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RAINFALL VARIABILITY OVER BLUE NILE BASIN

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School of Graduate Studies

This is to certify that the thesis prepared by Berhan Teferi, entitled; *Rainfall Variability over Upper Blue Nile River Basin* and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Physics (Atmospheric Physics) complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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Dedication

To my parents, all the good things in me, it is from you. I wish you long lives to see more fruits from your children.

ABSTRACT

In most of African countries whose economy is heavily depending on rain fed agriculture, so Ethiopia's economy is mainly dependent on rain-fed agriculture, the failure or the goodness of seasonal rainfall is very important to the country's socio economic functioning- in particular, food production and for water resource. As a result, the reliable seasonal rainfall prediction would have several advantages for agricultural activities, water management, health and increasing the frequency of extreme prolonged events such as drought and floods at local and transboundary. In this paper, an attempt is made to study the predictability and variability of rainfall over Blue Nile basin during two rainy seasons using statistical methods Mann Kendall analysis technique with standard rainfall statistical descriptors. Where the technic is a statistical test widely used for analyzing trends in climatologic and hydrologic time-series. In this study we examines the spatial and temporal rainfall characteristics of upper Blue Nile river basin of four meteorological stations with 33 years of daily rainfall data and monthly have been used. In this case, the climatology over the stations vary 1059 to 1427.5mm. With respect to the main wet seasons, the June–September precipitation has strong connection with neighboring ocean basins. The spring rainfall variability is strongly linked to sea level pressure over Pacific and most parts of Indian Ocean. Belg ("small rainfall" in March – May) rain makes a considerable contribution to the annual total to Kombolcha but little contribution around Debre Markos region. Annual rainfall has shown negative and positive anomalies for much of the 1980's and 1990's, respectively. Heavy and deficiency rainfall is frequent occurred at stations due to local factors, which are relatively close to the lake and any linkages to large-scale ocean–atmosphere effect of climate change.

Key words: Africa, Ethiopia, upper Blue Nile River basin, seasons, spatial and temporal variability, rainfall trend

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LIST OF ACRONYMS

AD	After Death
Aw	Tropical Wet and Dry or Savanna Climate
BC	Before Christ
CEEPA	Centre for Environmental Economics and Policy in Africa
CH_4	Methane
CO_2	Carbon Dioxide
Cwa	Monsoon-Influenced Humid Subtropical Climate
Cwb	Subtropical Highland Climate Or Temperate oceanic Climate with Dry Winters Or Dry-winter highland climate
DOY	Day of Year
EEA	European Economic Area
EN	El Niño
ENSO	El Niño–Southern Oscillation
EPRI	Electric Power Research Institute
FAO	Food and Agriculture Organization
FDRE	Federal Democratic Republic of Ethiopia
FEWS	Famine Early Warning Systems
FMAM	February, March, April and May
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
IFPRI	International Food Policy Research Institute

LIST OF ACRONOMYS (Continued)

IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
JA	July and August
JJAS	June, July, August and September
MAM	March, April and May
MoFED	Ministry of Finance and Economic Development
NMA	National Meteorology Agency of Ethiopia
N_2O	Nitrous Oxide
NMSA	National Meteorological Services Agency
ppb	Part Per Billion
ppm	Parts Per Million
SLP	Sea level Pressure
SST	Sea Surface Temperatures
SWIO	Southwestern Indian Ocean
UN	United Nations
UNDP	United Nations Development Program me
UNESCO	United Nations Education, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USAID	United States Agency for International Development

1. INTRODUCTION

1.1. Background

Climate change amplify unfavorable climatic and environmental situations, particularly for developing countries is an undeniable, pervasive and insidious world crisis with prominent increases in the intensity and frequency of many extreme events such as heat waves, tropical cyclones, prolonged dry spells, intense rainfall, tornadoes, thunderstorms, and severe dust storms in some regions. The occurrence of extreme events in poor and developing countries commonly cause a high number of deaths, as well as an exponential increase in costs due to the damage. Related health problems, such as mortality and morbidity due to floods and heat waves, vector-borne diseases, water-borne diseases, meningitis, and air pollution-related respiratory diseases are increasing in Ethiopia. Sensitive systems such as agriculture, health, and water have been affected, and the effects of climate change will continue to magnify without the right adaptation and mitigation measures. The poor developing countries are generally recognized to be the most vulnerable and likely to be hit the hardest by climate change .The negative consequences of climate change in Africa are already happening as frequent floods, droughts and shift in marginal agricultural systems (Collier et al., 2008). Agriculture and food security, water resources, biodiversity and ecosystems, and human health are identified as the key vulnerable sectors for Africa. Global and regional climate have evolved during the last century due to natural and anthropogenic influences with associated changes in rainfall amounts and rainfall patterns (IPCC 2007).

Trends in precipitation and in the maximum and minimum temperatures are useful indicators of climate variability and change (Braganza *et al.*, 2004) and Climate variability has been attributed to changes in rainfall patterns (Adger et al., 2003; Obot et al., 2010). Studies have shown that climate variability is as a result of changing rainfall pattern (Goswami et al., 2006; Adger et al., 2003). Gregory, 1983 reported that changing spatial pattern of annual and rainy season monthly rainfall indicated a long run of dry years for sub-Saharan West Africa during the 1940s. Climate is classified based on the average annual rainfall, which assists in differentiating climatic regimes. Rainfall variability in Africa has been studied by several researchers since the inception of recent drought period in the 70's. East African precipitation is strongly dependent on the moist southwesterly monsoon flow, which has the unique characteristics of high seasonal, monthly and daily variability in its moisture content and (vertical) depth.

Rainfall is one of the most important atmospheric phenomena. It has a strong impact on the global-scale atmospheric circulation as well as on local weather. Of the heat energy that the global atmosphere receives (and the balances is net radiative energy loss), about 70 to 85 percent is latent heat released by the formation of precipitation (Simpson et al., 1996; Barry and chorely, 1987; Salby, 1996). The total rainfall received in a given period at a location is highly variable from one year to another. The variability depends on the type of climate and the length of the considered period. In general it can be stated that the drier the climate, the higher the variability of rainfall in time. The same hold for the length of the period: the shorter the period the higher the annual variability of rainfall in that period. Study of spatial and temporal characteristics of rainfall has a significant impact on human activities. The agricultural production and the urban water supply depend not only on the total amount of the annual rainfall collected in dams, but also on the spatial and temporal distribution of rainfall (Michaelides, Tymvios, and Michaelidou 2009). Rainfall is very important weather and climate parameter that affects social and economic activities in Ethiopia. It has the largest space and time variability therefore making it the most important weather element (Ogallo, 1980). Rainfall variability is the degree to which rainfall amounts vary across an area or through time, it is an important characteristic of the climate of an area and has two components i.e. spatial and temporal variability (Banchiamlak and Mekonnen, 2010). Moreover rainfall variability is associated with too much rainfall or decrease in rainfall amount i.e. it may be associated with drought or floods which are, often linked with food insecurity, energy and water shortages, death of people and animal, destruction of property and many other socioeconomic miseries (Omeny and Okoola, 2008). The rains failure extends from a delayed onset of the rains, an early withdrawal, or short but intense rainfall events separated by long dry spells (Camberlin and Okoola, 2003).

Ethiopia is among the countries that regularly suffer from various weather and climate related problems, therefore the study of rainfall variability have received much attention due to increases economic losses which sometimes associated to death of people. Ethiopian's mainland climate is characterized by two rainfall regimes; these are the Seasonal rains in Ethiopia are largely provided by the Inter-tropical Convergence Zone (ITCZ), which migrates up and down equatorial Africa, bringing rain to the northern highlands in July and August (JA), and to the central highlands between June and September (JJAS). Known in Ethiopia as the summer (Kiremt), these are the long rains (long rainfall regime), and areas affected receive between 200 and 1200 mm per year. Shorter rain (short rainfall regime), less consistent rains – the spring (Belg) - occur in parts of the south between March and May (MAM), and in parts of the northern and central highlands between February and May (FMAM), and provide an annual rainfall of between 100 and 750 mm. As the ITCZ moves south, another set of short rains in the south - the Bega – sweep briefly across much of central and south-west Ethiopia, bringing to the area between 100 and 300mm annually. Rainfall is very pertinent for the economic growth and development of Ethiopia at large and Amhara State in particular as the greater percentage of the people actively participate in rain fed agricultural practices (crop production, animal husbandry and plantation). As a state whose economy largely depends on efficient and productive rain-fed agriculture, rainfall patterns and trends are often quoted as one of the major causes of several socio-economic problems like food insecurity in the state. The impact of climate change is becoming more pronounced worldwide with consequences of climatic hazard such as severe storms, floods, heat waves and droughts. As a result of the large inter-annual rainfall variability which often results in climatic and environmental hazards, there is dire need to study rainfall characteristics in the study area as a result of recent socio-economic developments such as urbanization, industrialization and over-population.

C. Onyutha and P. Willems. (2014) studied Spatial and temporal variability of rainfall in the Nile Basin, to find the driving forces for the temporal variability in rainfall over the Nile Basin, correlation analyses were carried out using global monthly sea level pressure and sea surface temperature. However, Block et al. (2006) studied precipitation in the Blue Nile basin flows are heavily dependent upon the Kiremt season. ; Alemseged et al (2008) studied variation of rainfall at the source of the Blue Nile is affected by terrain elevation and distance to the center of the lake.

Studies have shown that although shortage of rainfall is stress but most significant problem is often inter and intra seasonal rainfall variability. In fact, the performance of a rainy season, for most social economic activities does not only depend on overall total amount, but needs an adequate distribution of the rains throughout the daily year. Therefore, Rainfall distribution influences the population densities over most parts of Ethiopia. Hence, there is need of study rainfall variability so as to better inform agricultural decision maker, energy sectors and farmers among others. Likewise this knowledge is of great importance when elaborating seasonal rainfall predictions, combating desertification, and reduction of flood impact. This work attempts to study rainfall variability over Blue Nile basin.

1.1. Statement of problem

Rainfall is also an essential requirement in many aspects of agriculture, forestry, industry, education and other activities. Rainfall is rarely uniform in intensity or duration across a wide area, so rainfall and local conditions is particular important to farmers and those concerned with irrigation, scientists researching in to crop performance and soil erosion and to water and river authorities in respect of reservoir supply and ground water feeding in to rivers.

Rainfall variability over Blue Nile basin are not well studied in recently. Rainfall variability in amount and their distribution has significant short and long-term effects on natural resources system, such as lake and Rivers particularly for those who live around the shore of the region’s major lakes, wetland and river flood plains. In addition, rainfall variability is the major cause of yield variation of most major crops in many parts of Blue Nile basin. Although other factors such as soil type, temperature, lack of agricultural inputs and supervision practice may also play a role in reduction of crop yield. Further more rainfall fluctuation has continuing impacts on fisheries and livestock keeping. Therefore, the study of rainfall variability in Blue Nile basin is of utmost importance. Currently, there are some research out puts in to the Nile Basin of the country. C. Onyutha and P. Willems. (2014) studied Spatial and temporal variability of rainfall in the Nile Basin, to find the driving forces for the temporal variability in rainfall over the Nile Basin, correlation analyses were carried out using global monthly sea level pressure and sea surface temperature. However, Block et al. (2006) studied precipitation in the Blue Nile basin flows are heavily dependent upon the Kiremt season. ; Alemseged et al (2008) studied variation of rainfall at the source of the Blue Nile is affected by terrain elevation and distance to the center of the lake. They were also able to identify factors influencing rainfall variability and rainfall to climate change and climate variability. Studies carried out so far are limited to some part of the country, so there is a need to study other part of the country in order to fill the spatial gap of information. Therefore, there is no appropriate research conducted on rainfall variability over Blue Nile basin in the study area. Hence, this study attempted to analyze the spatial and temporal variations of rainfall on climate change/variability in the some Amhara city (Kombolcha, Gondar, Bahir Dar and Debre Markos) in the part of Blue Nile basin.

1.3. Objectives

1.3.1. General objective

To investigate the spatial and temporal trend and variability of rainfall in the Blue Nile Basin for the year 1982 to 2014.

1.3.2. Specific objectives

- To understand rainfall trends over Blue Nile basin for the year 1982 to 2014.
- To determine seasonal and annual variability of rainfall over Blue Nile Basin.
- To determine the spatial and Temporal variability of rainfall over Blue Nile Basin for the year 1982 to 2014.

1.4. Significance of the study

Research is a tool to acquire knowledge point out problems and inform decision makers. So, this study is important to many aspects of agriculture, forestry, industry, education and other activities to know and document rainfall variability over Blue Nile basin and analyze determinant factors that influence rainfall to climate change and variability. Knowing the above will help for intervention by government and/ institution to minimize the influence of the barriers on climate change /variability and for future plan and policies on climate change /variability inputs, it guides policy makers to design climate change /variability policies that promote effective strategies for rainfall and to develop rainfall awareness options. In addition to the above significance of the study, research is an ongoing process and this study initiates other researchers to make further study about the issue.

1.5. Scope and limitation of the study

The study was conducted on urban cities of some Amhara regions and it focused only rainfall variability over Blue Nile river basin. The data taken at Bahir Dar and Kombolcha Metrological Station in the period of 1982 to 2014 daily rainfall and monthly recorded data. The study could have interest to include more cities. However, due to financial and time constraints the study relied only on the four selected cities. The other limitation of the study is that, meteorological data some are missed in the analysis of rainfall and have limitation as they are highly aggregated. Better understanding would have been easier at daily level. More over the meteorological station at specific location may not represent the microclimate differences in the study area.

1.7. Organization of the thesis

The study is organized in five chapters. The first part is introduction part and it consist background, study. The second part reviews different important literatures related with rainfall, climate change and its impact. The third part presents description of the study area and approaches and methods employed for data collection and analysis. Finding of the study is presented in fourth part. And Finally based on the discussion result conclusion and recommendations are presented in the fifth.

2. REVIEW OF RELATED LITERATURE

2.1. Evidence of climate change

2.1.1. What history says about climate change?

The Earth's climate has not been stable in either historical or geological time scales. The historical record shows abundant examples of climate change. For example, during the Roman Warm Period (250BC-400AD), climate was favorable to agriculture in northwest Europe and the Mediterranean, with vineyards in what is now Britain and olive production in parts of Turkey, where winters are now too severe for those crops. Later, in the Medieval Warm Period (950-1250 AD), Norse settlers found favorable settlement conditions for farming in Greenland, while extended droughts undermined Pueblo agriculture in what is now the southwestern USA. This warm period was followed by the Little Ice Age (1250-1850), When the Thames River in London regularly froze, glaciers engulfed Swiss villages, and Norse settlers abandoned Greenland. Cool, rainy summers in northwest Europe led to repeated famine, especially the great famine of 1315 to 1317. Thus, history shows that climate changes can significantly affect agriculture and food security. Longer geological time spans show major changes in the Earth's climate. Ice ages have been a recurring feature in geological time. Some 2.5 million years ago, the glaciation of the Quaternary Period began, with ice sheets of up to 3,000 meters thick covering much of what is now North America and northern Eurasia. This glaciation reached a peak about 22,000 years ago. The Earth is now in an interglacial period that began some 10,000 to 15,000 years ago.

2.1.2. Is climate changing today?

There is strong evidence that climate change, in the form of global warming, is occurring today. Over the last century, temperatures have risen nearly everywhere over land as well as on the ocean surface and in ocean air. These trends have accelerated since the 1970s. Average global land temperatures have risen 0.74° C over the last century. The Earth is close to being warmer than it has been for more than 1,000 years and temperatures are not far from the upper bound of the temperature range of the last 400,000 years. Most glaciers have been in retreat since the 1960s, while Arctic sea ice coverage is also falling, reaching a record low in the summer of 2012. Ice sheets in Antarctica and Greenland have also been declining. Sea level is rising both because of melting ice and because warmer water expands. Total water vapor in the atmosphere has increased due to warmer air (IPCC 2007a). Changes in the behavior of plants and animals are also consistent with a warming climate. According to the Audubon Society, more than 60 percent of migrating bird species in North America have extended their winter range northward by an average of 35 miles in the last 40 years, indicating generally warmer conditions. Season creep earlier springs and later autumns has also led to the earlier flowering of many wild plants as spring warming comes earlier in high latitudes. Coral reefs are dying off as oceans become warmer (Wilkinson 2008). Rainfall trends over the last century present a complex picture. Precipitation has generally increased in northern latitudes, but there has been a downward trend in rainfall since the 1970s in southern Africa and parts of southern Asia. There is a significant downward trend in rainfall in the Sahel the zone between the Sahara Desert in the north and the Sudanian Savanna in the south since 1920. Moreover, in the tropics and subtopics, droughts have become longer, more intense and affected wider areas due to the combined effects of decreased rainfall and a higher demand for water by crops when temperatures are higher (IPCC 2007a).

2.2. Concept of climate change

Climate change is defined as the change in climate attributed directly or indirectly to human activity, which, in addition to natural climate variability, is observed over comparable time periods. The definition adopted by the United Nations Framework Convention on Climate Change (UNFCCC) focuses only on the human activity that alters the composition of the global atmosphere and excludes other human activity effects such as changes in the land surface. Sometimes the term 'climate change' is used to include all climate variability, which can lead to considerable confusion. Climate has variability on all time and space scales and will always be changing.

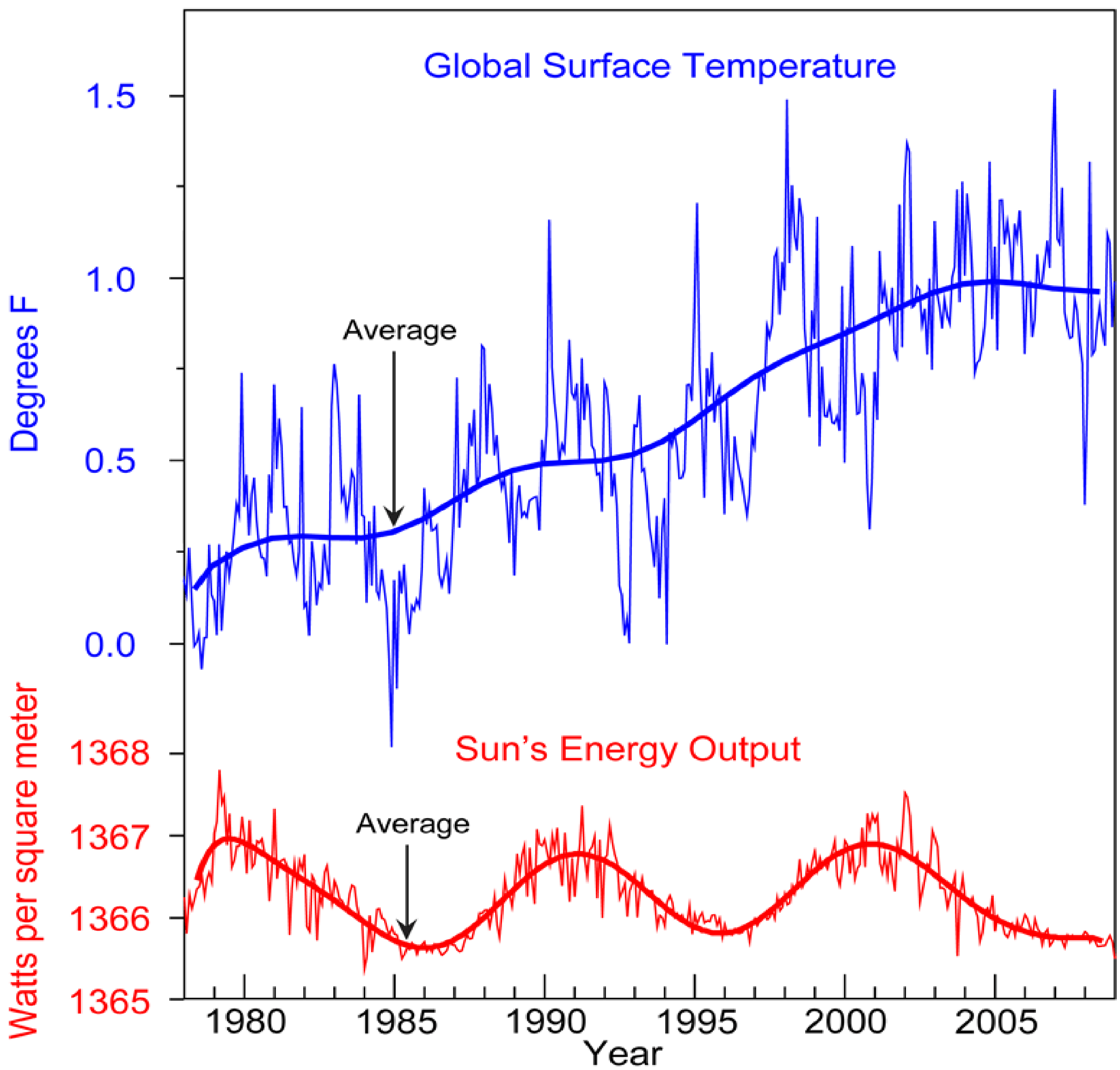
According to IPCC, Climate change is any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007a). This definition differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over time. Concentration of greenhouse gases (GHGs) produced by human activity has increased significantly (UNFCCC, 1992).

2.3. Causes of climate change

2.3.1. What causes climate change?

The causes of climate change are complicated and occur over different time scales. For example, eccentricities in the Earth's orbit around the sun and shifts in its tilt toward the sun affect the amount of heat it receives. Known as Milankovich Cycles, and confirmed by studies of ice cores and sediments, these movements have had impacts on climate over tens of thousands of years. In the 1970s, forecasts based on these cycles predicted that the Earth was on the verge of entering a cooling period, so these cycles are not responsible for ongoing global warming (National Aeronautics and Space Administration).The amount of heat that the sun emits also affects the

Earth's climate. There are regular cycles in the amount of heat radiated by the sun that reaches Earth. Such sunspot variations are correlated with changes in global temperature and have continued in their 11-year up-and-down cycles while the Earth's temperature has risen steadily instead of following the sunspot cycles (Figure 1). While scientific understanding of changes in the sun's emission of energy is imperfect, the current scientific consensus is that an increase in heat radiated by the sun is a much less important factor to global warming than changes in the Earth's atmosphere (IPCC 2007a).



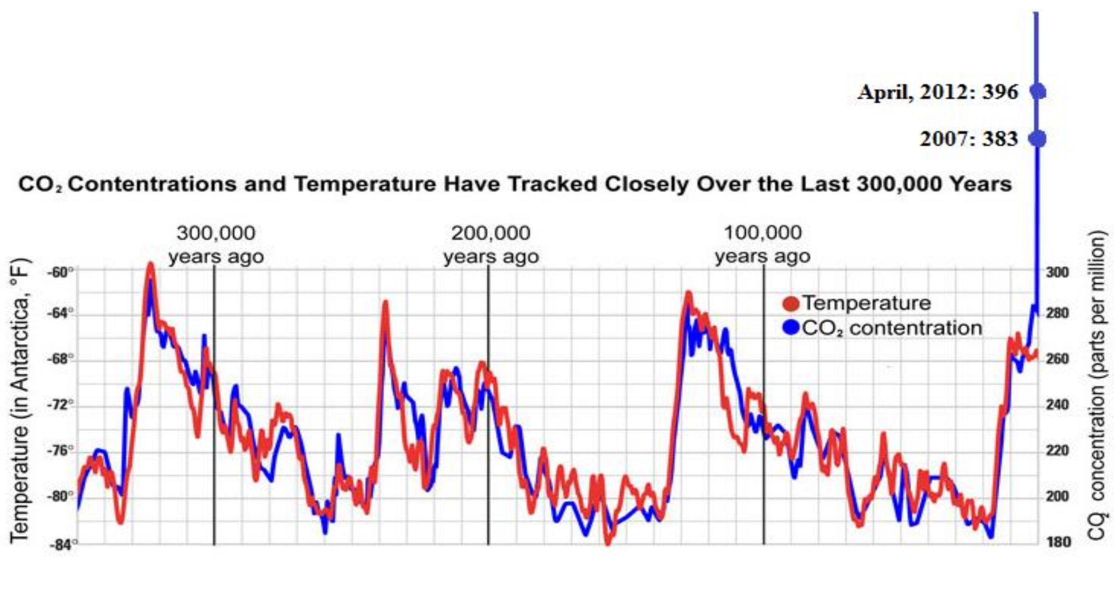
Source: Global Climate Change Indicators. 2011. National Oceanic and Atmospheric Administration, National Climatic Data Center: Washington, DC, USA. http://www.ncdc.noaa.gov/indicators/

Figure 1: Energy from the sun has not increased

The composition of the atmosphere is strongly related to the Earth's climate. Over the last 400,000 years, the concentration of carbon dioxide (CO_2) in the atmosphere and temperature (Figure 2) have been closely correlated. Four peaks in temperature over this period have coincided with four peaks of CO_2 in the atmosphere. Similarly, when there is less CO_2 in the atmosphere, temperatures have been cooler. Thus, CO_2 is said to have a "greenhouse" effect on the Earth's temperature. Since most climate scientists believe that recent rapid changes in the atmosphere are responsible for recently observed global warming, the guide will now consider the effects of greenhouse gases (GHG) on climate.

Greenhouse gases and climate change

Climate scientists see the accumulation of CO_2 and other greenhouse gases in the atmosphere as the fundamental cause of current global warming. Greenhouse gases capture and hold solar heat that warms the air. The more greenhouse gases there are in the atmosphere, the more heat is trapped and the higher the Earth's temperature becomes.



As ice core records from Vostok, Antarctica show, the temperature near the South Pole has varied by more than 20º F during the past 350,000 years in a regular pattern that constitutes the ice age/interglacial cycles. Changes in CO_2 concentrations (blue) track closely with changes in temperature (red) during these cycles, but CO_2 levels are now higher than at any time during the past 650,000 years. Source: Southwest Climate Change Network. 2009. Tucson, Arizona, USA. http://www.southwestclimatechange.org/figures/icecore_records.

Source: Image modified and courtesy of the Marian Koshland Science Museum of the National Academy of Sciences. http://www.koshland-science-museum.org/

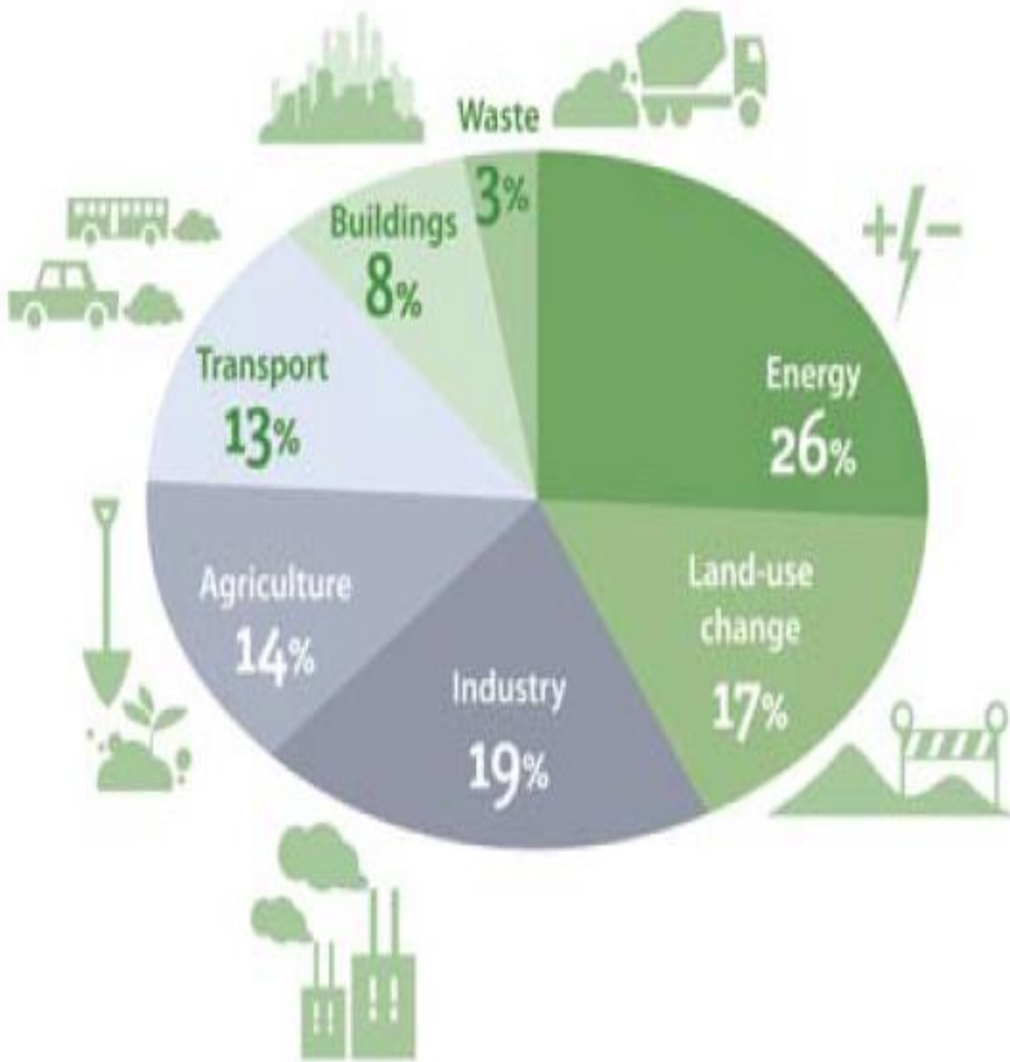
Figure 2: CO2 Concentrations and temperature have tracked closely

In 2010, the concentration of CO_2 in the atmosphere was 389 parts per million (ppm), higher than any indicated in ice cores which contain samples of the Earth's atmosphere over the last 650,000 years. During that period, CO_2 levels varied from a low of 180 ppm to a high of 270 ppm. For the last 20 million years, CO2 concentrations have been less than 300 ppm but are now climbing rapidly, from 313 ppm in 1960 to 389 ppm in 2010. Furthermore, the rate of accumulation of CO_2 in the atmosphere is accelerating (IPCC 2007a). Although volcanic activity was the original source of much of the CO_2 in the atmosphere, today the major cause of the increase in CO_2 emissions is human activity (anthropogenic). Currently, volcanoes contribute less than 1 percent of CO_2 emissions. The major effect of volcanoes today is to cool the Earth by releasing massive quantities of ash and gaseous particles (aerosols) that reflect the suns heat back into space, causing global temperatures to fall. For example, in 1815, Mount Tambora in Indonesia erupted causing "the year without a summer" and, in 1991, the eruption of Mount Pinatubo in the Philippines led to a global temperature fall of about 0.4°C (Self et al 1995). Global emissions of CO_2 reached 34 billion tons in 2011 and this amount continues to rise. Since 2000, an estimated total of 420 billion tons of CO_2 was cumulatively emitted due to human activities (including deforestation). Scientific literature suggests that limiting the average global temperature rise to 2°C above pre-industrial levels – the target internationally adopted in UN climate negotiations – is possible if cumulative emissions in the 2000–2050 period do not exceed 1,000 to 1,500 billion tons of CO_2. If the current global increase in CO_2 emissions continues, cumulative emissions will surpass this total within the next two decades (Jos et al 2012). Anthropogenic greenhouse gas emissions also include methane (CH_4) and nitrous oxide (N_2O) and others such as hydrofluorocarbons that are released by various industrial processes. These are recognized as less important than CO_2 to the greenhouse effect because they are generated in much lower quantities (IPCC 2007a).

The role of agriculture in causing climate change

The major sources of anthropogenic greenhouse gases are shown in Figure 3 .Energy (26%) and industry (19%) are the most important. Land-use change (17%), consisting mainly of the harvesting of forestry products and the clearance of natural vegetation for agriculture, is also an important source. Direct agriculture activities (14%) are about as important as transport (13%).

Developing countries account for 74 percent of agriculturally related greenhouse gases. (IPCC 2007b).

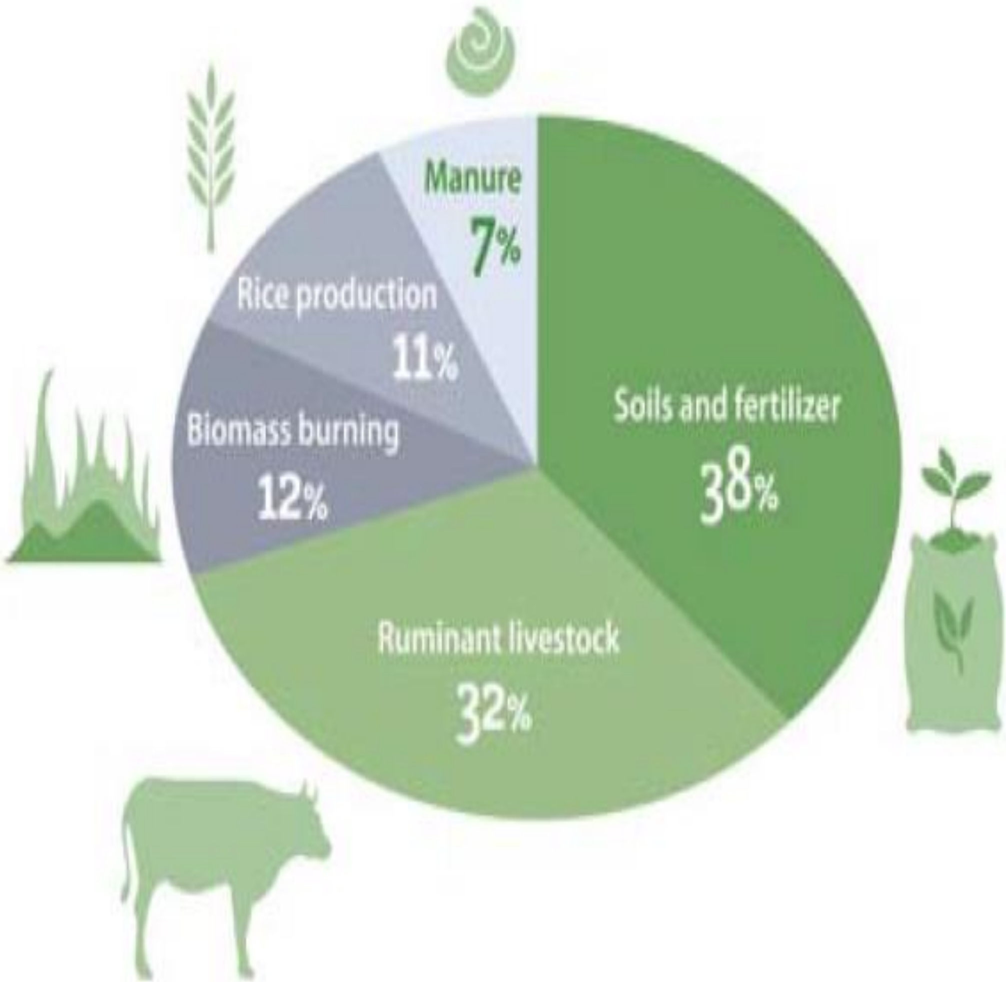


Source: The World Bank 2010,

Figure 3 : Greenhouse gas emissions by sector

There are several ways that agriculture directly contributes to greenhouse gases (Figure 4). The most important is the release of nitrous oxide (N_2O) by microbial transformation of nitrogen in the soil, emitting N_2O as a by-product. While this is a natural part of the nitrogen cycle, additional N_2O is released beyond natural levels when fertilizer or compost is added to the soil. Nitrous oxide is a potent greenhouse gas and accounts for 38 percent of greenhouse gas emissions directly related to agriculture. From 1990 to 2005, N_2O emissions increased 17 percent, and with continued rising fertilizer use it is expected to rise another 35 to 60 percent by 2030 (Smith et al 2007). The second most important source of greenhouse gas coming directly from agriculture is methane (CH_4). Methane is produced by the digestive process in ruminant livestock (enteric fermentation). It contributes 32 percent of agriculture's direct emission of greenhouse gases and has also grown 17 percent in the 1990-2005 period. Livestock also generate N_2O, which is released from manure, causing 7 percent of agriculture's emission of greenhouse gases. Combining methane and nitrous oxide, livestock produce a total of 39 percent of agricultural greenhouse gases. As the demand for meat grows, and therefore the number of livestock increases, it is anticipated that methane and nitrous oxide emissions from livestock will rise 60 percent by 2030 (IPCC 2007b).

The burning of crop residue emits CO_2 into the atmosphere, and produces 12 percent of agriculture's direct emissions of greenhouse gases. Most of the world's biomass burning occurs in Sub-Saharan Africa and Latin America, which together account for 74 percent of the total. There is also movement of carbon between agricultural soils and the atmosphere, but the current net of this exchange is generally considered to have only a minimal effect on the global carbon cycle. Rice production in flooded conditions produces methane when organic matter is decomposed in anaerobic conditions, accounting for 11 percent of agriculture's direct greenhouse gas emissions. Most of rice's CH_4 emissions come from South and East Asia, which together contribute 82 percent of global emissions from this source. These emissions can be expected to grow in proportion to the expansion of the area under irrigated rice that is expected to be in the range of 4 to 16 percent by 2030 (Smith et al 2007).



Source: Smith et al 2007, p. 503.

Figure 4: Sources of agricultural greenhouse gas emissions

These “direct” emissions of greenhouse gases from agriculture do not include CO_2 emissions from the conversion of natural vegetation, mostly forests, to agriculture. When trees are burned to clear land, CO_2 is released into the atmosphere. Land-use changes, such as clearing forests for pastures or agriculture, account for 17 percent of global greenhouse gas emissions. As much as80 percent of these CO_2 emissions are estimated to come from conversion of land to agriculture, making this “indirect” source of agricultural greenhouse gases about as important as the direct effects discussed above. South America and Asia are each responsible for about 40 percent of land conversion, with Africa accounting for most of the rest (Smith et al 2007). In addition, agriculture makes several other indirect contributions to greenhouse gas emissions. For example, CO_2 is emitted in the manufacture of fertilizer, pesticides, and machinery, while fuel is burned in transport of farm products, farm inputs and in the use of farm machinery, also emitting CO_2. Taking into account direct activities of agriculture and the clearing of natural vegetation for agricultural land use, all world agriculture in total accounts for about one-third of world greenhouse gas emissions.

2.4. Global climate change trend

Climate is changing more rapidly than ever before. The evidence comes from direct measurements of rising surface air temperatures, ocean temperatures and from phenomena such as increase in sea levels, retreating glaciers, and changes to physical and biological systems. The existence of greenhouse gases in the atmosphere is vital to life on Earth in their absence; average temperature would be about 30^0c lower than they are today (IPCC, 2001a). The report of IPCC (2001a) shows that, human activities are causing atmospheric concentration of greenhouse gases including carbon dioxide, methane, troposphere ozone, and nitrous oxide to rise well above pre industrial level. The composition of GHGs is 9 -26% for CO_2, 4-9% for NH_4, 3-7% for Ozone and 36-70% for water vapor. Carbon dioxide is the most important anthropogenic greenhouse gas and that the global atmospheric concentration of carbon dioxide has increased from a pre-industrial level of about 280 parts per million (ppm) to 379 ppm in 2005. This figure is rising by 1.502ppm annually (Ibid). According to the IPCC (2001a) report, the atmospheric concentration of CO_2 and ozone has increased by 35% each from the per-industrial level. The global average temperature has increased by about 0.6 ^{0}c and the concentration of methane has increased by 1060ppb (151%) per year. The atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650 000 years (180 to 300ppm). It is predicted that the global mean annual surface temperature will increase by 1-3.5 ^{0}c by 2100 and the global sea level will rise by 15-95 cm, and change in the spatial and temporal patterns of precipitation would occur (IPCC, 1996).

2.5. Climate change observations in Ethiopia

Ethiopia is a land locked country in eastern Africa covering an area of 1.1 million km^2. The population is estimated to be 80 million, with an annual growth rate of 3.2 percent. Agriculture plays the most important role in Ethiopia’s Economy. The sector directly supports about 85% of the total population in terms of employment and livelihood, contributes about 50% of the country’s gross domestic product (GDP), generates about 88% of the export earnings, and supplies around 73% of the raw material requirement of agro based domestic industries (CEEPA,2006). In addition, it plays a major role in overarching policy response to Ethiopia's food security and agricultural productivity challenges.

According to UNDP Climate Change Profile for Ethiopia, the mean annual temperature in Ethiopia has increased by 1.3^0c between 1960 and 2006, at an average rate of 0.28^0c per decade. The temperature increase has been most rapid from July to September (0.32^0c per decade). It is reported that the average number of hot days per year has increased by 73 (an additional 20% of days) and the number of hot nights has increased by 137 (an additional 37.5% of nights) between 1960 and 2006. The rate of increase is seen most strongly in June, July and August. Over the same period, the average number of cold days and nights decreased by 21 (5.8% of days) and 41 (11.2% of nights), respectively. These reductions have mainly occurred in the months of September to November (McSweeney et al., 2008).

It is very difficult to detect long-term rainfall trends in Ethiopia, due to the high inter annual variability. Between 1960 and 2006, no statistically significant trend in mean rainfall was observed in any season. The decrease in rainfall observed in July to September in the 1980"s recovered in the 1990s and 2000s. In addition, there are insufficient daily rainfall records to identify trends in daily rainfall variability and change in rainfall intensity (McSweeney et al., 2008).

According to National Meteorology Agency of Ethiopia (NMA, 2007), Ethiopia experienced 10 wet years and 11 dry years over the last 55 years, demonstrating the strong inter annual variability. The wet years included 1958, 1961, 1964, 1967, 1968, 1977, 1993, 1996, 1998 and 2006. Dry years were 1952, 1959, 1965, 1972, 1973, 1978, 1984, 1991, 1994, 1999, and 2000.

2.6. Impact of Climate Change and variability in Ethiopia

Climate varies over seasons and years instead of day-to-day like weather. Some summers are colder than others. Some years have more overall precipitation. Even though people are perceptive of climate variability, it is not as noticeable as weather variability because it happens over seasons and years. Evidence includes statements like "the last few winters have seemed so short," or "there seem to be more heavy downpours in recent years." Scientists think of climate variability as the way climate fluctuates yearly above or below a long-term average value. You can think of it as a story with two parts: average and range. These parts complement each other; understanding the range gives context to the average and vice versa. Common drivers of climate variability include El Niño and La Niña events, which are shifts of warm, tropical Pacific Ocean currents that can dramatically affect Michigan's winters. El Niñas give us milder, less snowy winters while La Niñas give us colder, snowier winters. Other drivers of climate variability include volcanic eruptions and sunspots. Sometimes climate varies in ways that are random or not fully explainable.

If climate variability is year-to-year variation, what is climate change? Climate change is a long-term continuous change (increase or decrease) to average weather conditions (e.g. average temperature) OR the range of weather (e.g. more frequent and severe extreme storms). Both can also happen simultaneously. Long-term means at least many decades. Climate change is slow and gradual, and unlike year-to-year variability, is very difficult to perceive without scientific records.

How do scientists detect climate change? They look for long-term continuous changes (trends) in climatological averages and normals and the variety around these averages. Climate in the Great Lakes region is generally highly variable in the short term, which makes it difficult to tease apart natural variability from long-term change. However, looking at data since the late 1800s reveals some significant shifts in temperature, total precipitation, and extreme events in recent decades in the Great Lakes region. Scientists use this evidence to conclude that climate is indeed changing.

Climate change occurs because of changes to Earth's environment, like changes in its orbit around the sun or human modification of the atmosphere. There is nothing inherently wrong with climate change. It has happened in the past and will happen again. The current concern stems from the rate of change – how quickly changes are happening. Scientists have found that the current rate of temperature increase is higher than any previously seen in the last 800,000 years. Evidence strongly indicates that human-driven changes in the atmosphere are contributing to the unprecedented rate of temperature increase.

Currently climate change and variability is already impose significant challenge to Ethiopia by affecting food security, water and energy supply, health, poverty reduction and sustainable development efforts (Abebe, 2007). Furthermore, extreme weather events, such as droughts, floods, or landslides, may cause death to domestic animals. Livestock suffering and death often means that farmer's wealth is decreased and they lose much of their resources (Pettengell, 2010).

The adverse impact of climate change are not only these particularly climate change/variability also has significant impact on rain fed agriculture (IPCC, 2007). According to IFPRI (2009), agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. Changes in precipitation patterns increase the likelihood of short run crop failures and long run production declines. The overall impacts of climate change on agriculture are expected to be negative. Agriculture plays a dominant role in the economy of Ethiopia, contributing about half of the GDP, provides employment opportunity for majority of working force and generates considerable foreign exchange earnings (MoFED, 2006). Despite its high contribution to the overall economy, this sector is challenged by many factors, of which climate related disasters like drought and flood (often causing famine), are the major ones (Temesgen, 2007). As a result of this, the country becomes highly vulnerable to climate change and variability. It has been indicated that climate change and variability could have significant impact in Ethiopia for various reasons; its economy mainly depends on small-scale rain fed agriculture, which is very sensitive to climate variation. Large part of the country is arid and semiarid and is highly prone to desertification and drought. It has also a fragile highland ecosystem, which is currently under stress due to population pressure (NMA, 2001). Abate (2009) argued that, climate change affects agriculture and its effect is pronounced on the subsistence farmers, which have low adaptive capacity. Under dry-land conditions where the biological productivity is low and majority of the poor are found, climate change is manifested not only by increasing temperature but also through changes in hydrological cycles characterized by both increased droughts and flooding (Thomas et al., 2007). Generally, climate changes will most likely increase poverty in Ethiopia (Mideksa, 2010). Long term trends towards reduced rainfall, and recurring droughts, have played a role in weakening of Ethiopian economy (USAID, 2004).

2.7. Over view of rainfall in Ethiopia

Ethiopia encompasses five agro-climatic zones that have different topographic and climatic conditions, as shown in Table 1. Temperature ranges from about 10°C in the highlands in the Northwest, Central and Southeast to 35°C in the Northeastern lowlands. Rainfall ranges from 2,000mm over some areas in the Southwest to less than 250mm over the Afar and Ogaden lowlands (EEA & EPRI, 2010).

Ethiopia is in the tropical zone laying between the Equator and the Tropic of Cancer. It has three different climate zones according to elevation and consists of a complex blend of massive highlands, rugged terrain and low plains. They are three generally altitude influenced distinguished environments, Dega (cool), Weynadega (temperate) and Kola (hot).The Dega covers the central parts of the western and eastern sections of the northwestern plateau, and a small area in Harer, is and generally above 2,400 meters in elevation. The surrounding low lands between 1500 to 2400 meters constitute the temperate zone. The hot zone which encompasses the Denakil Depression, the Eritrean lowlands, the eastern Ogaden, the deep tropical valleys of the Blue Nile and Tekeze rivers, and the peripheral areas along the Sudanese and Kenyan borders has an elevation lower than 1500 meters (U.S Library of Congress, 2005), 40% of the population is estimated to live above 1500 meters (FDRE, 1997b).

According to NMSA (1996), three distinct seasons locally known as *Bega* (October to January), *Belg* (February to May) and *Kiremt* (June to September) are observed in Ethiopia. In these three seasons, *Kiremt* is the main rainy season, in which about 85% to 95% of the food crops of the country are produced (Degefu, 1987; NMSA, 1996; Mesay, 2006). While Rainfall distribution and amount during *Belg* season is highly variable in time and space (NMSA, 1996; Mesay, 2006).The western half of the country, with one dry and one wet season in a year, receives the highest amount of rainfall in *Kiremt.* Which is generally decreasing from 10 months in the southwest to only two months in the North West (NMSA, 1996; Mesay, 2006; Viste *et al.*, 20120). The central and south-eastern high lands and the adjoining lowlands experience all the three seasons and receives about 60% of the total annual rainfall during the *Kiremt* (NMSA, 1996). The southern and southeastern low lands of the country have a bi-modal rainfall pattern with main rainy season occurring from March-May and the second short rains from September-October. On the other hand, the northeastern part of the country receives very small amount of *Kiremt* rainfall in a year (Mesay, 2006; NMSA, 1996; Viste *et al*., 2012).

According to Funk *et al*. (2005), Mesay (2006) and McSweeney *et al.* (2008), seasonal rainfall in Ethiopia is driven mainly by the migration of the tropical rain belt, the Inter-Tropical Convergence Zone (ITCZ). Moreover, the main season (*Kiremt*) rain-producing systems such as the ITCZ, cross equatorial flow from (Mascarene high) southern Indian Ocean, moisture flow from (St. Helena high) Atlantic Ocean and the monsoon low and the associated trough have a great role to play for main season (*Kiremt*) rainfall performance over Ethiopia. According to Mason and Goddard (2001), El Niño–Southern Oscillation (ENSO) have an impact on a seasonal shifting of the normal rainy seasons in some regions, as a result a shortening or lengthening of the rainy seasons, particularly over tropical regions. In line with this, Gissila *et al*. (2004) and Segele and Lamb (2005) indicated that there could be a significant teleconnection linkage between ENSO and the Ethiopian *Kiremt* rainy season. The correlation showing that rainfall could be below average through El Niño episode further more high drought probabilities during strong El Niño years whereas, La Niña events favored further temporal expansion of seasonal activities beyond the normal duration of the rainy season over a region (Gissila *et al*.,2004).

However, Conway (2009) and Conway and Schipper (2011) noticed d that despite clear evidence on the consequences of climate change, the drivers of climate change in the country are poorly understood. In Ethiopia, the distribution of rainfall varies over the diverse agro-ecological zones that exist in the country (Viste *et al*., 2012) and the appearance remains usually not understood (Conway and Schipper, 2011).

Table 1: Agro-climatic zones of Ethiopia

Zone	Altitude	Mean annual temperature	Mean annual rainfall
Berha	< 500m	> 25°C	< 600mm
Kolla	500 to 1,500m	20 to 28°C	600 to 900mm
Weyna Dega	1,500 to 2,300m	16 to 20°C	> 900mm
Dega	2,300 to 3,200m	6 to 16°C	> 900mm
Wurch	> 3,200m	< 6°C	> 1,400mm

Source: Calow et al (2013).

There are three seasons, which are largely determined by the Inter-Tropical Convergence Zone (ITCZ): in Ethiopia due to the country’s geographical location, topography and large-scale circulations dominating the climate in the horn of Africa. *Bega* is the dry season from October to January; *Belg* is the short rainy season from February to May; and *Kiremt* is the long rainy season from June to September. The central, eastern and northern parts of the country experience a bimodal pattern receiving rains from June to September and spring rains from March to May. The southern and southwestern parts of the country, experience unimodal pattern where precipitation falls from March to November. The highlands generally receive more precipitation than the lowlands.

The intensity of rainfall is also determined by the El Niño Southern Oscillation (ENSO), which tends to reduce rainfall in the main rainy season and increase rainfall in the *Belg* season (Calow et al, 2013). Additional estimations also show that in the past 60 years, the country has experienced several dry and wet years, as well as an increase in the number of warm and cool years. Rainfall trends have remained relatively constant across the whole country, although there is some indication that annual rainfall is decreasing in the South (EEA & EPRI, 2010; McSweeney et al, 2010).

2.8. Rainfall trends and variability in Ethiopia

Rainfall in Ethiopia is characterized by seasonal and inter-annual variability (e.g. Camberlin 1997; Shanko and Camberlin 1998; Conway 2000; Seleshi and Zanke 2004). Declining rainfall trends have been reported for parts of the country. FEWS (2003) detected a clear downward trend in rainfall since 1984 in the central highlands for the period 1961-1996. Similarly, Sileshi and Zanke (2004) identified significant recent declines in the annual and *kiremt* rainfalls in eastern, southern and southwestern Ethiopia. They, however, found no significant trend in annual and seasonal rainfall totals in the central, northern, and northwestern Ethiopia. This was supported by Conway (2000), who noted no evidence of any long –term trend or change in rainfall in the northeast Ethiopian highlands. In addition, Conway et al. (2004) spotted no trend in rainfall for the period (1898-2002) in Addis Ababa in the central Ethiopian highlands. Looking at recent seasonal changes in dry spell and extreme rainfall events, Sileshi and Camberline (2006) noted a weak increasing trend over the 10-11^{o} North band of the Ethiopian highlands and a decreasing trend in *kiremt* extreme intensity in the eastern, southern and part of southwestern Ethiopia. This is in line with a previous study by Sileshi and Zanke (2004) who reported a significant decline (at 5% level) in *kiremt* rainy days in eastern Ethiopia since 1982, compared with the period 1965-81. Daily climate extreme analysis has been carried out in various parts of Africa. New et al. (2006) indicated a decrease in total precipitation, accompanied by increased average rainfall intensity in southern and West Africa for the period 1961 – 2000. The Sahel, the zone between the arid Sahara and humid tropical Africa covering an area of 1,200,000 square miles, has experienced prolonged dry episodes characterized by years of below average rainfall totals. Drought prone tropical African regions are characterized by a high variability of seasonal and annual rainfall across time and space (Sileshi and Demaree, 1995).

Precipitation patterns vary widely throughout the country due to elevation, atmospheric pressure patterns, and local features monthly precipitation distribution for most parts of the country, and clearly illustrates the diversity between regions. In the lowlands, rainfall is typically quite meager, whereas the southwest, central, and northwest regions receive quite appreciable quantities, but in varying patterns. In the southwest, a relatively even month-to-month distribution may be observed, while the dominant pattern in the northwest and western regions, containing the Blue Nile basin, is generally associated with tropical monsoon-type behavior, delivering significant June-September rainfall.

The main weather parameter affecting crop growth are rainfall, temperature and radiation (Sreenivas *et al*. 2008; Hadgu *et al*., 2014). Therefore, having knowledge on sequences of rainfall variability, events can assist acquiring specific information for agricultural planning (Reddy *et al*., 2008; Mandal *et al*., 2013). Within variable seasonal rainfall patterns, understanding the events of the occurrence of rain features like; onset and end date of rainy season, dry spells are crucial to decrease the adverse effects and exploit opportunities (Yemenu *et al*., 2013). According to Sun *et al.* (2006), understanding how climate variability influences the yields can be helpful in designing policies that aim at reducing climate vulnerability and improving food security. According to the study of past and future intra seasonal rainfall variability in terms of onset, end date and length of rainy season, number of rainy days, length of dry spell with in the growing period and its trend is important for agricultural purposes in the dry land area than annual and seasonal totals (Hadgu *et al*., (2013).

2.8.1. Onset of rainy season

Onset marks beginning of a season though different researchers have put it differently. For example: Stern *et al*. (1982) defined onset of a season as the date when the rainfall accumulated over 2 days is at least 20 mm and when no dry spell (exceeding 10 days) occurs within the following 30 days. Whereas, Tesfaye and Walker (2004) defined onset as the date in which 20mm or more rainfall accumulated over three consecutive rainy days after a specified date with no dry spell greater than 7 days in the next 30 days. Raman (1974) and Mamo (2005), Hadgu *et al.* (2013) and Taye *et al*. (2013) also followed the definition of Tesfaye and Walker (2004) but Hadgu *et al.* (2013) specified dry spells up to 10 days. Rita Ngozi Edoga (2007) and Hulme (1987) applied the monthly minimum threshold of 60 mm and 30 mm, respectively to determine the onset of rainy season. Kowal and Knabe (1972) defined onset as the first ten-day period (decade) with more than 25mm rain, provided that rainfall in the next decade exceeded half the potential evapotranspiration.

For *Belg* onset as indicated in Mesay (2006), rainfall total of 10 mm or more in consecutive 3 days or more with no dry spell length of 9 days or more in the next 30 days should occur with an earliest starting day first of February . What so ever might the definition used, a study conducted in Ethiopia by Mesay (2006) noted that northern and north eastern regions have a late start of *Belg* rain in April with standard deviations of 31.9 -46.1. Another study conducted in western Amhara Region of Ethiopia revealed variability in the onset of *Kiremt* rain among stations (Taye *et al.* (2013). According to Taye *et al.* (2013) on average the *Kiremt* rain at Bahir Dar, Motta, Debre Markos and Dangla stations begins on 153th,151th, 144th and 132th day of the years (DOY), respectively. On the other hand Ayalew *et al*. (2012) reported June 15 (167 DOY) as a mean date of onset for *Kiremt* rainfall in the Amhara National Regional State.

2.8.2. End of rainy season

End of rainy season marks withdrawal of rainy season. Like onset, end of rainy season is also defined differently by different authors. For instance, Mesay (2006) used to determine end of *Belg* rain with an earliest possible day of May 1, the capacities of soils to persist precipitation with a water balance equal to zero. Whereas Tesfaye and Walker (2004) defined end of rainy season (for *Kiremt)* as the date when the available soil water content drops to 10 mm/m of the available water after September 11. Hadgu *et al.* (2013), Hadgu *et al.* (2014) and Kassie *et al*. (2014) used the same definition to determine end of rainy season. In another study, Stern *et al.* (1982), Mamo (2005), Mesay (2006) and Taye *et al*. (2013), defined as any date when water balance reaches zero after the first date of September (for *Kiremt*). FAO (1978) defined end of growing period when precipitation amount is below half of the reference evapotranspiration. For the regions except southwestern Ethiopia, Segele and Lamb (2005) defined end of rainy season for *Kiremt* as the first day of a dry-spell (<0.1mm per day) of at least 20 days duration that occurred after onset. According to the authors, this definition need to be modified when dry periods of more than 20 days extended occurred in mid-season, after which persistent rains returned. They noticed that the definition need to be complemented by the prerequisite that, if rain occurs on more than 2 days in a 30-day period after an extended dry-spell, the search for a cessation date is advanced so that a date satisfying the above basic criterion is determined from the last day of the dry-spell. Zargina (1987) and Benoit (1977) defined end date of growing season as the date in which the minimum daily rain fall threshold is 25mm in which the soil is assumed to be at field capacity (100mm). On the last day of rain that is greater than 0.5 PET, provided that the date is not proceeded by a dry spell (< 1mm average daily rainfall) or more than five days (Mubvuma, 2013). In his study end of rainy season is defined as the first dry day of the last month of the season in a period of 14 days whose cumulative rainfall total was less than 40 mm. According to Ilesanmi (1972), end of growing period is taken as the time when an accumulated 90% of the annual rainfall totals is obtained. Odekunle (2004) used the same method to determine cessation of growing period. In another study, Admassu *et al. (*2014) used the definition proposed by Panigrahi and Panda (2002) to determine end of rainy season. According to the authors, end of rainy season is determined using backward summation of weekly rainfall starting from 48th week until 20mm of the rainfall is accumulated.

What so ever might the definition used, a study conducted on end of rainy season in north western of Ethiopia revealed that on average the *Kiremt* rain ends on 302^{th}, 304^{th}, 292^{th}, 302^{th} and 317^{th} DOY at Bahir Dar, Motta, Yetmen, Debre Markos and Dangla, respectively (Taye *et al*., 2013). As Ayalew *et al*. (2012) indicated, the average date of end of rainy season ranged from September 2 (246 DOY) at Mahil Meda to October 30 (304DOY) at Debark in Amhara region.

2.8.3. Length of rainy season

Length of rainy season is the duration in days between onset date and cessation date (Ayoade, 1974; Adefolalu, 1983; Madeoye, 1985; Zargina, 1987; Odekunle, 2004; Segele and Lamb 2005; Hadgu *et al*., 2013; Hadgu *et al*., 2014; Kassie *et al.*, 2014). According to Stewart (1988) and Borrell *et al.* (2003), length of growing season analysis is very important to advice farmers in selecting suitable crop variety that can be produced in specific area. Accordingly, Taye *et al.*

(2013) reported that on average the *Kiremt r*ainy season has length of 149,153,142,158 and 185 days at Bahir Dar, Motta, Yetmen, Debre Markos and Dangla stations, respectively in the north west of Ethiopia. In another study, Hadgu *et al.* (2013) reported that the average length of growing period in northern Ethiopia varies from 66 to 85 days depending on the location of the study area. At Mekelle, Alamata and Edagahamus, Hadgu *et al.* (2013) observed length of growing season of 85, 79 and 66 days, respectively. Models projection have also shown moderate reduction (< 20%) in the length of the growing period across Africa including Ethiopia (Thornton *et al.*, 2006).

2.8.4. Number of rainy day

Even though the smallest recorded rainfall amount is 0.1 mm, a threshold value 1mm was used to determine wet and dry days (NMSA, 2001). This is because 0.1mm rainfall has almost no effect on growth of crops (Robel *et al*., 2013). A day is considered rainy if it accumulates 1 mm or more rainfall and the opposite is true for dry day. Based on this definition, in the Tigray region of northern Ethiopia, Hadgu *et al*. (2013) counted number of rainy days for *Kiremt* season (starting from the first day of June to September 31 following the traditional classification of JJAS as *Kiremt* and found 50 days at Adigudum, 66 days at Alamata and 61 days at Mekelle. In a similar region, Seleshi and Zanke (2004) observed no-significant change in number of rainy days at Mekele for the period 1965-2002. As Ayalew *et al*. (2012) indicated, by the years of 2080s the number of rainy days will decrease in the ANRS of Ethiopia.

2.8.5. Length of dry spells

According to NMSA (2001), a day is said to be dry if it accumulate rainfall<1 mm and dry spell length is the maximum number of consecutive dry days with rainfall less than 1 mm per day exceeding 5, 7, 10, and 15 (Tesfaye and Walker, 2004). The same definition was used by Mesay (2006) to determine the dry days in rainy season. Mesay (2006) found mean dry spell length of up to 28 days in the north western, northern and eastern parts of Ethiopia during *Belg* season. Hadgu *et al.* (2013) found dry spells of 21 days at Mekele, 26 days at Alemata and Edamame during the *Kiremt* season. In another study, Seleshi and Camberlin (2006) reported dry spell length of 20.3 days at Mekele in the northern Ethiopia and 16.2 days at Jijiga in the eastern Ethiopia.

2.9. Factors Influencing Rainfall Variability

Rainfall in northern Africa from the Atlantic to the Red sea is strongly related to changes in sea surface temperature patterns (Folland et al. 1986; Conway, 2000). SST anomalies in the Indian and Pacific Oceans have a fundamental influence on Sahel rainfall and have been associated with Nile flows (Folland et al. 1986). These variations in the Indian and Pacific oceans are affiliated with rainfall changes in Ethiopia and East Africa (Beltrando and Camberlain, 1993; Sileshi et al., 1995; Conway, 2000). It has also been suggested that positive SST anomalies in the southwestern Indian Ocean (SWIO) may increase oceanic precipitation and decrease rainfall over eastern Africa, especially during March-May (Funk et al. 2005). It is believed that the low pressure systems associated with the storms of April1984 in the SWIO accounted for the severe and widespread drought in the horn (Macodras et al., 1989). The occurrence of droughts, floods, hurricanes, and other weather phenomena across the globe have been associated with ENSO episodes and has been the subject of intense research over the last 20 years (Larkin and Harrison, 2001).

Furthermore, in Ethiopia and Eritrea, *Belg* rainfalls have been shown to be associated with the Northern Hemispherical subtropical westerly jet (Habtemichael and Pedgley, 1974). Marked differences in inter annual behavior between the rainy seasons are evident reflecting different large and regional scale influences. Rainfall in the northeastern Ethiopian highlands is influenced by three mechanisms: the summer monsoon (Inter-tropical Convergence Zone, ITCZ), tropical upper easterlies, and local convergence in the Red Sea coastal region (Conway, 2000). The *bega* and *belg* seasons are over whelmed by the north east continental cool air- stream from the Sahara and progression of the ITCZ in its south- north migration (Camberlin and Philippon, 2002; Conway 2000; Sileshi and Zanke, 2004). The *belg* season also coincide with the development of a thermal low (Cyclone) over southern Sudan, and winds blowing from the Gulf of Aden and the Indian Ocean highs (Sileshi and Zanke, 2004).

El Niño, which is a quasi-periodic positive shift in sea surface temperatures (SST) in the central and eastern equatorial pacific. El Niño is closely coupled with the shift in the airflow pattern (southern oscillation) over the pacific. Climatic changes associated with the El Niño Southern Oscillation (ENSO) have profound effects on terrestrial arid and semiarid ecosystems (Holmgren et. al; 2006).The onset and cessation and variability of the *kiremt* rains fall under the influence of the ENSO phenomenon and tropical depression over the Indian Ocean (Block et al; 2007)**.** ENSO has been shown to strongly interact with climate dynamics in the Indian Ocean where during most El Niño events, anomalies are observed in the Indian Ocean (Cadet 1985; Reveredin et al 1986; Beltrando and Camberlin 1993). There exist a strong coupling between the short rainy season in the neighboring East African countries, and both the ENSO and the east – west circulation over the Indian Ocean (Beltrando and Cambrlin 1993).

However, other studies have contradicted similar findings. Ogallo et al. (1988) observed a ‘ see – saw’ pattern between the eastern Pacific Ocean and the Indonesia region which coincides with positive anomalies over the coast of Eastern Africa indicating a relationship between rainfall variability in the region and ENSO phenomena. Nicholson and Entekhabi (1986) also identified significant Teleconnection between the southern oscillation and seasonal rainfall over part of east Africa. Coupling between the East African long rains and ENSO, however did not show any significant correlations (Ogallo 1988, Hastenrath et al. 1993; Rowell et al. 1994; Philipps and McIntyre 2000). These findings are at odds with several other studies that noted a relationship between Nino-3 SST and rainfall across the season (Nicholson 1996; Nicholson and Kim 1997; Indeje et al. 2000). On the other hand, Warming in the Indian Ocean which has been linked to anthropogenic causes (Funk et al. 2005, 2008) have had major impacts on eastern African rainfall from March to June (*Belg*, Funk et al. 2008, Funk and Williams ,2010). It was suggested that long established inter annual teleconnections between large scale climate variability and long rains precipitation are being altered due to warming with in the south central Indian Ocean.

Reduced rainfall across eastern Africa, thus, is linked to deep atmospheric convention over the Indian Ocean due to warming near tropical Pacific-Indian Ocean (Funk et al, 2008; Funk and Williams 2010). Consistent weakening and pole ward expansion due to reduced upward Convective mass flux as diagnosed in climate change simulations imply reduced subsidence in the tropics (Held and Soden 2006; Lu et al. 2007). The weakening of the atmospheric overturning is driven by changes in the atmospheric hydrologic cycle (Held and Soden 2006) and is primarily evident as a reduction in the zonally asymmetric Overturning of air (i.e., the Walker circulation) rather than in the zonal-mean overturning, the Hadley circulation (Vecchi and Soden 2007). A projected weakened walker circulation as a result, resembles a more “El Nino like” climate with withered subsidence over eastern tropical Pacific and eastern tropical Africa (Vecchi and Soden 2007).

Consecutive occurrences of several tropical depressions over the SWIO coincide with the drought years of Ethiopia (Shanko and Camberlin 1998). In contrast, years of low frequency tropical cyclones are associated with heavy rainfall in Ethiopia. Shanko and Camberlin (1998) have shown that *Belg* rainfall is influenced much more by the cyclonic activity than *Kiremt* rainfall, which occurs outside the cyclonic season of the SWIO. Ogallo (1988) presented cases from further south in East Africa where rainfall is influenced directly and indirectly by tropical storms that originate from SWIO and the Arabian Sea. Shanko and Camberlin (1998) quoted four well documented cases of cyclones which have hit the East African coast in April 1872, April 1952, May 1966 and April 1974.Inter annual variability of rainfall is remarkably coherent with in Eastern Africa implying major large scale influences (Nicholson, 1996). Camberlin (1996) further investigated the Teleconnection between Nile floods and the Indian monsoon, and found a close relationship between summer (July – September) sea level pressure (SLP) in India and concurrent inter annual rainfall variations over the horn of Africa. He also noted a direct link between monsoon variations in these two regions suggesting that ENSO plays a prominent part in the India–East Africa co-variability of rainfall.

3. STUDY AREA DESCRIPTION AND METHODOLOGY

3.1. Study area description

The Upper Blue Nile River Basin (hereafter called the Basin) is the largest river basin in terms of the volume of discharge, and the second largest in terms of watershed area in Ethiopia. The Blue Nile River flows from Lake Tana and crosses through the central Ethiopian highlands to the Sudanese boarder and joins the White Nile at Khartoum, the Sudan. It is the largest tributary of the Nile, and it is locally known as the Abay. The main source of the Nile River is the Blue Nile River (Peggy and Curtis, 1994). The Upper Blue Nile Basin of the Central Ethiopian Highlands it has 176 000 km^2 a drainage area or 17% of the total area of Ethiopia and It has a mean annual discharge of 48.5 km^3 ($1536 m^3 s^{-1}$) (Conway, 2000). Eighty six% of the annual flow of the Nile comes from Ethiopia with contributions of the Upper Blue Nile Basin (59%), the Baro–Akobo–

Sobat sub-system (14%) and 13% from the Tekeze/Atbara/Gash sub-system (Degefu, 2003). The remaining 14% comes from the equatorial lakes (Lake Victoria, Lake Albert, Lake Edward, Lake Tanganyika, and Lake Kivu) after losses of evaporation in the Sudd region and Machar marshes (Degefu, 2003). The Upper Blue Nile Basin is relatively wet. Annual rainfall ranges from over 2000 mm in the South to a 1000mm in the northeast (Conway, 2000) .

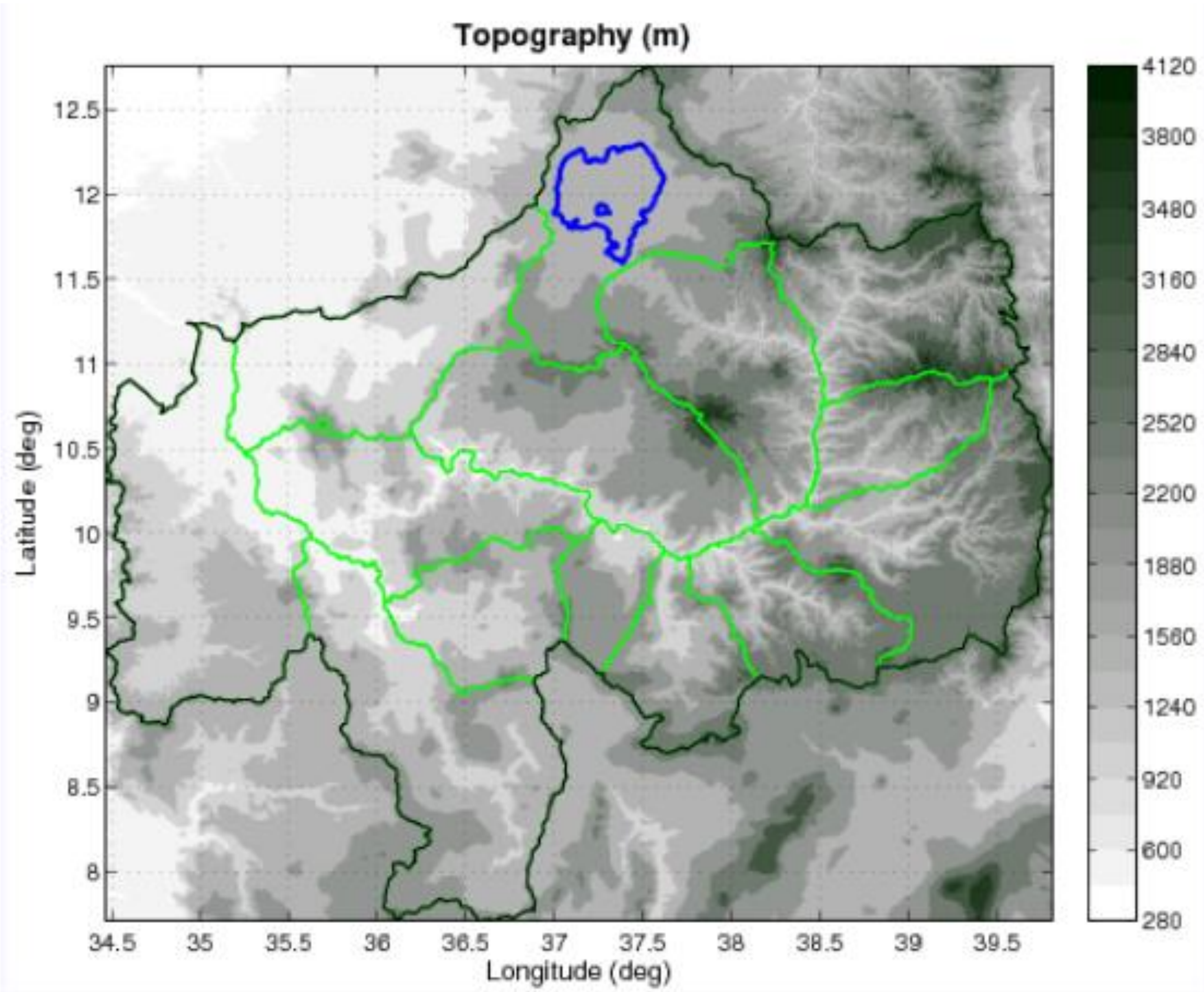


Figure 5: Topography and location of Blue Nile basin

3.1.2. Climatic condition of the study areas

Bahir Dar

Bahir Dar is a city in north-western Ethiopia. It is the capital of the Amhara Region (kilil). Bahir Dar is one of the leading tourist destinations in Ethiopia, with a variety of attractions in the nearby Lake Tana and Blue Nile River. The city is known for its wide avenues lined with palm trees and a variety of colorful flowers. In 2002, it was awarded the UNESCO Cities for Peace Prize for addressing the challenges of rapid urbanization. Bahir Dar is situated on the southern shore of Lake Tana, the source of the Blue Nile (or Abay), in what was previously the Gojjam province. The city is located approximately 578 km north-northwest of Addis Ababa, having a latitude and longitude of 11°36′N 37°23′E Coordinates and an elevation of about 1,800 meters (5,906 feet) above sea level.

The Köppen Climate Classification subtype for this climate is "Aw". (Tropical Savanna Climate).

The average temperature for the year in Bahir Dar is 62.0°F (16.7°C). The warmest month, on average, is March with an average temperature of 68.0°F (20°C). The coolest month on average is January; with an average temperature of 59.0°F, (15°C).The average amount of precipitation for the year in Bahir Dar is 56.2" (1427.5 mm). The month with the most precipitation on average is July with 17.1" (434.3 mm) of precipitation. The month with the least precipitation on average is January with an average of 0.1" (2.5 mm).

Debre Markos

Debre Markos (was called Mankorar) is a city and woreda in east-central Ethiopia. Located in the Misraq Gojjam Zone of the Amhara Region, it has a latitude and longitude of 10°20′N 37°43′E and an elevation of 2,446 meters. Debre Markos's climate is classified as warm and temperate. In winter, there is much less rainfall in Debre Markos than in summer. According to Köppen and Geiger, this climate is classified as Cwb. In Debre Markos, the average annual temperature is 15.9 °C. About 1321 mm of precipitation falls annually. The least amount of rainfall occurs in January. The average in this month is 12 mm. With an average of 309 mm, the most precipitation falls in July. The temperatures are highest on average in March, at around 17.9 °C. July has the lowest average temperature of the year. It is 14.5 °C. The variation in the precipitation between the driest and wettest months is 297 mm. During the year, the average temperatures vary by 3.4 °C.

Gondar

Gondar is a city and separate woreda in Ethiopia. Located in the Semien Gondar Zone of the Amhara Region, Gondar is north of Tana Lake on the Lesser Angereb River and southwest of the Simien Mountains. It has a latitude and longitude of 12°36′N 37°28′E with an elevation of 2133 meters above sea level. The temperatures here are the same as those found in Bahir Dar, but the levels of precipitation peak in July and August at just over 300mm, making it slightly more manageable, but only just. Both middle to late June and early September are still very wet, May and October the buffer months, making the dry season reasonably short. The long rains beginning in June, becoming increasingly heavy through July and August, before thinning out towards the September. Temperatures average around 16 °C.

The climate here is mild, and generally warm and temperate. The summers here have a good deal of rainfall, while the winters have very little. The Köppen-Geiger climate classification is Cwa. The temperature here averages 19.3 °C. The average annual rainfall is 1151 mm. Precipitation is the lowest in January, with an average of 4 mm. Most of the precipitation here falls in July, averaging 328 mm. At an average temperature of 22.0 °C, April is the hottest month of the year. August is the coldest month, with temperatures averaging 17.6 °C. Between the driest and wettest months, the difference in precipitation is 324 mm. throughout the year; temperatures vary by 4.4 °C. In addition, another site there is different information Gondar receives on average 1161 mm (45.7 in) of rainfall per year, or 96.8 mm (3.8 in) per month. On average, there are 126 days per year with more than 0.1 mm (0.004 in) of rainfall (precipitation) or 10.5 days with a quantity of rain, sleet, snow etc. per month. The driest weather is in January when an average of 3 mm (0.1 in) of rainfall (precipitation) occurs. The wettest weather is in July when an average of 326 mm (12.8 in) of rainfall (precipitation) occurs.

Kombolcha

The subtropical highland variety of the oceanic climate exists in elevated portions of the world that are within either the tropics or subtropics, though it is typically found in mountainous locations in some tropical countries. Despite the latitude, the higher altitudes of these regions mean that the climate tends to share characteristics with oceanic climates, though it also tends to experience noticeably drier weather during the "low-sun" season. In locations outside the tropics, other than the drying trend in the winter, subtropical highland climates tend to be essentially identical to an oceanic climate, with mild summers and noticeably cooler winters, plus, in some instances, some snowfall. In the tropics, a subtropical highland climate tends to feature spring-like weather year-round. Temperatures here remain relatively constant throughout the year and snowfall is seldom seen. Without the elevation, many of these regions would likely feature either tropical or humid subtropical climates. Kombolcha is a city and woreda in north-central Ethiopia. Located in the Debub Wollo Zone of the Amhara Region, it has a latitude and longitude of 11°5′N 39°44′E with an elevation between 1842 and 1915 meters above sea level. Some guidebooks describe Kombolcha as the twin city of Dessie, which lies some 13 km to the northwest. Kombolcha is connected with Dessie through Ethiopian Highway.

The Köppen Climate Classification subtype for this climate is "Cwb". (Oceanic Subtropical Highland Climate).

The average temperature for the year in Kombolcha is 64.4°F (18°C). The warmest month, on average, is June with an average temperature of 70.0°F (21.1°C). The coolest month on average is December; with an average temperature of 59.4°F, (15.2°C).The average amount of precipitation for the year in Kombolcha is 41.7" (1059.2 mm). The month with the most precipitation on average is August with 10.1" (256.5 mm) of precipitation. The month with the least precipitation on average is December with an average of 0.7" (17.8 mm). There are an average of 74.0 days of precipitation, with the most precipitation occurring in August with 11.3 days and the least precipitation occurring in December with 2.3 days.

Table 2: Selected weather stations and their general geographic information

Weather stations Latitude	Latitude (North)	Longitude (East)	Altitude (m)	Years of observation
Bahir Dar	11°36′	37°23′	1800	1986-2016
Debre Marqos	10°20′	37°43′	2446	1986-2016
Gonder	12°36′	37°28′	2133	1986-2016
Kombolcha	11°5′	39°44′	1916	1984-2014

3.2. Methodology

3.2.1. Data Type and Source

Rainfall variability and climate change were two important variables, which would be used in the analysis daily rainfall variability of the study area. So as, Precipitation data of daily rainfall record for the selected stations collected from Bahir Dar and Dessie meteorological station from the period 1985 to 2016. Monthly, seasonal and annual rainfalls were derived from the daily data of those stations. Rainfall for the study stations computed the Monthly, seasonal and annually average rainfall data for further analysis.

3.2.2. Methods of Data Analysis

In this study, Rainfall variability over upper Blue Nile river basin selected sites/cites and thirty years will recorded observation data of metrological station used from (1982– 2014) from Bahir Dar and Dessie meteorological station. Monthly, seasonal and annually rainfall for the selected sites analyzed statistically based on the variability as well as the stochastic features of precipitation have been investigated in a semiarid agricultural region. Several characteristics of regional and temporal precipitation distribution were explored in terms of precipitation shortages and surpluses for agricultural purposes. Furthermore, the trend and time analysis is performed using Mann-Kendall test and Sen’s Slope estimator for trend detection. The methods of analysis include MINITAB statistical software (2010) and Microsoft office (2016).

The methodology applied in this article is Trend analysis using the statistical non-parametric tests i.e. Mann-Kendall test and Sen’s Slope Estimator test on the monthly rainfall data for Raipur for

102 years. Generally, non-parametric tests are preferred over parametric tests because the problems aroused due to data skew can be evaded by non-parametric ones. Mann-Kendall test is most commonly used test for trend analysis of any hydro-climatic series for checking spatial variation and temporal deviation. This formula was derived by both Mann and Kendall i.e. Mann (1945) formulated it as non-parametric test to detect trend whereas Kendall (1975) gave the test statistic distribution to test non-linear trend and turning point. Sen's Slope Estimator test is also used to determine the magnitude of trend. This was formulated by Sen (1968), in which slope of data pairs are to be used to detect the trend.

Mann Kendall analysis is a statistical test widely used for analyzing trends in climatologic (Mavromatis & Stathis, 2011) and hydrologic time-series studies (Yue & Wang, 2004). There are two advantages of using this test. First, it is a nonparametric test and does not require data to be normally distributed. Second, it has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari et al., 2011).

Mann-Kendall Test

The Mann-Kendall statistic S is given as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \text{ ---------- (1)}$$

The application of trend test is done to a time series xi that is ranked from i = 1, 2,……, n-1 and x_j, which is ranked from j = i+1,2, ………., n. Each of the data point x_i is taken as a reference point, which is, compared with the rest of the data point's x_j so that,

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ 1, < (x_j - x_i) \end{cases} \text{ ---------- (2)}$$

For n > 8, S follows approximately Normal distribution with mean i.e.

$$E(S) = 0 \text{ ---------- (3)}$$

The variance statistic is given by,

$$\mathrm{var}(s) = \frac{n(n=1)(2n-5)-\sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18} \text{ -- (4)}$$

Where, t_i is considered as the number of ties up to Sample i.

The test statistics Z_{mk} (Mann-Kendall Co-efficient) is computed as,

$$z_{mk} = \begin{cases} \frac{s-1}{\sqrt{\mathrm{var}(s)}}, & s > 0 \\ 0, & s = 0 \\ \frac{s+1}{\sqrt{\mathrm{var}(s)}}, & s < 0 \end{cases} \text{ -- (5)}$$

Z_{mk} here follows a standard normal distribution. A positive and negative value of Z_{mk} indicates an upward trend and downward trend respectively. A significance level α is also utilized for testing either an upward or downward monotone trend (a two tailed test). If Z_{mk} appears greater than Zα/2 where α depicts the significance level, then the trend is considered as significant. Generally, Z_{mk} values are 1.645, 1.960 and 2.576 for significance level of 10%, 5% and 1% respectively. But for greater length of data, Z_{mk} /sqrt (n) is also used as Mann-Kendall statistic to determine the trend, where n is the number of data values.

Sen's Slope Estimator Test

This is better than the linear regression test to analyze trend. The slope is to be obtained to check the trend. Therefore, it is the most powerful method for a linear trend.

The slope T_i of all data pairs can be computed by,

$$T_i = \frac{x_j - x_k}{j-k} \text{ -- (6)}$$

Where, x_j and x_k are considered as data values at time j and k (j > k) correspondingly.

The median of N values of T_i is represented as Sen's estimator of slope is given by,

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & if\ N\ is\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & if\ N\ is\ even \end{cases} \text{ -- (7)}$$

After calculating Q_i, for testing the significance, Q_{median} is computed by a two sided test at 100 (1-α) % confidence interval and then a true slope can be obtained by the non-parametric test. Like Mann- Kendall test, positive and negative value of Qi represents an upward and downward trend respectively.

Standardized anomaly index

Standardized Anomaly Index (SAI) was used as a tool. SAI was used to determine dry and wet years and to assess frequency and severity from rainfall records, as in Bewket (2009) & Hadgu et al., (2013). The formula was:

$$Z= \frac{x_i - x_m}{\sigma} \quad (8)$$

Where, Z is standardized anomaly index; x_i is total annual rainfall of year i; x_m is long time average annual rainfall; and σ is standard deviation of annual rainfall over period of observation.

4. RESULT AND DISCUSTION

4.1. Rainfall time Series analysis

Climate variability such as rainfall is pervasive. This variability ranges over many time and space scales, from small-scale weather phenomena. The different atmospheric systems affecting Ethiopian rainfall, the temporal and spatial variations western half, northeastern, eastern and central parts of the country receive varied amount of rainfall for the JJAS season. In similar way, temporal distribution of the seasonal rainfall has highly odd characteristics though, play a great impact on various agricultural and water management activities in topographical features of the country and the onset, cessation and the spatial and temporal distribution of Kiremt rainfall varies from place to place.

In (Figure 6a) belg, rainfall season of Bahirdar in the period of March 1982, 2005 and 2014, April 2000 and 2008 and May 1997 there were extremely rainfall events occurred. The years of April 1985, 1992 and 2014, and May 1987 and 2014 strongly rainfall occurred years. Generally, the belg years had characterized by rainfall shortage, but there were small increased events some years. Nevertheless, Belg rain season, which is the not major rainy season for the city.

In (Figure 6b) kiremt, rainfall season of Bahirdar in the period of June 2002, August 2009 year there was extreme rainfall than other season years but there is moderate rainfall occurred in the years of July 2003, 2006 and 2013, August 2001 and September 1989 and 2005 moderate rainfall at Bahirdar. In June 1992, 1990 and 2009, July 1982, 1987 and1997, August 1997, 2005 and September 1982, 1995 and 2009 had characterized by strongly rainfall shortage in summer, which is the major rainy season in the city. However, increase amount of rainfall is frequent at stations that are relatively close to the lake.

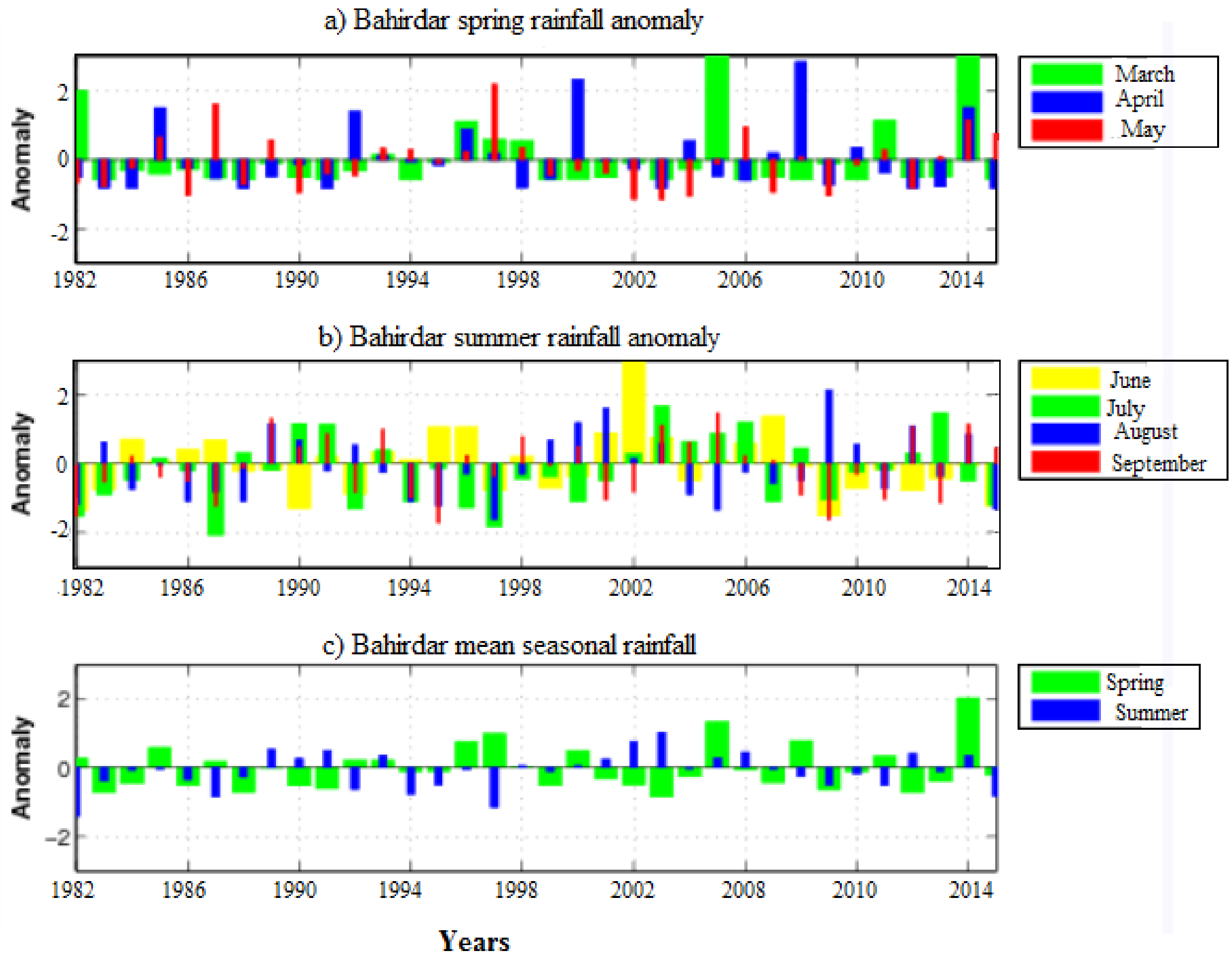


Figure 6: Rainfall variability and trend of Bahir Dar (1982 – 2014)

In (Figure 6c) clearly see the mean seasonal rainfall distribution of Bahirdar in the spring 1997 and 2014 higher rainfall years, in the main rain season of the city not much more variability but in the year of 2003 and 2004 is higher. In 1997, the summer rainfall moderately decreased at Bahirdar. From 1998–2008 decade except 1999 and 2004 when a slight positive anomaly had occurred.

The occurrence of such high discrepancy between the positive and negative variation of rainfall within a short interval of time has a negative implication on the reliability of expected variability. Generally, Bahirdar city were predominantly characterized by positive rainfall in summer than spring.

In (Figure 7a) belg, rainfall season of Debre Markos in the period of March 1989 there were an extreme rainfall occurred in this season. In March 1986, 2005 and 2011, April 1993, 2004 and2014 and May 1996, 2011 and 2015 there were moderate rainfall events occurred. The years of April 1991 and 1998 there was moderately decreased rainfall, and but there was dramatic rainfall pattern occurred in belg season of May. In the period of May 1993-1998 for five consecutively years strong rainfall occurred. Also in May 1986-1991for 4 consecutively except 1988 strongly decreased rainfall occurred years. Similarly happened from 1999-2005 for 5 years except 2001. Generally, in May characterized by rainfall shortage in belg but there were small increasing after to 2006, which is the not major rainy season in the city but it is better belg rainfall happens due to local factor and basically its topography was the main case for belg rainfall.

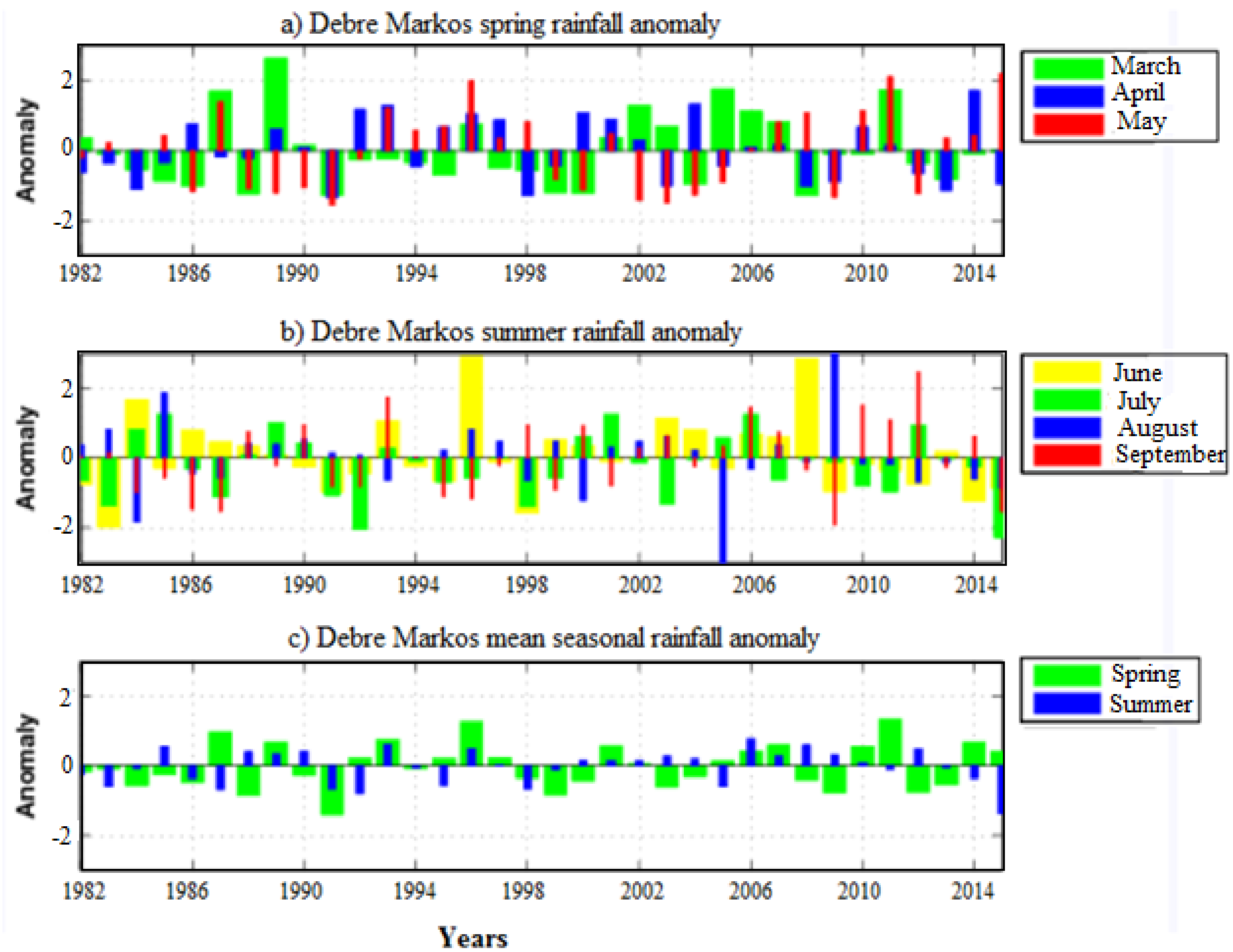


Figure 7: Rainfall variability and trend of Debre Markos (1982 – 2014)

In (Figure 7b) kiremt, rainfall season of Debre Markos in the period of June 1996 and 2008, August 2009 and September 2012 there was extreme or surplus increased rainfall than other season years but there is moderately increased. Rainfall occurred in the years of July1984, July 2001 and 2006, August 1985 and September 1993, 2006 and 2010 rainfall at Debre Markos. In the years of June 1983 and 1998, July 1997, August 1984 and September 2009 were characterized by strongly rainfall shortage in kiremt in Debre Markos, which is the major rainy season in the city.

In (Figure 7c) clearly see the mean seasonal rainfall distribution of Debre Markos belg and kiremt. In the spring 1987, 1996 and 2011strong rainfall years, the main rain season of the city not much more variability but in the year of 2000-2012 decade except 2005 and 2011 is slightly positive rainfall, anomaly event has been occurred at Debre Markos. In 1991, kiremt rainfall moderately decreased. However, Debre Markos was better belg and kiremt decreasing rainfall anomaly occurred.

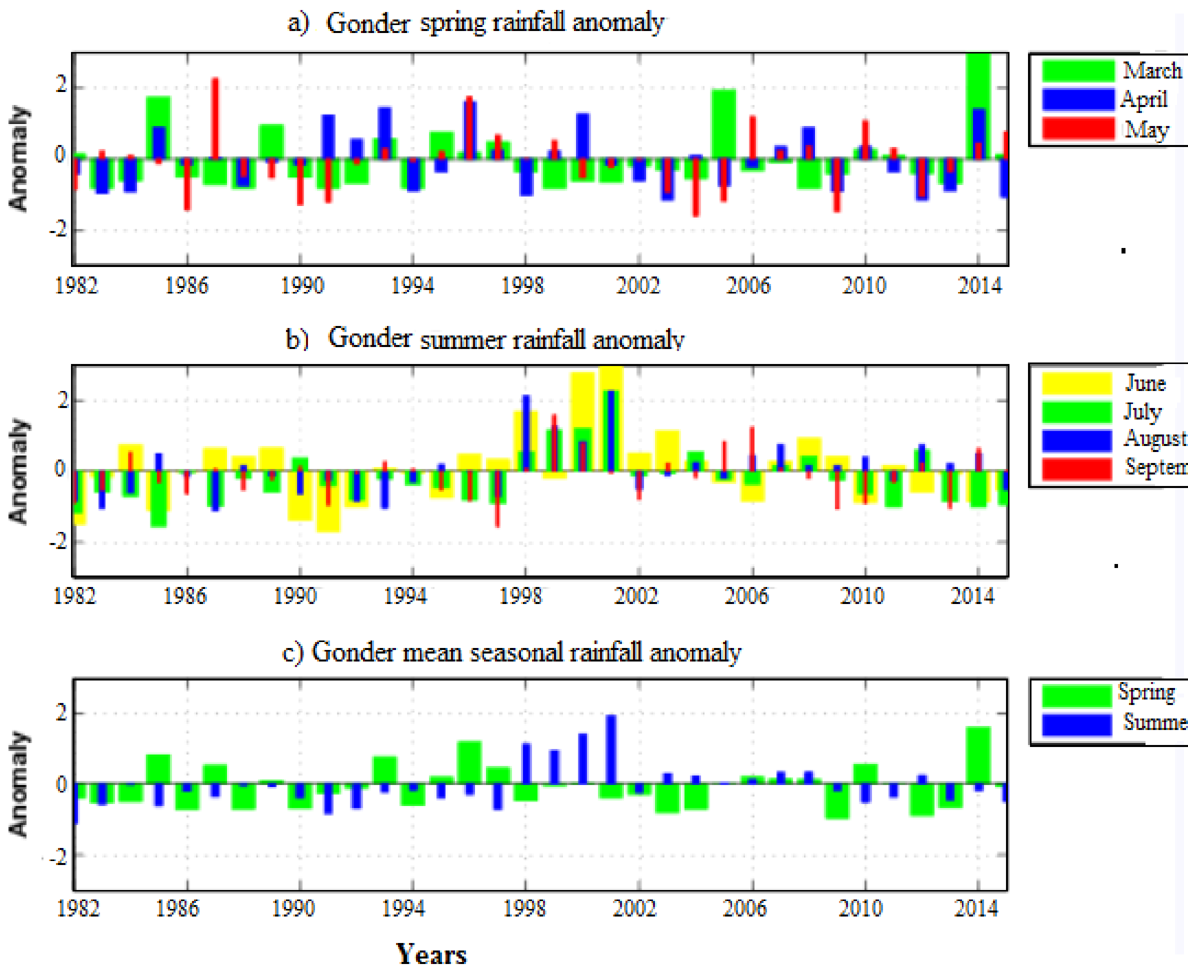


Figure 8: Rainfall variability and trend of Gonder (1982 – 2014)

In (Figure 8a) belg, rainfall season of Gonder in the period of March 2014 and May 1987 there was an extreme increased rainfall occurred. In March 1985 and 2005, April 1991, 1993, 1996, 2000 and 2014 and May 1996 there was strong rainfall events occurred. The years of April 1983, 1984, 1994, 1998, 2003and 2012 there was moderately decreased rainfall, and rainfall pattern occurred in belg season of May strongly decreased in the year of 1986, 1990, 1991and 2004 strongly belg rainfall decreased in Gonder. Therefore, belg rainfall is not good events in Gonder.

In (Figure 8b) kiremt, rainfall season of Gonder in the period of June 2000 and 2001, July 2001, August 1998 and 2001 there was extreme or surplus increased rainfall, but there is strongly increased rainfall occurred in the years of June 1998, July 1999 and 2000, and September 1999 and 2006 rainfall at Gonder. In the years of June 1982, 1991and 1992, July 1985 and September 1997 was characterized by strongly rainfall shortage in kiremt in Gonder, which is the major rainy season in the city.

In (Figure 8c) clearly see the mean seasonal rainfall distribution of Gonder belg and kiremt. In the belg1996 and 2014 moderately increased and in summer 1998-2001 strong increased. But in the year of 1990-1992 at all seasons consecutively for three years the rainfall moderately decreased and similar result we get in previous study to Degefu (1987) and Webb et al. (1992). However, Gonder rainfall not extremely increased and decreased events in belg or kiremt rainfall pattern it occurs slight variation in seasons.

In (Figure 9a) belg, rainfall season of Kombolcha in the period of March 1983, April 1985, 1993 and 1995 and May 1984 and 1993 there was an extreme increased rainfall occurred. In March 1996 and 2001, April 1999 and 2011 and May 1987 and 2011 there was strong rainfall events occurred. However, there is moderately decreased events in belg seasons. Before 1997, the belg rainfall is good but after 1997, the belg rainfall in Kombolcha is decreased. However, belg rain more significant for Kombolcha and dominant rainfall season. There is study, topography have had major impacts on eastern African rainfall from March to June (Belg, Funk et al. 2008, Funk and Williams, 2010) and Ethiopia is both topographically and climatically complex, with vastly different rainfall regimes across the country. About 10% of the Ethiopian population is entirely dependent on this belg rainy season. The kiremt rains are more reliable and run from June to mid-

September, providing water mainly for agriculture in the western half of the country (Walker, 2016).

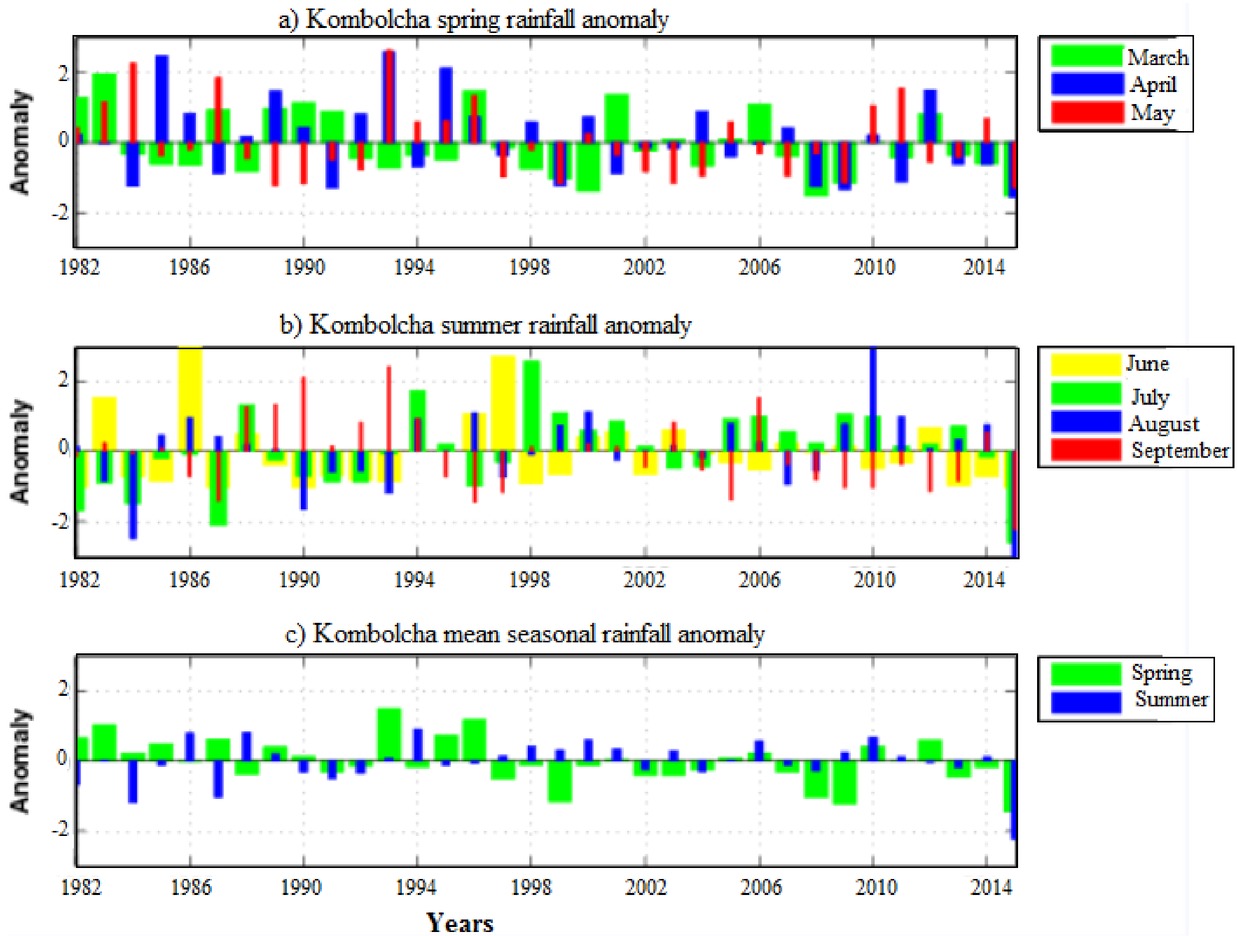


Figure 9: Rainfall variability and trend of Kombolcha from (1982 – 2014)

In (Figure 9b) kiremt, rainfall season of Kombolcha in the period of June 1986 and 1997, July 1998, August 2010 and September 1990 and 1993 there was extreme or surplus increased rainfall, but there is strongly increased rainfall occurred in the years of June 1983, July 1994 moderately but September in the year of 1987-1994 strongly rainfall increased at Kombolcha. In July 1987, August 1984 extremely decreased rainfall and July 1982 and 1984, August 1990 and September 1987 and 1996 moderately rainfall decreased. However, in September from 2007-2013 there is strongly decreased consecutively at Kombolcha.

In (Figure 9c) from 1984-1996 kiremt, rainfall shows a decreasing strongly at the same years of belg rainfall were a positive event. But in the year of 1990-1992 at all seasons consecutively for three years the rainfall decreased and similar result we get in previous study to Degefu (1987) and

Webb et al. (1992). Kiremt rainfall shows events that are more positive in the station for Kombolcha at the period 1997-2014. Belg rainfall, on the other hand, shows a decreasing trend at the station in the same years. Driest and wettest year's kiremt and Belg of Kombolcha. The year 1984 by far remains as the extreme driest kiremt year. which is in agreement with earlier studies. It has been widely reported that the 1980's stand out as the driest decade in the last century (Conway, 2000; Bewket and Conway 2007) and the year 1999 and 2009 the driest belg in the stations receiving a record low rainfall. The extreme wettest kiremt year 1994, 1986, 1988 and 2010 and belg year 1883, 1993 and1996. The driest belg occurred more in between in1997 and 2010, similarly between in the period of 1993 and 1996 in wettest belg of the stations

Kiremt claim higher rainfall contribution to the annual total rainfall in Ethiopia and Belg season rainfall (MAM) makes a significant contribution to total annual rainfall in the Kombolcha and little to Debre Markos of Ethiopia or in most part of central Ethiopia. Inhabitants of these parts of the country are agricultural and hydrological beneficiaries despite that the largest share of rainfall occurs during Kiremt season (JJAS). The residents of this area are nomads whose livelihoods revolve around cattle, and the MAM rainfall over the area is crucial for social and economic benefits such as water harvesting and grazing.

Generally Warming in the Indian Ocean which has been linked to anthropogenic causes (Funk et al. 2005, 2008) and topography have had major impacts on eastern African rainfall from March to June (Belg, Funk et al. 2008, Funk and Williams ,2010). It was suggested that long established inter annual teleconnections between large scale climate variability and long rains precipitation are being altered due to warming with in the south central Indian Ocean. Reduced rainfall across eastern Africa, thus, is linked to deep atmospheric convention over the Indian Ocean due to warming near tropical Pacific-Indian Ocean (Funk et al, 2008; Funk and Williams 2010).

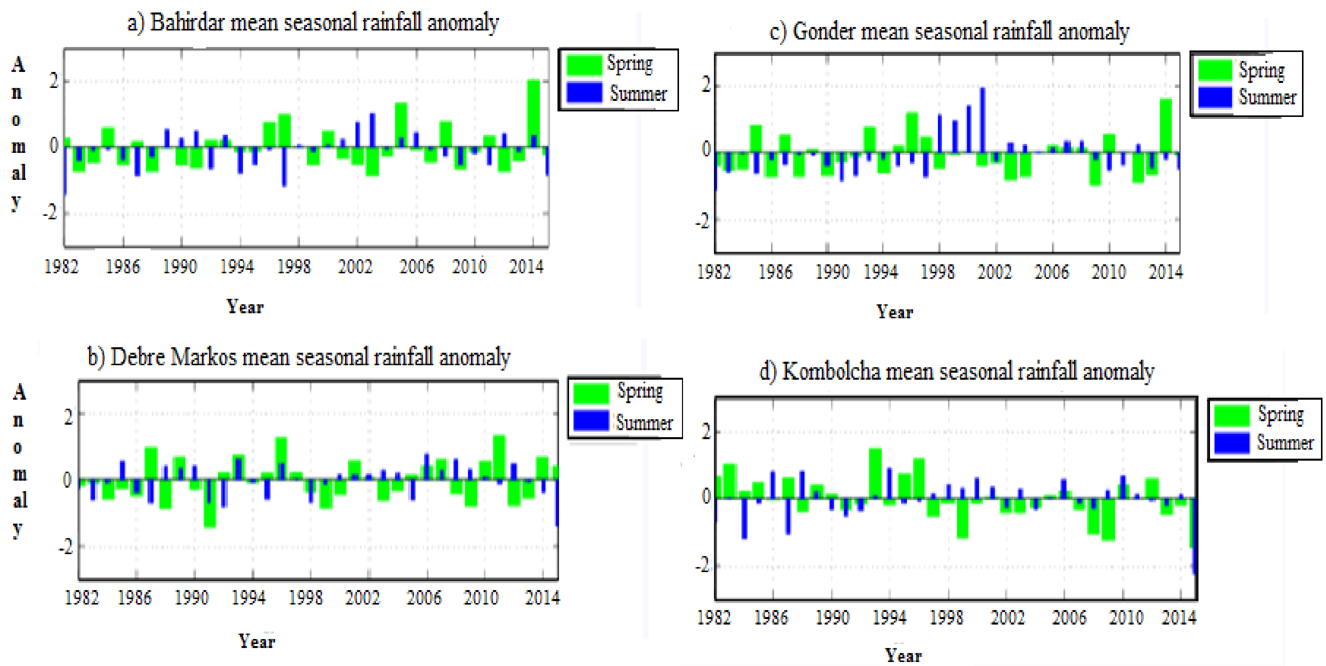


Figure 10: Inter annual Rainfall variability of the selected cities

There was high inter-annual variability in the amount of belg and kiremt rainfall. Kiremt rain has shown (Figure 10) an increasing variability trend of all cities (Bahir Dar, Debre Markos, Gonder and Kombolcha) there amount increased by 0.352mm, 0.105mm, 0.643mm and1.428 mm per year respectively in the period noted above. On the other hand, Rainfall of belg season has shown (Figure 9) decline trend from1982-2014. An increasing trend of Bahir Dar, Debre Markos and Gonder the amount increased by 0.505mm, 0.510mm and 0.359mm but Kombolcha has decreased by 1.106 mm per year over the past three decades. Were as a similar conclusion with Dereje et al. (2012) also found positive Kiremt rainfall trends at Bahirdar, Gondar and Kombolcha stations, whereas negative trends of Belg (spring) rainfall were identified at Kombolcha stations in the period of 1978-2008 for a decade.

In (Figure 10) belg at Bahirdar 2005 and 2014, Debre Markos 2011 and 1996, Gonder 2014 and Kombolcha 1993 and 1996 extremely increased the rainfall events and similarly at all thus cites in Bahirdar 1985, 1996 and 2008, Debre Markos 1987, 1989, 1993 and 2014, Gonder 1985 and 1993 and Kombolcha 1982, 1983, 1995 and 1996 strongly rainfall events increased. Similarly, there were decreased events at Bahirdar 1983, 1987, 2003 and 2013 and Gonder 1986, 1988, 1990, 2004, 2012 and 2013 moderately decreased events occurred. Also Debre Markos 1988, 1999, 2009, 2011, Gonder 2003, 2009 and 2012 and Kombolcha 1999, 2008, and 2009 strongly decreased rainfall events and at Debre Markos there is extremely decreasing rainfall event seen on 1991there is El Niño event occurred.

Kiremt claim higher rainfall contribution to the annual total rainfall in Ethiopia and Belg season rainfall (MAM) makes a significant contribution to total annual rainfall in the Kombolcha and little to Debre Markos of Ethiopia or in most part of central Ethiopia. Inhabitants of these parts of the country are agricultural and hydrological beneficiaries despite that the largest share of rainfall occurs during Kiremt season (JJAS). The residents of this area are nomads whose livelihoods revolve around cattle, and the MAM rainfall over the area is crucial for social and economic benefits such as water harvesting and grazing. However, we look belg rainfall in recent in 2000-2010 year for a decade trend over Gonder and Kombolcha there was decreasing strongly. Due to local, population and anthropogenic effect.

In (Figure 10) Kiremt at Bahirdar 2002 and 2003, Debre Markos 1985, 1993, 2006, and 2008 and Kombolcha 2000, 2006 and 2010 moderately increased rainfall event but also Kombolcha 1986, 1988 and 1994 strongly increased rainfall event. However, Gonder at 1998- 2001 extremely increased rainfall events. Similarly for cites there is decreased rainfall events occurred at Bahirdar 1997 and Kombolcha 1984 and 1987 extremely decreased rainfall events and also at Bahirdar 1987, 1992 and 1994, Debre Markos 1983,1987, 1991 1992, 1995, 1998 and 2005 and Gonder 1983,1985, 1991 1992 1997 and 2010 strongly rainfall decreased events occurred. However, the strong and extreme rainfall events occurred in the cites are related to ENSO, The El Niño - Southern Oscillation (ENSO) phenomenon is a global event arising from large-scale interactions between the ocean and the atmosphere in the tropical Pacific Ocean. ENSO have an impact on a seasonal shifting of the normal rainy seasons in some regions. As a result a shortening or lengthening of the rainy seasons. So there was similar conclusion Ethiopian Kiremt rainfall failures caused by El Nino and the mechanism not fully understood (Stephanie et al., 2016) and ENSO is the main source of predictive skill for Ethiopian seasonal rainfall so as ENSO and Ethiopian seasonal rainfall have negative and positive linkage (Kassa, 2015) .

All most in all stations annual rainfall has shown negative anomalies for much of the1980s but Gonder and Bahirdar the annual rainfall is continue to the middle of 1990's. There is similar result Historical Ethiopia droughts had been linked with ENSO events in the past years (Umer, 2000). Studies have shown links between large scale climate patterns and Ethiopian rainfall. Principal causes of extreme events had strongly been linked to fluctuations of global circulations. The cycles dominated by El Niño were associated with more area affected by drought at the global agricultural level (FAO, 2014).

Generally, Rainfall in much of the country is often erratic and unreliable; rainfall variability and associated droughts have historically been major causes of food shortages and famines. Rainfall in Amhara region show moderate inter-annual variability. A similar conclusion that Belg rainfalls are more variable than Kiremt rainfall.

4.2. Rainfall climatology of Amhara Region

The rainfall climatology of Ethiopia is by the traverse movement of the ITCZ, whereby it brings surplus of moisture in summer from the Indian and Atlantic oceans as it move northward of the equator hence more rainfall in the country. On the other hand, it brings dry air hence no or less rainfall during its Southward movement; this is due to continentally effect where by the north hemisphere is mostly continental.

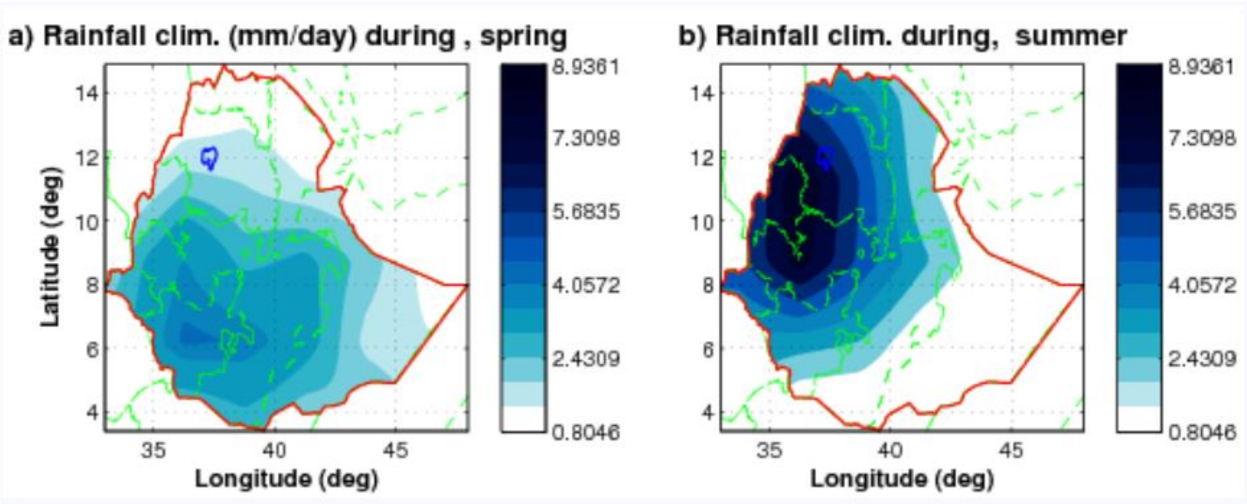


Figure 11: Rainfall climatology of Ethiopia (1982-2014)

In (Figure 11) below describe the rainfall climatology of the country for spring and summer. Accordingly in spring some western, southwestern and central parts of the country obtains a rainfall measured up to 6 mm/day, whereas northern and north eastern parts remains dry or obtains little rainfall. During summer which is the main rain season of the country western and northwestern parts obtains high rainfall amount up to 8.9mm/day where as other parts remains dry.

Similarly, the Amhara region, which mostly covers the central and northwestern parts of the country, obtains rainfall during the spring and summer. Figure 12. Illustrates the rainfall climatology of Amhara region for spring and summer. During spring while the southern and southeastern parts of the region obtains a rainfall up to 3 mm/day other parts of the region remains dry. Rainfall in spring in the region generally decreases from north to south. On the other hand, in summer which is the main rain season like other parts of the country the region obtains surplus of rainfall up to 8.5 mm/day. During summer rainfall decreases from east to west.

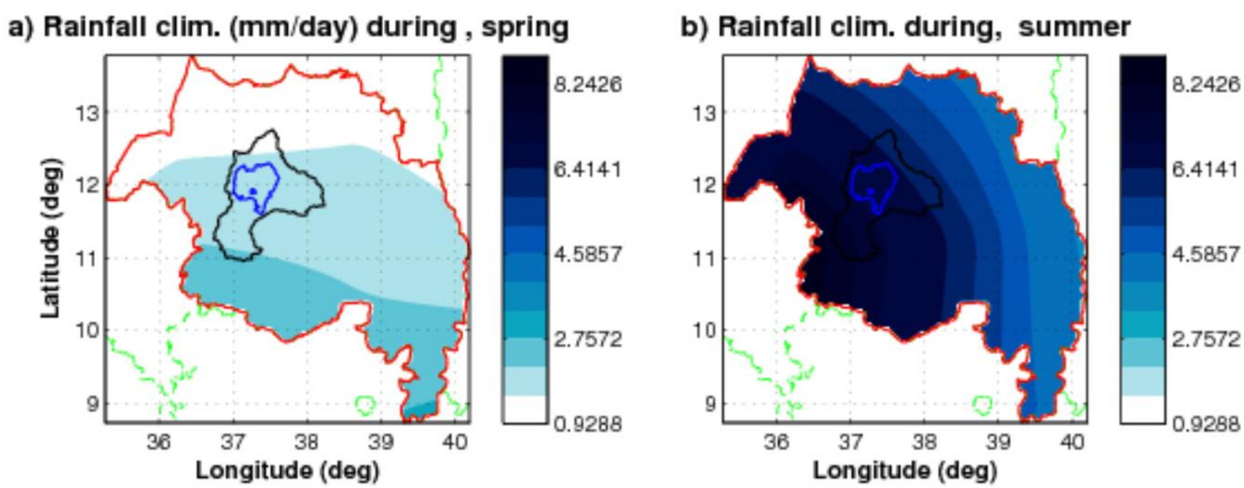


Figure 12: Rainfall climatology of Amhara Region (1982-2014)

4.3. Trends of Rainfall for Amhara Region

In order to understand the spatial changes in rainfall in Ethiopia and the Amhara region we have described the rainfall trends in (Figure 13) and (Figure 14) respectively. As it can be seen in (Figure 13 a) rainfall has been decreasing in spring for most parts of along the central rift valley region.

Similarly, in summer there have been a decrease of rainfall in most western and southwestern parts of the country. However, the rate of decrease during the study period was significant. Previous reports also show a decrease in rainfall of Ethiopia. For example Between the mid-1970s and late 2000s, spring and summer rainfall, based on quality controlled station observations, decreased by 15-20 percent across parts of southern, southwestern, and southeastern Ethiopia. Osman and Sauerborn (2002) determined that summer rainfall (known as Kiremt) in the central highlands of Ethiopia declined in the second half of the 20th century. In addition, a study by Verdin et al. (2005), Conway (2000) reported that there are no recent trends in rainfall over the northeastern Ethiopian highlands. Results of this study also confirm the above points.

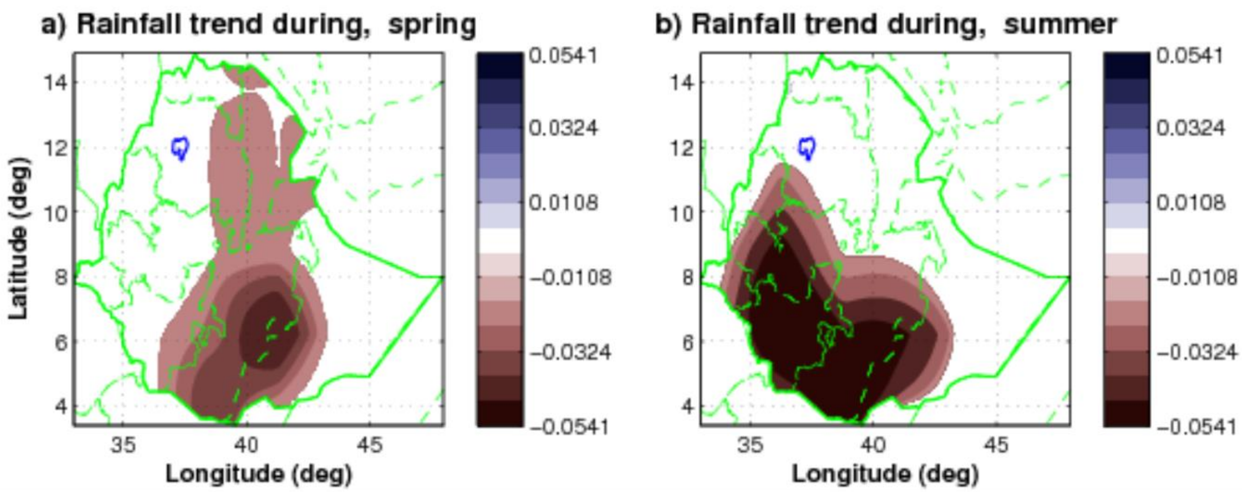


Figure 13: Trends of rainfall in Ethiopia (1982-2014)

In figure (14) Similar to Ethiopia in the Amhara region during spring there was a decrease in rainfall in its eastern tips. This is part of the central rift valley of Ethiopia. The central rift valley region is characterized as most erratic rainfall receiving region. Surrounding the highlands are regions known as the lowlands (<1500 m), where most of the remaining population (mostly pastoralists) lives (Devereux, 2000). During summer, the region shows no trend except few west central parts showing a decreasing.

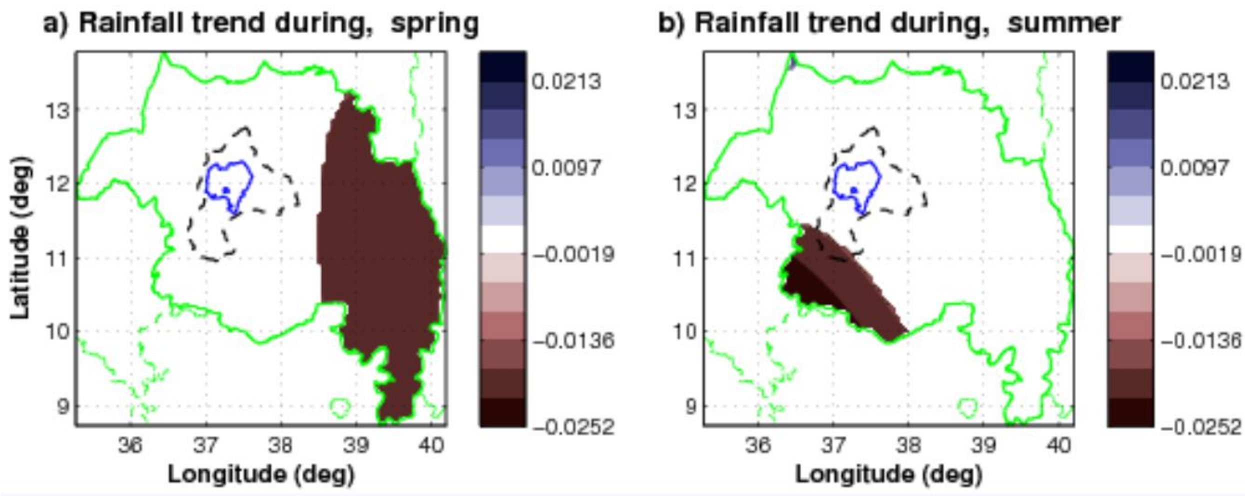


Figure 14: Trends of rainfall in Amhara region (1982-2014)

Generally, the trend of rainfall in the country as a whole and in Amhara region shows a decrease. However, the trend of decrease is not significant.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study has presented a detailed analysis of spatial and temporal variability of rainfall and its current trend in four upper Blue Nile river basin stations; using records of daily and monthly rainfall data from 1982 to 2014. The study of precipitation time series and trend of selected four stations using with various graphical and methods enabled to characterize and analyze the long-term temporal behavior and spatial trend of rainfall in the study stations.

Kiremt rainfall contributed the highest percentage of rainfall at the stations and Belg rainfall is in significant but for Kombolcha it is dominantly and at Debre Markos less significant, this rainfall is significant for annual rainfall at those stations. The use of different time periods in the analyses of rainfall is the main reasons for the contrasting and comparing clearly to look the weather and climatological results of the selected stations.

All most in all stations annual rainfall has shown negative anomalies for much of the1980s but Gonder and Bahirdar the annual rainfall is continue to the middle of 1990's. In Ethiopia, droughts had linked with ENSO events in the past years. The intensity of rainfall had also determined by the El Niño Southern Oscillation (ENSO), which tends to reduce rainfall in the main rainy season and increase rainfall in the Belg season. The local features and anthropogenic activities factors have effect on rainfall variability. Similarly, local factor have had major impacts on Kombolcha and Debre Markos rainfall of Belg. In addition, the distance from the lake there was significant effect on the rainfall events in the stations.

The main wet seasons, the June–September precipitation has strong connection to the influence from the Indian and Pacific Oceans. In the spring season, the annual variability precipitation had positively linked to sea level pressure (SLP) at Pacific and most parts of Indian Ocean whereas negatively correlated with Atlantic Ocean and Asian Peninsulas in summer season. Similarly, SST in spring season has positive correlation with Southern parts of India Ocean. On the other hand, during summer season precipitation variability had positively linked to SST at Atlantic and Indian Ocean and negatively correlated with southern parts of India and Pacific Oceans.

5.2. Recommendation

It is highly recommended that data recording and management have to be improved, to facilitate for further atmospheric research and development. Modern and reliable weather and climate observation facilities with reasonable spatial temporal distribution need to be establish, to enhance atmospheric research in the country. In the light of decreasing precipitation during the main rainy season of the research area, water resource management and supporting policies should be thoroughly designed and strictly implemented. This would enable to tackle the challenges of rainfall deficit, and meet the ever-increasing demand of progressively growing water potential. Furthermore, future climate research in Ethiopia should focus on integrated climate and agro-ecosystems research, to ensure efficient resource development and its effective management at national level, and to contribute to the global climate and environmental research and management. Therefore, a lot have to done in awareness creation work on climate change at the local and regional level.

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