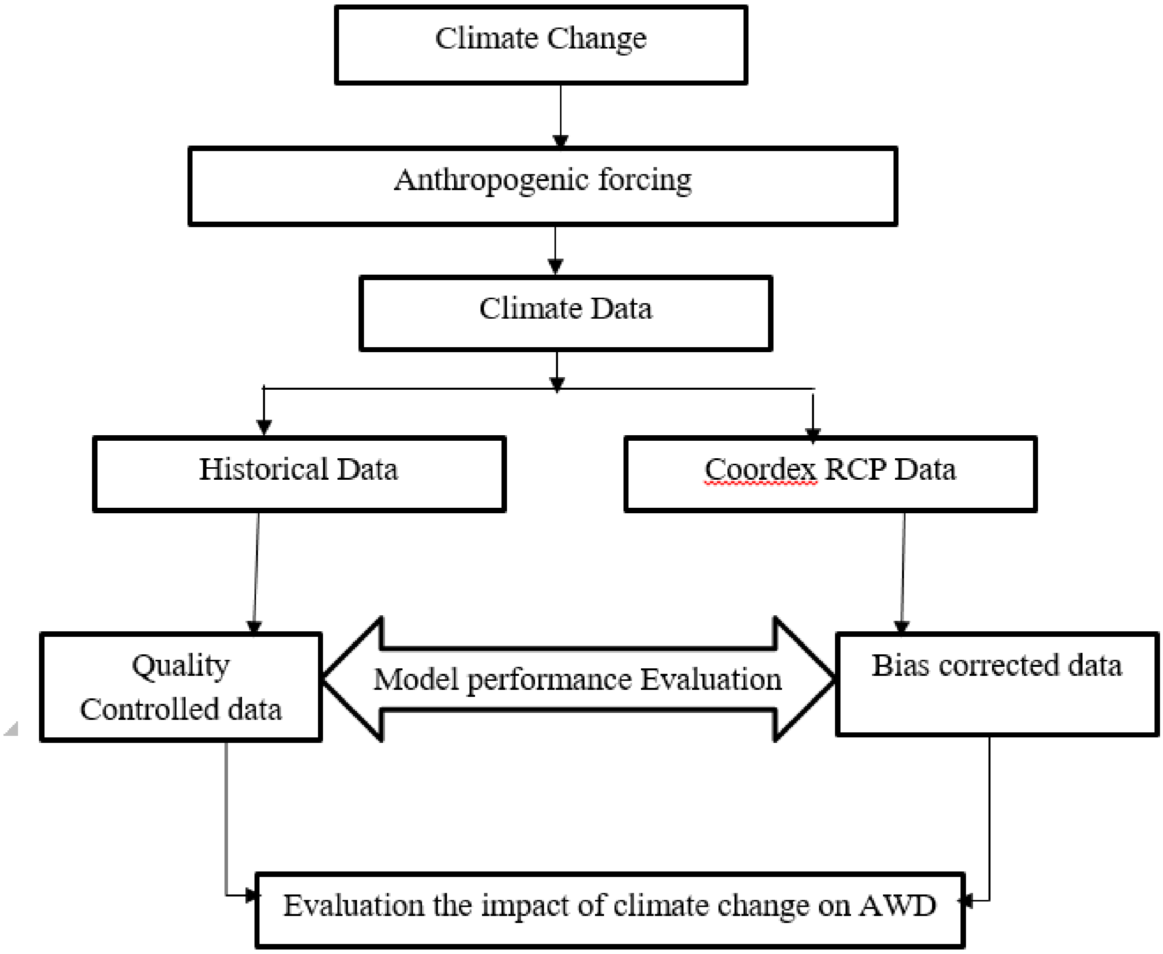

Figure 1.1 Research Frame Work

1.7 Significance of the Study

Analysing the Impact of climate change on Agricultural water demand at Bilate River catchment would be the solution to existing and future expected problems. Generally, the outcome of this study will enable to formulate and implement strategy, may help as a tool for interdisciplinary sectors to combat extreme events and may be input for further study.

1.8 Limitation of the study

In this study the impact of climate change was assessed by using single climate model and by assuming the irrigable and rain fed agricultural area will remain the same. However, in real world the area will change due to natural and human influences.

2. Literature Review

Definition of basic terms

Climate is generally defined as the average state of the atmosphere for a given time scale and generally for a specific geographical regions. The average-state description involves a wide range of variables depending on what is of interest. Hence, climate is long term state of atmospheric variables like precipitation and temperature. Temperature and precipitation are the most commonly used. The method of description focuses on statistical parameters, the mean and measures of variability in time such as the range, standard deviation, and autocorrelations. Whereas, Weather refers to the actual state of the atmosphere at a particular time, Short term changes in atmospheric variables such as precipitation and temperature (IPCC, 2014). Thus, Climate is what we expect; weather is what we get. Climate Variability refers to variations in the mean state and other statistics of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system internal variability or external variability. Internal variability is present on all time scales.

Concepts of climate change

According to IPCC (2007), definition of climate change refers to a change in the state of the climate system that can be identified by changes and the variability of its properties and that persists for an extended period, typically decades or longer.

UNFCCC defines climate change as: It is 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 time periods.

2.1 The causes of climate changes

According to IPCC (2007) the factors that causes climate change are; natural factors such as, aerosols from volcanic eruptions: reflect sunlight away and the Earth tends to cool (-Ve) and Solar variations (11-years Sun-pot cycle) that +Ve forcing. The second one, Anthropogenic factors that changes in atmospheric composition: GHGs from fossil fuel (+ve), and Aerosols from industry (-Ve) and Land use (+Ve/-Ve). While many natural factors continue to influence climate, scientists have determined that human activities have become a dominant force, and are responsible for most of the warming observed over the past 50 years.

According to the (IPCC, 2007) there is increasing evidence that the climate of the world is changing already. It is probable that it will continue to change, where humans contribute to these changes. Hence, climate change is expected to cause serious difficulties for agriculture, especially in developing countries. It is predicted that Africa is highly vulnerable to climate change since its economy largely relies on agriculture and uses low capital and inputs. Climate variability can be thought as climate changes depart from some average state, either above or below the average value. It often used to denote deviations of climate statistics over a given period of time from the long term climate statistics relating to the corresponding calendar period.

Natural greenhouse vs. enhanced greenhouse effect

Parts of the Earth's atmosphere act as an insulating blanket of just the right thickness, trapping sufficient solar energy to keep the global average temperature in a pleasant range. Greenhouse gases are trace gases in the Earth's atmosphere which do have a blanketing effect on the infrared radiation. The most important greenhouse gases include CO2, CH4, N2O, O3, water vapor (H2O), etc. The natural greenhouse effect increases Earth's surface temperatures by about 33ºC (from -18 to 15 ºc). Increasing GHG concentrations tends to increase surface temperatures (IPCC, 2014).

When anthropogenic GHGs are intruded into the atmosphere, more infrared radiation is trapped and reradiated back into the Earth and the natural greenhouse effect is accelerated up. This is similar to wearing thick blankets in warm areas. The primary consequence of Enhanced Greenhouse Effect will increase in the average temperature of the Earth's surface; the secondary consequences are other components of the climate system will be affected. Most computer climate models suggest that the globe will warm up by 1.5 - 4.5° Celsius if carbon dioxide reaches the predicted level of 600 parts per million by the year 2050 (IPCC, 2007).

Climate change indicators

Vulnerability is an indication of peoples' exposure to external risks, shocks and stress and their ability to cope with and recover from the impacts or the degree to which a system is susceptible to or unable to cope with, adverse effect of climate change, including climate variability and extremes (IPCC). An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks (IPCC, 2007). Most vulnerable sectors are water in the dry tropics, agriculture in low latitudes, human health in poor countries, where activities depend on sensitive ecosystems, like mountains and most vulnerable regions are Africa, Asian mega-deltas, small islands, the Arctic are more at risk from Climate change impacts as compared with developed countries. This is because of their weak resource-based and simple livelihood. Climate change had and will have predominant impact on the world that we live, it Cause mean sea level rise by 12-22cm. beside the sea level rise, global average temperature will rise between 1.4 and 5.8°C by 2100, the mean temperature rose by about 0.74 0C IPCC (2014).

Based on comprehensive data from multiple sources and scientific evidences, 10 key climate indicators are identified by (NOAA, 2010), to define measurable planet-wide features to gauge global temperature changes. The relative movement of each of these indicators proves consistent with a warming world (NOAA). Seven indicators are rising: air temperature over land, sea-surface temperature, air temperature over oceans, sea level, ocean heat, humidity and tropospheric temperature in the “active-weather” layer of the atmosphere closest to the Earth’s surface. Three indicators are declining (Arctic sea ice, glaciers and spring snow cover in the Northern hemisphere). Since, for the different time periods, the impacts of climate change were assessed at Global, National and Local levels in different point of view. Most of the study result shows that the causes of hydrological hazards are a complex mixture of meteorological, hydrological and human factors. Since, it is the current issue at many parts of the world level and some of the different studies are reviewed as follow at different places to overcome these problems.

2.2 Impacts of the Climate Change on Key Sectors

The standard approach to assessment has been the climate scenario-driven ‘impact approach’, developed from the assessment framework of IPCC (1994), which used to assess the impacts of potential Climate Change. It involves as the Definition of the problem, Selection of the method, testing the method, Selection of scenarios and Assessment of biophysical and socioeconomic impacts.

2.2.1. Impact of the Climate Change on Water Resources

Access to water resources plays a key role in poverty reduction and economic growth (Bates et al., 2008). Access relies on a number of factors including: the interplay between water resources, the technology used to access these resources, and changes in demands for water. Climate change is likely to have an impact on all of the above dimensions. Water availability: Increase by

10-40% at high latitudes and in some wet tropical areas and Decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics, water supplies stored in glaciers and snow cover are projected to decline, reduce water availability in regions supplied by melt-water from major mountain ranges, where more than one-sixth of the world population currently lives. Generally, dry regions of the world will get drier and wet regions will get wetter.

In the case of Senegal and Gambia River basin, the characteristic flow rates were calculated to evaluate their possible evolution under the projected climate scenarios at the 2050 horizon. For the near future (2050 horizon), compared to the 1971–2000 reference period, results showed that for both river basins, multi-model ensemble predicted a decrease of annual stream flow from 8% (Senegal River Basin) to 22% (Gambia River Basin) under the RCP4.5 scenario. Under the RCP8.5 scenario, the decrease is more pronounced: 16% (Senegal River Basin) and 26% (Gambia River Basin). The Gambia River Basin will be more affected by the climate change (Bodian et al, 2018).

2.2.2. Impact of the Climate Change on Agriculture

Potential agricultural-related impacts from climate change

Droughts and low water-tables leading to water stress, Transport of water to other locations, changing seasons will lead to different crop growth, Soil temperatures will remain warmer, changes in land, soil and water resources (quantity, quality).

Some Projected Impacts on Africa: Warming up to 5ºC by year 2100, and at least 2ºC by 2050, since by 2020, 75-250million peoples expose to increased water stress. In some countries, yields from rain-fed agriculture could be reduced by up to 50%. By 2080, an increase of 5 to 8% of arid and semi-arid land and Increasing extreme events, such as droughts, flokods, hurricanes, heat waves, high winds and landslides (NOAA, 2010).

2.3 Global Climate Change

The global average temperature showed a 100 year linear trend of 0.74^0c from 1996-2005. Trends in precipitation amount have been observed in many large regions. Globally, the area affected by drought has likely increased since the 1970's. (IPCC. 2007) As simulated by models, the change will continue into the future that Caribbean temperatures continue to increase to

2099, computer models suggest the Caribbean temperature will warm by 1 to 5°c by the end of the century.

2.3.1 Climate change and Rain fed agriculture at Global level

Globally, around 10% of current rain fed area might be unsuitable for rain fed agriculture in the future, mostly due to either large water deficit at present or increased water deficit in the future due to climate change. India is the most affected region in terms of water deficit for rain fed crops, Europe will have 25% of its current rain fed area that can be negatively affected by climate change (Zhang et al, 2013).

Global increase in CO2 concentrations is primarily due to fossil fuel use, with land-use change providing another significant contribution. The increase in CH4 concentration is predominantly due to agriculture and fossil fuel use. The increase in N_2O concentration is primarily due to agriculture. Changes in the atmospheric concentrations of GHGs and aerosols, land cover and solar radiation alter the energy balance of the climate system and are drivers of climate change. They affect the absorption, scattering and emission of radiation within the atmosphere and at the Earth's surface. The resulting positive or negative changes in energy balance due to these factors are expressed as radiative forcing, which is used to compare warming or cooling influences on global climate. (IPCC. 2007)

Rainfall contributes to an estimated 65 percent of global food production, while the remaining 35 percent of global food is produced with irrigation. In most parts of the world, rainfall is, for at least part of the year, insufficient to grow crops, and rain fed food production is heavily affected by annual variations in precipitation. A major part of the developed global water resources is used for food production. In most countries, 60 to 80 percent of the total volume of developed water resources is used for agriculture and may reach well over 80 percent for countries in arid and semiarid regions (Smith, 2000). The global renewable water supply is about 7,000 m3 per person per year (present population). The per capita minimum water requirement is estimated at 1,200 m^3 annually, of which 50 m3 is for domestic use and 1,150 m3 is for food production. (FAO.1994)

2.3.2 Climate Change and Irrigated Agriculture at Global Level

According to Rehana et al (2012) studied Regional impacts of climate change on irrigation water demands and reported that for all crops at all nine locations, the projected irrigation demands are higher compared to the current demands. Even though the projected demands are higher compared to observed ones, the relative difference in the future demands for the periods of 2020–2044, 2045–2069 and 2070–2095 are small, due to the projected increase in the rainfall in the Bhadra command area. The annual irrigation demand assessment carried out in this study will give an overall idea about the changes in demands for each particular crop at each downscaling location. Moreover, the monthly analysis of demands for each crop at a particular location will be useful for the decision makers for better management of irrigation systems.

Potential impacts of climate change on irrigated agriculture can be summarized as Water Demand projections for the 1,400 km2 study region in the western San Joaquin Valley range from a decrease of 13% to an increase of 3% by the end of the 21st century. Reductions are largest in dry and warm scenarios, for which increased fallowing and decreased crop transpiration was projected, both leading to reductions in irrigation water demand. (Schoups et al. 2008)

Sub–Sahara Africa is among the most vulnerable continents or regions to climate change impacts, because the majority of the sub-Sahara African population lives in abject poverty, and are heavily dependent on rain fed agriculture for their economic and livelihood sustenance. Therefore, variations in rainfall patterns and temperature adversely impact their economic and social survival. Because the main long-term impacts include significant changes in rainfall patterns and temperature which affect agriculture, there is a projected significant reduction in food security; worsening water security; decrease in fish resources in large lakes due to rising temperature; increase in vector-borne diseases; rising sea level affecting low-lying coastal areas with large populations; and rising water stress. African Partnership Forum(APF.2007). According to the FAO (2008) all the climatic factors, the daily and inter-annual variations in rainfall are most crucial for rain-fed and runoff for irrigated production.

Irrigation is an obvious option to increase and stabilize crop production. Major investments were made in irrigation during the latter half of the twentieth century by diverting surface water and extracting groundwater, the irrigated areas, in the world during the last three decades of twentieth century increased by 25 present. (FAO.1993)

The change of temperature and rainfall patterns will directly deplete soil moisture which can greatly reduce agricultural yield, also causes more demand for irrigation, the effects will be felt directly, in the case of rain-fed agriculture, and indirectly, in the case of watershed hydrology and runoff and, therefore, irrigated agriculture (Zhou et al. 2010).

Major changes in our climate system have been observed since 1950 while future changes are highly likely. Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to likely exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (high confidence). There will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases (IPCC, 2014).

Model simulations suggested that increasing agricultural demand under climate change brought on by increasing temperature will place additional stress on the water system, such that some water users will experience a decrease in water supply reliability (Joyce et. al.2006).

The continent of Africa is warmer than it was 100 years ago. Warming through the twentieth century has been approximately 0.7°C. An average annual mean increase in surface air temperature of about 2.9°C in the past 100 years has been observed in boreal regions of Asia. Climate models simulate a climate change-induced increase in precipitation in high and mid-latitudes and most equatorial regions but a general decrease in the subtropics (IPCC, 1996). Precipitations over North America increased by 70 mm per year, the latter half of the twentieth century. These trends, like those of temperature, have been fairly heterogeneous. The largest increases have been in the North-eastern and western coastal regions, with some regions of decreasing precipitation in the midcontinent (http://ipcc.ch/pdf/assessment-report/.pdf).

According to Chaowiwat et al (2014) studied Impact of the Climate Change Assessment on Agriculture Water Demand in Thailand; climate change has caused damage to cultivated areas in both wet and dry seasons. The future climate model adopted in this study is focused on 7 general circulation model datasets with Representative Concentration Pathways (RCPs) 4.5 and 8.5 scenarios. The results show that the changing climate will result in about a 15% increase in water demand in both scenarios. However, while the changing water demand depends on the local climate change. The main impact areas are public health, agriculture, food security, forests, water resources, coastal areas, biodiversity, human settlements, energy, industry and financial services.

2.4 Climate change and Agriculture in Ethiopia

The climate of Ethiopia is characterized by high variability annually, seasonally and geographically. Increasing temperature and higher variability in rainfall will influence Ethiopia's agriculture and is expected to worsen the existing conditions, which could lead to further increase of land degradation, soil erosion, deforestation, loss of biodiversity and desertification (Bewket et.al, 2007). Where, some agro ecological zones (AEZs) can benefit from a slight increase in temperature during the right time of the season, whereas others will experience detriments. Likewise, change in precipitation will affect different AEZs differently (Deressa et.al, 2009). In general, Ethiopia is highly vulnerable to current variability and there are also signs showing that climate change will increase rainfall variability which will likely increase losses from rain-fed agriculture.

The most important environmental problems in Ethiopia include climate change, land degradation, overgrazing and deforestation, indoor air pollution and Water pollution. Continued climate change is expected to bring greater variability, and extreme weather events (e.g. droughts) which will further drive degradation of the country's ecosystems. As mentioned above, climate change is already taking place, thus past and present changes help to indicate possible future changes. Over the last decades, the temperature in Ethiopia increased at about 0.2°C per decade and minimum temperatures is more pronounced with roughly 0.4° C per decade (Keller, 2009).

The impact of climate change in Ethiopia is already apparent in the increasing temperature and declining rainfall, particularly in northern parts which are exceptionally vulnerable to drought. Impacts of increased climate variability and change include increased food insecurity from occurrences of droughts and floods. Ethiopia's economy and social wellbeing are already exposed to climate variability and weather extremes. A recent study by the World Bank projects that unless steps to build resilience are effective, climate change will reduce Ethiopia's GDP growth by between 0.5 and 2.5% each year. Agriculture: 50% of GDP and 80% of working population; sensitive to Climate change, because: 79% of the land is >16% with 25% having a slope of >30%. There will also be changes in production system viability; cropland area and

cropping patterns; pest and disease frequency and distribution brought about by changes in seasonality; timing and distribution of rainfall; higher evapotranspiration (EACC, 2010)
Diao et al, (2007), find out in their study that type of rainfall in Ethiopia is highly erratic, and most rain falls intensively, often as convective storms, with very high rainfall extreme and intensity spatial and temporal variability. Since the early 1980s, the country has suffered seven major droughts, five of which led to famines in addition to dozens of local droughts.

Temesgen et al, (2008), argues that climate change and adaptation to climate change in Ethiopia is highly related to poverty, lack of coping or adaptive capacity in most of the regions. Hence, IPCC (2007) stated that to understanding adaptation vulnerability adaptive capacity and are important concepts for; vulnerability can be seen as the context in which adaptation takes place. Adaptive capacity means is the ability or potential of a system to respond successfully to climate variability and change, in order to reduce and adverse take advantage of new opportunities.

At the end of the month, rain giving meteorological phenomena over Rift valley, eastern and central parts of the country caused to receive unseasonal rain. Slight deficit WRSI observed over southern and eastern Tigray, eastern Amhara and some parts of central and eastern parts of the country. WRSI analysis of long cycle crops indicated deficient as compared to that of 2008. On the other hand, the observed adverse condition in some areas like hail damage and flood due to the observed unseasoned rainfall condition over some areas caused damage on some crops (NMAE, 2010).

2.5 Studies at Ethiopian Main Rift Valley Level

Water Resources modelling helps to understand the relationship between available water resources and the demand for those resources under existing conditions and under future development scenarios, and used to identify areas of conflict caused by water scarcity, to identify potential mitigation measures. The key principle of sustainability will be Impact assessment on particular sectors by using different scenarios and taking mitigation measures. Based on the 1992 Reconnaissance Master Plan Study during the Phase 1 review of irrigation within the RVLB, 147 separate irrigation sites were identified. The Rift Valley Lake Basin has a variety of soil types that are moderately to marginally suitable for irrigated agriculture in different agro-ecological zones (AEZs). The study carried out by FAO in 1988 estimated the potential land suitable for irrigation to be of the order of 129,500ha (FAO, 1988). At the study area some of the researches and international journals have done to indicate existed problems at different time periods.

A feasibility study was carried out in 1985 for the Bilate Irrigation Development Project. The Bilate River basin covers an area of 5650 sq.km or 565,000 ha with an altitude range of between 3280 masl in the north and 1180m.a.s.l in the south. It has three sub-basins, including: Upper Bilate, Mid-Bilate and Lower Bilate. Four dam sites were identified along the main stream, two of which are proposed to impound water while the remaining dams were planned to serve for diversion and head regulation. The total command area of the irrigation project was indicated to be 10,700 ha, of which 3,100 ha were already under cultivation by the State Farm that was operating at that time. Proposed crops for the project included maize, teff, chillies, wheat and sorghum for small scale farmers and few cash crops included in the case of the State Farms (FAO, 1985).

At the Bilate River Basin Irrigation project originally investigated by FAO in 1980s and assessed to have a gross area of 8,700ha. Four dam sites were originally identified, three on the Bilate River at Boyo, Ropi, Dendo; and one on the Derba River. They identified different soil types ranging from young Fluvisols to well-developed poorly drained Vertisols. The study discusses previous soil studies by some organizations and firms at lesser intensity at basin and site specific levels in the Bilate basin.

According to Rift Valley Lakes Basin Integrated Resources Development Master Plan Study reported as Bilate irrigation project area was developed as a series of state farms, commencing with the Abaya State Farm (1,250ha) in the 1960s, followed in 1972 by the Tobacco State Farm. The 1974 LRDC report and plans prior to 1986, proposed a dam at Boyo aimed principally at the mid to lower Bilate areas of Alaba-Kulito to overcome water scarcity on the Bilate River. The lower catchment, including; the Bilate delta focused on the existing state farms in the lower Bilate, and is considering a combination of rehabilitation and extension of farm SF1 by up to 900ha net, to be allocated to settler farmers and rehabilitation of 3,015ha and new extension of 3,800ha of the existing Tobacco State Farms. The project aims at rehabilitation and extension of a total of 7,715ha with maize, haricot, soya, groundnuts, etc., being cultivated by smallholders on farms SF1, SF2 and SF3, and tobacco and cotton being continued at Tobacco Farm and Abaya State Farm respectively.

The frequency of hydrologic drought resulted from plausible climate change impact for long time median value (LTMV) of monthly constant threshold level shows for both time period there is no change. However ,the rest threshold defining method considered by the author in the study like the annual constant , seasonal constant ,daily constant for long time average value (LTAV) -

at 70%,80% and 90% Exceedance probability shows a decreasing trend (11.36% for the medium time period and 5.11% for the long time period) . There is a decreasing trend in stream flow for both time horizons in the study area. From the result it is observed that Bilate catchment is porn to hydrological drought in the future time (Geta, 2012).

Wagesho (2013), investigated the potential impact of climate change on runoff generation at two agricultural watersheds (Hare and Bilate). Climate change and key future signals of its variability were assessed using general circulation models (GCMs). The result concluded that increased extreme daily precipitation and temperature events prevailed for future scenarios. Dry spell length increased during the driest months and remained stable during wet seasons. At both watersheds, the simulated runoff varied from to 18% and 14%, respectively. Simulated average annual runoff showed slight variation between the GCMs at both watersheds.

According to Kassa et al (2014), Assessment of Climate Change Impact on Water Availability of Bilate Watershed, Ethiopian Rift Valley Basin, average annual water balance for both calibration and validation period result from simulation showed that the largest portion of the average annual precipitation (76.26%) falling in the watershed is lost through evaporation. This value indicates that there is high sensitivity of evapotranspiration to any change than any other hydrologic parameter governing the sub watersheds' water balance. Since the change in climate variables such as decrease in precipitation and increase in temperature thereby increase in evapotranspiration which is very sensitive parameter that can be affected by changing climate than any other hydrological component are likely to have significant impact on Stream flow. There is an increase of water demand due to an increase of human need of water for different purposes. This in combination of the future climate change impact on reduction of the available water in the watershed causes a water stress within and around the watershed. According to Wagesho (2014), investigated that impact of land use dynamics in two rural watersheds (Bilate and Hare) in the Rift Valley lakes basin of Ethiopia. The simulated surface runoff component increased progressively since 1970s. Percentage annual surface runoff varies from 10 to 23% at Bilate, and 16% to over twofold at Hare watersheds. Statistical time-trend analysis reveals that annual stream flow do not show significant monotonic trend, whereas, extreme daily stream flow at Alaba Kulito of Bilate catchment is characterized by increasing trend during the analysis period.

Tekle et al. (2014) investigated the potential impact of climate change on runoff generation at Bilate and Hare agricultural watersheds using A2a and B2a scenario and one general circulation model. For hydrologic analysis the study used SWAT model. Based on the study, the change in maximum and minimum temperature shows increasing trend for the all-time period (2020s, 2050s, and 2080s). The results indicate that for A2a and B2a scenarios, the future river flow is projected to drop by 3.7% and 1.5% in March of 2020s and increase by 2.6% and 3.7% in 2050s. The decrease in future flow for A2a scenario is due to decrease in precipitation in Belg and Kiremt season in the specified time horizon.

The recent studies in Bilate river catchment that considered the implications of climate fluctuations for water resources availability was examined the extent and nature of rainfall variability from measured data while estimation of evapotranspiration was made from recorded weather data. The result showed that the main rainy season ends earlier in the lower zone; it is on July 12 ± 10 days with CV of 14% (Wodaje et al, 2016).

2.6 General Description of Climate Models

In general, there are two types of models which are Physical and Mathematical models. A physical model is a physical copy of an object and the object being modelled may be small or large. Physical models allow visualization of information about the thing the model represents, whereas; mathematical model uses mathematical languages to describe the system.

Climate models are mathematical models which are code of the fundamental equations that describe the behaviour of the climate system and the interactions of the components within the system. Models of the earth’s climate are based on laws of physics, conservation of energy, conservation of momentum, conservation of mass and the Ideal Gas Law.

There are three major sets of processes that must be considered when constructing a climate model which are radiate, dynamic and Surface process. Radiate that the transfer of radiation through the climate system, Dynamic process is the horizontal and vertical transfer of energy and Surface process which is inclusion of processes involving land/ocean/ice, and the effects of albedo, emissivity and surface-atmosphere energy exchanges. Categories/ Types of Climate Models are Energy Balance Models (EBMs), One Dimensional radiate-convective Models (RCMs), Two-dimensional Statistical-dynamical Models (SDMs); and three-dimensional

General Circulation Models (GCMs). These models increase in complexity, from first to last, in the degree to which they simulate the particular processes and in their temporal and spatial resolution. The Coordinated Regional Downscaling Experiment (CORDEX), after applying a variety of methods, will produce high-resolution “downscaled” climate data based on the CMIP5 simulations (Jones et al, 2011).

The historical runs cover much of the industrial period (from the mid nineteenth century to near present). Within the core set of runs, there are also two future projection simulations forced with specified concentrations (referred to as “representative concentration pathways” (RCPs), consistent with a high emissions scenario (RCP8.5) and a midrange mitigation emissions scenario (RCP4.5) (Taylor .et.al, 2009). The long-term scenarios are run at approximately 2° resolution, while the near-term scenarios have higher (0.5° to 0.5°) resolution. These projections can be scaled upward or downward according to the ratio of simulated global mean temperature for the RCP and the temperature change defined in simple CMs forced with different scenarios. The CMIP5 projections of climate change are driven by concentration or emission scenarios consistent with the RCPs. For CMIP5, four RCPs have been formulated that are based on a range of projections of future population growth, technological development, and societal responses. The labels for the RCPs provide a rough estimate of the radioactive forcing in the year 2100 (relative to preindustrial conditions). For example, the irradiative forcing in RCP8.5 increases throughout the twenty-first century before reaching a level of about 8.5 W/ m^2 at the end of the century (Jones et al, 2011).

The use of cropland and grasslands increases in RCP8.5, mostly driven by an increasing global population. Cropland also increases in the RCP2.6, but largely as a result of bio-energy production. The use of grassland is more-or-less constant in the RCP2.6, as the increase in production of animal products is met through a shift from extensive to more intensive animal husbandry. The RCP6 shows an increasing use of cropland but a decline in pasture. This decline is caused by a similar trend as noted for RCP2.6, but with a much stronger implementation. Finally, the RCP4.5 shows a clear turning point in global land use based on the assumption that carbon in natural vegetation will be valued as part of global climate policy. As a result of reforestation programs, the use of cropland and grassland decreases, following considerable yield increases and dietary changes (Vuuren et.al. 2011).

3. Description of the study Area

3.1 Location

The study area of Bilate River catchment is situated in South Western Escarpment of the Main Ethiopian Rift valley at 130 Km in North West of the regional town Awassa, and 340km from Addis Ababa. The River catchment includes the portion of SNNPRS regional zones; Hadiya, Kambata-tambaro, Gurage, Silte, Wolayita, Sidama, and Alaba special woreda and small parts of the South-central Oromiya Regional states. It covers an area of about 5306 km^2 and is bounded in geographic coordinates of 365483 to 426838E at Abaya Lake in southern part Sidama and Wolayita Zones to 726037 to 896469N at Gurage and Silte zones border in the Northern part. The altitude of the catchment ranges from 1177 meter at Lake Abaya to 3328 meter at Mt. Ambaricho and at Alicho Wiriro Woreda above sea level.

The catchment is bounded by Omo –Gibe basin to the south west, Ziway–Abijata–Shala, Lakes basin to the east and Lake Abaya to the south.

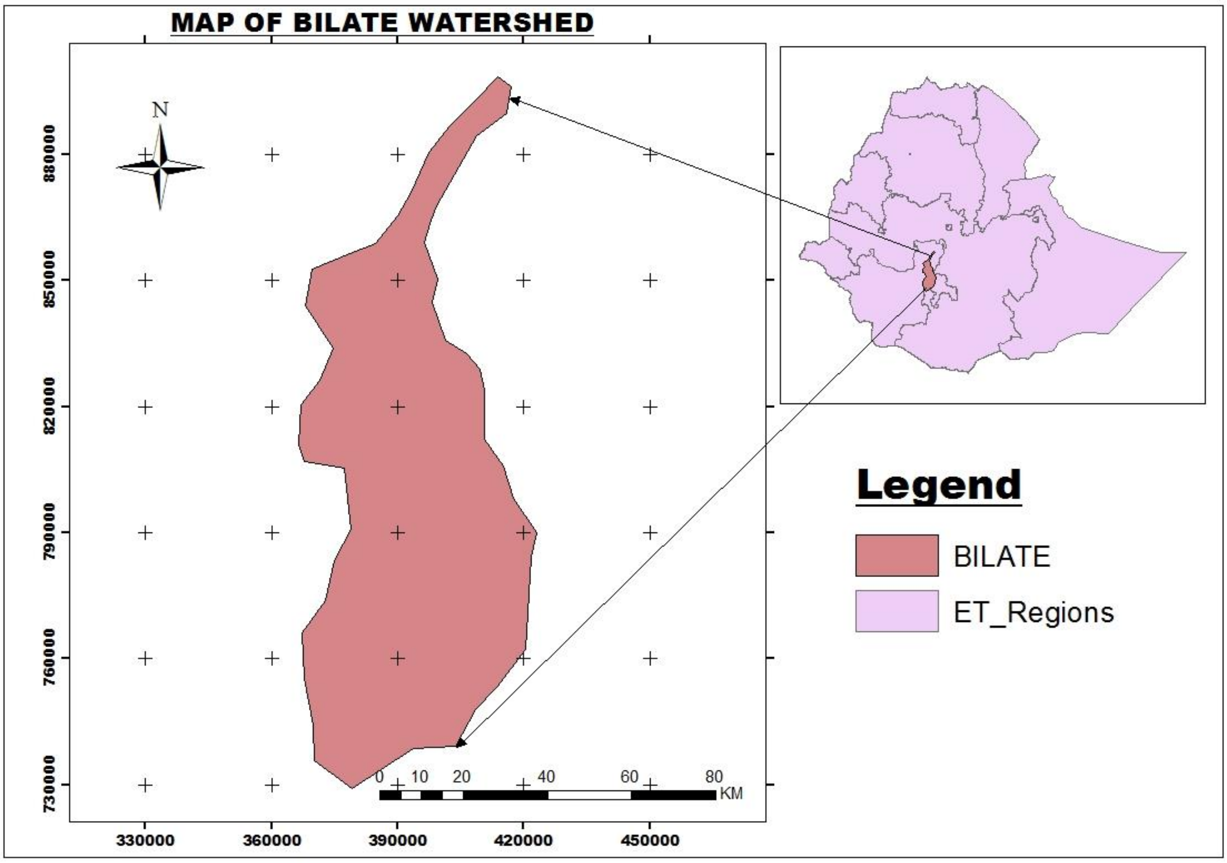

Figure 3.1 map of the study area

3.2 Climate of the Study Area

The climate of the study area follows a humid to semi- arid tropical bimodal distributed precipitation pattern. Variability is caused by alternating dry and rainy seasons, as well as long-term influences, which is overlapping with regional orographic effects (Stefan et al, 2004). The analysis of data of 11 meteorological stations in the area and nearby stations shows the area receives an average rain fall of 1145.82mm per year. From the analysis it was observed that two rainfall pattern exist in the area, uni-modal in the northern and north western part which receives relatively higher precipitation (1366.92mm) and that of bimodal rainfall pattern in the Southern and South Eastern receives relative mean annual precipitation amount of 998.16mm. The long term mean annual temperature vary widely, it ranges from 16.65˚C in the highlands and around 27.10˚C in the lowlands.

3.3 Land Use/Cover of the Study Area

The land use/land cover map of the study area was collected from MoWIE, GIS department which was obtained in shape file format and downloaded from the digital soil map of the Ethio-map sheet clipped to the extent of the region under study.

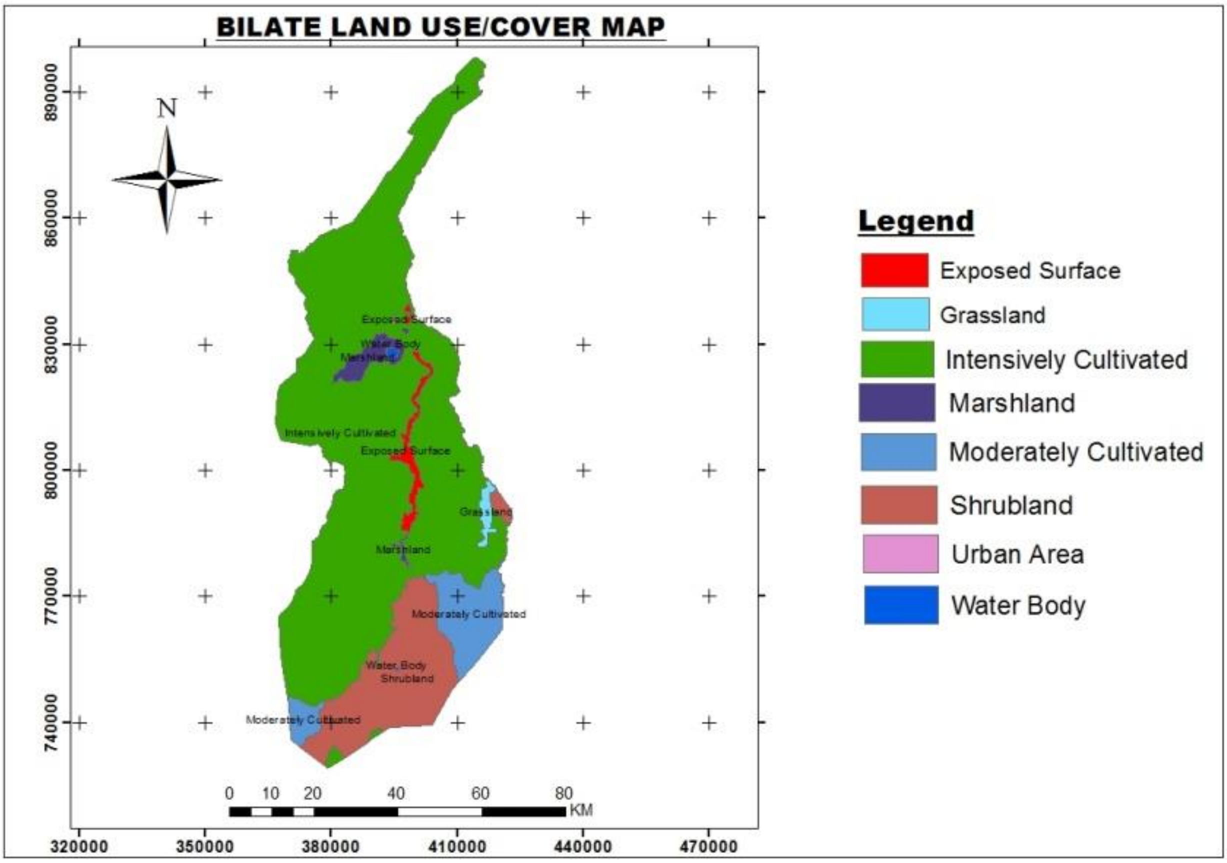

Figure 3.2 land use/cover of the study area

Table 3.1 major land use/cover of the study area

FID	Shape *	Major cover	Area_Km2	Area_ha
0	Polygon	Exposed Surface	80.564122	8056.412
1	Polygon	Grassland	36.092162	3609.216
2	Polygon	Intensively Cultivated	3749.32576	374932.6
3	Polygon	Marshland	90.91368	9091.368
4	Polygon	Moderately Cultivated	354.698189	35469.82
5	Polygon	Shrub land	752.324471	75232.45
6	Polygon	Urban Area	1.659046	165.9046
7	Polygon	Water Body	6.961846	696.1846

3.4 Soil Type of the Study Area

Soil data are collected from the Ethiopian MoWIE, GIS department. The soil data used for this study was rather downloaded from the digital soil map of the Ethio- map sheet, Digital Soil Map of the World and FAO soil, clipped to the extent of the region under study. Andosols, Arenosols, Cambisols, Fluvisols, Vertisols, Luvisols, Nitosols, and Leptosols are the major soils in the study area. Since, Soil is a key factor in determining for agricultural water demand in general and irrigation in particular.

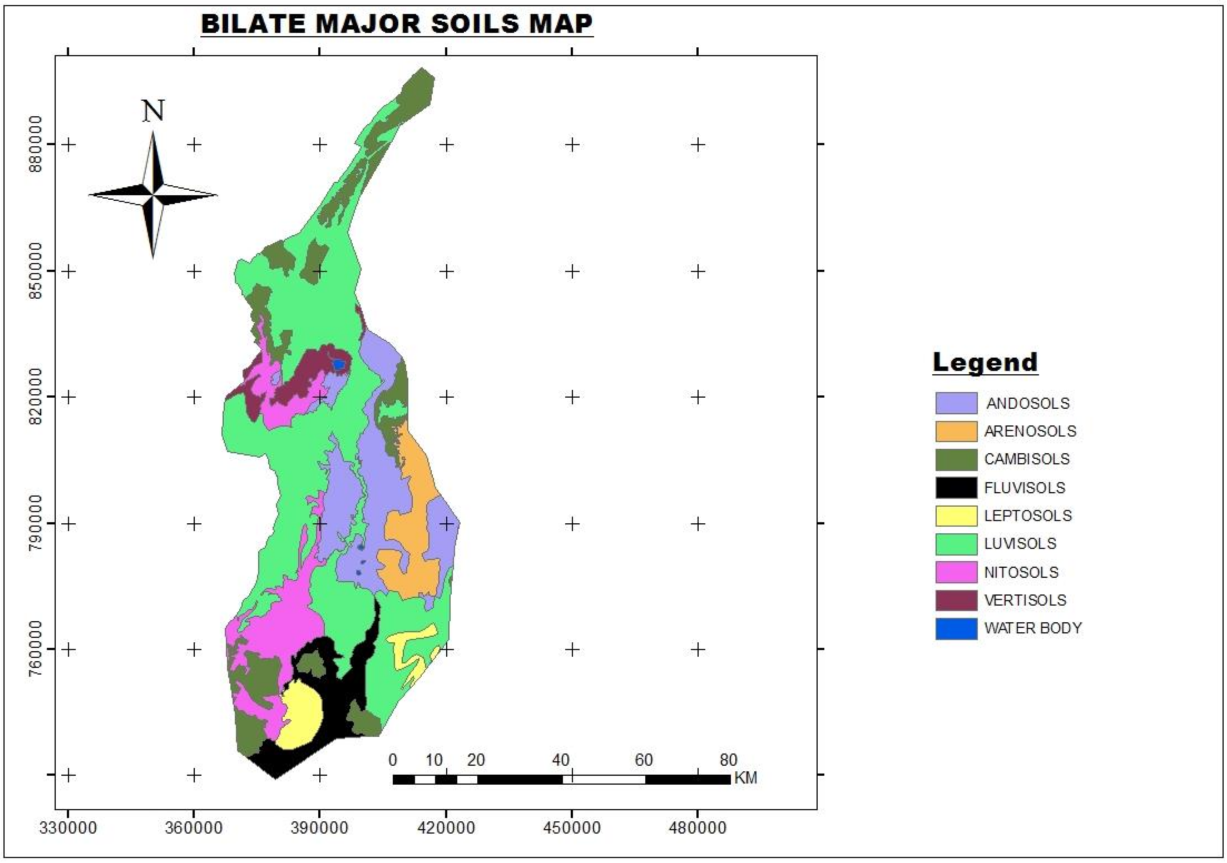

Figure 3.3 Soil map of the study area

Table 3.2 morphological characteristics of the major soil in study area

Soil group	Depth	Texture	Consistency	Drainage
Andosol	Deep to very deep	Loam, sandy loam	Very friable to friable; slightly sticky and none plastic	Well to excessively drained
Arenosols	Moderately deep to very deep	Sandy loam	Very friable to friable; none sticky and none plastic	somewhat excessively drained to excessively drained,
Cambisols	Shallow to very deep	Sandy loam, sandy clay ,loam,	Very friable to firm, none sticky to very sticky, none plastic to very plastic	well to excessively drained

4.0 Materials and Methods

4.2 Data Collection and Analysis

4.2.1. Meteorological Data

The climate data or meteorological data required for this study collected from the Ethiopia National Metrological Agency (NMA). There are about twenty climatologically stations in and around the study basin. The recorded climate data used in this study are rainfall, maximum and minimum air temperature, relative humidity, wind speed and sunshine duration.

Collecting and arranging the data into monthly or annual time series. Initial quality control of the daily or sub-daily data to identify and possibly correct errors or deal with missing data is also required. This step was carried out before the actual data screening. Since, at the study area (Bilate river catchment), there are only few meteorological stations with relatively long records inside the catchment, data include neighbouring stations too. A 32 year period (1985–2016) of daily data for eight weather stations were collected for the analysis. Weather stations providing meteorological data for this study (data source: Ethiopian National Meteorological Service Agency) tabulated as follow:

Table 4.1 meteorological Climate data availability

						Missing (%)				
No	Name	Lati	Long	Alt(m)	year	Preci	Temp	Rh	U	Rad
1	Bilate	6.82	38.08	1361	1985-2016	2.4	9.2	45	20.6	65
2	Boditschool	6.95	37.96	2043	1985-2016	2.5	1.8	-	-	-
3	BilateTena	6.92	38.12	1496	1985-2016	5.8	-	-	-	-
4	Humbo	6.70	37.76	1628	1985-2016	12.3	-	-	-	-
5	Butajira	8.15	38.37	2000	1985-2016	7.1	6.4	-	-	-
6	Indibir	8.12	37.94	2076	1985-2016	1.9	13.5	75	60	55
7	Wuliberg	7.74	38.12	1992	1985-2016	6.1	5.5	-	-	-
8	Fonko	7.64	37.97	2246	1985-2016	6.0	-	-	-	-
9	Hosana	7.57	37.85	2307	1985-2016	2.6	17.1	34	17.9	42.2
10	Alaba	7.31	38.09		1985-2016	15.62	14.3	-	-	-
11	Angecha	7.34	37.86	2317	1985-2016	14.9	19.6	-	-	-

4.2.2 Meteorological data screening

The basic data-screening procedure used here is based upon split-record tests for stability of the variance (F-test) and stability of mean (t-test) of such a time series.

The data screening procedure passed through the following principal steps in order to check the absolute and relative consistency, homogeneity and sationarity of the data, for the selected stations.

1. Rough screening of the data and compute or verify the totals for the hydrological year or season;

2. Plot these totals according to the chosen time step (yearly for this study) and note any trends or discontinuities (visual examination);

3. Test the time series for absence of persistence by computing the first serial-correlation coefficient (used only for Rainfall data); and test the time series for relative consistency and homogeneity with double-mass analysis.

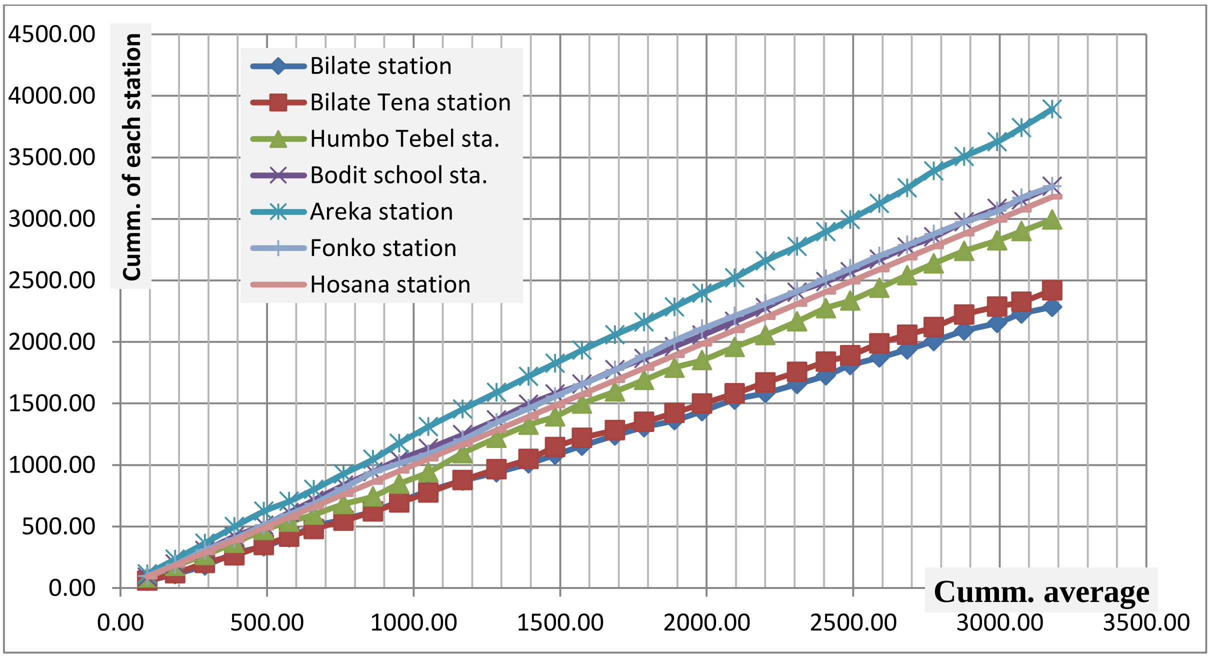

Figure 4.1 Double mass curve for the selected Metrological stations

Filling of missing data

Stations with missing data were filled by simple linear interpolation and normal ratio method. Normal ratio method are expressed by the following relationship

$$Px = \frac{Nx}{n} (\frac{P1}{N1} + \frac{P2}{N2} + \cdots + \frac{Pn}{Nn} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 4.1$$

Where,

Px= Missing value of precipitation to be computed.

Nx= Average value of rainfall for the station in question for recording period.

N1 =Average value of rainfall for the neighboring station.

Pn…P1= Rainfall of neighboring station during missing period

N= Number of stations used in the computation.

4.2.3 Quality control of modelled data

The Bilate Catchment is one of the regions where the rainfall projection is highly uncertain. However, estimating impact of climate change on agricultural water demand typically involves the utilization of climate model outputs from general circulation models (GCM). In this study bias correction is used to correct the large systematic errors which are pertinent in simulations of the single GCM models For this study the downscaled products include daily projection of daily minimum and maximum temperature and daily precipitation data. The systematic error in the REGRID precipitation and maximum and minimum temperature scenarios data from CORDEX have been corrected by using bias-correction method.

Step 1: Preparing observed data that Precipitation and temperature data files in ASCII format

Step 2: Extracting historical and scenario climate model data

Step 3: Processing the data using CMhyd

Bias correction aim to minimize the error of the simulations using outputs from GCMs, based on the assumption that the biases in climate modeling are of similar magnitude for both the control and the future scenario (Kundzewicz et al., 2007).

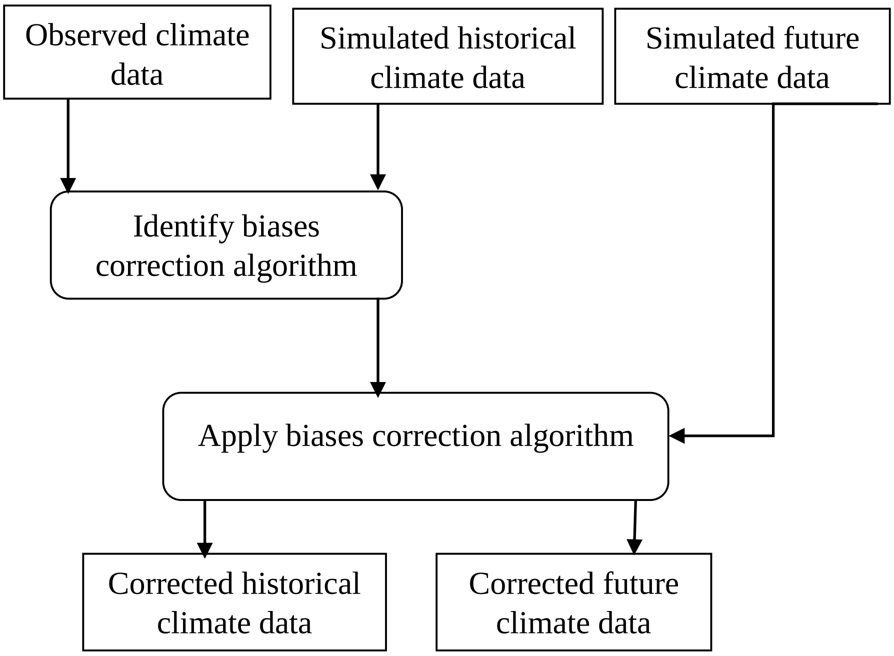

Figure 4.2 Bias correction framework

The means of the observed and controlled simulation climate output values (temperature and precipitation) are calculated for each month of a year. The simplest and most commonly used biased adjustment method is the so-called delta approach (Zelalem, 2013)

For the temperature bias correction Δ is defined as the difference between observed and controlled simulation at the monthly time scale, i.e.

$$\Delta T = \mathrm{Tobs}\ (j) - \mathrm{Tcont}(\ j); j = 1 \ldots 12; \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . .4.2$$

Where:

Tobs (j)- is the mean daily observed temperature for month D averaged over all 31 years of the reference (control) period.

Tcont (j)- is the mean daily simulated temperature for month j averaged over all 31 years of the control period using historical GCM output.

This ΔT value is then added on the future simulated time series for the temperature data, to give a bias- corrected value.

In contrast to the temperatures, the bias correction for precipitation is slightly different. In order to remove impossibly negative values for the precipitation, ΔP is as the ratio of observed to simulated precipitation, i.e.

$$\Delta \mathrm{P(j)} = \frac{Pobs(j)}{Pcont(j)}; j = 1 \dots 12; \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 4.3$$

Where:

Pobs (j)- is the mean daily observed precipitation for month D averaged over all 30 years of the reference (control) period.

Pcont (j)- is the mean daily simulated precipitation for month D averaged over all 30 years of the control period using historical GCM output.

Then the bias correction for future precipitation is as done by multiplying this ΔP with the future simulated time serious of precipitation, i.e.

$$Pcor(i,j) = \Delta \mathrm{P}\ (\mathrm{j}) * \mathrm{Psim(i,j)}; \mathrm{i} = 1 \dots .31; \mathrm{j} = 1 \dots 12; \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots ..4.4$$

Where: Pcont(i, j)- is the bias-corrected future precipitation time series.

Psim(i, j)- is the simulated precipitation for future scenario period

4.3 Crop Data and Agronomy

A cropping pattern is the yearly sequence and spatial arrangement of crops and fallow on a given area. Mixed farming involves the raising of crops, animals and trees. There is cultivated land, grazing land, forest covered land, cultivable, uncultivable and also other land which is occupied by different institutions on the Bilate sub-basin. Out of such land use pattern the cultivated land in all sub-catchment. However, the cultivable land is concentrated in the middle basin Eastern part. Whereas, the North and North-Western part is covered by Wood land and the South and South-Eastern part (Lower basin is) dominated by bare land.

Rain fed and irrigated agriculture command area and crop coverage at selected study area, the data, area of coverage, obtained from regional agriculture and natural resources office. The study area farming systems (either irrigated or rain fed) were using mixed farming. Inter cropping was often practice in the upper and middle sub-catchment, Silte zone, Shankar and Alaba Humbo and Bitana at Lower bilate river basin. The crops grown under such practices were maize, Haricot bean, cabbage and cotton and tobacco at Lower sub basin. In generally the major cereal crops commonly grown in the study area were maize, sorghum, haricot bean, chickpeas, teff barley and wheat.

Table 4.2 Command area and and crops at study area

Basin	Zone	Location	Total area(ha)	crops	ACZ
Rain-fed agriculture					
Lower Bilate	Wolayita	scattered	31,390	Diversified	Lowland
Irrigated Agriculture					
Lower Bilate	Wolayita	Abbaya prevate and s/farm	2226	Cotton	Lowland
Lower Bilate	Wolayita	Tobacco farm	1262	Tobacco	Lowland

Cropping Calendar

The crops are grown in the two major growing seasons in the sub-basin that is summer (Meher) and winter (Belg) growing season. Wheat, Haricot bean, Onion and Tomato are major crops grown during the Meher season; while Maize, Sorghum, Haricot bean and Potato are predominant crops cultivated during the Belg season. The winter cropping is supported by irrigation which could be further classified as first and second irrigation seasons.

Table 4.3 Cropping Calendar at study area

Sub-Catchment	Sample Zone	Woreda	Kebele	Meher	Belg	Common Crops
Lower	Wolaita	Humbo	A/Bilate	Red bean, Onion, Tomato	Maize, Sorghum	maize
			A/Bisare	Onion	Maize, Sweet potato	maize
			A/Chokore	Onion, Tomato, Cabbage	Maize, Sorghum	maize
			A/ Guricho	Onion	Maize, Sweet potato, Haricot	Maize, Haricot bean

Table 4.4 crop development stage and crop coefficient (Kc) at study area (FAO 56)

	Crop development stage					
Crop	initial	crop development	mid-season	late season	at harvest	Total growing period
Maize	0.3-0.5	0.7-0.85	1.05-1.2	0.8-0.9	0.55-0.6	0.75-0.9
Haricot bean	0.3-0.4	0.65-0.75	0.95-1.05	0.95-1.05	0.8-0.95	0.85-0.9
Cotton	0.3-0.4	0.7-0.8	1.05-1.25	0.8-0.9	0.65-0.7	0.8-0.9
Tobacco	0.3-0.4	0.7-0.8	1.0-1.2	0.9-1.0	0.6-0.65	0.85-0.95

Meteorologists usually define season from the characteristics of the basic patterns of the atmospheric-Oceanic interactive systems (Kiremt, Bega and Belg)

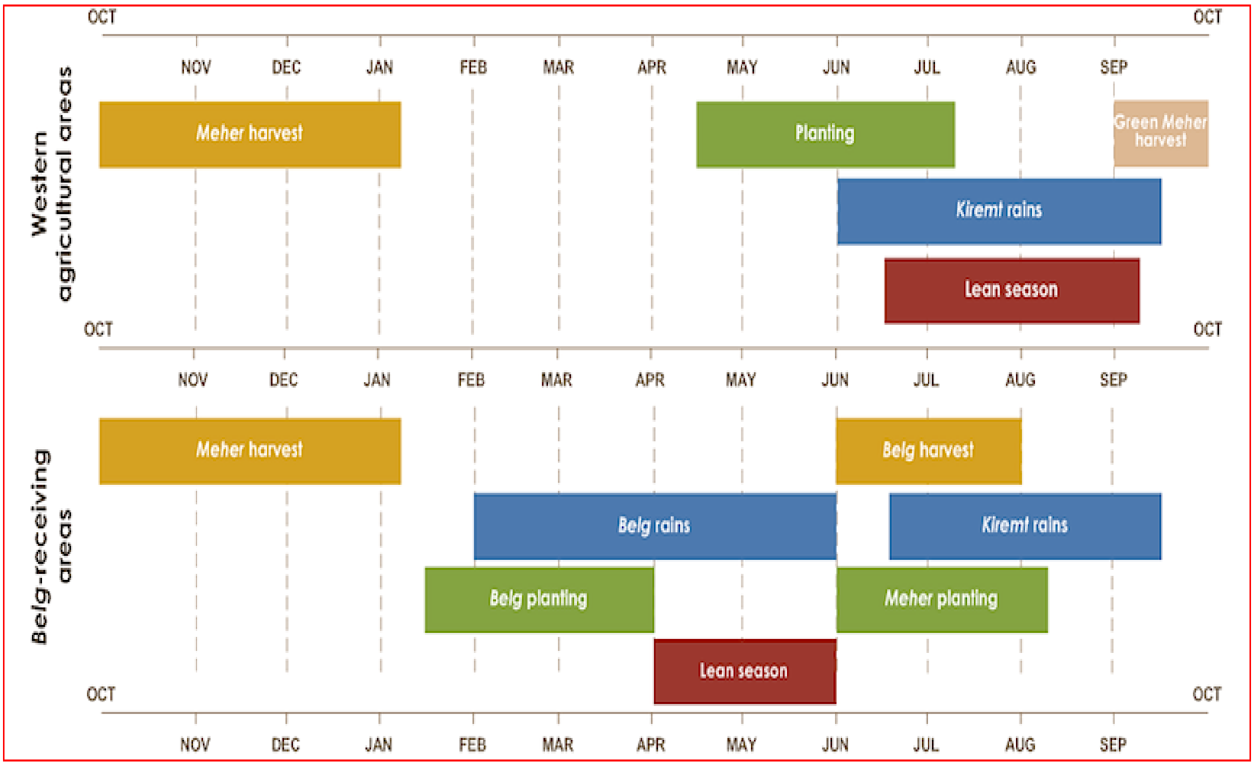

Figure 4.3 National cropping pattern/crop calendar

The study area are categorized into belg-receiving areas that the main seasons are kiremit (JJAS), bega(NDJF) and belg(FMAMJ) seasons.

4.4 Soil Data

Soil data are main input to estimate agricultural water demand. Field capacity and Permanent wilting point of the three selected fields from head, middle, and tail were obtained from the regional agriculture and natural resources office soil laboratory using a pressure plate apparatus by applying a suction of 1/3 bar and 15 bar to a saturated soil sample for the depth from irrigated fields at depth interval of 30 cm to maximum of 1.20 cm depth. This depth was considered as effective root zone of the crops at the time of measurement.

Table 4.5Soil physical properties of the three sub basin (Lower Bilate sub-basin)

S/N	Profile Code	FC(mm/m)	PWP(mm/m)	AWHC(mm/m)	X	Y
1	BP_014	344.13	207.80	136.60	405639	816705
2	BP_015	280.67	147.67	130.00	403629	815812
3	BP_002	275.33	133.33	140.00	397526	751103
4	BP_005	284.25	151.50	130.00	377677	774941
5	BP_007	358.00	223.20	134.80	296366	679283
6	BP_031	290	170	120.00	400321	763139

Soil water content is computed by using soil and plant characteristics such as crop coefficient, root depth, field capacity, permanent wilting point, percentage of rocks, apparent density of the rocks and maximum allowable depletion. Most of the listed parameters are used from FAO 56 soil manual and regional agriculture and natural resources office.

4.5 Climate model used at study area

Climate models attempt to simulate the behaviour of the climate system. The ultimate objective is to understand the key physical, chemical and biological processes that govern climate.

Single climate model, ICHEC-EC-EARTH are used in the case of this study. Precipitation and temperature time series, historical and future time period, from the Eth_CORDEX grids archive based on RCP4.5 and RCP8.5 Scenarios.

Since, Simulation of Climate variables corresponding to future climate conditions by using the downscaled precipitation and temperature data for each emission scenarios helps to identify any specific trend in the Agricultural water demand corresponding to future time horizon comparing with base period historical climate data at Bilate sub-basins.

Sequences of steps for climate model works are estimating future GHGs concentration, Using future GHG levels, calculate what future climate (e.g. temperature and precipitation) will be, finally, assessing the uncertainty of the predictions are the main task.The future simulation is done with the downscaled precipitation and temperature data. The downscaled precipitation data were divided in to two time horizon (2046s and 2076s) data periods. The greenhouse gas concentrations for the Representative Concentration Pathways (RCPs) and the projections include a major anthropogenic greenhouse gases. Emissions estimates for greenhouse gases (GHGs) through the historical period (1985-2004) with emissions projected for 2017-2080.

4.6 Agricultural Water Demand Estimation

Agricultural water demand is water requirement either irrigated or rain fed agriculture. In generally the methodology used in this study are shown in figure below.

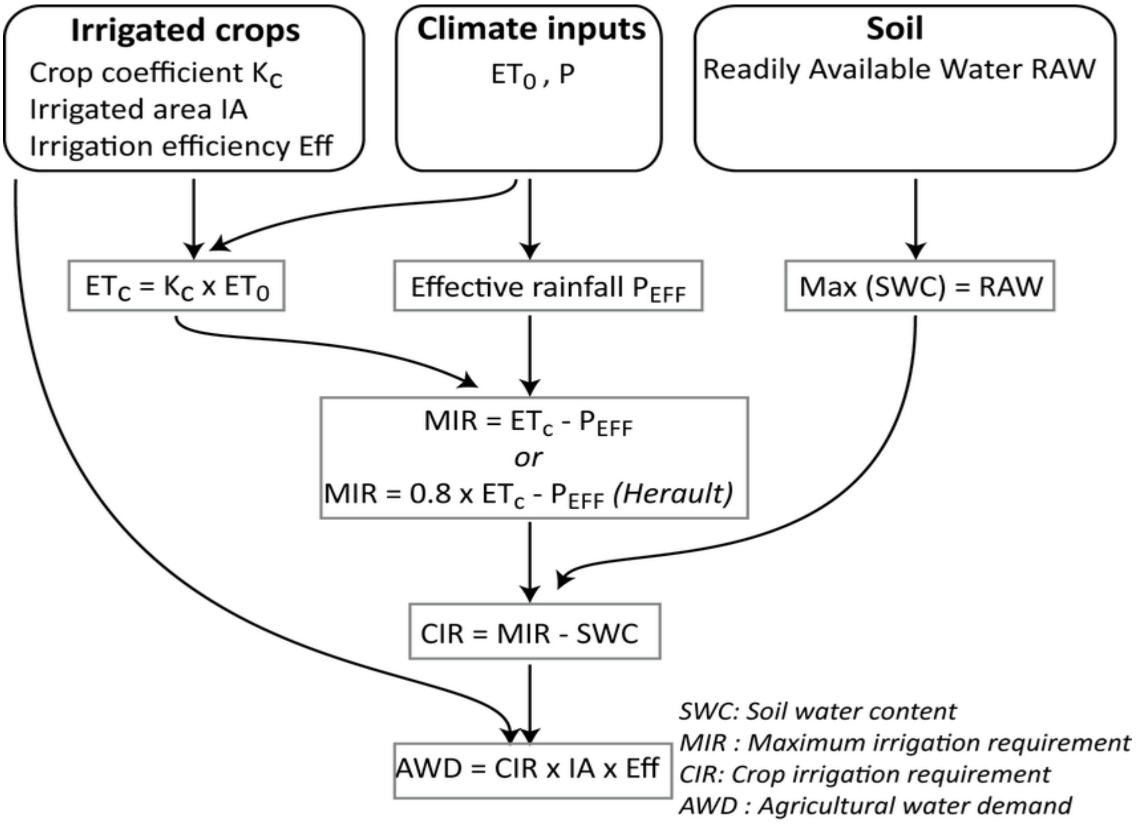

Figure 4.4 agricultural water demand estimation framework

FAO Penman-Monteith method is standardize and recommended as the best method for determining reference ETo. It was selected as appropriate approach and used to estimate ETo in this study. The evapotranspiration of this reference surface (ETo) can be unambiguously determined, and as the method which provides consistent ETo values in all regions and climates. (FAO, 56)

Since, FAO Penman-Monteith Modified equation to determine ET_o as follow:

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{Rn} - \mathrm{G}) + \gamma \frac{900}{\mathrm{T} + 273} \mathrm{U2}(\mathrm{es} - \mathrm{ea})}{\Delta + \gamma(1 + 0.34\mathrm{U2})} \dots\dots\dots\dots\dots\dots\dots\dots..4.5$$

Where: ETo-reference evapotranspiration (mm day-1)

Rn-net radiation at the crop surface (MJ m-2 day-1)

G-soil heat flux density (MJ m-2 day-1)

T-mean daily air temperature at 2 m height (°C)

U2-wind speed at 2 m height (m s-1)

es- Saturation vapour pressure (kPa)

ea- actual vapour pressure (kPa)

(es-ea)-saturation vapour pressure deficit (kPa)

Δ-slope vapour pressure curve (kPa °C-1)

ϒ- psychroetric constant (kPa °C-1).

$$\mathrm{ea} = \mathrm{e}°(\mathrm{Tmin}) = 0.611 \exp\left(\frac{17.27\mathrm{Tmin}}{\mathrm{Tmin} + 237.3}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 4.6$$

Where: Tdew- dew point temperature (is near the daily minimum temperature (Tmin)

To fill the gap of solar radiation the Hargreaves' radiation formula, adjusted and validated at several weather stations in a variety of climate conditions, becomes:

$$\mathrm{Rs} = \mathrm{KRs} * (\mathrm{Tmax} - \mathrm{Tmin})^{0.5} * \mathrm{Ra}\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..4.7$$

Where; Ra extra-terrestrial radiation (MJ m-2 d-1)

Tmax maximum air temperature (°C)

Tmin minimum air temperature (°C),

kRs adjustment coefficient (0.16-0.19)

Accordingly, the FAO Penman-Mointeith Method was used to determine reference evapotranspiration (ETo) in case of this study.

It is important to make a distinction between crop water requirements (CWR) and irrigation requirement (IR). Whereas crop water requirement refers to the water used by crops for cell construction and transpiration, the irrigation requirement is the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirement. Calculating the crop water requirements for each crop.

$$ETc=ETo*Kc$$

The rain fed water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and to compensate for non-uniformity of water application. (FAO, 56)

Rain fed Agriculture Water Demand

$$\mathrm{Rfed.agri.dem} = (\mathrm{ETc} - \mathrm{Peff}) * \mathrm{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.8$$

Where Rfed- the rain fed water demand, MCM,

ETc is water consumption of plant,

Peff is effective rainfall.

Irrigated Agriculture Water Demand

Irrigation water demand is calculated from reference evapotranspiration and effective rainfall.

$$\mathrm{Irr.agri.dem} = (\mathrm{ETc} - \mathrm{Peff}) * \mathrm{A} * \mathrm{effi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.9$$

$$\mathrm{ETc} = \mathrm{Kc} * \mathrm{ETo} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.10$$

Where: Irr.dem-is the irrigated water demand, MCM,

ETc - the water consumption of the plants,

Peff - effective rainfall, mm,

Kc -crop requirement coefficient,

ETo - the reference evapotranspiration,

A- the irrigated area, m2

effi - the efficiency of irrigation.

Effective Rainfall method

To account for the losses due to runoff and percolation a choice can be made of one of the four methods given in CROPWAT8.0 manual FAO irrigation and drainage paper No 46. There are different types of methods to calculate effective rainfall one of them is used in this study which are recommended for Ethiopian case. Assumptions concerning Rainfall (for effective and dependability) the following formula is used.

$$\mathrm{Peff} = 0.6 * \mathrm{Ptot} - 10 \text{ for } \mathrm{Ptot} < 70\mathrm{mm} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.11$$

$$\mathrm{Peff} = 0.8 * \mathrm{Ptot} - 24 \text{ for } \mathrm{Ptot} > 70\mathrm{mm}$$

Where P_{eff}-precipitation effective and dependable

Ptot-mean monthly Rainfall for the given month and year

Soil Water Content

Soil is a key factor in determining the agricultural water demand in general and irrigation in particular. The soil data was obtained from Ethiopian Ministry of Water and Energy (EMWE), Digital Soil Map of the World and FAO soil manual.

$$\mathrm{RAW} = \mathrm{TASW} * \mathrm{MAD}$$

$$\mathrm{TASW} = (\omega\mathrm{FC} - \omega\mathrm{PWP}) * \mathrm{Z} * (1 - \mathrm{Pr} \quad) * \frac{\rho\mathrm{a}}{\rho\mathrm{H20}} \ldots\ldots\ldots\ldots\ldots\ldots 4.12$$

$$\mathrm{MAD} = \mathrm{MADR} + 0.04 * (5 - \mathrm{MET})$$

$$\mathrm{MET} = \mathrm{PET} * \mathrm{Kc}$$

Where; TASW-total available soil water

ωFC-field capacity

ωPWP-permanent wilting point

Z-root zone

ρa-apparent density of the soil

$\rho H20$-water density

MET- maximum crop evapotranspiration

4.7 Trend Analysis using Mann-Kendall test

Trends can be either inconsistencies or non-homogeneities. Non-homogeneities (internal effects) result from changes in the phenomenon itself, either natural or man-induced, such as: Changes in land use, water use, climatic changes. Mann-Kendall methodology is applicable to detect statistically significant trend analysis. To confirm its significance, the Mann-Kendall- test have been carried out, based on the following test hypothesis the Mann-Kendall (MK) statistical trend test (Mann, 1945; Kendall, 1975) was employed to investigate trends in time series data. Ho: there is no trend in the series and H1: there is a trend in the series. For both test procedures, p-values and the significance level α=0.05,would be compared for the purpose of decision making meaning that one should reject the null hypothesis Ho, and accept the alternative hypothesis H1, and vise verse. The test statistic S is:

$$S = \sum_{k=1}^{n-1} * \left[\sum_{j=k+1}^{n} sign(x_j - x_k)\right] \quad \text{Where; } sign\left(x_j - x_k\right) = 1 \text{ if } x_j - x_k > 0$$

$$sign(x_j - x_k) = 0 \text{ if } x_j - x_k = 0$$

$$sign(x_j - x_k \; = -1 \text{ if } x_j - x_k < 0$$

A positive value of S is an indicator of an increasing trend, and negative value indicates a decreasing trend.

$$\mathrm{VAR(S)} = \frac{1}{18}[n(n-1)(2n+5)]$$

$$Z = \frac{S}{\sqrt{\mathbf{VAR(S)}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..4.13$$

Where, S is Mann-Kendall trend test statistic

Z is Standard normal variate

Var(x) is variance,

n is size of data

- The trend is said to be decreasing if Z is negative and the computed probability is less than the level of significance.
- The trend is said to be increasing if the Z is positive and the computed probability is greater than the level of significance.

In this study, the 1% level of significance was considered. This statistical analysis is performed using Spell-stat statistical software and MAKESENS 1.0 that Mann-Kendall Test and Sen's Slope Estimates for the Trend of Annual Data.

4.8 Characteristics of Climate at the Study Area

4.8.1 Rainfall Characteristics of the Lower Bilate River Sub-basins

In most parts of the world, rainfall is insufficient to grow crops; rain fed agriculture was heavily affected by annual variations in precipitation. More detail shown in figure below.

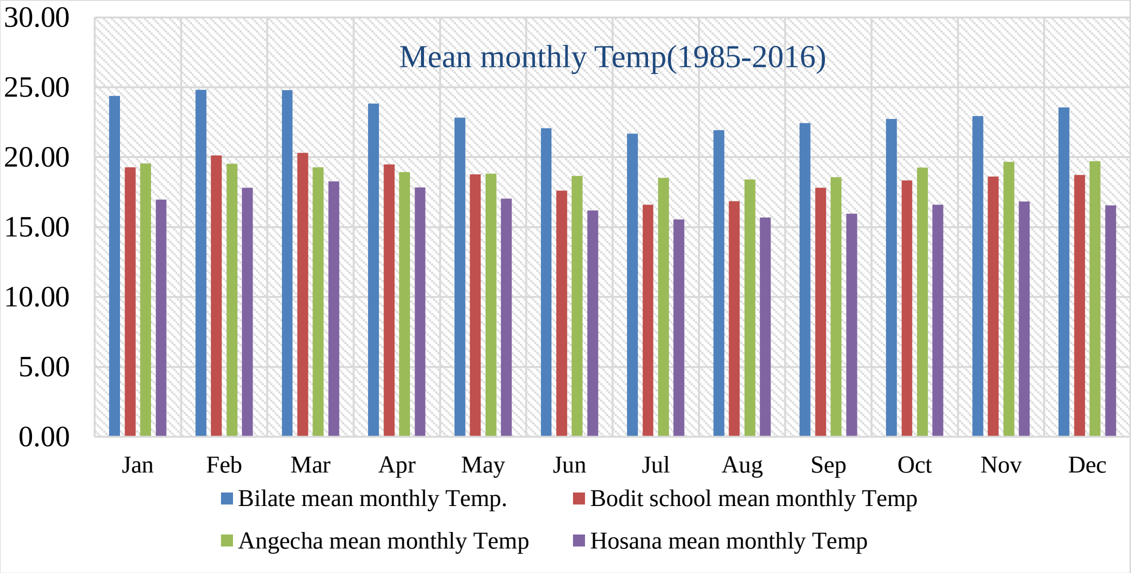

Figure 4.5 Mean monthly temperature of the base period (1985-2016) at selected stations

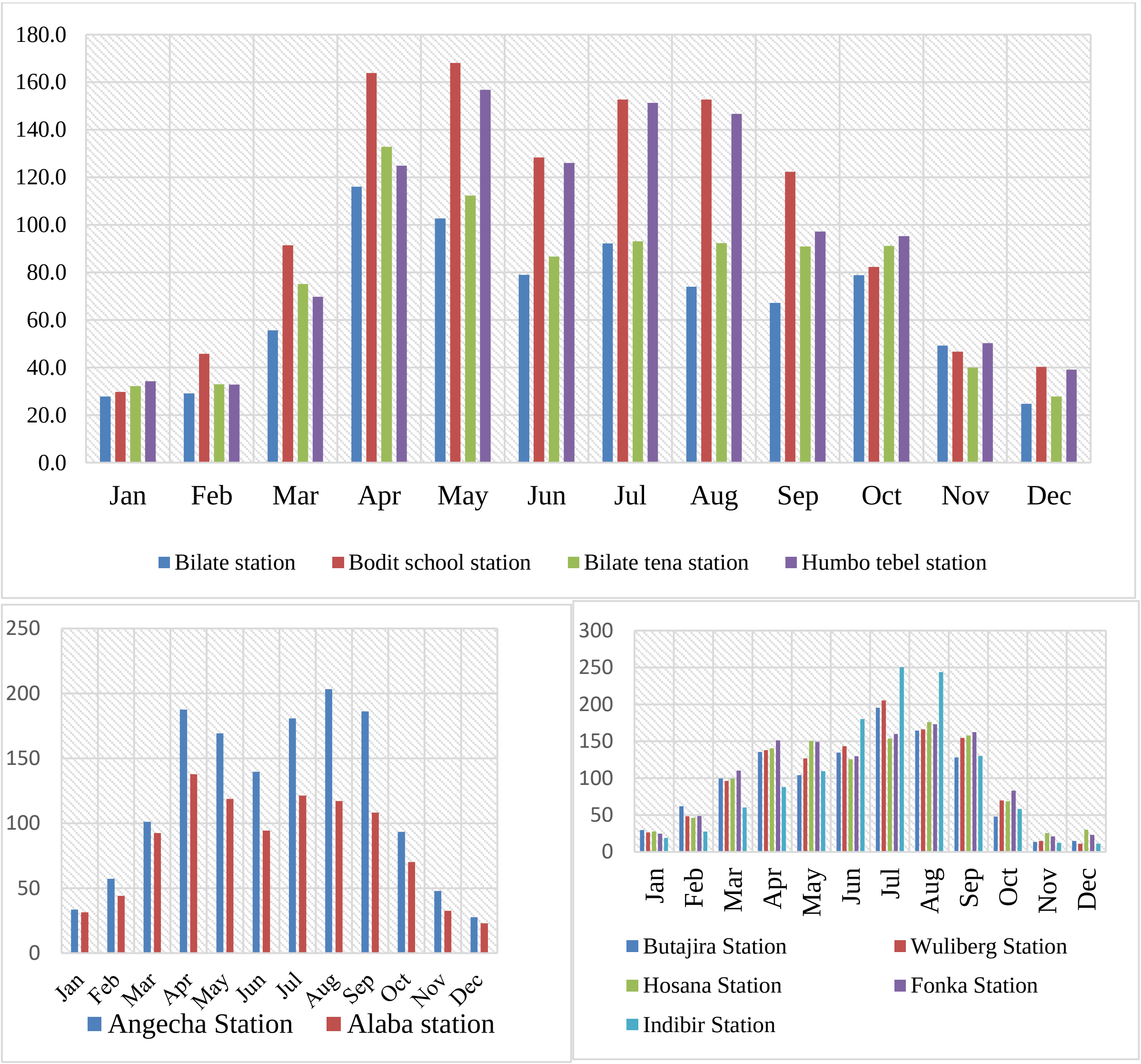

Figure 4.6 Mean monthly rainfall distributions at middle, upper and lower Bilate sub-basins (1985-2016)

4.8.2 Climate variability over the Lower Bilate sub-basin stations

Climate Variability on onset of rainfall season can be considered as the major problem in dry land rain fed agriculture and it varies from year to year and differs from place to place.

Variability (dispersion) measures the amount of scatter in observed data and used to decision making. Method of variability measurement used is the approach of coefficient of variation, i.e. the standard deviation divided by its mean, usually expressed in percent.

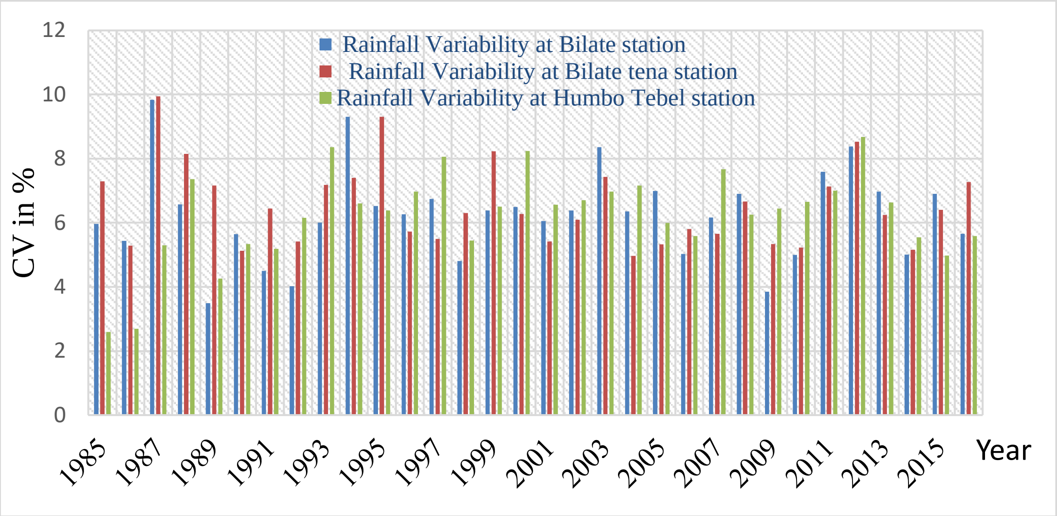

Figure 4.7 Annual mean monthly Rainfall variability (%) at lower Bilate stations

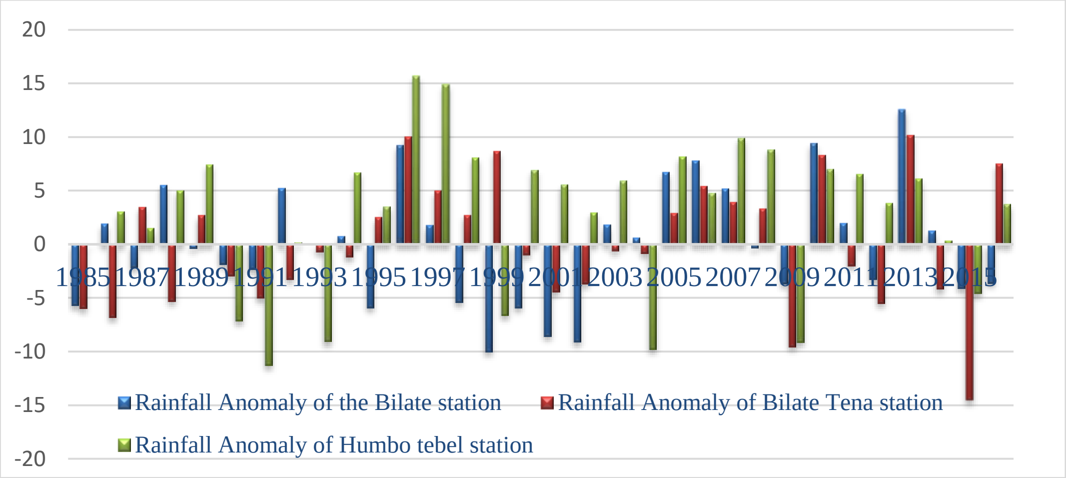

Figure 4.8 Standardized annual mean monthly Rainfall anomaly at lower Bilate sub-basin

4.9 Trend Analysis of the Climate Change at Study Area

This portion presents the trends of the climate change variables at a global and national scale, more specifically it analyses the rainfall and temperature trends using meteorological data collected over the past three decades or so in the study area. Moreover, Impact of the climate change on agricultural water demand is analysed through the analysis of the meteorological data.

4.9.1 Trend analysis of the observed mean annual rainfall at Bilate river catchment

The analysis of rainfall and temperature trends in the study areas was based on the data collected from meteorological stations located in Lower, Mid and Upper Bilate sub-basins that lie in the

Lowlands(Kolla), Midlands(Woine dega) and Highland(dega) climatic zones of Bilate River watershed respectively.

Table 4.6 Descriptive statistics of mean annual precipitation at Bilate River catchment

	Stations	No of year	Min (mm)	Obs. year	Max (mm)	Obs. year	Mean	Sd	Cv
1	**Bilate**	32	492.2	1999	1205.2	2013	798.5	175	0.22
2	**B/Tena**	32	437.5	2015	1277.8	1996	901.6	181	0.201
3	**Humbo**	29	685.2	1991	1853.6	1996	1126	256	0.228
4	**Boditsch**	32	794.1	2016	1527.8	2007	1211	183	0.151
5	**Alaba**	26	710.2	2012	1261.4	1993	991	159	0.16
6	**Angecha**	30	805.7	2015	2007.6	2001	1420	310	0.218
7	**Fonko**	30	890.9	1994	1659.7	1997	1236	193	0.156
8	**Hosana**	32	920.4	1994	1556.4	1998	1193	162	0.136
9	**Indibir**	32	383.2	1992	1738.4	2010	1186	333	0.281
10	**Wulberg**	32	426.4	2004	1663	2000	1173	272	0.232
11	**Butajira**	32	417.8	2016	1783.6	2005	1117	351	0.314

Sd= standard deviation, Cv= coefficient of variations

The trend analysis of mean annual Rainfall for the eleven (11) meteorological Stations in the study area is presented in Table along with its Mann-Kendall parameters.

Table 4.7 Annual Rainfall trend analyses at Bilate River basin with Mann-Kendell parameters

	Mean Annual Rainfall trend analysis at Bilate River Basins			
	Meteorological Station	No of years	Z	Interpretation
1	Bilate	32	0.81	Increasing*
2	Bilate Tena	32	1.04	Increasing*
3	Humbo Tebele	29	2.04	Increasing*
4	Bodit school	32	-0.54	Decreasing*
5	Alaba Kulito	26	1.72	Increasing*
6	Angecha	30	1.05	Increasing*
7	Fonko	30	-0.09	Decreasing*
8	Hosana	32	-0.97	Decreasing*
9	Indibir	32	1.26	Increasing*
10	Wulberg	32	-2.01	Decreasing**
11	Butajira	32	-0.49	Decreasing*
Average		32	-0.83	Decreasing*

* implies trend is not significant and ** implies trend is significant

Analysis of the rainfall records in the meteorological stations, most of the upper Bilate statons revealed that there is a general declining; whereas at lower and middle stations shows the increasing trends during the last 1 to 3 decades.

Among the lower Bilate sub-basin stations, the minimum mean rainfall was recorded at Bilate Tena station (437.5mm) and the maximum annual rainfall received in Humbo Tebel stations (1853.6 mm) during third and second decades respectively. Similarly, in mid Bilate Sub-basins, the minimum mean annual rainfall was recorded at Alaba kulito (710.2mm) and maximum at Angecha station (2007.6mm). The mean annual Rainfall of the study area had a range from 437.5mm at Bilate Tena station (lower Bilate sub-basin) to 2007.6mm at Angecha station (middle Bilate sub-basin). These values indicate that there is high annual rainfall variability across ecological regions in the study area. During the past 1 to 3 decades, the rainfall deviated annual by a maximum of 351mm from the mean in the case of Butajira station (Upper Bilate sub-basin) and a minimum deviation of 159mm in the case of Alaba Kulito station (middle Bilate sub-Basin).

The trend on the decadal basis was also analysed to determine the changes over time within the study periods. In order to detect statistically significant changes in the annual rainfall across stations in lower, middle and upper Bilate sub-basins, a time-series study was undertaken. The parameter estimate of the slope was then tested for statistical significance using the Sen’s estimate at α= 0.01 level of significance. As shown in table above most of the slope of the trend line is negative 1.8711 which implies that the long year’s average rainfall is declining.

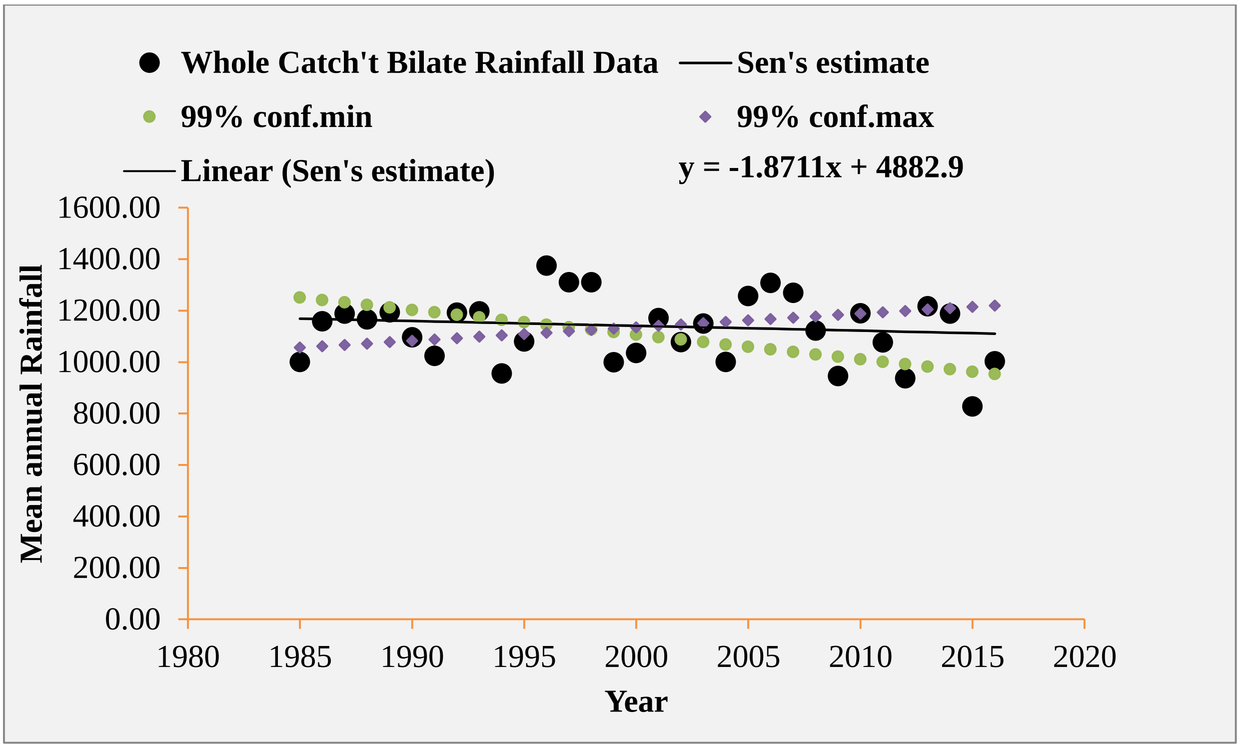

Figure 4.9 Averaged annual Rainfall trend analyses of observed meteorological data

The slope of the figure 4.7 shows that decreasing trend of rainfall and the change of mean annual rainfall conditions within the stated period. As it is depicted in table 4.5 the mean annual rainfall decreased for most of the upper Bilate sub-basin stations and at α=0.01 level of significance. This shows that the climate was changing within the stated decades.

4.9.2 Trend Analysis of the Climate Data at Lower Bilate sub-basin

- **The trend analysis of mean annual Rainfall amount in the study area**

Based on the data obtained from Ethiopia national meteorology agency, the study tries to analyze annual and seasonal rainfall of the last three decades. As it is indicated in table, the annual rainfall in the study area ranged between 675.56mm to 1380.91mm with mean annual Rainfall was 927.59mm and SD 142.49mm over the period of 1985 to 2016. Whereas, long-term average temperature in the area was 20.69, 21.43^{o}C, 19.46^{o}C and 21.24 for annual, Belg, kiremt and Bega season, respectively. Mean annual maximum and minimum temperature of the area was 27.14^{o}C, and 14.23^{o}C, respectively. Bega Mean Rainfall was highly variable (CV=35.43%); while belg (CV=27.66%), Kiremt rain had (CV=26.89%) and mean Annual (CV=14.8%) relatively lower variability in the study area. The study also showed that Bega rain was more variable than belg and Kiremit, signifying that Bega was more dependable for Irrigated type of agriculture especially for cropping. And mean annual Rainfall was less variable (CV=14.8%); then belg (CV=27.66%) and Kiremt Rain had (CV=26.89%) in the study area. The study also showed that, signifying that Kermit was more dependable for rain-fed type of agriculture especially for cropping.

Studies indicate that temperature and rainfall have been changing over time. Rainfall projections are more uncertain (Rowell, 2012) and exhibit higher spatial and seasonal dependence than that of temperature. (Orlowsky et.al, 2012) revealed that minimum temperature has been increasing by about 0.37 degrees celsius every decade. East Africa's Rainfall projection in particular is more uncertain due to coarse resolution of GCMs and extremely complex topography of the region (IPCC, 2013). The average annual rainfall of the country has recently shown a very high level of variability. For the past five and half decades a few years were characterized by dry conditions, resulting in drought and famine, whereas others are characterized by wet conditions. (NMS, 2007)

Table 4.8 Descriptive statistics of mean annual and seasonal Rainfall at lower Bilate sub-basin

Rainfall (1985-2016)	**annual**	**Belg** (MAM)	**Kiremit** (JJAS)	**Bega** (ONDJF)
Mean Rainfall amount (mm)	927.59	344.59	436.31	220.83
Co-efficient of Variation (%)	15.36	27.66	26.89	35.43
Maximum (mm)	1380.91	575.39	776.55	492.52
Minimum (mm)	675.56	198.75	271.75	91.37
Standard Deviation (mm)	142.49	95.34	117.32	78.24

Sd= standard deviation, Cv= coefficient of variations

The trend on the decadal basis was also analyzed to determine the changes over time within the study periods. In this analysis it could be noticed that every year the data had a negative correlation coefficient, the slope of the regression line was negative. Similarly, studies on Ethiopian rainfall indicate that rainfall in the country is highly variable spatially and temporally (EPA, 2011).

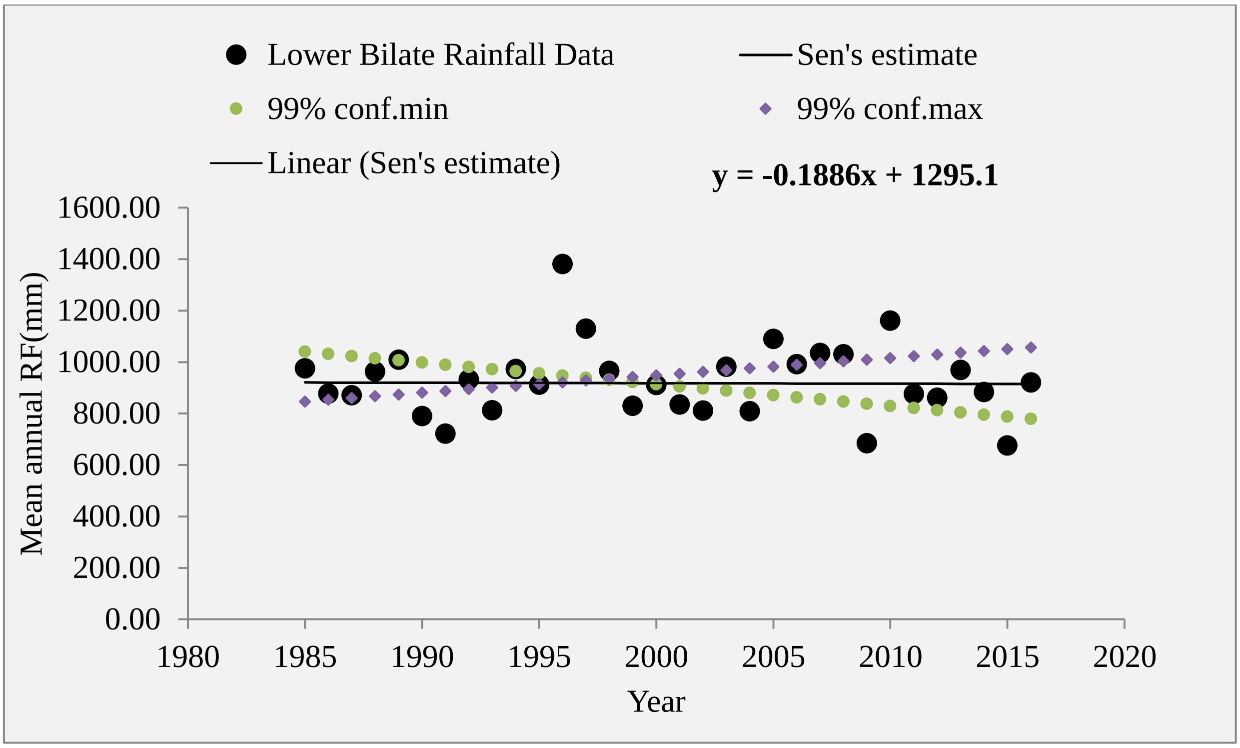

Figure 4.10 the trend analysis for base period at Lower Bilate observed Rainfall data

As indicated in Figure 4.8, there was a generally decreasing mean annual Rainfall change from 1985 to 2016 at lower Bilate sub-basin. The rate of the decreasing slopes of the trend line is 0.1886mm/yr @ α=0.01 the significance level for mean annual Rainfall for last three decades. Then the nature of significance is tested by Spell-stat software, Spearman Rank correlation (Rs) =-0.011; t (30, 2.5%) <-0.06<t (30, 97.5%), -2.042 <-0.06<2.042: TRUE then trend is not significant. This value is indicated by the slope equation given, Y =-0.1886x+1295.1. To the average, the mean annual Rainfall is found to be 1295.1mm, however; this value is not kept constant because of the change in climate.

Table 4.9 Mann-Kendall's test trend analyses result of observed Rainfall data at lower Bilate station

Lower Bilate sub-basin Rainfall (1985-2016)				
MK. Variable	Annual	Kiremit(JJAS)	Bega(ONDJF)	Belg(MAM)
Alpha	0.01	0.01	0.01	0.01
Test Z	-0.08	0.04	-0.93	-0.07
Interpretation	decreasing	increasing	decreasing	decreasing

The trend Analysis of the Temperature at study area

Trend analysis of the maximum and minimum temperature, at lower Bilate sub-basin meteorological stations;

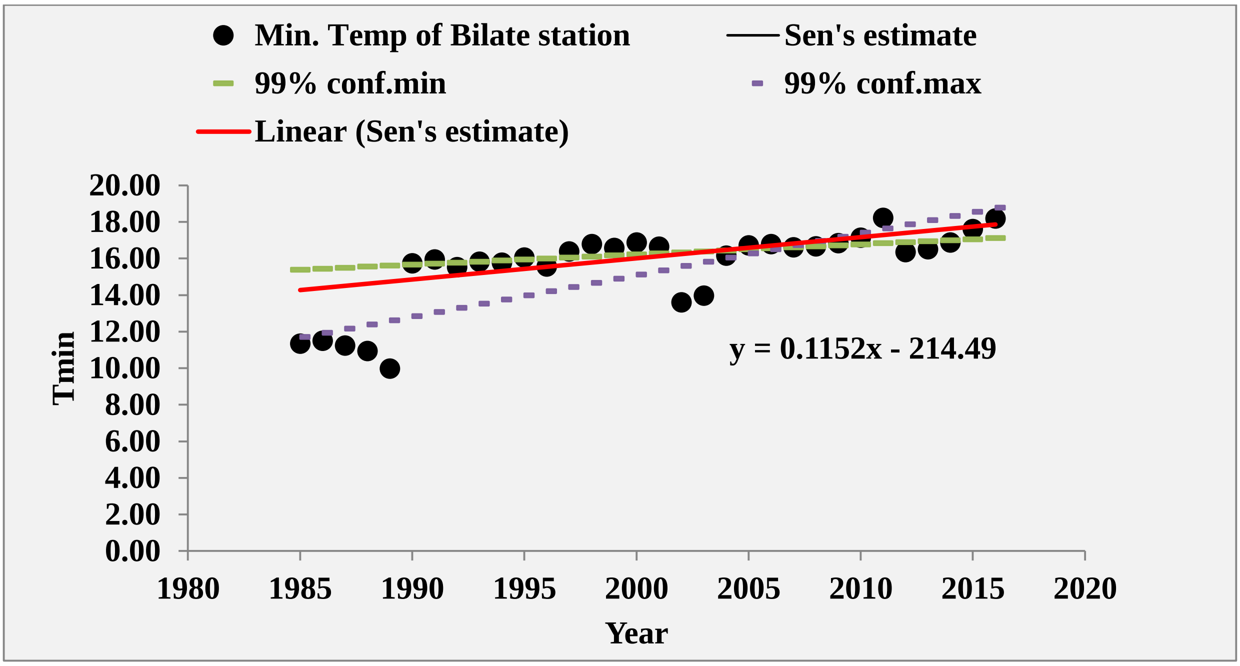

Figure 4.11 Graphical representations of the trends of the observed Tmin (1985-2016)

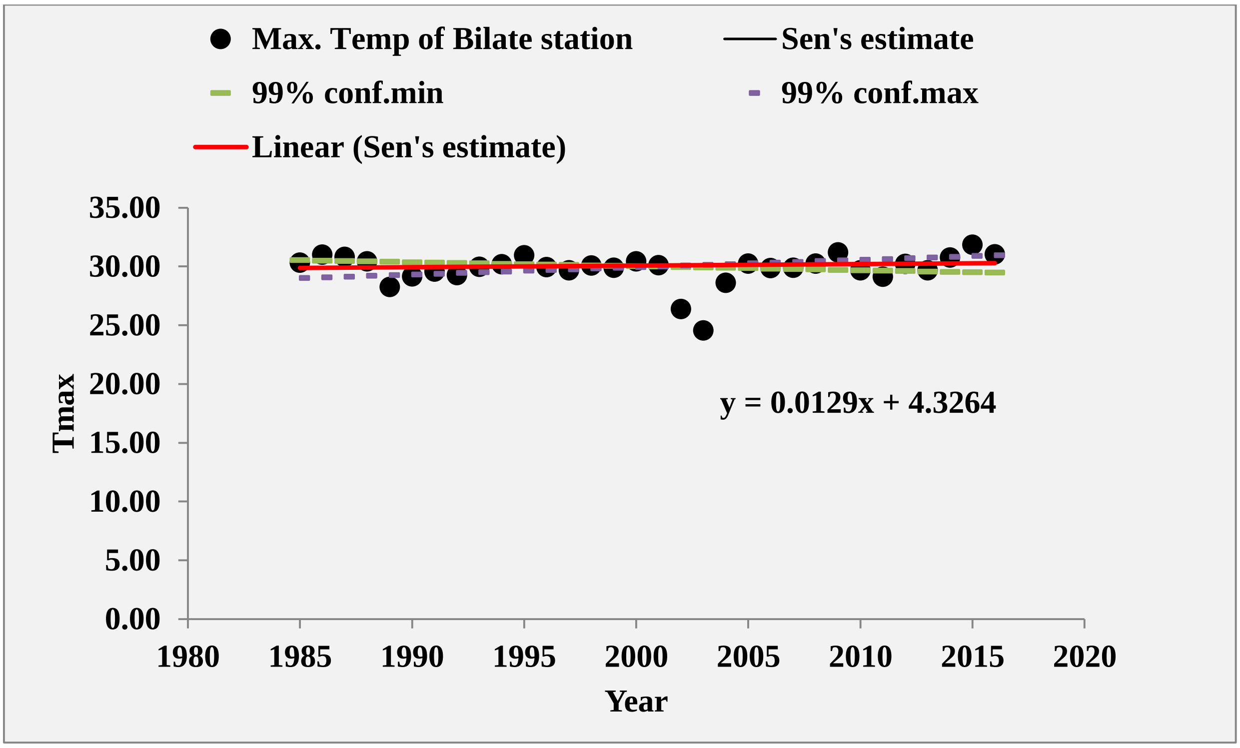

Figure 4.12 Graphical representations of the trends of the observed Tmax (1985-2016)

As indicated in Figure 4.9 and 4.10, there was a generally increasing annual mean daily maximum temperature change from 1985 to 2016. The trend line shows that the annual mean daily maximum temperature increased by the rate of 0.0129 @ α=0.01 significance level. To the average, the mean annual maximum temperature is found to be 29.649^{0}C, however; this value is not kept constant because of the change in climate.

Similarly, there is a general increasing mean annual minimum temperature change as indicated by the trend line. To the average, the annual minimum temperature is found to be 12.69^{0}C, however; this value is not kept constant as a result of the change in climate by the rate of 0.153. The annual minimum temperature shows a great difference compared to the annual maximum temperature change. Since, analyses of the observed temperature data at Lower Bilate sub-basin station the average record indicated a general increasing annual maximum and minimum temperature change from 1985 to 2016. The trend line equations showed positive slope value, which indicated a general increasing trend. In generally trend test results are tabulated below by Mann-Kendall's methodology.

Table 4.10 Mann-Kendall's test, trend analyses result of the observed temperature at Bilate station

	Tmax at Bilate stations (1985-2016)				**Tmin at Bilate stations (1985-2016)**			
MK. Variable	Annual	Kiremit JJAS	Bega ONDJF	Belg MAM	Annual	Kiremit JJAS	Bega ONDJF	Belg MAM
Alpha	0.01	0.01	0.01	0.01	0.05	0.05	0.05	0.05
Test Z	0.50	1.72	1.25	1.43	5.08	4.02	3.93	4.15
Interpre'n	increase	increase	increase	increase	increase	increase	increase	increase

4.10 Analysis of the change points and seasonal shift detection at lower Bilate sub-basin

Climate changes are dynamic and is an important component in understanding the interactions of the human activities with the environment and thus it is necessary to simulate climate changes. Since, in present study the change points and seasonal shift detection takes major part. SPELL-stat v 1.7.5.47 Beta software was used for the meteorological data time series analysis to evaluate existing change point and shift detection. Spell-stat software output value for spring and summer season (appendix 3)

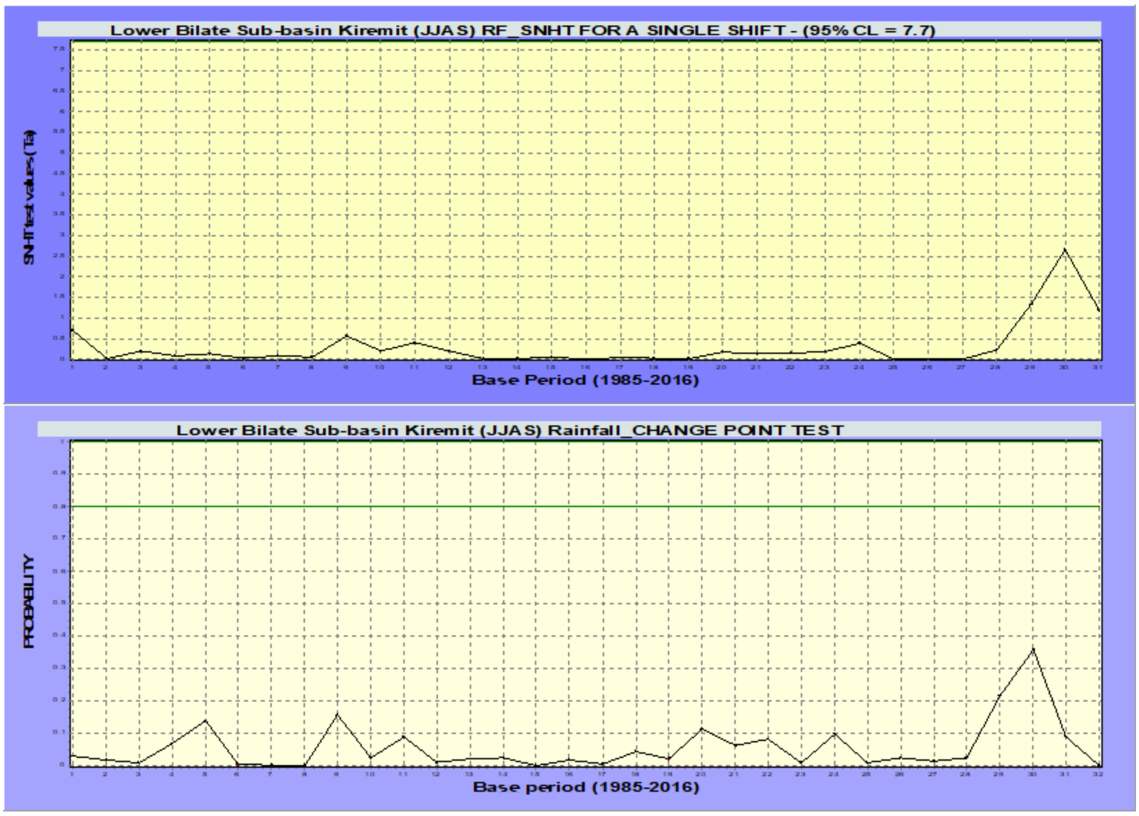

Figure 4.13 Change point and shift detection of the mean seasonal Rainfall Kiremit Season (JJAS) at the study area

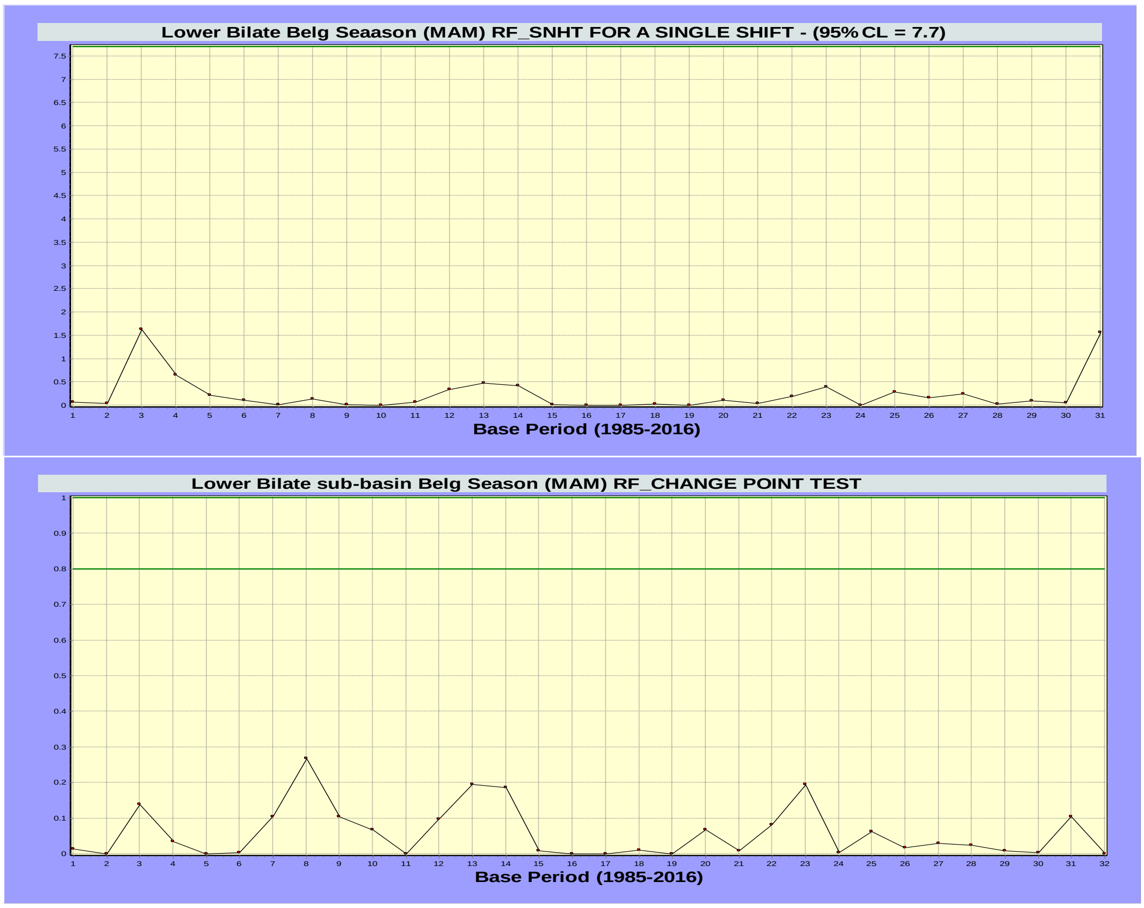

Figure 4.14 Change point and shift detection of the mean seasonal Rainfall Belg Season (MAM) at the study area

According to spell-stat output result there are no significant change and shift of the mean value of the Rainfall for summer and spring season at the study area from year to year during base period. But the spring season more sensitive to change and shift of the mean value in the case of the study area.

4.11 Current Agricultural Water Demand Analysis

Ethiopia's agriculture is highly influenced by climatic conditions and has a long history of coping with severe weather events (Bewket et.al, 2007). Specifically, the same condition may face problem for Lower Bilate agriculture due to increasing temperature and decreasing effective rain. Since integrated Water Demand analysis will view to take adaption measure for future time period.

Computation of the water Demand are under took at the lower Bilate, Abbaya state and private farm and Tobacco farm areas for the Cotton and tobacco respectively in the case of Irrigated agriculture and Maize and Haricot beans at scattered farm areas for rain fed agriculture are selected for analysis. This end result of the analysis at selected farm areas and scattered rain fed agriculture are used for future analysis and climate change impact assessment.

Table 4.11 Computed current agricultural water demand at lower Bilate sub-basin for baseline period

	Peff, mm/mo	**Eto, mm/mo**		**Etc ,mm/mo**		**Maize/23,500ha**	**Haricot beans/7,890ha**
			kc*/kc**	Maize*	Haricot beans**	**Rain fed Agri. WD in Mm3**	
Jun	42.7	112.5	0.4/0.4	45	45	0.54	0.18
Jul	49.4	97.34	0.8/0.8	77.87	77.87	6.69	2.25
Aug	33.9	104.78	0.8/1.15	83.82	120.5	11.73	6.83
Sep	31.3	103.5	1.15/0.5	119.03	51.75	20.62	1.61
Oct	38.8	114.7	1.15	131.91		21.88	
Nov	18.9	122.1	0.7	85.47		15.64	
				Sub-total		**77.1**	**10.87**
				Grand-total		**87.98**	
Computation of Current Irrigated Agriculture Water Demand for Baseline						**Cotton/2226ha**	**Tobacco,1262ha**
			kc*/kc**	cotton*	Tobacco**	**IRR.AWD (Mm3)**	
Jan	6.7	130.51	_/0.35		45.68		0.76
Feb	7.7	127.68	_/0.75		95.76		1.71
Mar	24.1	146.32	0.45/1.1	65.84	160.95	1.43	2.66
Apr	69.6	128.4	0.75/0.9	96.3	121.98	0.91	1.02
May	56.5	123.07	0.75	92.3		1.23	
Jun	42.7	112.5	1.2	135		3.16	
Jul	49.4	97.34	1.2	116.81		2.31	
Aug	33.9	104.78	0.85	89.06		1.89	
Sep	31.3	103.5	0.85	87.98		1.94	
					Sub-total	**12.87**	**6.14**
					Grand total	**19.01**	

4.12 Future Agricultural Water Demand Analysis

Future agricultural water Demand analysis under different scenarios RCP4.5 and RCP8.5 at study area in the case of Irrigated agriculture and rain fed agriculture are undertook in the same manner with baseline methodology for analysis. The analysis are used bias corrected simulated data for future analysis and climate change impact assessment on agricultural water demand.

Table 4.12 Projected annual Rainfall data

Dataset Annual RF	Bilate station		
	Mean	Min	Max
BC_DS RCP4.5 (2017-48)	534.3	329.8	807.5
BC_DS RCP4.5 (2049-80)	478.5	295.3	723.1
BC_DS_RCP8.5 (2017-48)	398.7	246.1	602.6
BC_DS RCP8.5 (2049-80)	318.9	196.9	482.1

Table 4.13 Projected average daily aggregated temperature in degree Celsius

Projected daily averageTemprature(°c) at Bilate Station								
	BC_ RCP4.5 data				**BC_RCP8.5 data**			
	2048		2080		2048		2080	
month	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax
Jan	14.5	27.3	15.3	28.1	14.5	27.6	16.7	29.2
Feb	15.7	28.4	16.3	29.3	15.8	28.9	17.7	30.4
Mar	16.9	28.9	17.6	29.9	17.1	29.2	18.9	31.2
Apr	16.6	27.3	17.8	28.8	17.1	28.3	19.1	30.2
May	15.1	25.5	16.3	26.7	15.7	26.1	17.6	27.9
Jun	14.2	22.3	15.3	23.7	14.7	23.0	16.8	25.3
Jul	13.6	20.4	14.6	21.6	14.0	20.9	16.0	22.7
Aug	13.8	20.7	14.8	22.0	14.1	21.3	16.0	22.9
Sep	14.2	21.5	15.4	22.7	14.7	22.2	16.6	24.1
Oct	13.8	23.5	14.7	23.9	14.2	23.7	16.1	25.2
Nov	13.8	25.3	14.5	25.7	14.1	25.6	16.1	26.9
Dec	13.9	26.2	15.1	26.8	14.2	26.5	16.2	27.9

Table 4.14 Projected agricultural water demand

	Rain fed Agri. WD in Mm3	**IRR.AWD (Mm3)**
Base Period	87.98	19.01
RCP4.5(2017-2049)	86.65	24.01
RCP4.5(2049-2080)	104.28	25.05
RCP8.5(2017-2049)	100.39	25.33
RCP8.5(2049-2080)	125.42	28.36

The analysis result shows increasing rate for all time horizon but first time horizon i.e. RCP4.5 (2017-2049) slightly decreasing for the reason increasing of the rainfall and decreasing temperature relative to base period in the case of rain fed agriculture.

5. Results and Discussions

5.1 Evaluation of Model Performance

The calibration was carried out from 1985-1996 for ten years and the withheld data from 1997-2004 were used for model validation. The model develops a better multiple regression equation parameters for the maximum and minimum temperature than the precipitation. This is mainly due to the conditional nature of precipitation. In conditional models, there is an intermediate process between regional forcing and local weather (e.g., local precipitation amounts depend on wet–/dry–day occurrence, which in turn depend on regional–scale predictors.

This can clearly be seen in the R^2 values presented in table. In the table below Calibration and Validation, R^2 values of the downscaled of precipitation, maximum and minimum temperature at Bilate station.

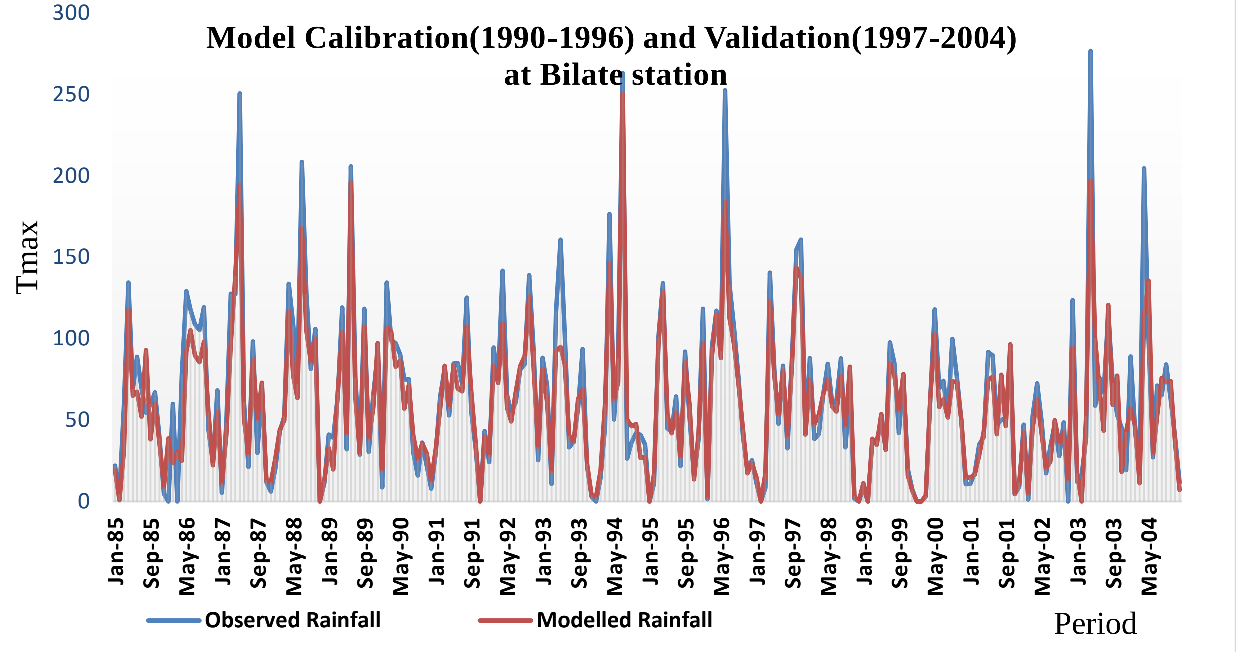

Figure 5.1 Model calibration and validation of precipitation data at Bilate station

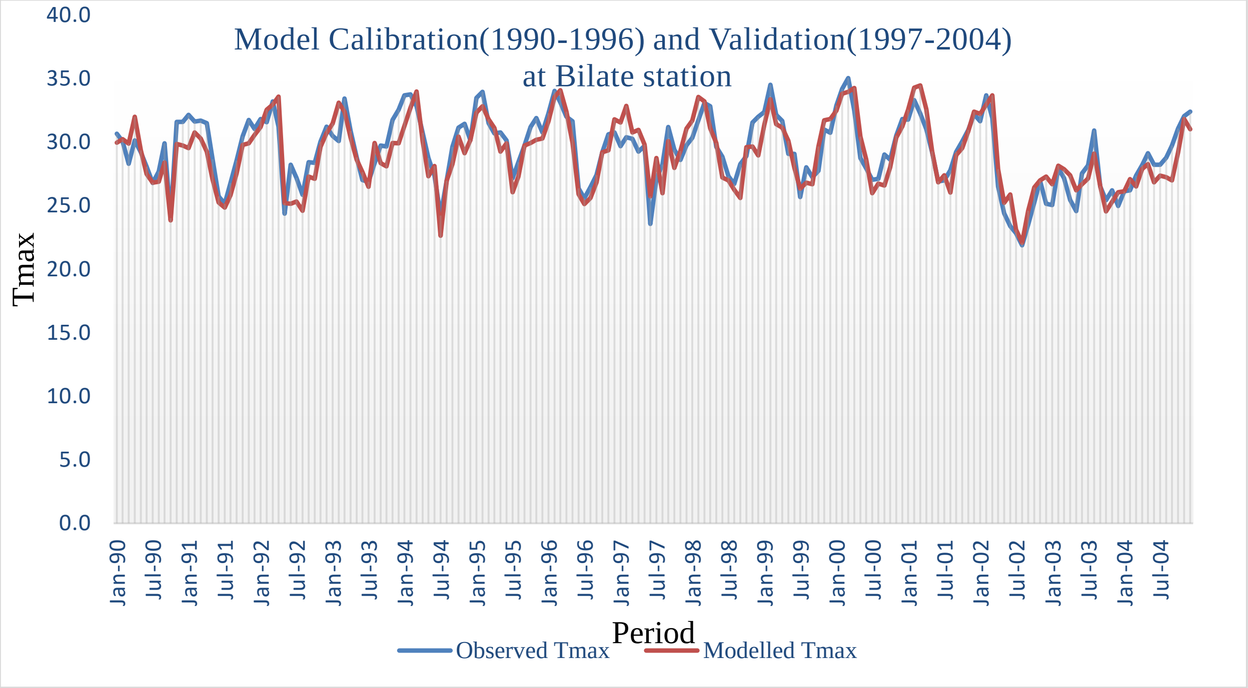

Figure 5.2 Calibrations and validation of the maximum temperature

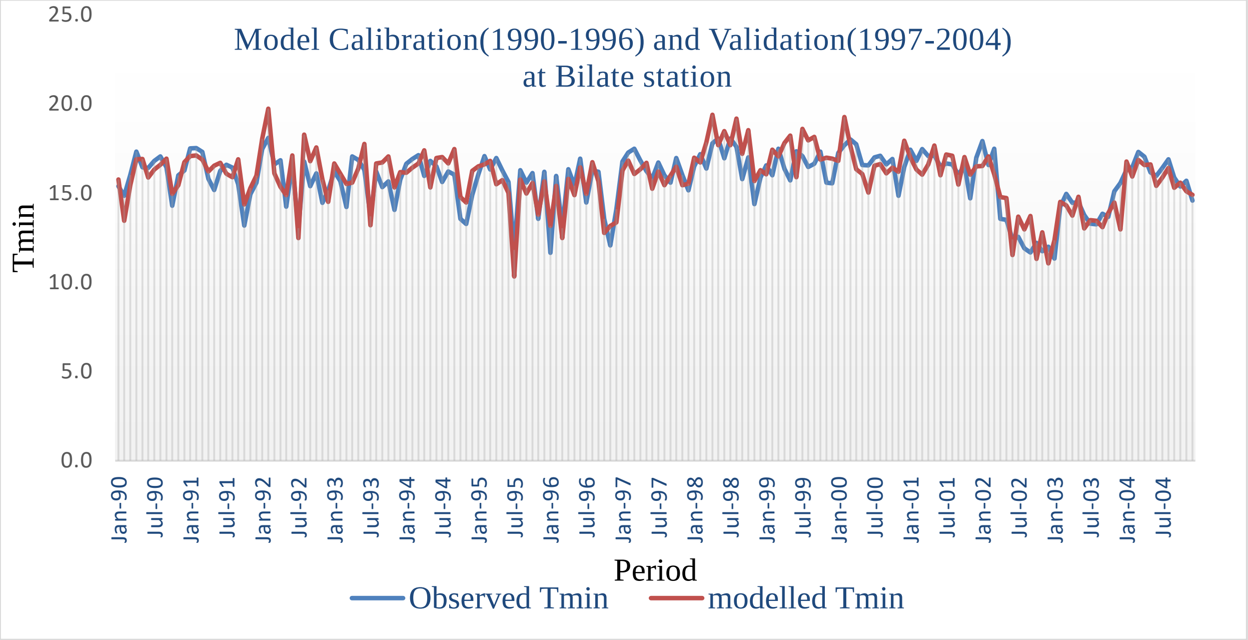

Figure 5.3 Calibrations and validation of the minimum temperature

$$NSE = 1 - \frac{\sum_{i=1}^{n}(\mathrm{Obs} - \mathrm{hist.downscaled})^2}{\sum_{i=1}^{n}(\mathrm{Obs} - \mathrm{Obsav})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5.1$$

$$R^2 = \frac{\left[\sum_{i=1}^{n}(\mathrm{obs} - \mathrm{obs}_{av})(\mathrm{hist.downscaled} - \mathrm{hist.downscaled}_{av})\right]^2}{\sum_{i=1}^{n} \ (\mathrm{obs} - \mathrm{obs}_{av})^2 \ \sum_{k=0}^{n}(\mathrm{hist.downscaled} - \mathrm{hist.downscaled}_{av})2} \ldots\ldots\ldots\ldots\ldots\ldots 5.2$$

Table 5.1 Model performance evaluation by multiple regression equation parameters

	R^2		
	Precipitation	Max Temperature	Min Temperature
Calibration	0.610	0.806	0.650
Validation	0.645	0.796	0.687
	NSE		
Calibration	0.55	0.721	0.572
Validation	0.613	0.787	0.635

5.2 Impact of the climate change on precipitation

Table 5.2 Projected averages monthly aggregated rainfall in mm during dry and rainy season

Projected Average monthly Rainfall(mm)					
		RCP4.5 Scenarios		**RCP8.5 Scenarios**	
Months	**Baseline period**	**During2048**	**During2080**	**During2048**	**During2080**
Jan	28.09	8.82	6.86	1.05	1.24
Feb	29.44	11.72	7.66	1.72	1.78
Mar	56.88	18.11	11.13	8.44	2.75
Apr	116.98	38.17	70.17	28.33	46.67
May	100.64	37.43	60.39	50.32	40.26
Jun	83.49	95.94	93.09	77.75	73.40
Jul	92.12	99.30	84.90	95.75	36.60
Aug	72.62	78.66	83.57	72.31	57.05
Sep	69.07	56.27	21.44	34.53	27.63
Oct	78.47	22.57	27.08	19.23	11.39
Nov	48.50	31.45	8.16	13.47	10.78
Dec	23.42	15.69	4.05	5.71	9.37
Average	66.64	42.84	39.86	34.05	26.58

As figure below shows, the change of the rainfall at the study area will be -35.71% and -40.18% rate for the period of 2048 and 2080 respectively for RCP4.5 Scenarios whereas

Based on RCP8.5 scenarios the change will be -48.90% and -60.11% rate for the period of 2048 and 2080 respectively depending on baseline period. Since the following figure shows the decreasing trends over three decades for both scenarios.

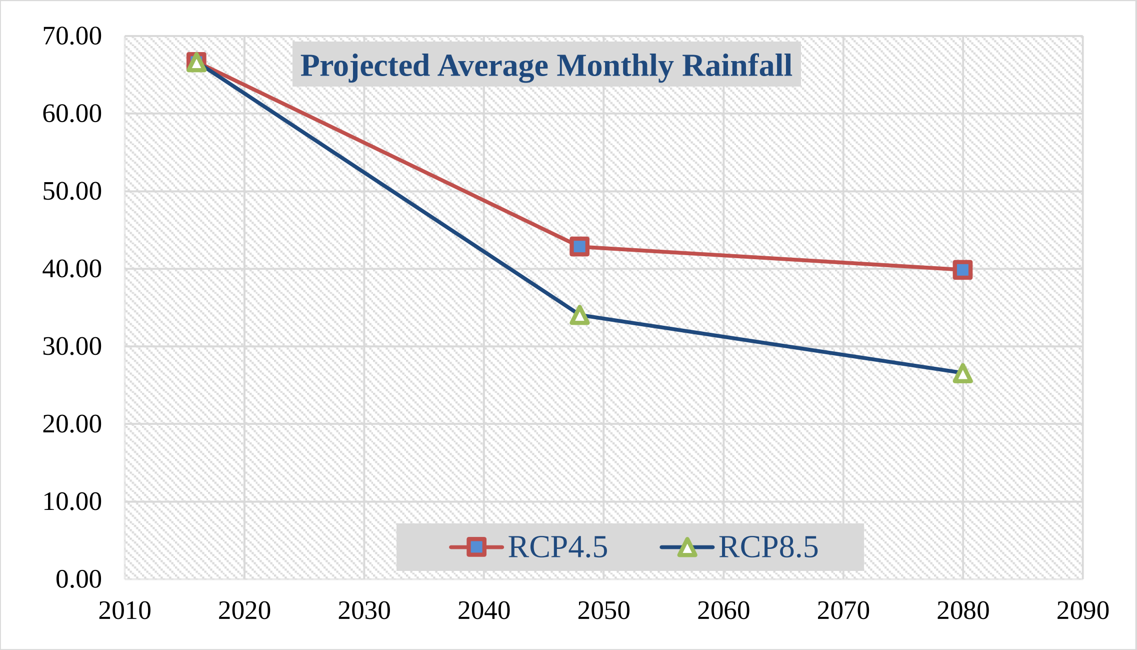

Figure 5.4 Trend of the base period and projected rainfall from different scenarios

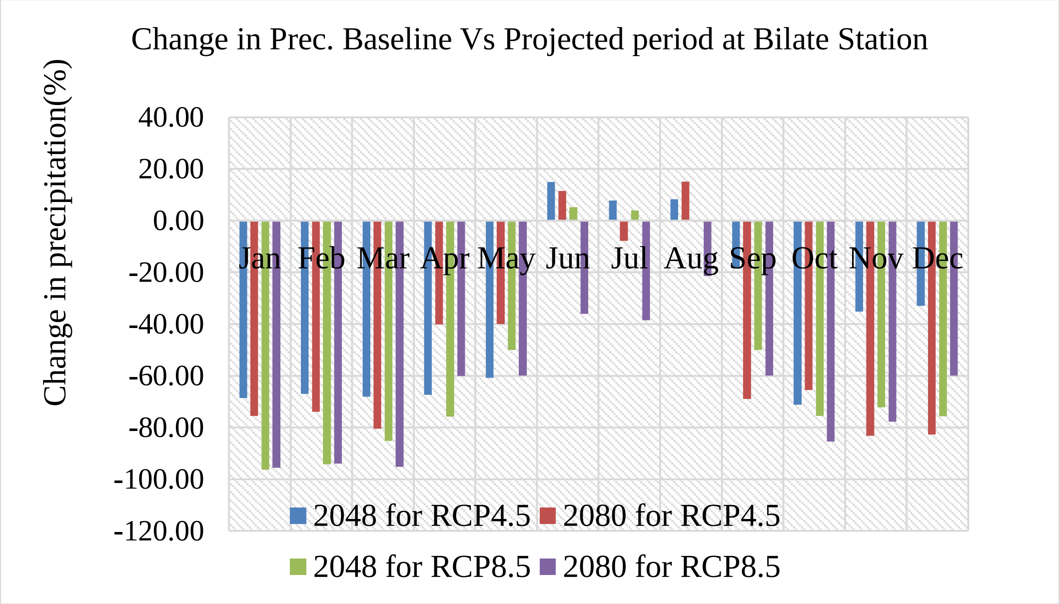

Figure 5.5 Change in precipitation for future time horizon

5.3 Projected Climate Change and Impact on Agricultural Water Demand

The projected temperature and Rainfall for the years 2048 and 2080, aggregated average temperature and rainfall, during the dry and Rainy season in the year values are used in the present study for the calculation of change in Agricultural water demand considering Irrigation and Rain fed agriculture.

- **Irrigated Agriculture Water Demand**; Change in daily evapotranspiration with the projected temperature, the result shows an increase in daily evapotranspiration. The change in effective precipitation in the study area is given in table 5.4. The effective precipitation will be decreasing at all irrigation period.

Table 5.3 Projected average daily evaporation during Irrigation period

Daily evapotranspiration(mm)									
RCP4.5Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Baseline average	4.21	4.56	4.72	4.28	3.97	3.75	3.14	3.38	3.45
2048	4.09	4.45	4.69	4.29	3.93	3.58	2.95	3.15	3.19
2080	4.17	4.53	4.77	4.42	4.05	3.71	3.04	3.26	3.29
RCP8.5Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Baseline average	4.21	4.56	4.72	4.28	3.97	3.75	3.14	3.38	3.45
2048	4.12	4.48	4.71	4.36	3.99	3.65	2.99	3.19	3.24
2080	4.28	4.64	4.91	4.55	4.17	3.86	3.15	3.33	3.39

Table 5.4 Projected average effective precipitation during Irrigation period

Effective Precipitation(mm)									
RCP4.5 Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Baseline average	6.7	7.7	24.1	69.6	56.5	42.7	49.4	33.9	31.3
2048	0	0	0.9	12.9	12.5	52.8	55.4	38.9	23.8
2080	0	0	0	32.1	26.2	50.5	43.9	42.9	2.9
RCP8.5 Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Baseline average	6.7	7.7	24.1	69.6	56.5	42.7	49.4	33.9	31.3
2048	0	0	0	7	20.2	38.2	52.6	33.8	10.7
2080	0	0	0	18	14.2	34.7	12	24.2	6.6

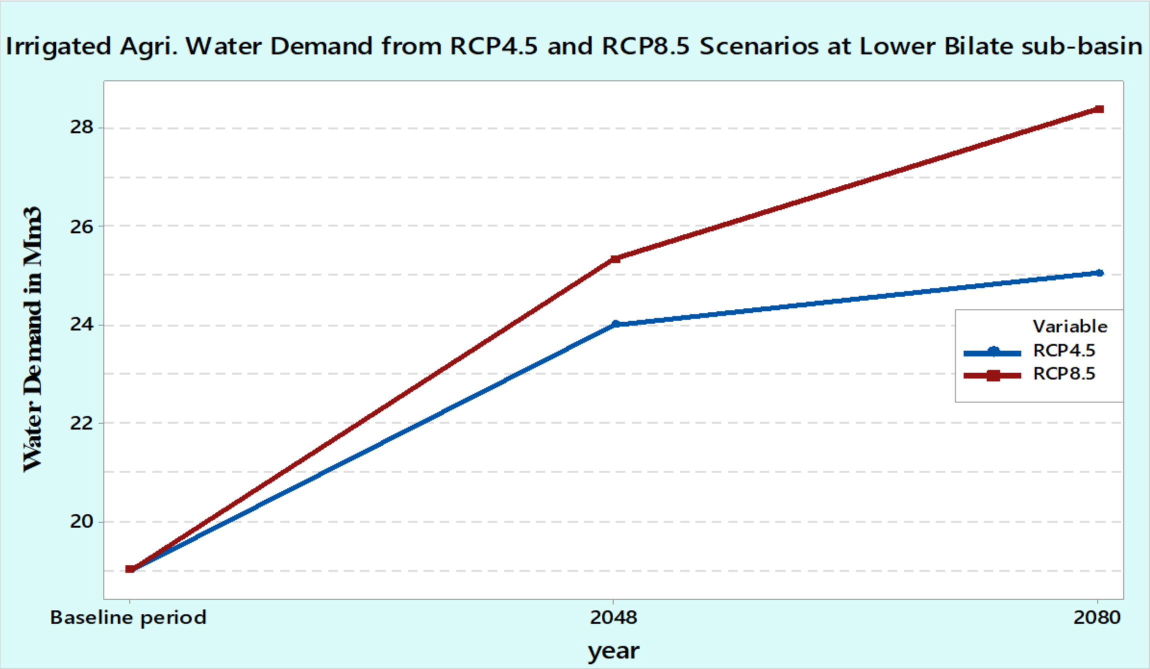

Figure 5.6 Change in Irrigated agriculture water demand at the study area

As above figure shows, the average irrigated agriculture water demand for base period was 19.01Mm3. However, this value is not kept constant as a result of the change in climate that for future time period (2017-2048) and (2049-2080) found to be 24.01Mm^3 and 25.01Mm^3 respectively for RCP4.5, and in case of RCP8.5 is found to be 25.33Mm^3 and 28.36Mm^3 respectively. Whereas rain fed agriculture water demand in the same manner with Irrigate agricultural water demand, there are fluctuates in daily evapotranspiration for rain fed agriculture; but the change in effective precipitation at the study area fluctuates as shown in Table below for both scenarios.

Table 5.5 Projected average daily evapotranspiration during rainy fed period

	Daily evapotranspiration(mm)					
RCP4.5 Scenarios	Jun	Jul	Aug	Sep	Oct	Nov
Baseline average	3.75	3.14	3.38	3.45	3.7	4.07
2048	3.58	2.95	3.15	3.19	3.47	3.85
2080	3.71	3.04	3.26	3.29	3.53	3.89
RCP8.5 Scenarios	Jun	Jul	Aug	Sep	Oct	Nov
Baseline average	3.75	3.14	3.38	3.45	3.7	4.07
2048	3.65	2.99	3.19	3.24	3.5	3.89
2080	3.86	3.15	3.33	3.39	3.65	4.02

Table 5.6 Projected average effective precipitations during rain fed period

	effective precipitation(mm)					
RCP4.5Scenarios	Jun	Jul	Aug	Sep	Oct	Nov
Baseline average	42.7	49.4	33.9	31.3	38.8	18.9
2048	52.8	55.4	38.9	23.8	3.5	8.9
2080	50.5	43.9	42.9	2.9	6.2	0
RCP8.5 Scenarios	Jun	Jul	Aug	Sep	Oct	Nov
Baseline average	42.7	49.4	33.9	31.3	38.8	18.9
2048	38.2	52.6	33.8	10.7	1.5	0
2080	34.7	12	24.2	6.6	0	0

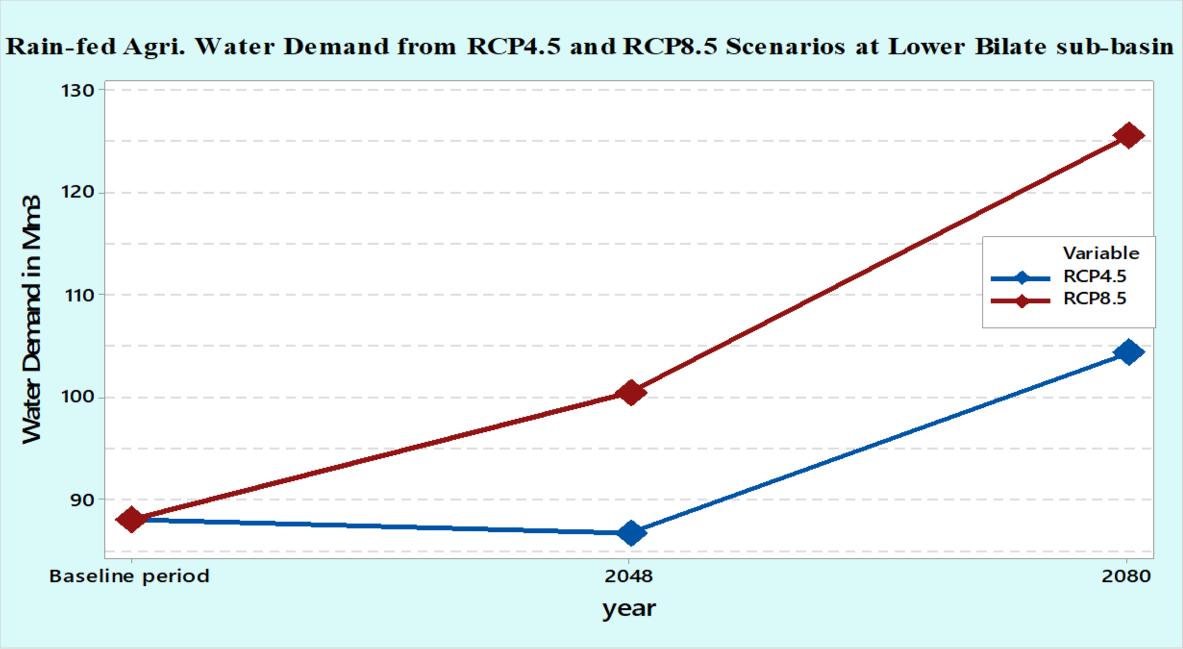

Figure 5.7 Change in rain fed agriculture water demand at lower Bilate sub-basin

The rain fed agriculture water demand for the base period is 87.98Mm3 at the study area. However; this value is not kept constant as a result of the change in climate computed as 86.65Mm3 and 104.28Mm3 for the period of 2048 and 2080 respectively for RCP4.5 Scenarios, whereas based on RCP8.5 Scenarios the change will be 100.39Mm3 and 125.42Mm3 respectively as shown in the above figure.

Table 5.7 projected agricultural water demand and effect of climate change

	Rain fed Agri. WD in Mm3	Change (%)	**IRR.AWD (Mm3)**	Change (%)
Base Period	87.98		19.01	
RCP4.5(2017-2049)	86.65	-1.53	24.01	20.82
RCP4.5(2049-2080)	104.28	15.6	25.05	24.11
RCP8.5(2017-2049)	100.39	12.36	25.33	24.95
RCP8.5(2049-2080)	125.42	29.85	28.36	28.36

According to expert meeting on climate change adaptation and mitigation FAO Headquarters (2008), vulnerability to food insecurity shocks has grown global. Global and local food security vulnerability patterns will be modified by climate change. Small-scale rain fed farming systems, pastoralist systems, inland and coastal fishing and aquaculture communities and forest-based systems are particularly vulnerable to climate change. Technical adaptation measures range from temporal and spatial variations in production systems (e.g. adjusting planting or fishing dates, rotations, multiple cropping/species diversification, crop-livestock culture systems, agroforestry) to confer better protection against temperature changes, changing rainfall variability and patterns.

6. Conclusions and Recommendations

6.1. Conclusions

This study entitled as impact of climate change on agricultural water demand, the case of Bilate river catchment aimed to achieve specified objectives.

Studies indicate that temperature and rainfall have been changing over time at the study area. The trend on the decadal basis was also analyzed to determine the changes over time within the study periods. As analysis indicates, there was a generally decreasing mean annual Rainfall change for the base period (1985 to 2016) at lower Bilate sub-basin. The rate of the decreasing slopes of the trend line is 0.1886mm/yr at $\alpha=0.01$ the significance level for mean annual Rainfall for last three decades. Then the nature of significance is tested by Spell-stat software, Spearman Rank correlation (Rs) =-0.011; t (30, 2.5%) <-0.06<t (30, 97.5%), -2.042 <-0.06<2.042: TRUE then trend is not significant. To the average, the mean annual Rainfall is found to be 1295.1mm. But, there are no significant shift and change point for the rainfall climate variable at the study area. However, there was increasing annual mean daily maximum temperature change. The trend line shows that the annual mean daily maximum temperature increased by the rate of 0.0129 @ $\alpha=0.01$ significance level and the mean annual maximum temperature is found to be 29.649^{0}C, however; this value is not kept constant because of the change in climate. Similarly, increasing mean annual minimum temperature change as indicated by the trend line. To the average, the annual minimum temperature is found to be 12.69^{0}C as a result of the change in climate increasing rate was 0.153%. The model performance is evaluated using, the Nash-Sutcliffe model efficiency (NSE), and the square of the Pearson's product-moment correlation coefficient (R2). The statistics indicate that for calibration and validation NSE/R^2 are 0.55/0.61 and 0.613/0.645, in the case of precipitation respectively. These values indicate that a good adjustment of the modeled to the observed precipitation for both calibration and validation period. In generally temperature value shows more good performance than precipitation value.

The analysis shows that an increasing trends for the temperature and decreasing trend for the Rainfall amounts. In the same manner, for future time horizon; the change of the monthly aggregated precipitation at the study area will be -35.71% and -40.18% for the year of 2048 and 2080 respectively from RCP4.5 Scenarios. But also, based on RCP8.5 Scenarios the change will be -48.90% and -60.11% rate for the period of 2048 and 2080 respectively depending on baseline period.

As a result, the current agricultural water demand are under took at the lower Bilate, Abbaya state and Tobacco farm areas for the Cotton and tobacco respectively in the case of Irrigated agriculture and Maize and Haricot beans at scattered farm areas for rain fed agriculture are selected for analysis. The computed average irrigated agriculture water demand for base period computed as 19.01Mm3 and 87.98Mm3 for irrigation and rain fed agriculture respectively. However, this value is not kept constant as a result of the change in climate that for future time period (2017-2048) and (2049-2080) found to be 24.01Mm^3 and 25.01Mm^3 that the change based on base period estimated as 20.82% and 24.11% respectively for RCP4.5, and in case of RCP8.5 was found to be, 25.33Mm3 and 28.36Mm^3, the change estimated as 24.95% and 28.36% respectively. Whereas the Rain fed agriculture water demand for the base period is 87.98Mm3 at the study area. However; this value is not kept constant as a result of the change in climate computed as 86.65Mm3 and 104.28Mm3 for the period of 2048 and 2080 respectively for RCP4.5 Scenarios, whereas based on RCP8.5 Scenarios the change will be 100.39Mm3 and 125.42Mm3 respectively.

6.2. Recommendations

According to the nature of the data and based on the findings and results of the study the following recommendations are suggested to minimize the impacts of climate change at lower Bilate sub-basin.

- Government policies should ensure that in terms of credit services to water stress tolerant crop and soil moisture management strategies in response to climate change.
- Furthermore, given the inadequate extension services in the area, improving the knowledge and skills of extension service personnel about climate change adaptation strategies, Developing Ground water Irrigation system rather surface irrigation.
- The provision of access to education, credit, extension service on crop and information on climate and adaptation measures are necessary to better scope with climate change in the study area. Therefore, Government should interventions that encourage informal social networks.
- National, regional governments and NGOs are needed to combat the current issue of climate change i.e. increasing temperatures, decreasing precipitation and increasing agricultural water demand which would require integration and involvement of government to enable community survive in the changing climate and its adverse impact on water availability.

- Growing drought tolerant crops, Aware of climate related impact and Modify water management practice are recommended.

The manual approach is used to estimate agricultural water demand in this study; Since, it is recommended to apply computer model approaches for future use in agricultural water demand analysis for the study area. And single climate model is used in this study rather it is reccomended to apply three or more GCM model to fill the gap or limitation of the study. In general, further detail studies should under go considering major mitigation measures and strategic responses.Climate change impact studies on agricultural water demand under different scenarios provide important information for agricultural and water resources sectors.

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Appendices

Appendix 1 Climate data of the meteorology station at the study area

1a: Mean annual and monthly rainfall data of Alaba Kulito meteorological station.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1989	6.3	93.7	114.4	125.6	66.7	103.2	138.5	108.2	134.2	84.3	1.4	106.5	1083.0
1990	72.3	188.1	90.4	148.6	142.1	39.6	70.0	58.9	101.4	37.3	4.8	14.0	967.5
1991	0.0	0.0	106.4	55.6	138.4	77.1	97.4	132.1	192.2	12.3	0.0	73.1	884.6
1992	19.5	148.6	115.8	92.3	98.4	67.6	88.2	209.8	89.2	155.7	49.7	27.8	1162.6
1993	62.4	34.7	85.5	297.1	248.6	60.9	105.7	162.5	82.3	121.7	0.0	0.0	1261.4
1994	0.0	0.0	84.6	140.9	117.3	147.1	136.6	105.0	56.7	8.6	9.3	0.0	806.1
1995	0.0	55.7	131.2	257.0	105.7	57.1	132.2	74.2	89.0	26.5	0.0	28.1	956.7
1996	123.8	6.3	141.2	138.7	174.6	165.1	134.8	110.6	56.6	76.3	30.3	0.0	1158.3
1997	72.9	8.8	85.0	167.2	83.5	101.0	95.3	104.8	106.4	180.7	181.4	6.2	1193.2
1998	75.1	74.1	121.5	184.5	123.4	140.2	199.2	127.9	86.5	99.2	19.4	0.0	1251.0
1999	6.1	0.0	71.9	71.1	125.4	114.9	109.5	96.4	40.5	127.6	0.0	0.0	763.4
2000	0.0	0.0	9.0	180.9	140.8	72.8	132.9	65.1	104.0	106.6	43.4	23.5	879.0
2001	8.5	12.5	190.2	89.9	98.6	117.9	121.5	124.8	129.7	47.8	0.0	2.8	944.2
2002	29.4	61.8	81.1	86.3	57.2	78.1	71.1	109.3	87.9	10.9	0.0	122.9	796.0
2003	42.3	62.1	110.7	139.5	75.5	73.5	66.8	168.9	99.5	9.5	48.8	44.0	941.1
2004	150.4	22.3	39.4	183.6	76.3	34.5	106.0	112.4	178.2	75.2	14.4	0.0	992.7
2005	39.0	7.7	65.7	235.8	84.3	56.1	94.9	70.9	116.3	37.2	48.2	0.0	856.1
2006	4.9	40.6	137.3	121.5	50.0	113.5	135.4	91.7	59.5	80.4	11.5	27.5	873.8
2007	18.6	93.7	85.1	109.9	160.9	114.8	118.1	120.4	166.8	63.3	0.0	0.0	1051.6
2008	0.0	1.0	26.6	55.0	110.6	123.7	107.4	139.2	162.4	74.1	148.0	2.3	950.3
2009	33.1	35.1	47.9	83.4	78.7	83.4	78.3	128.1	57.9	110.8	10.3	103.3	850.3
2010	29.4	93.8	131.5	193.3	177.2	53.5	140.3	99.1	130.8	32.2	12.8	11.9	1105.8
2011	8.8	21.0	48.4	71.5	130.8	155.4	214.5	165.1	55.4	0.6	84.5	0.0	956.0
2012	0.0	0.0	58.0	101.9	37.2	111.2	190.1	89.5	100.7	10.0	9.0	2.6	710.2
2013	10.4	9.6	111.0	137.0	125.0	167.4	135.5	178.1	157.1	118.9	60.3	0.2	1210.5
2014	6.3	73.8	111.3	113.8	261.4	22.5	132.1	89.3	169.5	118.9	60.3	0.2	1159.4
Mean	31.5	44.0	92.4	137.8	118.8	94.3	121.2	117.0	108.1	70.3	32.6	23.0	991.0
Max	150.4	188.1	190.2	297.1	261.4	167.4	214.5	209.8	192.2	180.7	181.4	122.9	1261.4
Min	0.0	0.0	9.0	55.0	37.2	22.5	66.8	58.9	40.5	0.6	0.0	0.0	710.2
STD	39.7	49.2	40.4	61.6	54.3	40.8	37.5	36.8	43.0	50.3	45.9	36.9	158.6

1b: Mean annual and monthly rainfall data of Angecha meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1985	10.5	0.4	40.6	214.5	141.7	80.8	116.0	196.1	376.4	64.2	6.2	18.8	1266.2
1986	1.5	178.0	125.2	197.8	282.4	135.8	196.8	101.2	133.5	35.7	0.9	29.1	1417.9
1987	5.9	81.8	117.5	86.0	264.7	63.8	69.7	190.8	119.6	88.5	0.0	0.0	1088.3
1988	25.5	69.5	28.3	157.3	70.1	106.8	224.4	177.7	233.2	174.3	0.0	0.0	1267.1
1989	83.8	45.8	208.7	147.9	29.1	213.7	142.1	234.2	191.5	69.0	3.5	173.9	1543.2
1990	29.5	308.7	146.8	125.1	140.9	153.5	203.4	187.2	138.1	31.7	10.0	20.2	1495.1
1991	30.0	77.9	75.9	62.5	160.1	118.5	136.9	160.6	184.1	58.9	0.0	48.2	1113.6
1992	57.5	115.1	56.0	186.5	137.1	124.6	99.9	237.4	182.5	97.8	52.5	5.0	1351.9
1993	110.7	104.5	40.0	234.4	285.7	75.1	225.5	85.5	177.5	180.0	8.0	0.1	1527.0
1994	0.0	2.5	88.3	103.4	87.9	80.8	194.9	142.6	147.5	0.0	24.3	0.0	872.2
1995	0.0	82.4	150.2	427.2	84.0	82.4	265.6	303.6	125.2	3.8	7.5	70.6	1602.5
1996	69.5	17.8	169.4	268.8	216.4	108.8	80.0	202.3	189.2	21.0	55.9	0.0	1399.1
1997	61.7	5.5	90.8	282.4	162.9	84.5	64.2	181.1	161.9	263.4	165.3	41.3	1565.0
1998	92.5	60.9	118.9	161.1	181.2	126.2	131.2	143.7	111.5	176.5	41.4	0.0	1345.1
1999	56.3	0.0	10.8	51.9	135.5	164.7	221.4	281.9	127.7	236.1	0.0	0.0	1286.3
2000	0.0	0.0	15.4	205.8	105.2	145.5	179.3	131.7	142.4	153.5	97.4	41.7	1217.9
2001	0.0	2.5	240.2	267.5	201.9	234.0	322.8	175.7	232.8	268.3	443.8	18.1	2407.6
2002	59.3	27.5	84.7	118.2	161.8	203.7	301.7	364.6	279.9	0.0	0.0	67.1	1668.5
2003	20.7	59.0	177.8	286.2	241.1	245.2	266.2	274.1	251.3	40.4	22.0	38.5	1922.5
2004	138.0	57.5	211.4	218.7	24.0	64.5	236.3	249.6	312.2	152.5	17.3	24.5	1706.5
2005	26.8	12.7	132.6	293.7	347.8	216.6	202.2	203.8	381.1	126.7	32.5	0.0	1976.5
2006	2.3	95.8	171.5	179.5	234.0	248.6	282.1	294.2	97.8	146.5	16.5	52.5	1821.3
2007	19.1	93.5	102.5	211.0	348.5	335.9	200.0	315.2	244.6	22.5	0.0	0.0	1892.8
2008	4.5	33.5	60.0	110.2	176.8	148.3	266.8	234.5	135.3	119.2	126.5	0.0	1415.6
2009	24.0	29.0	55.0	193.5	95.0	106.5	238.0	235.8	87.0	97.0	4.5	90.6	1255.9
2010	22.5	101.5	113.0	157.9	149.5	176.5	159.4	122.0	163.0	18.0	22.0	29.0	1234.3
2011	25.0	6.0	118.5	152.2	214.7	126.9	312.2	134.4	68.7	10.1	86.9	0.0	1255.6
2012	0.0	0.0	49.3	169.2	68.3	150.3	167.3	223.0	261.2	21.5	0.0	0.0	1110.1
2013	18.0	0.0	54.5	169.1	191.4	137.2	155.1	179.3	173.0	153.8	33.4	61.6	1326.4
2014	12.0	117.8	82.3	174.8	254.2	10.5	59.5	200.5	120.5	60.6	17.2	0.0	1109.9
2015	0.0	0.0	16.0	35.0	87.1	79.8	65.4	169.0	142.0	31.4	122.7	57.3	805.7
2016	66.0	43.2	88.2	351.7	135.9	117.8	0.0	167.5	260.5	68.8	111.2	0.0	1410.8
Mean	**33.5**	**57.2**	**101.3**	**187.5**	**169.3**	**139.6**	**180.8**	**203.2**	**186.0**	**93.5**	**47.8**	**27.8**	**1427.4**
Max	**138.0**	**308.7**	**240.2**	**427.2**	**348.5**	**335.9**	**322.8**	**364.6**	**381.1**	**268.3**	**443.8**	**173.9**	**2407.6**
Min	**0.0**	**0.0**	**10.8**	**35.0**	**24.0**	**10.5**	**0.0**	**85.5**	**68.7**	**0.0**	**0.0**	**0.0**	**805.7**
STD	**36.0**	**64.9**	**60.5**	**85.7**	**84.0**	**67.7**	**82.8**	**64.8**	**78.2**	**77.8**	**85.0**	**37.6**	**333.0**

1c: Mean annual and monthly rainfall data of Humbo meteorological station

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Sum*
1985	28.1	1.5	47.4	207.0	85.2	40.4	100.6	36.4	55.1	34.0	57.0	22.1	1076.7
1986	5.5	33.7	39.4	67.2	83.9	66.2	93.2	105.2	121.0	31.3	9.8	45.5	1268.2
1987	13.6	19.4	232.2	78.3	338.7	26.5	72.2	38.9	71.7	93.6	2.0	17.1	1306.4
1988	52.3	50.9	36.8	219.4	84.7	125.2	250.1	213.3	23.7	111.6	0.0	12.0	1180.0
1989	43.2	53.7	76.0	70.3	146.5	184.9	136.1	144.0	125.5	88.7	17.2	167.8	1253.9
1990	8.4	153.8	85.2	69.2	115.5	46.7	91.0	74.3	90.9	34.3	15.9	26.0	811.2
1991	25.1	110.3	76.2	36.7	99.0	62.7	94.0	79.2	59.1	22.5	8.4	12.0	685.2
1992	4.5	27.0	93.5	155.0	67.8	58.0	194.7	188.7	82.3	100.5	42.7	18.7	1033.4
1993	77.7	59.1	25.7	215.5	139.1	89.7	33.0	66.9	10.5	33.0	2.6	0.0	752.8
1994	0.0	25.0	64.3	103.0	178.0	215.0	257.2	121.0	55.5	125.0	78.5	8.4	1230.9
1995	2.0	43.7	33.5	146.4	225.5	116.3	212.7	97.1	105.4	79.8	63.2	9.1	1134.7
1996	34.6	7.6	155.3	196.3	195.0	333.1	202.5	377.5	261.6	39.3	50.8	0.0	1853.6
1997	1.9	0.0	0.0	224.7	104.2	116.9	221.1	84.8	28.1	387.0	221.3	89.2	1479.2
1998	156.4	44.3	82.1	88.6	108.6	211.5	133.3	205.1	63.1	162.8	13.3	4.1	1273.2
1999	13.9	0.0	52.2	99.1	48.7	142.9	104.4	102.3	65.9	146.5	8.2	0.0	784.1
2000	5.8	0.0	21.8	147.1	324.1	117.7	184.3	144.4	95.4	123.4	62.1	11.4	1237.5
2001	35.4	7.0	84.3	75.3	161.1	148.7	195.0	230.9	75.5	166.6	9.5	6.8	1196.1
2002	68.2	7.1	82.3	131.7	136.7	41.8	86.7	198.5	62.3	9.7	39.1	253.1	1117.2
2003	47.5	21.4	31.0	220.6	88.6	177.9	201.7	193.0	24.0	18.7	13.8	168.6	1206.8
2004	118.7	11.3	17.6	158.3	24.3	65.2	148.9	84.9	21.1	53.5	22.5	4.7	731.0
2005	12.5	8.4	107.9	166.8	233.2	126.3	149.7	124.5	196.0	107.3	42.2	0.0	1274.8
2006	3.6	41.2	110.0	215.7	101.0	105.4	87.1	204.0	64.3	150.3	46.9	42.2	1171.7
2007	44.7	44.1	46.7	75.7	210.5	142.9	205.0	289.6	241.1	19.0	8.6	0.0	1327.9
2008	14.5	19.2	0.0	85.6	139.7	93.3	189.6	169.2	209.8	198.9	169.0	6.7	1295.5
2009	19.5	5.6	41.3	63.9	199.1	33.4	55.7	43.1	65.5	78.3	34.6	54.0	694.0
2010	45.6	56.6	163.3	165.7	285.9	152.7	102.5	150.7	49.8	53.0	11.5	3.3	1240.6
2011	0.0	9.6	86.8	17.7	247.6	93.3	156.3	177.0	211.6	78.7	147.8	0.0	1226.4
2012	0.0	0.0	19.3	148.4	77.9	172.0	281.4	230.8	117.5	8.4	73.9	14.1	1143.7
2013	15.0	0.0	84.7	158.1	241.1	103.0	233.9	111.9	87.8	122.0	56.3	0.0	1213.8
2014	4.7	19.2	155.7	140.5	71.4	166.6	157.5	135.0	190.6	90.4	50.2	0.0	1181.8
2015	22.2	0.0	99.7	0.0	158.0	99.1	99.2	49.5	103.4	75.1	98.2	38.2	842.6
2016	19.6	51.5	101.0	178.6	210.5	160.7	89.9	61.0	95.1	83.7	35.4	0.0	1087.0
Mean	**29.5**	**29.1**	**73.5**	**129.0**	**154.1**	**119.9**	**150.6**	**141.6**	**97.8**	**91.5**	**47.3**	**32.3**	**1096.3**
Max	**156.4**	**153.8**	**232.2**	**224.7**	**338.7**	**333.1**	**281.4**	**377.5**	**261.6**	**387.0**	**221.3**	**253.1**	**1853.6**
Min	**0.0**	**0.0**	**0.0**	**0.0**	**24.3**	**26.5**	**33.0**	**36.4**	**10.5**	**8.4**	**0.0**	**0.0**	**685.2**
STD	**35.3**	**33.9**	**51.59**	**63.8**	**79.97**	**64.84**	**64.755**	**78.29**	**66.44**	**73.8**	**50.9**	**58.5**	**264.96**

1d: Mean annual and monthly rainfall data of Bilate tena meteorological station

year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Sum*
1985	28.1	1.5	47.4	207.0	85.2	40.4	100.6	36.4	55.1	34.0	57.0	22.1	714.8
1986	5.5	33.7	39.4	67.2	83.9	66.2	93.2	105.2	121.0	31.3	9.8	45.5	701.9
1987	13.6	19.4	232.2	78.3	338.7	26.5	72.2	38.9	71.7	93.6	7.1	21.2	1013.4
1988	18.8	45.5	33.0	73.9	38.9	108.1	215.8	105.2	45.0	63.2	0.0	0.0	747.5
1989	61.2	25.1	79.1	219.9	66.8	205.7	76.1	28.7	137.7	73.6	16.2	0.0	990.1
1990	110.5	88.5	110.7	136.9	90.1	46.9	68.8	43.1	83.2	42.8	1.7	4.1	827.3
1991	23.5	78.7	67.4	27.4	63.1	163.7	132.7	87.8	63.7	38.6	0.0	9.7	756.3
1992	10.8	0.0	43.3	81.3	51.8	84.1	70.7	99.8	90.6	119.1	128.8	29.7	810.0
1993	121.2	73.6	22.6	109.6	217.8	95.7	33.2	52.9	34.2	127.4	0.2	0.0	888.4
1994	0.3	17.6	57.1	210.7	137.2	53.9	146.8	105.7	71.4	30.4	19.1	22.3	872.5
1995	0.0	38.7	136.1	330.5	76.3	68.6	88.3	16.1	146.9	33.4	0.0	49.1	984.0
1996	82.3	34.0	221.4	77.2	148.8	215.9	23.4	218.4	124.2	94.7	36.5	1.0	1277.8
1997	3.5	10.0	65.8	279.7	65.8	56.4	79.1	74.9	60.9	180.7	173.0	16.9	1066.7
1998	53.4	55.6	48.0	98.8	83.0	107.9	98.1	108.9	82.5	244.6	6.9	3.1	990.8
1999	21.7	0.0	90.7	50.2	105.6	141.8	139.8	346.8	94.9	158.4	9.1	12.8	1171.8
2000	0.0	0.0	26.2	103.3	141.4	49.2	115.5	84.9	74.2	155.7	71.8	56.6	878.8
2001	6.6	31.6	82.7	80.9	245.7	103.0	96.4	117.6	55.8	85.2	6.6	4.4	916.5
2002	0.0	28.0	134.0	119.5	89.5	47.0	41.3	146.6	78.7	59.9	0.0	53.2	797.7
2003	57.9	8.8	167.2	235.4	26.9	90.9	67.0	83.0	48.6	48.9	10.7	44.2	889.5
2004	101.5	71.1	22.5	203.2	89.3	55.5	46.1	74.3	78.7	89.7	26.1	24.2	882.2
2005	43.6	23.4	66.1	139.0	173.8	58.6	132.4	41.6	101.2	140.6	68.4	8.1	996.8
2006	11.0	38.2	66.5	152.4	63.7	65.5	71.7	252.0	78.9	115.1	92.0	64.9	1071.9
2007	26.7	71.6	98.7	129.1	189.9	125.9	129.2	80.7	127.3	35.2	12.8	0.0	1027.1
2008	6.9	7.2	0.8	106.5	91.4	63.4	145.8	131.6	111.8	257.8	72.2	13.6	1009.0
2009	26.2	8.7	72.6	52.1	36.0	29.1	36.0	36.0	113.4	113.4	56.0	39.2	618.7
2010	51.8	96.2	118.2	175.9	229.5	113.1	98.1	76.9	100.7	33.0	41.9	8.5	1143.8
2011	0.0	20.4	43.0	63.3	194.4	20.9	108.9	156.4	28.3	55.0	0.0	103.8	794.4
2012	0.0	8.6	17.8	140.7	38.0	133.7	165.7	18.8	111.5	52.1	16.3	8.5	711.7
2013	19.5	0.0	67.1	205.4	60.7	186.7	134.3	105.1	196.2	168.6	56.3	0.0	1199.9
2014	0.8	18.3	83.3	86.5	21.9	63.4	85.4	61.3	151.1	78.8	55.1	4.1	710.0
2015	0.8	0.0	10.1	28.1	31.5	64.9	37.2	33.7	92.9	27.2	78.9	32.2	437.5
2016	27.5	13.1	49.5	245.8	285.4	41.9	34.0	45.3	57.5	83.7	69.1	0.1	952.9
Mean	**29.2**	**30.2**	**75.6**	**134.9**	**114.4**	**87.3**	**93.2**	**94.2**	**90.3**	**92.7**	**37.5**	**22.0**	**901.6**
Max	**121.2**	**96.2**	**232.2**	**330.5**	**338.7**	**215.9**	**215.8**	**346.8**	**196.2**	**257.8**	**173.0**	**103.8**	**1277.8**
Min	**0.0**	**0.0**	**0.8**	**27.4**	**21.9**	**20.9**	**23.4**	**16.1**	**28.3**	**27.2**	**0.0**	**0.0**	**437.5**
STD	**34.3**	**28.4**	**55.3**	**76.3**	**80.9**	**51.4**	**44.6**	**70.7**	**37.2**	**61.2**	**41.7**	**24.4**	**181.3**

1e: Mean annual and monthly rainfall data of Bodit meteorological station

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Sum*
1985	65.9	0.0	116.1	191.9	133.8	109.5	186.8	86.6	74.5	50.2	26.3	35.1	1076.7
1986	0.0	79.2	84.3	146.6	164.7	221.3	127.2	228.1	109.6	43.1	6.4	57.7	1268.2
1987	5.6	14.6	217.1	105.2	303.0	148.6	60.8	136.7	131.3	142.8	23.5	17.2	1306.4
1988	34.8	51.5	44.1	238.0	101.2	176.6	215.0	179.0	207.6	124.2	0.0	5.7	1377.7
1989	31.9	100.3	87.2	150.7	66.3	113.8	92.6	111.2	87.5	93.2	18.1	145.0	1097.8
1990	53.4	163.6	165.0	125.0	111.0	101.3	120.1	142.9	137.8	62.0	11.5	26.6	1220.2
1991	34.0	70.1	145.3	78.3	223.6	166.1	125.1	136.8	137.8	6.8	5.7	83.4	1213.0
1992	13.7	147.1	97.6	110.2	145.8	114.3	195.6	231.1	133.1	133.7	86.8	54.6	1463.6
1993	63.0	86.6	64.5	228.7	294.0	112.6	141.4	132.3	112.9	53.1	11.8	3.1	1304.0
1994	1.5	28.3	125.1	154.9	158.4	198.3	213.1	177.8	72.0	27.7	33.7	8.4	1199.2
1995	0.0	63.4	106.8	264.1	105.6	122.8	107.1	115.0	111.3	52.0	4.0	26.9	1079.0
1996	72.0	28.9	101.9	196.7	121.3	245.1	168.4	218.4	149.2	15.7	20.5	1.0	1339.1
1997	3.5	10.0	84.1	247.6	206.4	101.8	120.8	128.3	41.2	227.5	265.3	13.4	1449.9
1998	79.3	109.8	133.1	230.3	290.4	160.9	150.9	145.8	67.5	131.8	20.2	6.0	1526.0
1999	32.3	0.0	42.7	105.9	98.5	94.3	200.7	180.5	40.1	174.4	17.9	15.2	1002.5
2000	0.0	0.0	26.4	92.6	202.8	96.9	83.1	142.1	69.8	130.5	81.7	22.5	948.4
2001	10.1	67.2	100.2	123.0	245.7	134.2	212.4	209.5	141.6	106.4	33.1	28.6	1412.0
2002	58.8	10.9	147.7	113.6	119.8	59.6	137.1	160.6	130.5	52.2	1.5	113.3	1105.6
2003	59.1	20.3	85.6	182.4	64.1	143.1	200.9	159.1	108.3	69.4	36.6	34.0	1162.9
2004	78.3	41.1	43.0	154.9	85.3	83.0	217.4	76.1	173.1	69.8	24.1	50.7	1096.8
2005	22.3	22.5	115.3	279.9	212.9	123.8	139.5	94.1	190.0	48.4	90.8	7.4	1346.9
2006	12.0	57.2	130.9	226.4	124.2	85.0	202.1	150.1	52.2	118.8	40.7	135.3	1334.9
2007	36.7	66.1	91.9	158.1	213.7	205.1	224.5	229.0	270.9	21.1	10.7	0.0	1527.8
2008	9.1	5.5	13.5	74.1	108.8	97.3	145.1	183.9	129.2	159.9	82.6	1.1	1010.1
2009	28.7	30.8	47.8	64.3	124.7	67.3	98.5	189.2	105.5	84.8	28.2	110.9	980.7
2010	18.3	91.1	71.2	233.7	280.5	121.4	91.3	118.1	97.6	30.1	19.5	25.9	1198.7
2011	13.1	20.4	43.0	63.3	371.9	170.6	157.9	172.8	60.8	18.4	112.0	3.4	1207.6
2012	0.0	0.0	44.6	180.8	38.0	67.1	196.6	169.7	135.3	13.0	32.9	16.8	894.8
2013	25.3	25.2	105.9	254.4	95.3	110.8	194.7	105.1	210.2	149.7	62.5	0.0	1339.1
2014	11.1	41.0	155.7	140.5	179.6	114.2	161.2	165.4	190.6	121.4	0.0	4.2	1285.0
2015	22.2	14.3	26.0	75.1	126.4	109.2	93.4	58.9	103.4	17.0	107.0	41.2	794.1
2016	55.8	5.4	101.0	275.1	166.5	136.2	89.9	80.8	140.2	83.7	35.4	0.0	1170.0
Mean	**29.7**	**46.0**	**92.6**	**164.6**	**165.1**	**128.5**	**152.2**	**150.5**	**122.6**	**82.3**	**42.2**	**34.2**	**1210.6**
Max	**79.3**	**163.6**	**217.1**	**279.9**	**371.9**	**245.1**	**224.5**	**231.1**	**270.9**	**227.5**	**265.3**	**145.0**	**1527.8**
Min	**0.0**	**0.0**	**13.5**	**63.3**	**38.0**	**59.6**	**60.8**	**58.9**	**40.1**	**6.8**	**0.0**	**0.0**	**794.1**
STD	**25**	**43**	**46.5**	**67.5**	**80.5**	**45.1**	**48.1**	**46.29**	**52.95**	**55.8**	**51.8**	**40.8**	**183**

1f: Mean annual and monthly rainfall data of Bilate meteorological station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	22.1	4.3	59	134.4	69.2	88.7	69.6	54.5	59.5	66.9	39.2	4.8	672.2
1986	0	60	0	78	129	117.7	108.7	105.3	119.2	44.1	23.5	68.1	853.6
1987	5.4	48.1	127.4	0	250.5	60.9	21.2	98.2	29.8	70.7	11.9	6.1	730.2
1988	20.3	43	52.3	133.5	108	72	208.4	127.4	81.4	105.9	0	11.2	963.4
1989	41	39	64.6	119.1	32	205.7	76.1	28.7	118.3	30.5	65.5	90.98	911.5
1990	8.7	134.3	99	97.1	90.1	74.8	75	30.1	16	36.05	22.1	7.8	691.1
1991	29.7	64.4	81.3	52.8	84.6	84.9	71.9	125.1	55.3	32.5	0	43.2	725.7
1992	24.2	94.5	73.9	141.7	65.2	54.7	60.9	81	84.2	138.8	92.5	25.3	936.9
1993	88.1	71.2	10.9	116.6	160.6	103.7	33.2	36.8	57.7	93.5	21.5	2.9	796.7
1994	0	14.5	45.8	176.4	50.2	88.1	263.1	26.3	36.3	42.1	40.8	35	818.6
1995	0	11	101.1	133.9	44.8	42.8	64.4	21.8	92	51.7	15.7	38	617.2
1996	118.3	1.3	96.8	126.5	80.9	252.5	133	106.7	76.3	39.4	18.7	25.4	1076
1997	11.3	0	8.5	146.5	76.2	57.4	72	32.6	89.2	164.3	150	41.3	849.3
1998	88.2	38.2	41.5	66.1	84.4	59.6	61.6	87.8	33.2	70	1.8	0	632.4
1999	8.6	0	37	37.5	48.7	32.5	97.7	84.9	42.1	76.1	19.8	7.3	492.2
2000	0	0	7.4	58.7	117.8	69.4	74	51.9	99.7	76.8	50.1	10.6	616.4
2001	10.9	17.4	34.9	39.4	101.3	80	53.5	45.9	48.7	91.3	4.6	9	536.9
2002	47.1	1.2	52.7	72.5	49	17.2	33.3	47.6	27.9	48.6	0	123.5	520.6
2003	12	16	39.3	276.6	58.7	75.9	66.7	115.5	72.8	53.1	45.1	19.3	851
2004	89	43.5	15.9	212.5	91.9	27.2	71.1	66.7	86.4	59.3	39	11.3	813.8
2005	37.6	9.7	58.3	141.8	235.6	41.6	185.8	41.1	91.4	71.7	71.3	14.8	1001
2006	4.7	41.9	147.8	126.5	136.7	38.8	86.5	136.3	82.1	144.4	18.8	67.9	1032
2007	40.2	23	82.3	120.5	143.3	174.1	58.5	65.6	169	47.7	29.1	0	953.3
2008	10.4	4.3	0.9	86.3	87.4	38.4	109.9	87.6	69.9	161.2	128	2.8	787
2009	52.2	19.9	26.1	99.2	85.3	61.4	47.8	62.7	42.4	100.1	34.6	54	685.7
2010	37	81.4	141.6	187.5	143	133.2	73.1	81.7	113.8	40.8	41.9	7.3	1082
2011	13.4	16.8	38.7	63.5	200.4	36.1	93	145.3	36.1	50.2	112	0	805.9
2012	0	4	9.5	130.7	38	67.1	176.8	52.8	82.9	41.1	70	5.8	678.7
2013	48.7	5.8	84.7	238.2	94.9	92.2	188.9	141.7	25.5	222.1	62.5	0	1205
2014	0.2	27.9	83.3	90.4	108.3	78.9	46.8	61.3	94.6	115.7	122	4.1	833.8
2015	2.2	0.8	48	74	123.7	150.7	63	27.7	50.3	40.6	80.4	11.57	673
2016	27.5	13.1	49.5	155	30.9	93.5	82.3	45.3	26.1	83.7	69.1	0.1	676.1
mean	**28.1**	**29.7**	**56.9**	**116.7**	**100.6**	**83.5**	**91.5**	**72.6**	**69.1**	**78.5**	**46.9**	**23.4**	**797.5**
max	**118.3**	**134.3**	**147.8**	**276.6**	**250.5**	**252.5**	**263.1**	**145.3**	**169.0**	**222.1**	**150.0**	**123.5**	**1205.2**
min	**0**	**0**	**0**	**0**	**30.9**	**17.2**	**21.2**	**21.8**	**16**	**30.5**	**0**	**0**	**492.2**
STD	**30.9**	**32.2**	**39.8**	**59.4**	**54.3**	**52.1**	**55.7**	**37.4**	**34.5**	**45.8**	**40.2**	**29.6**	**174.2**

1h: Mean annual and monthly rainfall data of Butajira meteorological station

year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
1985	9.7	2.1	29.3	188.1	91.4	73.8	189.3	154.9	151.9	0	0	0	890.5
1986	0	162.5	12.4	254.3	93.8	120.6	100.6	116.4	166.8	19.8	0	4.6	1052
1987	0	148.9	328.3	91.4	246	60.1	94.7	121.3	135.9	21.2	0	0	1248
1988	27.6	95.9	5.5	147	36	165.9	218.7	191.5	164.7	71.7	0	0	1125
1989	3	129.2	250.7	156.5	24.6	94.5	280.8	161.3	127.4	51	0	32.5	1312
1990	0	270.9	120.3	260.5	152	132.2	197.5	175.7	134.3	22	0	0	1466
1991	44	139.8	200.6	33.1	0	95.7	203.1	252.1	228.7	85.9	42.6	0	1326
1992	62.5	89	68.6	145.3	119	163.8	261.3	233.7	248.6	73.4	54.9	5.7	1526
1993	36.7	124.2	0	187.2	115	95.7	183.3	148	103.1	62.7	0	2	1057
1994	0	0	118	87.9	80.1	246.6	269.1	100.9	108.8	3	14.1	2.7	1031
1995	0	72.9	115.2	409.5	98.6	63.1	124.2	116.2	66.6	9.5	0	93	1169
1996	149	0	314.3	103.9	212	277.3	133	199.4	72.5	9	13.2	0	1484
1997	112	0	126.4	190.8	35.2	199.1	101.1	207.6	108.1	110	50.4	0	1240
1998	116	107.7	217.8	111.9	201	94.7	194	223.4	120.7	73.3	0	0	1460
1999	3	15.2	91	35.3	69.4	92.5	205.9	214.6	111.7	216	0	0	1054
2000	0	0	6.1	122.2	75.4	57.8	150	133.3	55.5	57	90	118	865.6
2001	0	59	262.6	59.2	195	234.3	136.6	189.3	120.5	24	9.4	1.8	1292
2002	49.2	38.8	143.5	82.4	105	182	93.6	249.3	167.8	0	0	48.3	1160
2003	10.4	58.3	129	155.1	43.4	230.1	272	114.9	122.6	0.3	7.7	44	1188
2004	75.4	6.1	58.5	190.4	6.9	109.1	145.3	116.1	136.1	67.2	2.1	0.2	913.4
2005	27	7	94	220.7	267	166.1	394.8	169	274.6	134	29.8	0	1784
2006	3	53.4	176.1	324.8	98.9	229.2	218.8	175.4	229.1	53.3	0.4	9.9	1572
2007	5.6	185.1	67	91.3	116	178.3	229.5	112.2	236.9	41.8	0	0	1264
2008	0	1.7	0	37.1	141	131.1	145.1	197.7	88.5	65	76.7	0	884.3
2009	35.5	4.5	23.8	31	42.3	26.3	187	68.1	34	52.2	0	0	504.7
2010	0	71	53.1	40.3	156	141.6	68.2	140.4	71.2	23.2	8.8	4.5	777.8
2011	7.6	3.2	29.7	23	184	121.1	197.4	164.5	121.1	7.7	17.5	0	876.5
2012	0	0	24.8	280.8	47.9	48.2	269.6	143.9	88	15.8	0	3.5	922.5
2013	0	0	88.6	145.5	66.4	274.2	438	164.7	48.1	50.1	0	0	1276
2014	170	129.4	0	72.7	97.8	76.8	403.4	412.4	161	13	5.6	0	1542
2015	0	0	22.3	0	52.1	78	79.8	56.4	70.6	6.6	0	97.6	463.4
2016	7.2	5	9	57.2	61.6	52.2	63.8	34	21.6	96.1	10.1	0	417.8
mean	**29.8**	**61.9**	**99.58**	**135.5**	**104**	**134.8**	**195.3**	**164.3**	**128**	**48**	**13.5**	**14.6**	**1129**
max	**170**	**270.9**	**328.3**	**409.5**	**267**	**277.3**	**438**	**412.4**	**274.6**	**216**	**90**	**118**	**1784**
min	**0**	**0**	**0**	**0**	**0**	**26.3**	**63.8**	**34**	**21.6**	**0**	**0**	**0**	**417.8**
STD	**46.5**	**70.19**	**94.83**	**96.64**	**68.3**	**70.35**	**94.66**	**69.87**	**63.42**	**46.4**	**23.7**	**31.5**	**326.2**

1i: Mean annual and monthly rainfall data of Wuliberg meteorological station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	6.9	0	14.7	199.7	176.9	64.6	120.1	216.4	191.2	39.5	0	0.6	1030.6
1986	0	141	67.2	118.4	96.1	236	307.6	201	140.2	99.1	0	5.5	1412.4
1987	0	72.8	337	91.4	325.2	165	120.2	157.9	132.1	57.7	0	0	1459.6
1988	8.6	60.6	24.8	262.3	113.1	183	188.1	264.6	231.4	128.8	0	0	1464.9
1989	7.5	85.9	102	184.2	33.1	184	280.8	138.6	155.3	83.6	0	25.7	1281.1
1990	0	297	134	139.9	61.3	76.2	199.2	120.5	221.2	9.5	8.9	0	1266.7
1991	24.8	87.6	256	40.7	118.9	107	203.1	252.1	228.7	85.9	42.6	0	1447.7
1992	62.5	89	68.6	145.3	118.9	164	261.3	233.7	248.6	73.4	54.9	5.7	1525.7
1993	36.7	124	0	187.2	114.5	141	106.6	230	179.4	257.5	0	0	1377.4
1994	0	0	92	134.4	189.4	128	288.4	143.9	50.7	0	0.5	0	1027.2
1995	0	17.7	25.6	409.5	98.6	63.1	282.3	194.6	102	0	0	28.9	1222.3
1996	76.8	33.6	187	148	222	283	199.4	164.6	105.5	0	8	0	1427.9
1997	74.4	0	62.2	132.5	58.8	179	112.8	164.1	79.2	258.4	30.6	0	1152.3
1998	31.2	76.4	218	122.5	190.6	123	169	207.5	197.7	164.5	0	0	1500.5
1999	50	0	136	30.4	88.9	108	187	129.1	207	200	0	0	1136.2
2000	0	0	18.3	222.5	168.3	298	181.9	243.7	308.4	77.2	83.6	61.6	1663
2001	0	17.7	169	61.7	238.6	213	193	142.1	109.5	50.9	1.1	2.9	1200
2002	177	20.1	133	38.2	146	68.1	113.9	215.8	133.5	0	0	119	1163.6
2003	36.2	4.9	20.6	202.1	49.6	169	309	115.3	225.2	2.3	20.5	22	1176.5
2004	0	23.2	75.3	151.8	0	47.4	128.7	0	0	0	0	0	426.4
2005	49.2	5.7	131	145.9	171.8	74	127.3	116.8	158.5	44.2	35.8	0	1060.2
2006	0	18.1	280	248.4	109.5	245	281.6	183.9	115.7	43.3	5.5	0	1530.8
2007	45.9	116	27.9	48.2	119.2	178	229.5	112.2	236.9	41.8	0	0	1155.9
2008	0	0.3	0	65	241.7	133	286.8	183	165.6	48.1	126	0	1249.6
2009	84.2	7.9	40	31.2	81.6	141	167.6	170.3	54.8	169.7	0	0	948.1
2010	0.6	152	188	104.2	155.5	83.2	99.4	208.1	179.2	8.4	21.2	12.7	1212.2
2011	7.6	3.2	3.6	24	133.2	121	197.4	164.5	157.6	7.7	17.5	0	837.4
2012	0	0	24.8	280.8	47.9	161	281.3	96.9	143	15.8	0	5.9	1057.1
2013	0	0	88.6	145.5	55	146	242.4	166.5	48.1	77.2	6.7	0	976
2014	0	88.7	80	77.4	97.8	18.4	403.4	231.6	210.5	83.7	0	0	1291.5
2015	0	0	17.9	14.5	173.9	195	119.7	63.2	79.9	2.2	0	60.5	727
2016	62.1	0	60.1	203.5	61.6	96.1	177.6	81.5	149.3	96.1	10.1	0	998
mean	**26.3**	**48.2**	**96.4**	**137.9**	**126.8**	**143**	**205.2**	**166.1**	**154.6**	**69.58**	**14.8**	**11**	**1200.2**
max	**177**	**297**	**337**	**409.5**	**325.2**	**298**	**403.4**	**264.6**	**308.4**	**258.4**	**126**	**119**	**1663**
min	**0**	**0**	**0**	**14.5**	**0**	**18.4**	**99.4**	**0**	**0**	**0**	**0**	**0**	**426.4**
STD	**38.9**	**65.8**	**87.9**	**88.65**	**70.5**	**67.1**	**75.98**	**59.73**	**69.05**	**72.78**	**28.1**	**25.3**	**259.46**

1j: Mean annual and monthly rainfall data of Hosana meteorological station

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
1985	10.5	0.4	40.6	214.5	141.7	80.8	116.0	196.1	376.4	64.2	6.2	18.8	1266.2
1986	1.5	178.0	125.2	197.8	282.4	135.8	196.8	101.2	133.5	35.7	0.9	29.1	1417.9
1987	5.9	81.8	187.7	112.2	320.4	90.0	105.6	170.4	154.7	47.3	0.0	4.5	1280.5
1988	20.5	79.2	35.5	93.1	69.5	121.2	194.6	299.1	191.4	112.1	0.0	0.0	1216.2
1989	29.4	81.3	104.0	142.5	60.4	121.0	131.5	165.8	146.0	78.4	0.0	139.4	1199.7
1990	0.0	144.8	153.1	92.0	114.9	107.2	133.8	125.6	135.3	40.5	6.8	1.0	1055.0
1991	7.1	45.7	94.0	31.6	128.7	138.6	210.5	185.9	110.2	9.7	0.0	66.3	1028.3
1992	58.9	88.1	119.6	174.5	106.2	171.7	121.4	280.1	104.3	106.2	52.9	3.7	1387.6
1993	78.1	107.0	20.6	255.2	285.7	75.1	122.8	199.0	92.7	177.2	0.0	0.1	1413.5
1994	0.0	0.0	146.7	83.9	128.9	80.8	148.3	128.7	192.8	0.2	10.1	0.0	920.4
1995	0.5	62.7	70.0	219.6	109.3	82.4	196.0	156.5	160.6	4.2	0.0	98.9	1160.7
1996	90.7	17.8	153.0	170.4	162.7	108.8	186.7	129.6	125.6	6.6	16.3	0.0	1168.2
1997	28.7	0.0	80.7	177.6	140.1	171.7	113.1	186.4	140.2	318.7	85.3	0.0	1442.5
1998	73.8	63.2	107.7	203.6	143.0	159.9	205.3	188.5	235.3	158.5	17.6	0.0	1556.4
1999	1.0	0.0	56.5	77.0	122.5	143.5	181.7	107.8	127.7	193.6	0.0	0.0	1011.3
2000	0.0	0.0	15.4	205.8	105.2	145.5	86.2	124.5	177.9	64.9	21.0	45.5	991.9
2001	4.8	70.1	184.0	109.6	172.1	91.0	151.9	188.0	101.8	62.0	4.7	5.5	1145.5
2002	83.3	47.2	150.7	111.7	135.5	90.0	103.6	314.7	154.7	2.8	0.4	151.8	1346.4
2003	35.8	58.9	118.7	194.4	78.7	108.3	135.9	213.3	182.9	11.7	14.3	0.0	1152.9
2004	96.8	19.4	90.6	176.2	104.6	123.4	133.6	152.3	181.8	75.1	17.3	14.0	1185.1
2005	31.5	18.8	177.8	162.1	197.2	64.6	160.1	98.9	162.6	37.7	67.7	0.0	1179.0
2006	28.9	53.9	135.5	160.0	75.8	169.8	183.9	222.2	88.2	50.3	6.0	27.2	1201.7
2007	6.0	0.0	119.4	152.1	121.3	163.1	179.9	127.3	210.3	19.4	0.0	0.0	1098.8
2008	0.0	1.2	61.9	46.5	238.4	144.0	192.5	136.2	139.0	114.6	128.0	0.5	1202.8
2009	43.1	4.8	73.4	85.5	120.1	122.7	188.5	181.1	156.7	169.4	5.1	90.6	1241.0
2010	11.8	110.0	139.9	111.3	182.8	94.4	116.0	145.0	138.5	18.8	19.3	33.7	1121.5
2011	15.5	11.2	101.7	115.9	232.8	166.8	158.8	182.5	119.3	0.0	49.2	0.0	1153.7
2012	0.0	0.0	67.4	138.3	68.3	150.3	233.1	155.9	163.5	1.4	2.4	1.0	981.6
2013	1.0	17.4	54.5	67.9	131.6	182.2	200.8	211.0	173.0	46.4	0.4	0.0	1086.2
2014	25.0	117.8	76.6	134.9	251.8	76.2	188.3	270.9	193.0	60.6	17.2	81.5	1493.8
2015	0.0	3.0	45.1	19.2	136.9	213.0	142.6	169.0	142.2	31.4	162.9	151.7	1217.0
2016	92.8	0.0	81.2	258.6	135.9	122.8	0.0	123.8	138.0	68.8	111.2	0.0	1133.1
mean	**27.6**	**46.4**	**99.6**	**140.5**	**150.2**	**125.5**	**153.7**	**176.2**	**157.8**	**68.4**	**25.7**	**30.1**	**1201.8**
max	**96.8**	**178.0**	**187.7**	**258.6**	**320.4**	**213.0**	**233.1**	**314.7**	**376.4**	**318.7**	**162.9**	**151.8**	**1556.4**
min	**0.0**	**0.0**	**15.4**	**19.2**	**60.4**	**64.6**	**0.0**	**98.9**	**88.2**	**0.0**	**0.0**	**0.0**	**920.4**
STD	**32.2**	**48.7**	**47.3**	**61.8**	**67.0**	**37.5**	**47.0**	**55.5**	**52.6**	**71.2**	**41.6**	**47.8**	**153.9**

1k: Mean annual and monthly rainfall data of the Fonko meteorological station

year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
1985	10.5	0.4	40.6	214.5	141.7	80.8	116.0	196.1	376.4	64.2	6.2	18.8	1266.2
1986	1.5	178.0	125.2	197.8	282.4	135.8	196.8	101.2	214.4	41.3	0.0	1.3	1475.7
1987	0.0	99.4	286.3	148.6	272.0	82.2	65.9	254.2	114.3	76.2	2.5	1.7	1403.3
1988	10.8	51.9	21.5	158.3	69.4	151.2	166.0	193.3	165.5	122.9	0.0	0.0	1110.8
1989	30.1	80.1	182.5	234.1	38.5	106.7	172.8	174.6	147.0	54.5	0.0	115.4	1336.3
1990	0.0	124.8	123.6	125.3	119.8	37.0	110.4	131.7	181.3	79.6	2.9	0.0	1036.4
1991	9.1	82.3	149.6	46.8	87.7	140.0	171.1	163.2	106.9	16.6	0.0	58.9	1032.2
1992	49.5	42.9	132.3	219.4	203.0	160.4	206.7	230.8	124.0	122.8	46.3	0.0	1538.1
1993	61.0	110.5	0.0	317.4	258.9	66.3	137.5	183.1	125.8	255.6	0.0	0.0	1516.1
1994	0.0	0.0	84.0	89.7	133.8	125.6	157.7	122.8	169.4	0.0	7.9	0.0	890.9
1995	0.0	23.0	61.6	217.4	118.6	66.4	128.3	156.5	119.6	0.0	0.0	54.7	946.1
1996	95.4	29.6	265.4	210.0	159.5	140.4	177.6	175.4	116.8	1.4	11.1	0.0	1382.6
1997	53.6	0.0	66.5	135.7	108.1	235.4	117.1	183.8	175.4	514.8	69.3	0.0	1659.7
1998	0.0	189.8	161.6	158.8	121.3	118.9	117.2	224.6	92.5	187.0	6.0	0.0	1377.7
1999	0.0	0.0	111.4	38.2	98.1	109.1	259.1	133.9	185.8	217.9	0.0	0.0	1153.5
2000	0.0	0.0	1.3	209.6	168.0	145.7	132.6	207.0	162.0	70.0	21.6	56.8	1174.6
2001	7.0	60.9	270.1	113.4	174.3	171.3	139.5	266.3	136.7	57.8	3.9	1.2	1402.4
2002	94.7	53.6	130.8	85.2	192.0	124.8	115.0	245.9	190.6	1.8	0.0	160.3	1394.7
2003	69.9	47.0	140.9	269.0	42.8	186.4	262.4	176.0	206.3	14.6	8.2	55.7	1479.2
2004	89.2	25.8	111.1	173.4	22.3	68.4	200.1	167.1	179.7	91.8	6.0	33.0	1167.9
2005	24.8	0.0	110.8	169.1	189.9	111.5	165.6	164.4	166.5	76.5	58.8	0.0	1237.9
2006	0.0	19.9	140.6	174.5	108.0	141.1	207.4	195.3	111.5	60.4	10.8	15.0	1184.5
2007	53.6	77.9	91.2	112.8	125.5	143.6	193.1	117.1	298.3	21.2	0.0	0.0	1234.3
2008	0.0	7.8	0.3	104.1	162.9	200.1	236.5	126.6	206.7	78.2	99.1	0.0	1222.3
2009	52.5	12.8	6.4	39.6	115.5	87.2	188.3	168.6	134.3	127.4	12.8	39.9	985.3
2010	13.9	104.5	215.3	126.9	220.6	84.7	198.6	61.1	122.5	10.1	57.6	16.9	1232.7
2011	14.1	6.3	199.8	80.0	207.9	91.1	155.9	152.3	129.6	0.0	27.4	0.0	1064.4
2012	0.0	0.0	57.9	108.0	61.1	221.6	166.5	183.9	244.5	0.0	19.2	12.3	1075.0
2013	0.0	54.7	155.3	114.7	143.6	177.7	174.3	171.2	99.6	70.8	7.9	0.0	1169.8
2014	14.6	63.2	56.2	111.9	265.7	28.2	107.1	221.8	120.0	60.6	16.4	0.0	1065.7
2015	0.0	0.0	32.9	19.2	206.0	239.6	90.0	175.2	100.3	163.5	103.5	92.8	1223.0
2016	37.1	17.4	0.0	309.0	152.8	164.9	86.8	108.6	174.2	0.0	67.6	0.0	1118.4
mean	**24.8**	**48.9**	**110.4**	**151.0**	**149.1**	**129.5**	**160.0**	**172.9**	**162.5**	**83.1**	**21.0**	**23.0**	**1236.2**
max	**95.4**	**189.8**	**286.3**	**317.4**	**282.4**	**239.6**	**262.4**	**266.3**	**376.4**	**514.8**	**103.5**	**160.3**	**1659.7**
min	**0.0**	**0.0**	**0.0**	**19.2**	**22.3**	**28.2**	**65.9**	**61.1**	**92.5**	**0.0**	**0.0**	**0.0**	**890.9**
STD	**31.0**	**51.6**	**80.9**	**75.1**	**68.6**	**53.7**	**48.4**	**46.1**	**60.5**	**102.8**	**29.7**	**39.0**	**186.9**

1l: Mean annual and monthly rainfall data of Indibir meteorological station

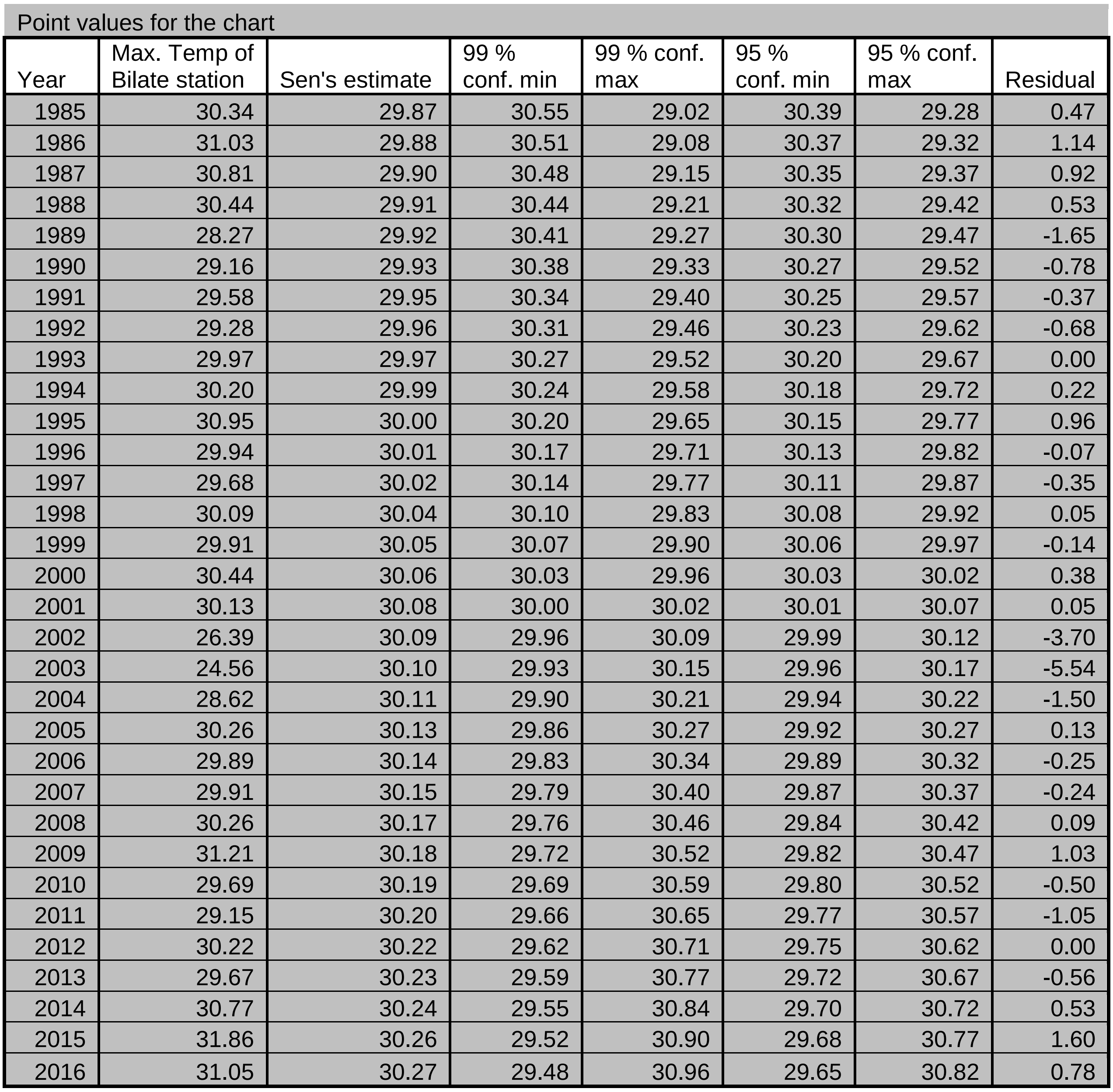
year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
1985	12.5	0	23.9	133.9	86.6	141.1	288	425	191	12	5.6	2.7	1322.5
1986	0	31.6	57.4	97.2	146.2	215.9	272.9	244.3	173	61.8	0	0	1300.2
1987	0	82.3	140	90.4	108.3	164.9	120.2	157.9	132	57.7	0	0.8	1054.7
1988	43.8	75.8	20.8	42.3	52.4	203.3	318	168.5	192	99.2	0	0	1216.2
1989	19.4	45.6	147	158.5	21	134.2	214.3	226.9	63.3	73.3	0	23.7	1127.4
1990	22.4	130	40.6	84.7	109.8	195.1	340.3	164.7	143	0	0	0	1230.5
1991	2.8	56.6	167	0	96.5	177	269.5	248.1	27	4	0	11	1059.1
1992	21.4	27.7	25.8	49.4	22.8	27.5	40.8	45.4	49	73.4	0	0	383.2
1993	0	20.5	0	54.5	248	224	276	285.5	170	0	0	0	1278.5
1994	0	0	92	134.4	11.3	127.9	288.4	143.9	50.7	0	0.5	0	849.1
1995	0	0	3.2	335.6	99.3	137.4	136.7	245	21.4	6	0	30.5	1015.1
1996	16.7	8.5	162	100.8	208.4	366.3	209.8	245	171	57.4	16.9	1	1563.4
1997	58.4	0	78.9	174.2	41	171.2	252.2	198.8	50	185	100	12.4	1322.2
1998	31.2	15.9	70	63.7	120.3	162.8	301.3	367.6	217	148	0	0	1497.7
1999	0	0	38.5	34.4	96.2	216.5	169.8	319.4	90.5	174	2	1.5	1142.4
2000	0	0	1	48.9	49.6	90.2	211.9	204.9	149	112	47.6	8.5	924.1
2001	0	4.5	76.5	47	133.9	171.9	129.6	91.9	83.8	70.4	24.8	0	834.3
2002	104	35.3	69.8	28.3	62.2	179.7	121.7	116.4	43.4	2	0	30.6	793
2003	13.3	30.8	46.1	109.7	11.8	146.7	169.8	87.2	39.2	7.1	2	17.3	681
2004	34.1	9.8	34.4	59.6	49	104.8	241.3	265.5	167	104	7	13.2	1089.6
2005	35.7	0	31.5	24.9	29.9	181.7	333.1	227.9	180	49.3	21.7	0	1115.9
2006	6.7	32.5	145	85	140.5	360.1	252.6	296.7	187	75.7	6.5	7.5	1595.8
2007	43.5	89	97.2	67.4	147.8	145	250	254.6	298	45.5	0	0	1437.6
2008	0	0	6.9	93.8	236.6	181.3	306.8	225.2	118	69.2	80.7	0	1318.7
2009	83.4	31.9	43.6	62.6	116	90.9	529.4	466.6	88.6	71.6	1.8	51.5	1637.9
2010	25.8	57.7	67.8	103.9	251.9	197	565.4	285.9	122	16.4	6.9	38	1738.4
2011	0	0	77.5	57.2	238.3	313	247.6	520.5	115	8.9	41.3	0	1619.7
2012	0	0	6.9	45.7	47.9	224.8	257.5	219.1	168	17.3	8.2	2.2	997.6
2013	3.8	0	88.6	145.5	140.1	201.1	241.5	255.5	218	72.3	14.6	0	1381
2014	0	88.7	45.1	93.9	206.2	122.7	210.8	336.7	211	83.7	0	0	1398.3
2015	0	0	25.6	10.9	178.2	277.1	209.9	214.2	70.6	6.6	0	97.6	1090.7
2016	32	12.3	0	177.8	0	106.3	230.4	241.3	160	96.1	10.1	0	1066.3
mean	**19.1**	**27.7**	**60.3**	**88**	**109.6**	**180**	**250.2**	**243.6**	**130**	**58.1**	**12.44**	**10.94**	**1190.1**
max	**104**	**130**	**167**	**335.6**	**251.9**	**366.3**	**565.4**	**520.5**	**298**	**185**	**100**	**97.6**	**1738.4**
min	**0**	**0**	**0**	**0**	**0**	**27.5**	**40.8**	**45.4**	**21.4**	**0**	**0**	**0**	**383.2**
STD	**25.6**	**34.2**	**49.2**	**64.16**	**75.48**	**73.42**	**103.6**	**103.8**	**68.1**	**50.9**	**23.74**	**20.57**	**302.19**

Appendices 2 Sen.'s slope output value for the trend analysis

Year	Lower Bilate Rainfall Data	Sen.'s estimate	99 % conf. min	99 % conf. max	95 % conf. min	95 % conf. max	Residual
1985	975.47	920.70	1040.17	847.11	1008.14	864.17	54.77
1986	877.75	920.51	1031.75	853.88	1002.32	868.79	-42.76
1987	871.80	920.32	1023.33	860.65	996.51	873.41	-48.52
1988	963.62	920.13	1014.91	867.41	990.70	878.03	43.49
1989	1009.43	919.95	1006.48	874.18	984.88	882.65	89.49
1990	790.52	919.76	998.06	880.94	979.07	887.26	-129.24
1991	722.28	919.57	989.64	887.71	973.26	891.88	-197.29
1992	932.68	919.38	981.22	894.47	967.44	896.50	13.30
1993	812.53	919.19	972.80	901.24	961.63	901.12	-106.66
1994	974.00	919.00	964.38	908.01	955.81	905.74	55.00
1995	911.97	918.81	955.96	914.77	950.00	910.36	-6.85
1996	1380.91	918.63	947.53	921.54	944.19	914.98	462.29
1997	1129.62	918.44	939.11	928.30	938.37	919.60	211.19
1998	965.47	918.25	930.69	935.07	932.56	924.22	47.22
1999	830.22	918.06	922.27	941.83	926.75	928.83	-87.84
2000	910.90	917.87	913.85	948.60	920.93	933.45	-6.97
2001	835.90	917.68	905.43	955.37	915.12	938.07	-81.79
2002	811.78	917.49	897.01	962.13	909.30	942.69	-105.71
2003	982.42	917.31	888.58	968.90	903.49	947.31	65.12
2004	809.00	917.12	880.16	975.66	897.68	951.93	-108.12
2005	1090.77	916.93	871.74	982.43	891.86	956.55	173.84
2006	992.00	916.74	863.32	989.20	886.05	961.17	75.26
2007	1036.10	916.55	854.90	995.96	880.24	965.78	119.55
2008	1030.50	916.36	846.48	1002.73	874.42	970.40	114.14
2009	685.14	916.17	838.06	1009.49	868.61	975.02	-231.04
2010	1161.01	915.99	829.63	1016.26	862.79	979.64	245.03
2011	876.93	915.80	821.21	1023.02	856.98	984.26	-38.87
2012	861.20	915.61	812.79	1029.79	851.17	988.88	-54.41
2013	969.43	915.42	804.37	1036.56	845.35	993.50	54.01
2014	884.24	915.23	795.95	1043.32	839.54	998.12	-30.99
2015	675.56	915.04	787.53	1050.09	833.73	1002.74	-239.48
2016	921.70	914.85	779.11	1056.85	827.91	1007.35	6.85

Point values for the chart

Year	Min. Temp of Bilate station	Sen's estimate	99 % conf. min	99 % conf. max	95 % conf. min	95 % conf. max	Residual
1985	11.36	14.28	15.40	11.72	15.19	12.47	-2.93
1986	11.50	14.40	15.45	11.95	15.26	12.67	-2.90
1987	11.25	14.51	15.51	12.18	15.33	12.86	-3.26
1988	10.95	14.63	15.56	12.41	15.40	13.05	-3.68
1989	9.98	14.74	15.62	12.64	15.47	13.24	-4.76
1990	15.74	14.86	15.67	12.86	15.53	13.43	0.88
1991	15.96	14.97	15.73	13.09	15.60	13.62	0.99
1992	15.54	15.09	15.79	13.32	15.67	13.81	0.45
1993	15.83	15.20	15.84	13.55	15.74	14.00	0.63
1994	15.78	15.32	15.90	13.77	15.81	14.20	0.46
1995	16.06	15.43	15.95	14.00	15.88	14.39	0.63
1996	15.57	15.55	16.01	14.23	15.94	14.58	0.02
1997	16.39	15.67	16.06	14.46	16.01	14.77	0.73
1998	16.79	15.78	16.12	14.69	16.08	14.96	1.01
1999	16.59	15.90	16.17	14.91	16.15	15.15	0.69
2000	16.89	16.01	16.23	15.14	16.22	15.34	0.88
2001	16.66	16.13	16.29	15.37	16.28	15.53	0.53
2002	13.61	16.24	16.34	15.60	16.35	15.72	-2.63
2003	13.98	16.36	16.40	15.82	16.42	15.92	-2.37
2004	16.16	16.47	16.45	16.05	16.49	16.11	-0.31
2005	16.73	16.59	16.51	16.28	16.56	16.30	0.14
2006	16.80	16.70	16.56	16.51	16.62	16.49	0.10
2007	16.63	16.82	16.62	16.73	16.69	16.68	-0.19
2008	16.67	16.93	16.67	16.96	16.76	16.87	-0.27
2009	16.86	17.05	16.73	17.19	16.83	17.06	-0.19
2010	17.14	17.16	16.79	17.42	16.90	17.25	-0.02
2011	18.22	17.28	16.84	17.65	16.97	17.44	0.94
2012	16.37	17.39	16.90	17.87	17.03	17.64	-1.03
2013	16.52	17.51	16.95	18.10	17.10	17.83	-0.99
2014	16.89	17.62	17.01	18.33	17.17	18.02	-0.73
2015	17.61	17.74	17.06	18.56	17.24	18.21	-0.13
2016	18.20	17.86	17.12	18.78	17.31	18.40	0.35



Point values for the chart

Year	Max. Temp of Bilate station	Sen's estimate	99 % conf. min	99 % conf. max	95 % conf. min	95 % conf. max	Residual
1985	30.34	29.87	30.55	29.02	30.39	29.28	0.47
1986	31.03	29.88	30.51	29.08	30.37	29.32	1.14
1987	30.81	29.90	30.48	29.15	30.35	29.37	0.92
1988	30.44	29.91	30.44	29.21	30.32	29.42	0.53
1989	28.27	29.92	30.41	29.27	30.30	29.47	-1.65
1990	29.16	29.93	30.38	29.33	30.27	29.52	-0.78
1991	29.58	29.95	30.34	29.40	30.25	29.57	-0.37
1992	29.28	29.96	30.31	29.46	30.23	29.62	-0.68
1993	29.97	29.97	30.27	29.52	30.20	29.67	0.00
1994	30.20	29.99	30.24	29.58	30.18	29.72	0.22
1995	30.95	30.00	30.20	29.65	30.15	29.77	0.96
1996	29.94	30.01	30.17	29.71	30.13	29.82	-0.07
1997	29.68	30.02	30.14	29.77	30.11	29.87	-0.35
1998	30.09	30.04	30.10	29.83	30.08	29.92	0.05
1999	29.91	30.05	30.07	29.90	30.06	29.97	-0.14
2000	30.44	30.06	30.03	29.96	30.03	30.02	0.38
2001	30.13	30.08	30.00	30.02	30.01	30.07	0.05
2002	26.39	30.09	29.96	30.09	29.99	30.12	-3.70
2003	24.56	30.10	29.93	30.15	29.96	30.17	-5.54
2004	28.62	30.11	29.90	30.21	29.94	30.22	-1.50
2005	30.26	30.13	29.86	30.27	29.92	30.27	0.13
2006	29.89	30.14	29.83	30.34	29.89	30.32	-0.25
2007	29.91	30.15	29.79	30.40	29.87	30.37	-0.24
2008	30.26	30.17	29.76	30.46	29.84	30.42	0.09
2009	31.21	30.18	29.72	30.52	29.82	30.47	1.03
2010	29.69	30.19	29.69	30.59	29.80	30.52	-0.50
2011	29.15	30.20	29.66	30.65	29.77	30.57	-1.05
2012	30.22	30.22	29.62	30.71	29.75	30.62	0.00
2013	29.67	30.23	29.59	30.77	29.72	30.67	-0.56
2014	30.77	30.24	29.55	30.84	29.70	30.72	0.53
2015	31.86	30.26	29.52	30.90	29.68	30.77	1.60
2016	31.05	30.27	29.48	30.96	29.65	30.82	0.78

Appendix 3 Change point and shift detection spell-stat software output value

	Belg/Spring season_MAM			**Kiremit/Summer season_JJAS**		
Year	Rainfall	Change pt probability	shift_Ta	Rainfall	Change pt probability	Shift_Ta
1985	371.5	0.0143	0.072	347.85	0.0296	0.704
1986	297.2	0.0007	0.038	552.23	0.0176	0.009
1987	569.4	0.1387	1.637	343.55	0.0087	0.197
1988	291	0.0342	0.655	588.46	0.0686	0.084
1989	294.6	0.0002	0.217	468.15	0.1387	0.139
1990	323.7	0.0028	0.103	310.72	0.0028	0.03
1991	258.9	0.105	0.01	411.47	0.0016	0.079
1992	281.8	0.2689	0.142	455.95	0.0007	0.048
1993	401.4	0.105	0.018	286.68	0.1569	0.557
1994	365.3	0.0686	0.003	525.38	0.0252	0.201
1995	426.2	0.0002	0.069	382.15	0.0897	0.401
1996	429.5	0.0972	0.336	776.55	0.0113	0.196
1997	377.4	0.1955	0.474	341.38	0.0213	0.014
1998	338.7	0.1856	0.424	444.43	0.0252	0.015
1999	204.2	0.0087	0.012	477.90	0.0002	0.054
2000	317.4	0	0	388.13	0.0176	0.004
2001	343.6	0.0002	0	487.18	0.0044	0.041
2002	312.3	0.0113	0.022	329.18	0.0444	0.022
2003	369.1	0.0002	0.004	457.10	0.0213	0.011
2004	279.7	0.0686	0.106	343.93	0.1131	0.177
2005	482.7	0.0087	0.043	459.40	0.0621	0.14
2006	400.5	0.0823	0.186	440.50	0.0823	0.152
2007	390.1	0.1955	0.393	684.60	0.0087	0.184
2008	198.8	0.0028	0	493.95	0.0972	0.395
2009	228.1	0.0621	0.287	271.75	0.0087	0
2010	549	0.0176	0.168	418.68	0.0252	0.005
2011	358.4	0.0296	0.251	456.33	0.0143	0
2012	223.4	0.0252	0.024	549.93	0.0252	0.231
2013	422.6	0.0087	0.1	557.00	0.2158	1.325
2014	329.3	0.0028	0.059	480.98	0.3585	2.66
2015	200.2	0.105	1.565	309.13	0.0897	1.181
2016	462.2	0	0	319.93	0	0

Appendix 4: Irrigated agriculture water demand assessment at study area by using observed data

	1st three decades, Observed (1985-2016)					Abbaya state&private	Tobaco farm
	P eff. mm/mo	ETo (mm/mo)		ETc (mm/mo)		Cotton/ 2226 ha	Tobaco /1262ha
			kc*/kc**	cotton*	Tobacco**	IRR.AWD (Mm3)	
Jan	6.7	130.51	_/0.35		45.68		0.76
Feb	7.7	127.68	_/0.75		95.76		1.71
Mar	24.1	146.32	0.45/1.1	65.84	160.95	1.43	2.66
Apr	69.6	128.4	0.75/0.9	96.30	121.98	0.91	1.02
May	56.5	123.07	0.75	92.30		1.23	
Jun	42.7	112.5	1.2	135.00		3.16	
Jul	49.4	97.34	1.2	116.81		2.31	
Aug	33.9	104.78	0.85	89.06		1.89	
Sep	31.3	103.5	0.85	87.98		1.94	
Oct	38.8	114.7					
Nov	18.9	122.1					
Dec	4.1	126.79					
Sub-total						**12.87**	**6.14**
Grand Tt						**19.01**	

Appendix 5: Future irrigated agriculture water demand assessment at study area by using downscaled RCP4.5 scenarios

	RCP4.5 Scenario(2017-2048), 2nd three decade					**Abbaya state &private farm**	**Tobacco farm**
	Peff mm/mo	**Eto mm/mo**		**ETc (mm/mo)**		**Cotton/ 2226 ha**	**Tobacco /1262ha**
			kc*/kc**	**cotton***	**Tobacco****		
						IRR.AWD(Mm3)	
Jan	0	127.41	_/0.35		44.59		0.87
Feb	0	125.44	_/0.75		94.08		1.83
Mar	0.9	146.01	0.45/1.1	65.70	160.61	2.22	3.10
Apr	12.9	130.8	0.75/0.9	98.10	124.26	2.92	2.16
May	12.5	123.69	0.75/_	92.77		2.75	
Jun	52.8	109.5	1.2/_	131.40		2.69	
Jul	55.4	92.69	1.2/_	111.23		1.91	
Aug	38.9	98.89	0.85/_	84.06		1.55	
Sep	23.8	97.2	0.85/_	82.62		2.01	
Oct	3.5	108.5					
Nov	8.9	116.7					
Dec	0	123.07					
					Sub-total	**16.05**	**7.96**
					Grand total	**24.01**	
			RCP4.5 Scenario(2049-2080)				
			kc*/kc**	cotton*	Tobacco**	IRR.AWD(Mm3)	
Jan	0	132.68	_/0.35		46.44		0.90
Feb	0	129.92	_/0.75		97.44		1.89
Mar	0	152.21	0.45/1.1	68.49	167.43	2.35	3.25
Apr	32.1	136.5	0.75/0.9	102.38	129.68	2.41	1.89
May	26.2	129.27	0.75/_	96.95		2.42	
Jun	50.5	115.8	1.2/_	138.96		3.03	
Jul	43.9	97.65	1.2/_	117.18		2.51	
Aug	42.9	103.23	0.85/_	87.75		1.54	
Sep	2.9	101.7	0.85/_	86.45		2.86	
Oct	6.2	113.15					
Nov	0	120.6					
Dec	0	127.41					
					Sub-total	**17.11**	**7.94**
					Grand total	**25.05**	

Appendix 6: Future irrigated agriculture water demand assessment at the study area by using downscaled RCP8.5 scenario

RCP8.5 Scenario(2017-2048)						**Abbaya state &privatefarm**	**Tobacco farm**
	Peff (mm/mo)	**ETo (mm/mo)**		**ETc (mm/mo)**		**Cotton/2226 ha**	**Tobacco/1262ha**
			kc*/kc**	**cotton***	**Tobacco****	**IRR.AWD(Mm3)**	
Jan	0	127.41	_/0.35		44.59		0.87
Feb	0	125.44	_/0.75		94.08		1.83
Mar	0	146.01	0.45/1.1	65.70	160.61	2.25	3.12
Apr	7	130.8	0.75/0.9	98.10	124.26	3.12	2.28
May	20.2	123.69	0.75/_	92.77		2.49	
Jun	38.2	109.5	1.2/_	131.40		3.19	
Jul	52.6	92.69	1.2/_	111.23		2.01	
Aug	33.8	98.89	0.85/_	84.06		1.72	
Sep	10.7	97.2	0.85/_	82.62		2.46	
Oct	1.5	108.5					
Nov	0	116.7					
Dec	0	123.07					
					Sub-total	**17.24**	**8.09**
					Grand total	**25.33**	
3rd three decade, RCP8.5 Scenario(2049-2080)							
	Peff	ETo	kc*/kc**	**cotton***	**Tobacco****	**IRR.AWD(Mm3)**	
Jan	0	132.68	_/0.35		46.44		0.90
Feb	0	129.92	_/0.75		97.44		1.89
Mar	0	152.21	0.45/1.1	68.49	167.43	2.35	3.25
Apr	18	136.5	0.75/0.9	102.38	129.68	2.89	2.17
May	14.2	129.27	0.75/_	96.95		2.83	
Jun	34.7	115.8	1.2/_	138.96		3.57	
Jul	12	97.65	1.2/_	117.18		3.60	
Aug	24.2	103.23	0.85/_	87.75		2.18	
Sep	6.6	101.7	0.85/_	86.45		2.73	
Oct	0	113.15					
Nov	0	120.6					
Dec	0	127.41					
					Sub-basin	**20.15**	**8.21**
					Grand total	**28.36**	

Appendix 7: Rain fed agriculture water demand assessment for lower Bilate sub-basin using observed data and historical data of the RCP scenarios

	1st three decade					**Wolayta zone**	
	Observed data(1985-2016)					**Maize/ 23,500 ha**	**Haricot beans/7,890ha**
	Peff (mm/mo)	**ETo (mm/mo)**		**ETc (mm/mo)**			
			kc*/kc**	**Maize***	**Haricot beans****	**Rf _AWD(Mm3)**	
Jan	6.7	130.51					
Feb	7.7	127.68					
Mar	24.1	146.32					
Apr	69.6	128.4					
May	56.5	123.07					
Jun	42.7	112.5	0.4/0.4	45.00	45.00	0.54	0.18
Jul	49.4	97.34	0.8/0.8	77.87	77.87	6.69	2.25
Aug	33.9	104.78	0.8/1.15	83.82	120.50	11.73	6.83
Sep	31.3	103.5	1.15/0.5	119.03	51.75	20.62	1.61
Oct	38.8	114.7	1.15	131.91		21.88	
Nov	18.9	122.1	0.7	85.47		15.64	
Dec	4.1	126.79					
					Sub-total	**77.10**	**10.87**
					Grand total	**87.98**	

Appendix 8: Rain fed agriculture water demand for lower Bilate sub-basin by using data's of the RCP4.5 scenarios

	RCP4.5 Scenario(2017-2048), 2nd three decade					Lower Bilate	
	Peff (mm/mo)	ETo (mm/mo)		ETc (mm/mo)		Maize /23,500 ha	Haricot beans /7,890ha
			kc*/kc**	Maize	Haricot beans	RfAWD(Mm3)	
Jan	0	127.41					
Feb	0	125.44					
Mar	0.9	146.01					
Apr	12.9	130.8					
May	12.5	123.69					
Jun	52.8	109.5	0.4/0.4	43.80	43.80	-2.12	-0.71
Jul	55.4	92.69	0.8/0.8	74.15	74.15	4.41	1.48
Aug	38.9	98.89	0.8/1.15	79.11	113.72	9.45	5.90
Sep	23.8	97.2	1.15/0.5	111.78	48.60	20.68	1.96
Oct	3.5	108.5	1.15	124.78		28.50	
Nov	8.9	116.7	0.7	81.69		17.11	
Dec	0	123.07					
					Sub-total	**78.02**	**8.63**
					Grand-total	**86.65**	

	3rd three decades RCP4.5 Scenario(2049-2080)						
			kc*/kc**	Maize	Haricot beans	RfAWD(Mm3)	
Jan	0	132.68					
Feb	0	129.92					
Mar	0	152.21					
Apr	32.1	136.5					
May	26.2	129.27					
Jun	50.5	115.8	0.4/0.4	46.32	46.32	-0.98	-0.33
Jul	43.9	97.65	0.8/0.8	78.12	78.12	8.04	2.70
Aug	42.9	103.23	0.8/1.15	82.58	118.71	9.33	5.98
Sep	2.9	101.7	1.15/0.5	116.96	50.85	26.80	3.78
Oct	6.2	113.15	1.15	130.12		29.12	
Nov	0	120.6	0.7	84.42		19.84	
Dec	0	127.41					
					Sub-total	**92.15**	**12.14**
					Grand total	**104.28**	

Appendix 9: Rain fed agriculture water demand for lower Bilate sub-basin by using data of the RCP8.5 scenarios

	RCP8.5 Scenario(2017-2048), 2nd three decade					**Lower Bilate**	
	Peff mm/mo	**ETo mm/mo**		**ETc mm/mo**		**Maize/ 23,500 ha**	**Haricot beans /7,890ha**
			kc*/kc**	**Maize**	**Haricot beans**	RfAWD (Mm3)	
Jan	0	127.41					
Feb	0	125.44					
Mar	0	146.01					
Apr	7	130.8					
May	20.2	123.69					
Jun	38.2	109.5	0.4/0.4	43.8	43.80	1.32	0.44
Jul	52.6	92.69	0.8/0.8	74.152	74.15	5.06	1.70
Aug	33.8	98.89	0.8/1.15	79.112	113.72	10.65	6.31
Sep	10.7	97.2	1.15/0.5	111.78	48.60	23.75	2.99
Oct	1.5	108.5	1.15	124.775		28.97	
Nov	0	116.7	0.7	81.69		19.20	
Dec	0	123.07					
					Sub-total	**88.95**	**11.44**
					Grand-total	**100.39**	
	RCP8.5 Scenario(2049-2080)						
			kc*/kc**	Maize	Haricot beans	**RfAWD(Mm3)**	
Jan	0	132.68					
Feb	0	129.92					
Mar	0	152.21					
Apr	18	136.5					
May	14.2	129.27					
Jun	34.7	115.8	0.4/0.4	46.32	46.32	2.73	0.92
Jul	12	97.65	0.8/0.8	78.12	78.12	15.54	5.22
Aug	24.2	103.23	0.8/1.15	82.58	118.71	13.72	7.46
Sep	6.6	101.7	1.15/0.5	116.96	50.85	25.93	3.49
Oct	0	113.15	1.15	130.12		30.58	
Nov	0	120.6	0.7	84.42		19.84	
Dec	0	127.41					
					Sub-total	108.34	17.08
					Grand-total	125.42	