Addis Ababa University

Collage of Development Studies

Center for Environment and Development Studies

# Hydro-Climatic Trends in the Upper Awash River Basin, Ethiopia

A Thesis Submitted to the Center for Environment and Development Studies Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in Water Resource Management.

By: Kidanu Belete

Advisor Dr. Ermias Teferi (PhD)

November, 2018

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# BOARD OF EXMINERS

This is to certify that the thesis prepared by Kidanu Belete, entailed Hydro-Climatic trends in Upper Awash River Basin, Ethiopia and submitted in partial fulfillment of requirements of Masters of Science in Water Resource Management complies with the regulation of Addis Ababa University, college of Development studies and meets the accepted standards with respect to originality and quality.

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# Declaration

I declare that this thesis is my original work and has not been presented in any other universities and for consideration of any certification. This research thesis has been completed by referenced sources where text, data, graphics, pictures have been borrowed from other sources including the internet, these are specifically accredited and references cited using current APA system and in accordance with anti-plagiarism regulations.

Advisor name______________________________ signature ______________

Date _____________________________________

Name: Kidanu Belete

Signature___________________________ Date: _____________________

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Center for Environment and Development Studies

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## Content

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# ABBREVIATIONS

| | |
|---|---|
| CFC | Chlorofluorocarbon |
| DTR | Diurnal Temperature Range |
| FAO | Food and Agriculture Organization |
| GHA | Great Horn of Africa |
| GHGs | Greenhouse Gases |
| $H_A$ | Alternative hypothesis |
| $H_o$ | Null hypothesis |
| IPCC | Inter governmental Panel on Climate Change |
| JJAS | June, July, August and September |
| Km | Kilometer |
| MCM | Million Cubic Meters |
| MER | Main Ethiopia Rift |
| MK | Mann-Kendall |
| mm | Millimeter |
| MoWE | Ministry of Water and Energy |
| NMA | National Metrological Agency |
| NMSA | National Meteorological Agency |
| UNDP | United Nation Development Program |
| UNFCCC | United Nations Framework Convention on Climate Change |

# ABSTRACT

The aim of this study is to detect and analyze the trends of monthly seasonal and annual temperature, precipitation and stream flow in the upper Awash River Basin. A number of statistical tests exist to assess the significance of trends in time series. One of the commonly used non-parametric trend tests is Mann-Kendall test. The null hypothesis in the Mann-Kendall test is that the data are independent and randomly ordered. In this study, mean monthly, seasonally, and annually temperature, precipitation, and streamflow have analyzed to determine the variability in magnitude over the period1986-2017. Trend in mean monthly, seasonally, and annually temperature, precipitation and streamflow trends are analyzed using Mann-Kendall test and sen's slop estimation for the data period 1986-2017. In this paper, therefore, an attempt has been made to identify the trends of temperature, precipitation and streamflow on different climatic and hydrological stations in the Upper Awash River Basin. The study has analyzed monthly, seasonally, and annually precipitation, maximum and minimum temperature, and streamflow trends over the upper Awash River Basin. The mean maximum and minimum temperature for monthly, seasonally, and annually has shown sharp increasing trends especially minimum temperature for most of the stations. Analysis of monthly, seasonally and annually trend in precipitation shows negative trends for months, seasons and annually of most stations. However, some stations show forward trend at the significant level alpha =0.05. The trends of the streamflow also show significant decreasing trend for the selected hydrological stations.



Key words; Mann-Kendall, hydro-climatic, upper awash River basin.

# Chapter One

# 1. Introduction

## 1.1. Background of the study

The hydro-climatic trends have become an increasingly important issue in the deployment and management of water resources. Hydro-climatic systems are highly complicated as they consist of atmosphere, hydrosphere, cryosphere, geosphere, and biosphere (Huagi et al., 2012).

Change in hydro-climatic series affects the environmental and economic development (Chen et al., 2009).studies on climate have been a focus on changes in precipitation, air temperature, and evaporation. The hydrological cycle in a catchment is complex and influenced by climate, the physical characteristics of the catchments, and human activities. However, it is still unclear that how precipitation on and temperature series changes mate have affected discharge (Birsan et al., 2005), and which is the main driving factor for the discharge. Precipitation is one of the most important hydrological variables of the basin. In particular, it greatly influences the amount of water flowing through the water cycle and water availability. In general, the higher the precipitation, the more water is accessible; low precipitation and drought generally reduce water contribute. Similar to precipitation temperature is another important parameter in assessing the climate change impact on water resource system. According to climate model predictors, using several scenarios of greenhouse gas emission, global mean temperature probably will be increased from 1.1 to 6.4 $^{o}$ c in the next 100 years (IPCC, 2007). The natural stream flow is defined as the characteristic pattern of rivers flow quantity, timing, and variability (Proff et al., 1997). It may be classify by seasonal variation in its stream flow and is usually characterized by a temporal pattern of monthly mean stream flow. It is widely accepted that the seasonal variation of river runoff depends on the climate and catchment characteristics (Burt, 2013). Important climatic factors include precipitation, air temperature, and evaporative demand controlling the recharge of surface and subsurface water shortage and influencing the loss of water though evaporation, other interacting factors responsible for the transformation of rainfall to runoff at the catchment scale are those related to topography, soil texture, ground water aquifer and vegetation cover. Rising global temperature have been accompanied by change in weather and climate. Many regions have seen significant changes in precipitation which have led to more floods, droughts, as well as more frequent and severe heat waves (IPCC, 2007; Shrestha et al., 2012; Kang et al., 2007; Dai, 2013). Stream flow as an important hydrological variable is a combination of what happens to precipitation, temperature, and other components of hydrological cycle with a large basin (> 100,000km$^2$); as such stream flow can be used as an indicator of hydrological responses to climate change ( Hao et al.,2008;Fu et al.,2007;Sankarasubramaian and Voger,2003;Li oubimtseva and Henebry,2009).

Precipitation is one of the key climatic variables that affect the spatial and temporal patterns of water availability. One of the challenges posed by climate change /climate variability is ascertainment, identification, and quantification of trends in precipitation and their implication on river flow in order to assist in the formulation of adaptation measures through appropriate strategies for water resources management. It is also recognized that rainfall is one of the key climatic variables that affect both spatial and temporal patterns on water availability (Deluis et al., 2000). In the analysis of trends of precipitation in the Ethiopia upper Blue Nile Basin, Srak et al. (2013) observed that the trends of precipitation are not significant both monthly and seasonal scale for the major stations. However, for some monthly values statically significant decreasing were observed. Trends in precipitation and in the maximum and minimum temperatures are useful indicators of climate variability and changes (Braganza et al., 2004). Hence, several studies have been carried out on precipitation (Nicholls et al., 1996; Hume et al., 1998; ICPP, 2001). And maximum and minimum temperature (Easterling et al., 1997; Vose et al., 2005, 2006) on the global scale over the last two decades. In general, there are increases of around 0.1-0.15 $o_C$ pre decade for the maximum temperature and 0.1- 0.12 $^o$ c per decade for the minimum temperature. Studies on precipitation over global land area also showed increasing trends. Nicholls et al. (1996) reported a 1.0 % increase precipitation, where as Hume et al. (1998) reported an increase of about 2% over the global land area during the $20^{th}$ centuries. Similar studies on these key climate variability and trend indicator have also been conducted in Ethiopia by Conway (2002), NMA (2001,2007), Osman and Sauer –born (2002), Conwary et al. (2004), Seleshi and Zanke (2004), Verdin et al.(2005), Bewket and Conway (2007), Cheung et al.(2008), McSweenery et al.(2012), Abebaw et al.(2009),ACCRA(2012), Ayalew et al.(2012), Tury and Funk (2012), Taye and Zewdu (2012), Tesso et al.(2012) and Viste et al. (2012). Regardless of the difference in temporal and spatial scales analyzed, these studies reported a consistent warming trend in maximum and minimum temperature over the past few decades in Ethiopia. NAM (2001, 2007) reported an increase of 0.1 $^{o}$ c per decade for the maximum temperature and 0.25-0.37 $o_C$ per decade for the minimum temperature. McSweenery et al. (2008) observed an increasing trend of about 0.28$o_C$ per decade for the mean annual temperature across Ethiopia. The warming varied with seasons; the most rapid rate of change of 0.32 $^{o}$ c per decade was found for summer (McSweeney et al., 2008). Many of the studies mentioned above found that minimum temperature has been increasingly faster than the maximum temperature. McSweeney et al. (2008) attribute the difference between the minimum and the maximum temperatures to the increase in hot nights. Studies on rainfall, on the other hand don't show any consistent pattern or trends. NMSA (2001) reported a declining trend for the northern and southern parts and an increasing trend for the central part of the country. In contrast, Osman and Saverborn (2002) observed a declining trend for the central highlands. Seleshi and Zanke (2004) and Cheung et al. (2008) did not find a trend in the central high lands. Instead, Seleshi and Zanke (2004) reported a declining trend in the east, south and southwest part of Ethiopia. Verdin et al. (2005) reported a similar declining trend in the south western and eastern parts. Jury and Funk (2012) also reported a similar declining trend in the south western region and they further projected these trends to continue until 2050.

There are many parametric and nonparametric methods that have been applied for detection trends (Zhang et al., 2006). Parametric tests are more powerful than nonparametric ones, but they require data to independent and normally distributed. On the other hand, non parametric test only require the data be independent and can tolerate outliers in the data. One of the widely used non parametric tests for detecting a trend in hydro-climatic time series is the Mann-Kendall (MK) test (Hirsch et al., 1982; Van Belle and Hughes,1984;Zetterq-vist,1991;Zhang et al.,2001;Burn and Elnur,2002;Yue et al.,2002;Yue and Wang,2002;Yue and Pilon,2004; Burn et al.,2004;Zhangbet al.,2005;Arora et al., 2005; Aziz and Burn,2006;Gemmer et al.,2004;Zhang et al.,2006; Zhu and Day,2005).. Burn and Elunr (2002) developed a trend detection framework with utilized the MK test to identify trends in hydrological variables.

## 1.2. Statement of the problem

Climate change will be have wide- ranging effects on the environment, and on socio-economic and related sectors, including water resource, agriculture and food security, and human health, terrestrial ecosystems and biodiversity and others. Changes in rainfall pattern are likely to leads to severe water shortages and /or flooding. Rising temperatures will cause shift in crop growing seasons which affects food security and changes in the distribution of disease vectors putting more people at risk from disease such as malaria and dengue fever. Temperature increases will potentially severely increase rates of extinction for many habitats and species.

The Awash basin is the most intensively important basin in Ethiopia. Extensive irrigation schemes have been functional for many years following the construction of the main structure, Koka dam in 1960. Now the reservoir is constantly filling up with sediment and has lost more than 30% of its water storage capacity. Due to this continuing reduction in capacity, the water management of the reservoir is becoming extremely difficult. One of the most results of climate change will turn in a major hydro-climatic variable, such as streamflow, temperature, precipitation, evapotranspiration etc. This, in turn, will lead to change in the hydrological cycle influencing the components of the water balance of drainage basins in several ways such as the availability and distribution of water resource in space and time, For instance, stream flow, etc.

There are some physical problems in the Awash River basin, such as flooding and sedimentation of Koka reservoir. These problems result in the decrease in storage capacity of the reservoir dynamically. The storage capacity of Koka reservoir is estimated to be reducing at a rate of 17Mm $^{3}$ per year and the possibility of high sedimentation rates is a major problem for downstream situations so there is an expectation that the energy supplied from Koka reservoir may not meet fully the demand of the basin in the future. On the other hand, there are some small and large-scale irrigation projects and currently planned, designed and on implemented. The unbalance between demand and supply may lead to conflicts among users in the basin (Berhanu, 2008).

Many researchers worked a research in upper Awash River basin in different aspects, for example, Zelalem (2015), Shimelis (2014), Mengstu (2008), but no one did hydro-climatic trends in the Upper Awash River Basin. Therefore, this research focuses on the hydro-climatic trends of the past 30 years ago.

## 1.3. Objective of the study

### 1.3.1. General objective of the study

The general objective of this study is to detect the presence of hydro-climatic trends in the upper Awash River basin.

1.3.2. Specific objectives of the study

- To analyze the trends in temperature and precipitation.
- To analyze the trends in streamflow of the Upper Awash River Basin.

## 1.4. Significance of the study

The significance of this study is to predict the future fates of hydro-climatic trends of the upper Awash River basin.

The detection and attribution of past trends, changes, and variability in climatic variable is essential for understanding of potential future change resulting from human being activities.

## 1.6. Delimitation of the study

Hydro-climatic trends are very important study because trend research is used to predict the future challenge that facing different country including Ethiopia. Hydro-climatic research includes many climatic and hydrologies but in this study focus only the trend of precipitation, stream flow and temperature in the Awash River basin for the last 30 years.

## 1.7. Limitation of the study

The main limitation of using secondary data is that the secondary researcher did not participate in the data collection process and does not know the exactly how it was collected. Therefore the secondary the secondary researcher does not know how will it was done and if the data are affected by problem such as low response rate or respondent misunderstanding of the survey question. The other limitations of this study are the lack of availability of the data occurrences and time lag issue.

Chapter Two

# 2. Literature Review

## 2.1. Climatic Variability and Trends in the Globe

The knowledge of climate variability over the period of instrumental records and beyond on different temporal and spatial scale is important to understand the nature of different climate system and their impacts on environment and society (Oguntande et al., 2012). The global climate has changed rapidly with the global mean temperature increasingly by 0.7 °c within the last century (IPCC, 2007). However, the rates of changes are significantly different among regions (IPCC2007). Several studies have been carried out at different temporal scale and in different part of the globe for example, Hasanean (2001) examined trends and periodicity of air temperature from eight meteorological stations in the east Mediterranean and observed positive significant trends in the Malta and Tripoli, and negative trend in Amman. Turkes et al. (2002) evaluated mean maximum and minimum air temperature data in Turkey during the period 1929-1999. Their analysis reveled spatiotemporal patterns of the long term trends, change point, and significant warming and cooling periods. Easterling 1997, Fan et al.2010 reported separately that diurnal temperature range (DTR) has been on decrease in most region of the world. Karl et al. (1993) analyzed temperature data from 37% of the global land mass and found high increment in the minimum and compared to the maximum temperature. Minimum temperature increase about twice as faster as maximum temperature over the global land areas since 1950, resulting in the abroad decline in the diurnal temperature range (DTR) (Folland et al.,2001). Annual maximum daily precipitation data represent one of the most important and readily variable measures of extreme rainfall and, are used frequently input to assessment of flood risk (Bate etal.2008; Field et al.2012; Min et al.2011). Observational studies of this variable from a critical line of evidence into how precipitation extremes have changed over the instrumental records and recent finding are showing that a global or continental scale, extreme precipitation events have been increasing in the intensity and /or frequency. For example, Alexander et al. (2006) used gridded precipitation data based on 5948 stations globally and found that precipitation change exhibited

a widespread and significant increase. Min et al. (2011), using the same dataset but different analysis approaches, found that 65% of the data covered areas have positive trends for annual maximum daily precipitation over the period of from 1951 to 1999. Groiman et al. (2005) used a different extreme (the magnitude of the daily precipitation even falling within the top 10% or 5% of all precipitation events) and found that in the mid latitudes, and in particular over Northern America, there has been a widespread increase in the frequency of very heavy precipitation events during the past 50-100 years.

Precipitation is one of the most important variables for climate and climate hydro- meteorology. Change in precipitation patterns may lead to floods, droughts, loss of biodiversity and agricultural productivity. Precipitation has changed significantly in different parts of the globe during the $20^{th}$ century (New etal. 2001). Climate change studies have been demonstrated that the land surface precipitation shown an increase of 0.5-1% per decades in most the Northern Hemisphere mid and high latitudes, and annual average of regional precipitation increase 7-12% for the areas in 30-85°N and by about 2% by the areas of 0°-55 ° S over the $20^{th}$ century (Houghton et al., Xu etal., 2005).

Table2.1: significant temperature trend around the world

| Region/ country | Significant trend | Source |
|---|---|---|
| Global | 0.5°c/100years | (Easterling etal.,1997) |
| Global | 0.3°c/10 years in 54 years data | ( Vose et al.,2005) |
| Pakistan | 0.5°c to 1°c increase | (Muhammed et al.,2004) |
| Pakistan | 0.133°c/10 years (1976-2005) | (Shan,2008) |
| Pakistan | 0.64°cincrease from 1901 -2007 | (Afzaal et al.,2009) |
| Himalayan region | Maximum temperature is more than minimum temperature | (Bhutiyani et al.,2010) |
| Northeast Himalayan | 1.0°c during winter 1.1°c during autumn over the last century. | (Dash et al.2007) |
| Turkey | 1.1°c/ 50 years | (Kadioglu,1997) |
| Bangladesh | 0.61°c from 1961-1999 | (Islam et al.,2008) |
| India | 0.4°c/100 years | (Kumar et al.,1994) |
| India | 0.25°c/decade | (Dash and Hunt.2007) |
| Nepal | 0.06°c/17 years | (Shrestha et al.,1999) |

| | | |
|---|---|---|
| Nepal | 0.04°c/ 30 years | (Shrestha,2005) |

## 2.2. Climatic Variability and Trends in Africa

Climate variability has been attributed to changes in the 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 along run of dry years for sub Saharan West Africa during the 1940s. Climate is classified based on the average rainfall which assists in differentiating climatic regimes. Rainfall variability in Africa has been studied by several periods in the 70s. Many studies compared sahelian rainfall with rain over west and central Africa sub-regions (Ogo and Adeyem 2009; Gbuyio et al., 2002). Others focus on spatial and sub-seasonal patterns of the long term trends (kumer et al., 1992). Omogbai (2010) studies rain day in south western Nigeria between1970-2006. Guhathakurta and Rajeevan (2006) study the trends in the rainfall pattern over India between1901-2003.  Subyan (2004) studied the Geostatistical study of annual and season –mean rainfall patterns in south west Saudi Arabia. The differences mean annual rainfall over west and central Africa because of the severity of drought was confirmed by Ragab and prudhomme (2002). Their founding s and results showed that long-term trends rainfall series over these regions depict major climatic discontinuity. The global mean surface temperature has increased in linear of 0.74°c over the last 100 years (IPCC2007). The continents of Africa is generally noted to be hot and dry with current trends showing warmer spells than was 100 years ago (Hulme et al.2005;Kurukulasuriya et al.2006; Vande Seteeg et al.2009).Observed temperature have shown a greater warming trend since the 1960s (IPCC2007). Warming through the twentieth century has been at the rate of about 0.5°c /century with slightly larger warming in the June – August and September –November season than in the December – February and March-May (Hulme et al.2005).The rate of warming does not differ from that experienced globally and the periods of most rapid warming the 1910-1930 and the past 1970s which occur simultaneously in Africa and the world (Hulme etal.2005; IPCC 2001). According to the third Assessment report (TAR) of the IPCC, the Earths average surface temperature increased 0.6±0.2 °c in the twentieth century. This trend is expected to with a rise of

1.4 to 5.8 °c by 2100 (IPCC2001). With respects to future changes, the whole of Africa is expected to warm across all seasons throughout this century (Boko etal.2007).

JJAS precipitation declined substantially throughout the much of the GHA during the 1948-2009 periods. GHA precipitation is decreased by approximately one standard deviation during the 1950-1989(Park Williams et al., 2011). Several studies investigating temperature trends over South Africa have been published in the literature. Analyses of both remote sensing derived and observed temperature records in South Africa agree that over the last decades the region has been experienced a warming trend. Several studies have analyzed the observed temperature trends and the basic conclusion from their investigation is that temperature in the region is rising, with minimum temperature rising faster than maximum temperature indicated that extreme daily maximum minimum temperature have warmed for the most region of the world including Africa 1950. Florida investigated the variation of near surface air temperature anomalies in Africa between 1979 and 2010 and found significant increasing temperature trends in each of the following regions examined all of Africa, Northern Hemisphere Africa, south Hemisphere Africa, tropical Africa, and subtropical Africa. Muhlenbruch (1992) reported a decrease in maximum temperature but increase in minimum temperature in South Africa between 1940 and 1989. These findings were later contrasted by karl et al. who reported an increasing in both maximum temperature and minimum temperatures but a decrease in the diurnal temperature range in South Africa, for the period 1951 to 1991 analyzed 26 climate stations showed positive trends in their annual mea maximum temperature series 13 0f them were significant. Annual mean minimum temperatures showed 21 stations having positive trends, with 18significant sinvestigated trends in daily maximum and minimum extreme temperature induce from 28 weather stations in south Africa for the period of 1962to 2009 and conclude that warm extreme increased and cold extremes decreased. Freddy et al. investigated the temperature trends over Limpopo province, South Africa, for the period 1950 to 1999, and observed an increase of 0.12 °c per decade in the mean annual temperature for the 30 catchments. Anon-uniform pattern of changes in temperature was evident across the different catchments; 13% of the catchment showed negative trends while 87%Showed positive trends in their annual mean temperature. Furthermore 20% catchment showed negative trends with 80% catchments showed positive trends in their diurnal temperature range. Samba and Ngamda analyzed maximum and minimum temperature time series of Congo-Brazzaville, where the temperature series showed an irregular increase. Moreover, reported that in the future the whole Zambezi river basin is expected to become hotter, drier and more variable, experiencing more prolonged drought periods and more extreme floods. In general, Africa has been increasing trend maximum and minimum temperature trends.

It is recognized that rainfall is one of the key climatic variables that affect both the spatial and temporal patterns of water availability. In recent decades may studies have been done on climatic trends, especially for precipitation and temperature, compared to the time before the issue of climate change which become more prominent during the 1980s. Rainfall variability and changes in southern Africa over the 20$^{th}$ century and their potential links to the global warming have been discussed, which indicated that rainfall variability in southern Africa has experienced significant modifications, especially in the recent decades. Inter annual variability has increased, drought and floods became more intense and widespread. Other studies examined spatial variations of trends of relevant extreme precipitation indices for 138 rainfall stations in South Africa for the period 1910to 2004 and concluded that while in the largest part of south Africa there has been no real evidence of changes in precipitation over the past century, there are however some identifiable areas where significant changes in certain characteristics of precipitation have occurred over the period 1910to 2004. Reported that currently, rainfall trends are characterized by more severe droughts in the southwest of southern Africa and enhanced rainfall further north in Zambia, Malawi, and northern Mozambique. According to Kitoh et al., the heavy precipitation indices have increased in al., regional domains of southern Africa although the mean precipitation decreased. According to Koninkliik Nederlands Meteorology institute, models generally show that drying trends for much of the 21 century for southern Africa. Humududu found increases in northern Zambia and southern Congo while the northern Congo basin found reductions and in southern Africa region, there is a tendency of decline in precipitation.

Instrumental and observational records have shown that climate and environmental conditions in Africa continue to exhibit significant changes. Alteration in temperature, rainfall, extreme weather events have been documented across SSA (e.g. Baker 2000; Hulme1996 a, b; Hulme et al.2001, 2005; LHote et al. 2002; Nicholson et al.2000, Nicholson2001). These studies have shown that change in climatic variables such as temperature, precipitation and, extreme weather events such as flood and droughts and their distribution have been dramatic across SSA. The situation is expected to persist in the coming decades.

## 2.3. Climatic Variability and Trends in Ethiopia

The seasonality of rainfall varies in different areas of Ethiopia. In eastern Somalia region, rains come twice a year during the March-June Belg season, and during the October-December dry season. In the south central part of the county, most area revives both Belg and summer (June – September) kiremt rains. Spring and summer rains in parts of Ethiopia have declined by 15-20 percent since the mid 1970s. Between the mid 1970s and late 2000s, Belg and Kiremt rainfall, based on quality controlled station observation, decreased by 15-20 percent across part of Southern, Southern Western, and Southeastern Ethiopia.

A range of studies on national climate trends since the 1960s showed that mean annual temperature in Ethiopia have increased by between 0.5 and 1.3° C. in addition the frequency of cold night (linked to forest in dry season) has decreased significantly in all seasons. Although national models and missing data obscure regional differences in variability and trends, there is evidence of a declining trend in the February to April short rains from 1981 to 2000, and slight increase in the June to August long rains, as well as in October and November over the same time. A review of 18 different models and emission forecasts predicted warming of 1.2 ° C by the 2020s in all four seasons. Another study predicts that temperatures could increase by 1.5 ° C and 5.1° C by 2090.

Similar studies by UNDP climate change profile for Ethiopia (2008), also show that the mean annual temperature increased by 1.3 ° C between 1960 and 2006. The temperature increased has been most rapid from July to September (0.32° C per decade). It is also reported that the average number of hot day and number of hot nights per year between 1960and 2006 has increased by 73 and 137, respectively. The rate of temperature change was highest in rainy season in the months of June, July and August.

Studies on rainfall, on the other hand, do not show any consistent pattern or trends. NMSA (2001) reported declining trends for the northern trends for the northern and southern parts and increasing trends for the central part of the century. In contrast, Osman and Saueborn (2002) observed a declining trend for the central highlands. Seleshi and Zanke (2004) and Chengu et al. (2008) did not find a trend in the central highlands. Instead, Seleshi and Zanke (2004) reported declining trends in the east, south, and southwest part of Ethiopia. Verdine et al. (2005) reported a similar declining trend on the south western and eastern parts. Jury and Funk (2012) also reported similar declining trends in the south western region and they further projected these trends to continue until 2050.Verdin et al (2005) and Conway (2000), however, did not find any trend in rainfall over the northern eastern Ethiopia highlands.

Several studies on the key climate variability and trend indicators have also conducted in Ethiopia by Conway (2002), NMA (2001, 2007). Osman and Sauer born (2002), Conway et al. (2004), Seleshi and Zanke (2004), Verdin et al. (2005), Bewket and Coway (2007) Cheung et al. (2008), Mc.Sweeney et al.(2008), Abtew et al.(2009), ACCRA(2012), Ayalew et al.(2012) , Jury and Funk (2012),Taye and Zewdu(2012), Tesso et al. (2012), and Vist et al. (2012). Regard less of different in temporal and spatial scale analyzed; these studies reported as consistent warming trend in the maximum and minimum temperature over the past few decades in Ethiopia. NMA (2001, 2007) reported an increase of 0.1°C per decade for maximum temperature and 0.25to 0.37°C per decade for minimum temperature trends.

According to the Ethiopian National Meteorological Service (NMA, 2001) study 42 meteorological stations, the country has experienced both dry and wet years over the last 50 years. Trend analysis of the annual rainfall shows that there was a declining trend in the northern half of the country and southern Ethiopia while there is an increasing trend in the central part of the country. However, the overall trend in the entire country is more or less constant (Haileyesus 2001).

## 2.4. Hydrological Variable and Trends in the Globe

A number of recent studies have also identified some trends in stream flow in U.S. Lins and Slack (1999) analyzed records from relatively undistributed water sheds across the U.S and found that low to moderate (but not high stream flows have increased in some regions. Douglas et al. (2000) found that trends observed in annual maximum stream flows disappear after accounting for their spatial correlation. Groisman et al (2001) found that stream flow has increased across the eastern united states during the month of maximum flow (spring for most station) and that these trends can be attributed to increases in the intensity of extreme precipitation events during that season.

## 2.5. Causes of climate change

Climate change refers to statistical changes of weather over time and includes long-term changes in rainfall wide, temperature and other pattern (Girma, 2017). There are different causes of climate change to the planet. Natural factors such as solar variability, volcanic dust levels, internal variability (geological changes), human factors (industry), and agriculture; GHGs emission (carbon from fossil fuel, from farm animal and rice paddies, Nitrogen oxides from vehicles), aerosols, Ozone depilation and land use change were the main contributors (Girma, 2017). The increase in the atmosphere carbon dioxide concentrations together with emission of carbon dioxide, volatile organic compounds, $CH_{4,}$ and halogenated compounds by industries destroy the stratospheric ozone layer and increase the global warming. Water vapor, carbon dioxide, methane, nitrogen oxides and ozone are among others that partly trap the reflected radiation to warm the surface temperature. Anthropogenic climate change has recently become a well established fact and the resulting impact on the environment is already being observed.

Recent projections suggested that average temperature could increase by 1.4° C-5.8° C by 2100 (UNFCCC). Most climate scientists agree that the main cause of global warming is human activity. Driving your car, using electricity in your house, and using aerosol products all contribute to GHGs. Three help reduce GHGs and produce oxygen. However, right now, the forests were being destroyed at unprotected rate (John, 2011).

The present warming of the globe that causes climate change is chief attributed to change in the concentration of various gases in the atmosphere, which affects the earth radiation balance including carbon dioxide, Methane, Ozone, nitrogen oxide and chlorofluorocarbons (CFCs). These gases are called green house gases as they trap heat in the atmosphere just as green house used to grow plant trap sunlight to raise the heat inside source of green house gases in the atmosphere are mainly the contribution of fossil fuels (oil and natural gas) for industry and transport rapid industrialization, fast growing population, deforestation for agriculture, upland urbanization and infrastructure developments. The level of these GHG has been increase and the net result is a gradual increase in global warming (McCarthy, 2001).

According to McCarthy (2001), the green house effects, due to the gases has been intensifying since the later part 20 $^{th}$ century and global climate will remain warmer in the next 21$^{th}$ century (Karl et al., 2006; Trenberth, 1999). Particularly responsible is carbon dioxide, whose level in the atmosphere has amplified, due to increase in use of fossil fuels. On the other hand, the destruction of natural vegetation has prevented the environment from restoring the balance.

Karl and Trenberth (1999) described that human induced actions are dominate factors in the recent global warming and if climate mitigation measurement not adopted at the right time, situation will become the worst in the near future.

The earth's climate has warmed and cooled for millions of years, as observed from the historical temperature data of earth surface and oceans (Solomon, 2007). This natural warming and cooling of the climate is mainly the results of natural process such as variation in solar irradiance, change in the earth's axial tilt, change in drifting and volcanic activity (Kondratyeve and Cracknell ,1998; Rod and Comin 2003). However, the abrupt increases in earths mean temperature since the beginning of the 20$^{th}$ century, especially after the inception of industrial revolution led the scientists to relate the man-made emission of carbon dioxide and other green house gases for being the principal case of contemporary climate changes. This human induced increases in temperature and the resulting climate change is either directly or indirectly causing of the rising of sea levels around the world, frequent and uneven rainfall circulation flash flooding, prolong droughts, glacial melting, tropical cyclones, hurricanes, severe dust storms, dry and cold spells, have altered the availability of water and its quality, impacted the plants and land use pattern and many other environmental impacts (Alam and Rabbani, 2007).

Some variations in average temperatures across regions are related to changes with the region itself, and others are caused by the large scale global change in the climate. Within an area, temperatures can vary naturally from year to year depending on the soil conditions and the rainfall and cloudiness that have occurred over the area. Wet years tend to be cooler than dry year since the precipitation and rain prevent the sun from the heating the ground. Dry years also tend to be the hottest years since the sun's energy goes to the heating the land and air. Over the time, an areas average temperatures can change because of change in land use, for example, cooling can occur as bare fields revert to forests, or warming can occur as pavement replace grass when cities expand.

Temperatures also change from one year to the next because of long- term cycles in the global atmosphere such as ELNino. ELNino winters tend to be cooler and wetter than normal because of a strong stream of tropical air over Florida and southern Alabama and Georgia.

Large volcanic eruptions, such as Tambora in 1815 and Krakatoa in 1883, can cause widespread cooling for several years after the eruptions occur. A solar activity also causes small changes in coming energy over time. Temperature increases in the southeast since the 1970s mirror increases in the temperatures that have occurred across the US and the world as whole. Most scientists believe that these increase in temperature are due to increase in green house gases, which trap heat near the surface of the earth rather than releasing it back in space. These trends are likely to continue for the next century.

## 2.6. Effects of Climate change

### Environmental impacts

Rise in sea level: melting ice and thermal expansion of oceans are the key factors for sea level rise. Global observations at different locations tell that an increase in global temperature is considerably causing seawater to expand and sea level to rise. Rise in sea levels was observed during 20th century around the northern and southern Pacific Ocean, Indian Ocean and Caribbean Sea; however the rise is not geographically uniform like warming of the land surface (UN-OHRILLS, 2009; Cruz et al., 2007). In the years 1961 and 2003, global sea level rose at an average rate of 1.8mm per year, however the rate was faster (about 3.1mm per year) during 1993 to 2003(Solomon,2007;WMO,2010). According to the IPCC 4th assessment projection a mean of 0.4m rise by the end of the century excluding future changes in glacier melt are projected. In Indian and Pakistan, the current rise in sea level is reported to be about 1mm per year since 1960.bangladish is particularly vulnerable with estimates of sea level rise varying from 0.30 to 1.3m by 2050 under alternative scenarios (Broactus, 1993).

Melting of Arctic ice: numerous of studies show that Arctic summer ice melting at an alarming rate than ever before due to global warming. In a study Stroeve et al. (2007) found that four out of five lowest years of sea ice coverage have occurred since 2002. A similar study on the decline of arctic summer sea ice melt was done by Overpeck et al., (2005). They predicted that Arctic could be completely free of summer sea ice well before the end of the century.

Uneven precipitation pattern： like the rising trend of global temperature in 21st century, no clear evidence with regard to a long- term change in the global precipitation has been found ( Allen and Ingram, 2002; Karl and Trenberth , 2003;Mc Carthy 200). Recent studies show a rising trend of only 9 (nine) mm, which is approximately 0.98% per decade for 20 century (New et al 2001). However, the above mentioned increase has been observed over high latitude areas and tropical oceans with a decrease over tropical lands (Bosilovich et al., 2005; Kumar et al., 2004; New et al., 2001). It is obvious that climate warming leads to increased moisture- holding capacity of air and cause changes in the characteristics of precipitation events, including their frequency, intensity, amount and duration (Karl and Knight, 1998; Trenberth, 1998; Treydte et al., 2006).

Extreme weather event： The largest impacts of global warming mainly come from the incidence of the extreme weather events, such as heavy rainfall, severe storms, heat waves and droughts (Glasby, 2002). Extreme cold waves and records snowfall were observed during winter season of 2009/2010 in Europe and U.S. in 2008, sever prolonged drought hit several states of the South America, such as Argentina, Uruguay, Paraguay and southern Brazil, causing severe damage to agriculture, livestock, and water resources. For most part of the South America, it was observed as one of the driest years on records. Heavy rainfall in 2010 in china contributed to floods and landslides along with devastating mud /rock slide in the northwest of the country. Similarly, extreme precipitation events in West Africa have been observed in 2010, with the worst flooding in 50 years (WMO, 2010). However, by their very nature, extreme events are hard to study and predict precisely because they are relatively rare and can be influenced by local factors, such as, terrain and sown pack. Unfortunately, the increase in heavy rain would not necessarily make more water available for hydropower or irrigation because natural and engineers reservoirs are generally affected by storms. Moreover, both the Northwest and the Gulf coast would also see increases in the number of dry days (Diffenbaugh et al., 2005).

Sever rainfall events： According to U.S global change research, the warmer temperatures are likely to increase evaporation from land surfaces and cause severe rain events. Increased rain events are responsible for an increase in surface runoff. An increase in precipitation of 1-5% per decade in mid/ high latitudes of the Northern Hemisphere has also been observed during 20 th century (IPCC, 2001). An analysis of the heavy rainfall events indicates a probability of over 90% that 2-4 % increase in frequency has observed during the past 50 years in the Northern Hemisphere (IPCC, 2001). Live et al. (2005) analyzed heavy precipitation events in china during 1960-2000. Although a total rainy days trends was observed negative. For India, Ryoo et al. (2004) found about two third of increasing trend for precipitation extremes during a study period from 1910 to 2000 and also observed some regions with significant increase and decrease across India. Brunetti et al. (2001) investigated the precipitation pattern (intensity and extreme events) for about seven stations located in the north eastern Italy for the period 1998-1920. They found a negative trend in the number of wet days associated with an increase in the number of rainfall events to total precipitation.

Flood and prolonged drought: According to climatologists, temporal and spatial variability in extreme weather events like both floods and drought have increased. In South Africa, Latin America, the Mediterranean, and some parts of south Asia, an increase in temperature may also induce a prolonged drought which along with anthropogenic factors causes deforestation, weathering and soil erosion (UNEP, 2007). More intensive and longer droughts have observed since 1970s, particularly, in tropical and sub tropic region (IPCC, 2001). One effect of the rising temperatures that expected in the next century is that the atmosphere capacity to hold moisture will go up. For every 1° C increase in temperature, the water –holding capacity of the atmosphere rise 7%. The increased moisture in the atmosphere will lead to more intense precipitation events –even when the annual total amount of precipitation is slightly reduced.

# Chapter Three

# 3. Materials and Methods

## 3.1. General Description of Study area

Awash River Basin is one of the significant River Basins among the twelve River Basins belongs to Ethiopia. The river originates over the high lands of central Ethiopia, about 150 km west of Addis Ababa, at an elevation of about 3000m above mean sea level and flows north east wards, where it eventually drains into the lake Abe (Wagnew 2004). The total length of the river is about 1200 km and its catchment area is 110,000km$^2$. The Awash River basin has been divided into three distinct zones: Upper basin, Middle basin, and lower basin. On the basis of various inter-related factors such as location, altitude, climate, topography, agricultural development, inhabitants, administrative boundaries etc… (MoWE,2012).

The mean annual rainfall at the basin varies from about 1600mm, in the high lands north east of Addis Ababa, to 160 mm the northern part of the basin. Rainfall distribution is generally bimodal in the middle and lower Awash and unimodal in the in the Upper Awash. The mean annual rainfall over the entire western catchments is 850 mm and over the head waters of the Awash, it is 1,216mm. Minor rains normally occur in March and April and major rains from July to August (Desalegn et al., 2009).

## 3.2. Description of the Particular study area

This study was conducted in the upper part of the Awash River basin in Ethiopia, which is located between 8° 16´ N-9°18´ N and 37° 57´E-39°17´E. It covers about 7240 km$^2$ and all topographic lands lie between 1500m to 3419 m above sea level. The physical setting of the study areas are characterized by the heterogeneity of the large natural systems such as the high plains, mountains and plateaus (Abdisa, 2015). The land use of the upper Awash River basin consists mainly of cultivated agricultural lands, grasslands, and shrub land, which covers 93.2%

of the total area about 3.6 %, is covered by sparse trees and the reaming 3.2 % comes from the other land cover types (Mussa, 2011).

According to Koei (1996) and FAO (1998) soil classification, the upper awash river basin soil types are pellic vertisol, Vertic cambisol, Chromic luvisols, Luvic phaeozoms and litho sols. However, the dominant soil types are cambisols and Vertisols. Hence, vertisols are unique group of soils, often described as black cotton soils and heavy, usually dark colored, clay soils that from deep cracks when they drought, and difficult to cultivate when dry, and become very sticky when wet Andrew(1995;Deckers et al.,2001). The upper Awash River basin rainfall is dictated by the inter-tropical convergence zone (ITCZ). The rainfall distribution, especially in the high land area is bimodal with a short rainy season in March, April and the main rains from June to September. The mean annual rainfall varies from 1600mm at Ankober, in the highlands of north east of Addis Ababa to 160 mm at Asayita on the northern limits of the basin. The mean annual runoff in the Koka basin is 1660 million cubic meters (MCM). About 90% of the runoff occurs from July to October. Minimum and maximum annual temperatures of at koka dam are 20.8 and 23.8 respectively.

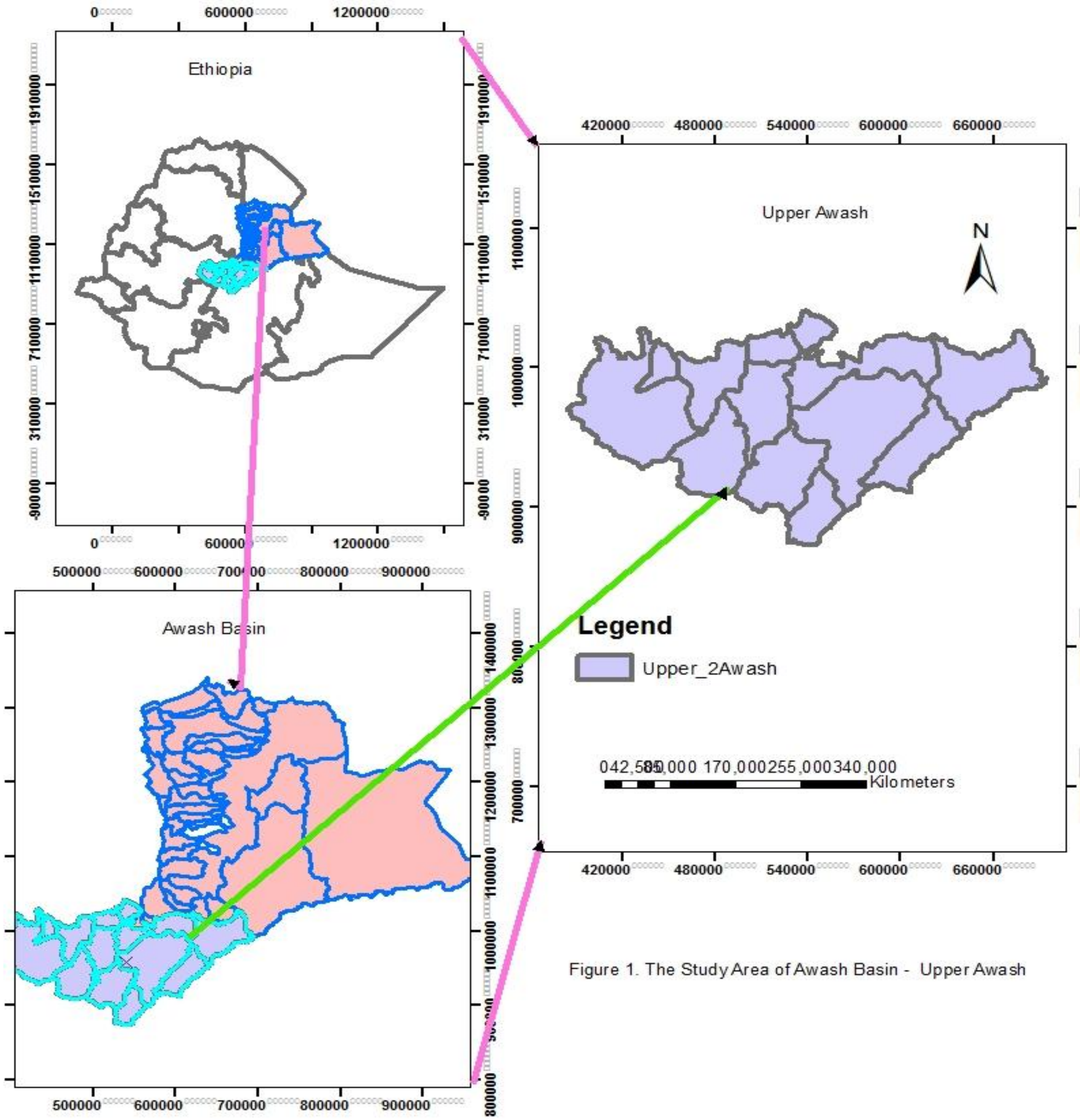



Figure 1. The Study Area of Awash Basin - Upper Awash

## 3.3. Vegetation in Awash river basin

The dominating vegetation in the Awash Basin is part of the Seasonal Tropics ecozone. At high altitudes this ecozone forms individual humid alpine microclimates. The Tropical Arid Lands ecozone predominates at low levels in the Rift. Primary vegetation underlies a strong anthropogenic impact. All over the upper and central Awash Basin, remains of different Savanna types are still clearly visible. They range from thorn savannas in the lower rift, bush, grass and open savannas above 800 m and woody savannas on the escarpments and the highlands. Forestry hardly exists inside the Awash River Basin, with a few exceptions of small eucalyptus plantations. Outside of Awash National Park the open and woody savannas have been almost completely cultivated with crops. This especially accounts for all escarpment terraces. Thereby the scattered tree cover remained similar to the primary state of the savannas, while the grass layer has been replaced by crops. Only highest altitudes still show connected woodlands. Partly reforestation was carried out on not cultivable altitudes with secondary coniferous forests. The cultivated crops are (endemic) teff, maize, sorghum, beans and vegetables. Pastures hardly exist where agriculture is possible. The cattle graze on field edges and waysides and on steep escarpments. This is one major reason for erosion, because vegetation cover is partly destroyed. Stubble-grazing is a common practice in the Awash Basin

# 3.5. Data

The following hydro-metrological data were used in this study. Monthly precipitation, monthly minimum and maximum temperature data of six (6) gauge stations were provided by national metrological agency. The selections of the stations are depending on the data availability. Several imputation methods have proposed in the literature. the adequacy of each methods depend on the missing data mechanism (Pubin,1996;Schafer,1997;Schneider, 2001;Tunninena et al.,2004;Coulibaly,2007; Gokturk,2008;Romos-Calzado et al.,2008). Mean imputation is a method in which the missing value on a certain variable is replaced by the mean of the available cases. This method maintains the sample size and is easy to use. The locations of climatic and hydrological stations in the basin are showing in Table 3.1and 3.2 respectively and their latitude, longitude, and elevations are listed in the same Table3.1 and 3.2. The monthly stream flow of the three hydrological stations in the Upper Awash River basin was provided by Ministry of Water, Irrigation and Electricity. The hydrological gauge stations include Akaki, Hombole, and Koka are listed below Table 3.2

Table3.1.The selected metrological gauge station in this study

| Station name | Elevation | Longitude | Latitude | Climatic data | Period |
|---|---|---|---|---|---|
| Abomsa | 1630 | 39.833 | 8.4667 | Precipitation and temperature | 1988-2017 |
| Addis Ababa | 2354 | 38.79871 | 8.981081 | Precipitation and temperature | 1986-2017 |
| Ambo | 2068 | 37.83967 | 8.984667 | Precipitation and temperature | 1986-2017 |
| Debrebitrhan | 2750 | 39.5 | 9.633 | Precipitation and temperature | 1986-2017 |

| | | | | | |
|---|---|---|---|---|---|
| Debre Zeit | 1900 | 38.95 | 8.733 | Precipitation and temperature | 1986-2013 |
| Nazeret | 1622 | 39.2833 | 8.55 | Precipitation and temperature | 1986-2017 |

Table3.2.The selected hydrological gauge station in this study

| Station name | River length (km) | Catchment slop (%) | Catchment area ($km^2$) | Lat (N) | Long (E) |
|---|---|---|---|---|---|
| Akaki @Akaki village | 44.799 | 68 | 884 | 981872 | 476159 |
| Awash @Melka homebole | 106.151 | 33 | 7656 | 950551 | 476159 |
| Koka | | | | | |

### 3.1.1. Methodology

There are a number of trends finding tests that can be carried out, though in earth sciences applications, where the hypothesis of normality of the data can rarely be accepted, and non- pap metric tests are usually preferred. Nonparametric tests are strong with respect to missing values, seasonality, nonnormality, nonlinearity and serial dependency. The most commonly used non-parametric tests for detection trends in hydro-climatic variables is Mann-Kendall (MK) test. (Mann 1945, Kendall, 1975), the randomness of the data against the trend. In this study, MK test was used to detect the trends of precipitation, temperature and stream flow with sen's slope estimator which used to test calculate the magnitude of the trends. Data analysis was under taken using XLSTAT soft ware and excels spreadsheet.

In using the Mann-Kendall test to define statistically significant trends, two hypothesis were tested; the null hypothesis, $H_{o,}$ that there is no trend in the time series and the alternative hypothesis, $H_a$, that there is a trend in the time series for a given significance level. Probability p (e.g., Karmeshu, 2012; Gavrilov et al.2015a) was calculated to determine the level of the confidence in the hypothesis. If the computed P is lower than the chosen significance level alpha (e.g., alpha 0.05), the $H_o$ (there is no trend) showed be rejected, and the $H_a$ (there is a significant trend) should be accepted; and if the p is greater than the significance level alpha then the $H_o$ (there is a significant trend) is accepted (or cannot be rejected). For calculating the probability P and hypothesis testing XLSTAT statistical analysis software was in use. It is considered that accepting the $H_a$ indicates that a trend is statistically significant. On the other hand, acceptance of the Ho implies that no trend (no change).

### 3.1.2. Mann-Kendall test

The Mann-Kendall test is a commonly used non-parametric test for time trends. Mann-Kendall test is a ranked based non parametric test which has been widely used for detection of trend in time series (e.g. Zhang et al., 2001; Burn and Hang Elnur, 2002; Yue and Hanshino, 2003; Zheng et al., 2007; Love et al., 2010; Tesemma et al., 2010; Hu et al., 2011). It is applicable for non-normality distributed data which are often encountered in hydrology or climatology and is a strong outlier (Yue and Pilon, 2004; Hess et al., 2001).

The advantage of this method include

1. It can handle non- normality, Censoring or data reported as a value less than missing values, or seasonally and
2. It has a high asymptotic efficiency (Gan, 1998; Fue et al., 2004). Therefore this method was used in this study to detect and Analysis of hydro-climatic trends for example precipitation, temperature and streamflow in the Upper Awash River Basin. For the case that n>10, the standard normal statistic Z is estimated by the following formula as Hirsch et al., 1982; Gan, 1998).

$$
Z=\begin{cases} \frac{(S-1)}{\sqrt{Var(S)}} & if\ S>0 \\ 0 & if\ S=0 \\ \frac{(S+1)}{\sqrt{Var(S)}} & if<0 \end{cases}
$$

Where S=

$$
\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \boldsymbol{sgn}(\boldsymbol{xi}-\boldsymbol{xj})
$$

$$
sgn(\theta)= \begin{cases} 1\ if\theta>0 \\ 0if\ \theta=0 \\ -1if\theta<0 \end{cases}
$$

$$
Var(S)=[n(n-1)(2n+5)-\sum_t t(t-1)(2t+5]/18
$$

In which t is the extent of any given tie, $\sum_t denotes$ the Summation over all ties?

Positive Z indicates increasing trend while negative Z value show decreasing trends. In this Analysis, applied the MK test to detect if a trend in precipitation, temperature and stream flow time series is statistically significant at significant level $\alpha=0.01$ or 99%confidence interval ) and $\alpha$=0.05( or 95% confidence intervals).at the 5% and 1% significance level, the null hypothesis of no trend is rejected if Z>1.96 and Z>2.576, respectively.

### 3.1.3. Trend magnitude

In addition to identifying whether a trend exist , the magnitude of the trend was estimated by a slopestimator $\beta$, which was extended by Hirsech et al., (1982) from that proposed by Sen (1968) defined as

$$\beta = \text{Median}\,\frac{Xj - Xi}{j - i} \qquad \text{where } 1<i<j<n$$

In the other words, the slop estimator $\beta$ is the median over the all possible combinations of pars for the whole data set (Hirsch et al., 1982). A Positive value of $\beta$ indicates an upward trend (increasing values with time), while a negative values of $\beta$ indicates a downward trend (Xu et al., 2007).

# Chapter Four

# 4. Result and Discussion

The Mann-Kendall test (MK) gives an interesting insight about monthly, seasonally and annually temperature, precipitation and streamflow for upper Awash River basin. The MK test positive slope indicated that increasing and negative slope indicated that decreasing trends.

## 4.1. Trends analysis of temperature, precipitation and stream flow

### 4.1.1. Monthly maximum temperature trend analysis

Table below shows that the monthly maximum temperature trends in upper Awash River basin. Monthly maximum temperature data from six stations were investigated in the upper Awash River basin over different time period. The results of MK test for the monthly maximum mean temperature of the station showed those statistically significant increasing trends were observed. However, for some monthly values statistically significant decreasing trends were observed: in May, August and December in Addis Ababa station with the p-value and slope (p=0.673 and slope=-0.009, p=0.961, slope=-0.001, p=0.58 and slope=-0.55) respectively. Ambo station months such as May with the p-value and slope statistic (p=0.217 and slope=-0.012, November with the p-value and slope (p=0.874 and slope=-0.001) showed that negative trends in Debrezeit station only August month show the p-value and slopes (p=0.96 and slope=-0.001) negative maximum mean temperature. Nazerite station some months such as February, May, and December with the p-value and slopes (p=0.935 and slope= -0.001, P=0.042, slope=-0.025 and p=0.167, slope=-0.028respectively) showed that the negative trends.

Strong increasing trends in temperature are apparent in the majority of the examined stations, therefore, the increase temperature particularly the small rainy months such as March, April and May has significant impact on the initial growing stage of the crop due to the evaporation. The small rainy has significant economic importance for Ethiopia, since it triggers the growing season for most of the crops in the country (Seleshi and Camberlin, 2006).

The results from present study are in agreement with the previous climate change studies in the basin station who reported increasing trends of temperature (Tekleab et al, 2013).

Table4.1. Trend results of Mann-Kendall p- value and Sen's slope for monthly maximum temperature time series. Positive /negative of Sen's slope indicate increasing or decreasing trends respectively.

| Month | MK test | Abomsa | Addis Ababa | Ambo | D/Brihan | D/Zeite | Nazeret |
|---|---|---|---|---|---|---|---|
| Jan. | P-value | 0.005** | 0.167* | 0.007** | 0.043** | 0.006** | 0.858* |
| | Slope | 0.062 | 0.02 | 0.028 | 0.029 | 0.033 | 0.02 |
| Feb. | P-value | 0.031** | 0.05** | 0.03** | 0.008** | 0.172** | 0.935* |
| | Slope | 0.082 | 0.032 | 0.065 | 0.05 | 0.033 | -0.001 |
| Mar. | P-value | 0.005** | 0.048** | 0.02** | 0.027** | 0.073* | 0.028** |
| | Slope | 0.118 | 0.045 | 0.074 | 0.047 | 0.05 | 0.05 |
| Apr. | P-value | 0.002** | 0.019** | 0.012** | 0.030** | 0.123* | 0.042** |
| | Slope | 0.1 | 0.05 | 0.048 | 0.043 | 0.056 | 0.065 |
| May | P-value | 0.138* | 0.673* | 0.217* | 0.746* | 0.690* | 0.042** |
| | Slope | 0.04 | -0.009 | -0.012 | 0.012 | 0.007 | -0.025 |
| Jun. | P-value | 0.03** | 0.042** | 0.129* | 0.551* | 0.584* | 0.602* |
| | Slope | 0.043 | 0.038 | 0.016 | 0.009 | 0.015 | 0.008 |
| Jul. | P-value | 0.001** | 0.275* | 0.426* | 0.453* | 0.709* | 0.019** |
| | Slope | 0.047 | 0.01 | 0.009 | 0.012 | 0.01 | 0.059 |
| Aug. | P-value | 0.003** | 0.961* | 0.275* | 0.348* | 0.960* | 0.053** |
| | Slope | 0.05 | -0.001 | 0.016 | 0.012 | 0.00 | 0.047 |
| Sep. | P-value | 0.014** | 0.321* | 0.320* | 0.006** | 0.516* | 0.205* |
| | Slope | 0.041 | 0.014 | 0.015 | 0.031 | 0.011 | 0.027 |
| Oct. | P-value | 0.011** | 0.028** | 0.035** | 0.00** | 0.602* | 0.614* |
| | Slope | 0.056 | 0.036 | 0.033 | 0.056 | 0.01 | 0.008 |
| Nov. | P-value | 0.007** | 0.059* | 0.874* | 0.012** | 1.00* | 0.757* |
| | Slope | 0.048 | 0.02 | 0.00 | 0.041 | 0.00 | 0.005 |
| Dec. | P-value | 0.028** | 0.58* | 0.077* | 0.195* | 0.784* | 0.167* |
| | Slope | 0.033 | -0.55 | 0.011 | 0.019 | -0.001 | -0.028 |

**As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis* $H_O$

*** As computed P-value is lower than the significance level alpha =0.05 reject the null hypothesis* $H_O$

### 4.1.2. Monthly minimum temperature trend analysis

Analysis of monthly minimum temperature data was under taken to detect the variability and trend of temperature change in the study area of for the different time period. Table six (6) represented the monthly minimum temperature and its trend in the period under examination. The mean minimum temperature in the study area ranges from five to fifteen. This founding is more close to the global warming rate which say that minimum temperature increase more than maximum temperature trends.

As demonstrated in Table six, the MK trend test results express that minimum temperature have been increasing through time significantly at 95% confidence level. The trend for monthly minimum temperature showed a significant increasing trend. However, some months in the station showed that a non-significant increasing trend. Some stations also the Mann-Kendall trend test statistic show negative trends in some months for example in the Table blow in Debrebrihan station in February months with the p-value and slope (P=0.746, slope=-0.02), March (P=0.385, Slope=-0.02), August (P=0.785, Slope=-0.01), September (P=0.088 ,Slope=-0.029),October (P=0.759,Slope =-0.006) and December (P=0.946,slope =-0.005). Debrezeit station is one of the major climatic stations in the upper Awash River basin in this stations the monthly minimum temperature MK statistic have been showed that negative trend or downward trends at 0.05 significant level.

Table4.2: Trend results of Mann-Kendall p- value and Sen's slope for monthly minimum temperature time series. Positive /negative of Sen's slope indicate increasing or decreasing trends respectively.

| Month | MK test | Abomsa | Addis Ababa | Ambo | Debrebrihan | Debrezeit | Nazeret |
|---|---|---|---|---|---|---|---|
| Jan. | P-value | | 0.008** | 0.132* | 0.307* | 0.002** | 0.014** |
| | Slope | | 0.079 | 0.04 | 0.035 | -0.157 | 0.067 |
| Feb. | P-value | | 0.417* | 0.002** | 0.746* | 0.009** | 0.211* |
| | Slope | | 0.03 | 0.053 | -0.018 | -0.158 | 0.02 |
| Mar. | P-value | | 0.02** | 0.011** | 0.385* | 0.010** | 0.001** |
| | Slope | | 0.064 | 0.046 | -0.02 | -0.147 | 0.084 |
| Apr. | P-value | | <0.0001** | 0.00** | 0.946* | 0.057* | <0.0001** |
| | Slope | | 0.065 | 0.069 | 0.00 | -1.9 | 0.114 |
| May | P-value | | <0.0001** | 0.007** | 0.05** | 0.090* | 0.00** |
| | Slope | | 0.1 | 0.06 | 0.037 | -0.045 | 0.07 |
| Jun. | P-value | | <0.0001** | 0.013** | 0.163* | 0.382* | 0.004** |
| | Slope | | 0.093 | 0.047 | 0.029 | -0.024 | 0.045 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Jul. | P-value | | <0.0001** | 0.002** | 0.719* | 0.152** | <0.0001** |
| | Slope | | 0.057 | 0.037 | 0.00 | -0.02 | 0.057 |
| Aug. | P-value | | <0.0001** | 0.001** | 0.785* | 0.769* | <0.0001** |
| | Slope | | 0.047 | 0.05 | 0.00 | -0.00 | 0.057 |
| Sep. | P-value | | <0.0001** | 0.001** | 0.088* | 0.028** | 0.000** |
| | Slope | | 0.069 | 0.058 | -0.029 | -0.05 | 0.053 |
| Oct. | P-value | | <0.0001** | 0.002** | 0.759* | 0.003** | <0.0001** |
| | Slope | | 0.1 | 0.059 | -0.006 | -0.183 | 0.107 |
| Nov. | P-value | | <0.0001** | 0.089* | 0.190* | 0.025** | <0.0001** |
| | Slope | | 0.154 | 0.06 | 0.043 | -0.121 | 0.123 |
| Dec. | P-value | | 0.01** | 0.285* | 0.946* | 0.124* | 0.249* |
| | Slope | | 0.081 | 0.035 | -0.005 | -0.107 | 0.042 |

**As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis* $H_O$

*** As computed P-value is lower than the significance level alpha =0.05 reject the null hypothesis* $H_O$

4.1.3. Seasonal maximum temperature trend analysis

Based on Ethiopia national metrological agency, in Ethiopia there are three seasons namely rainy season which refers to the months June, July, August and September, small rainy season which refers to the months March, April and May and the other is dry season which refers to the months October, November, December and January.

Table 6 (six) show that the seasonal maximum temperature trends in upper Awash River major climatic stations.

By referring the stations provided in Table six, the result of the MK test for the six temperature stations showed that, generally the trends are significantly increasing maximum seasonal temperature scale for the majority of the investigated temperature stations. However, for some seasonal values non –significant increasing trends. For example Ambo station rain season with the P- value and slope (P=0.138, Slope=0.02), Debrezeit temperature station also rainy and dry season with P- value and slope (P=0.728, slope=0.04 and P=0.206, Slope=0.02) respectively non-significant trends. In Nazerite station in dry season which refers to the months such as October, November, December and January the results the MK test have been the negative tends with the P-value and slope (P=0.922 and slope=-0.041) and also small rainy season non significant increasing seasonal maximum temperature trends with the P-value and slope (P=0.163 and slope=0.025).

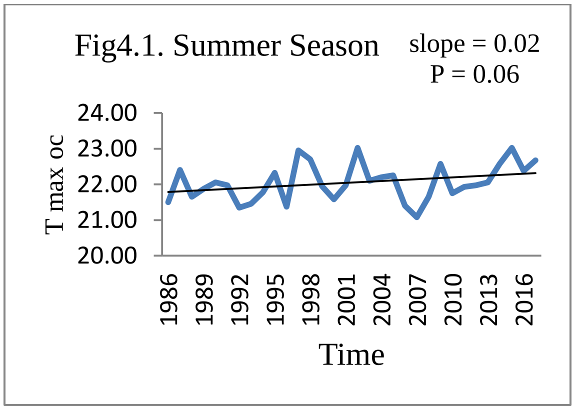
Table4.3: Trend results of Mann-Kendall p- value and Sen's slope for seasonal maximum temperature time series. Positive /negative of Sen's slope increasing or decreasing trends respectively.

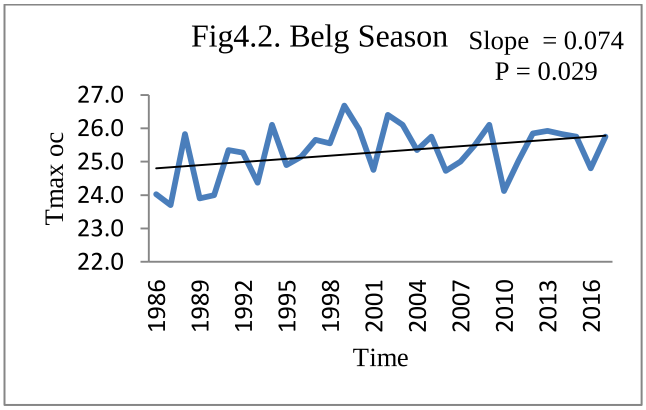
| Station name | Rainy season | | Dry season | | Small rain | |
|---|---|---|---|---|---|---|
| | P-value | Slope | P-value | Slope | P-value | Slope |
| Abomsa | 0.001** | 0.05 | 0.001** | 0.055 | 0.001** | 0.089 |
| Addis Ababa | 0.062* | 0.021 | 0.05** | 0.016 | 0.074* | 0.029 |
| Ambo | 0.138* | 0.02 | 0.038** | 0.018 | 0.004** | 0.041 |
| Debrebirhan | 0.008** | 0.029 | 0.007** | 0.035 | 0.018** | 0.036 |
| Debrezeit | 0.728* | 0.04 | 0.206* | 0.02 | 0.082* | 0.041 |
| Nazerite | 0.05** | 0.041 | 0.922* | 0.041 | 0.163* | 0.025 |

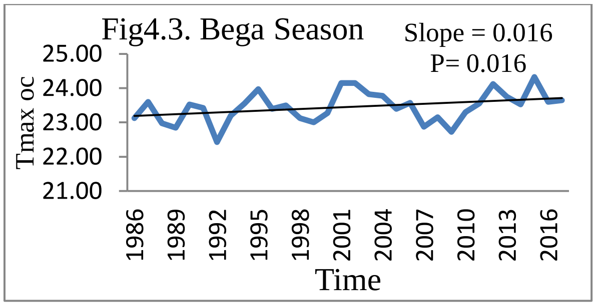
**As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis $H_O$*

*** As computed P-value is lower than the significance level alpha =0.05 reject the null hypothesis $H_O$*

Figures 4.1-4.3.Addis Ababa station seasonal maximum temperature trend



Ambo station

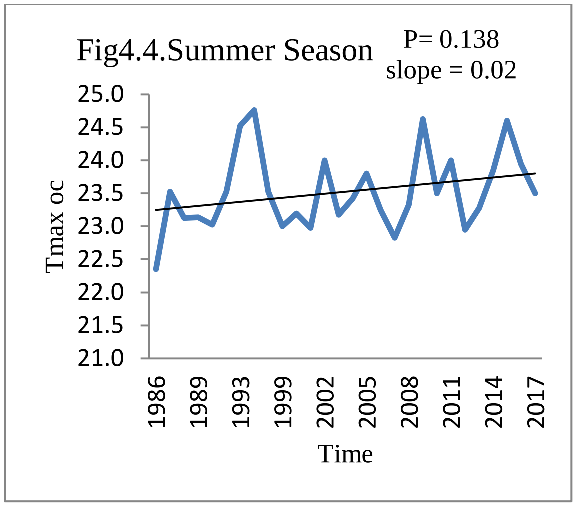



Fig4.4.Summer Season

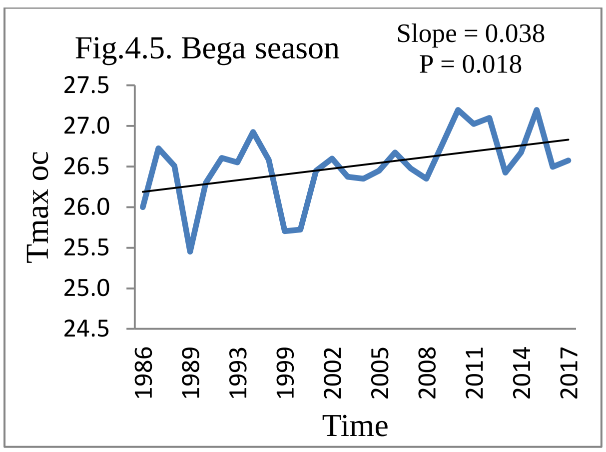



Fig.4.5. Bega season

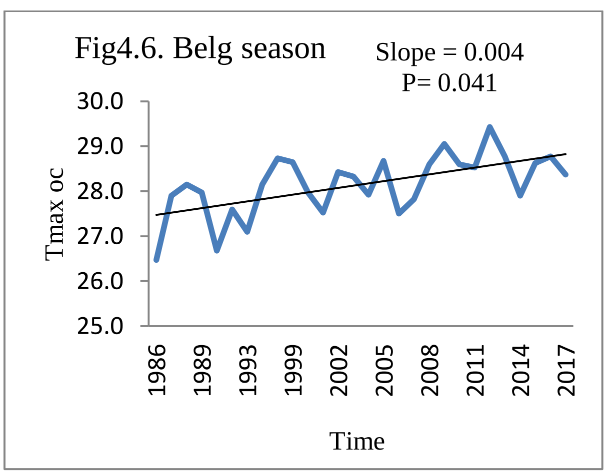



Fig4.6. Belg season

Debrebirhan station

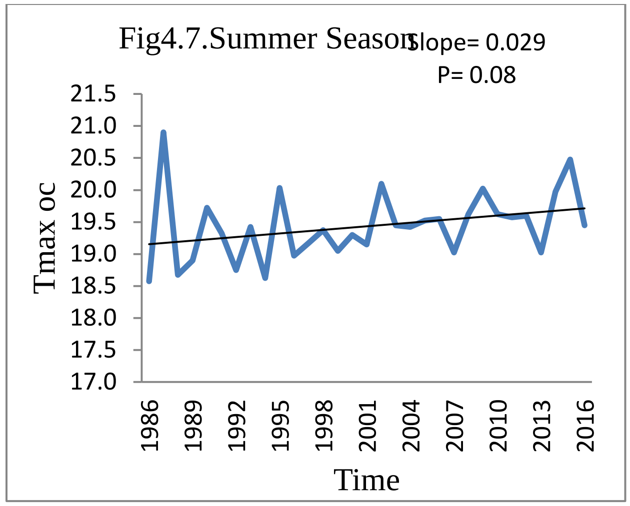



Fig4.7.Summer Season

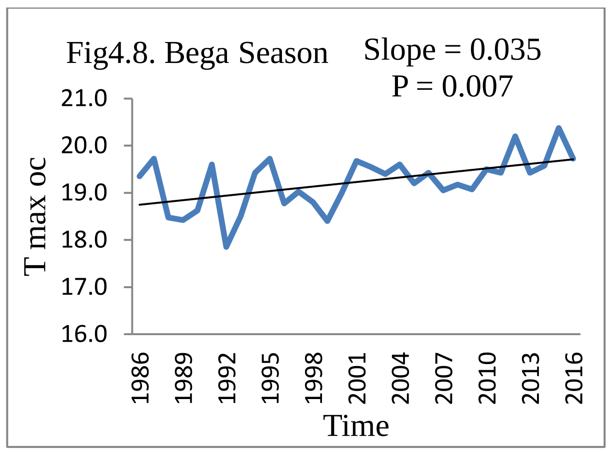



Fig4.8. Bega Season

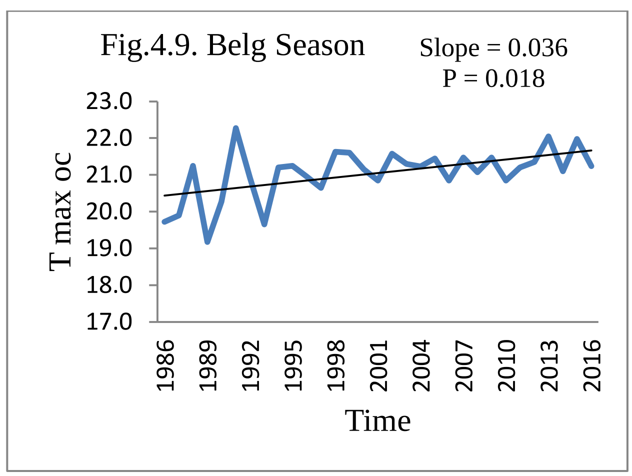
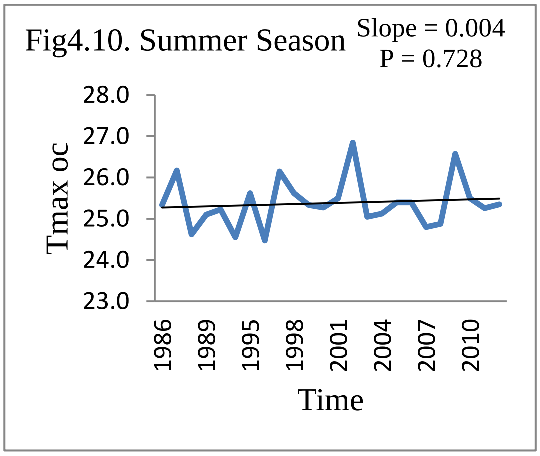


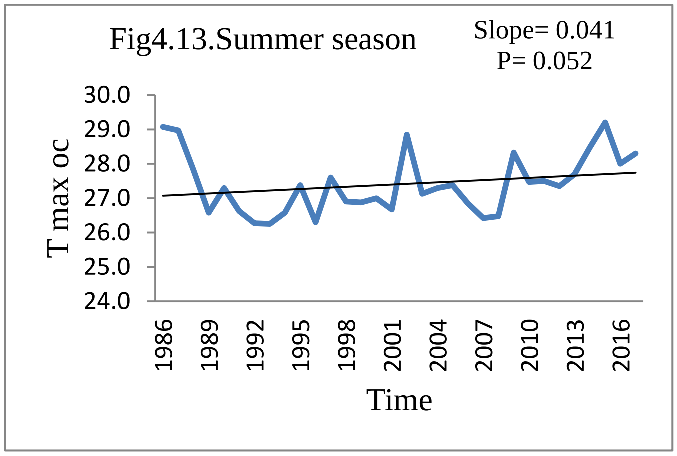

Fig.4.9. Belg Season

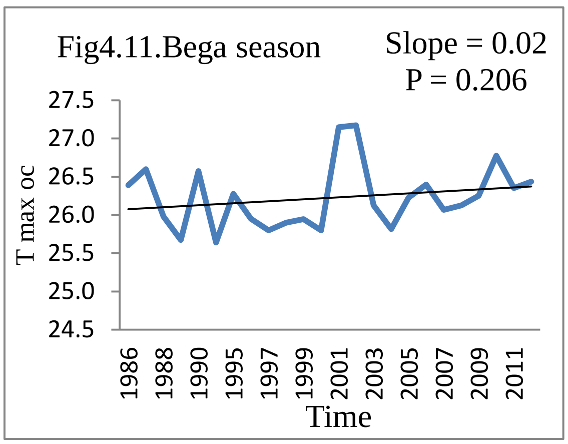
Debrezeit and Nazerite station seasonal maximum temperature figure

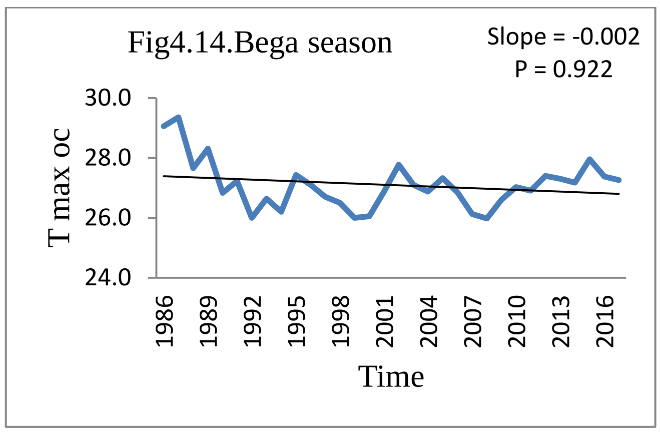
Debrezeit station Tmax.

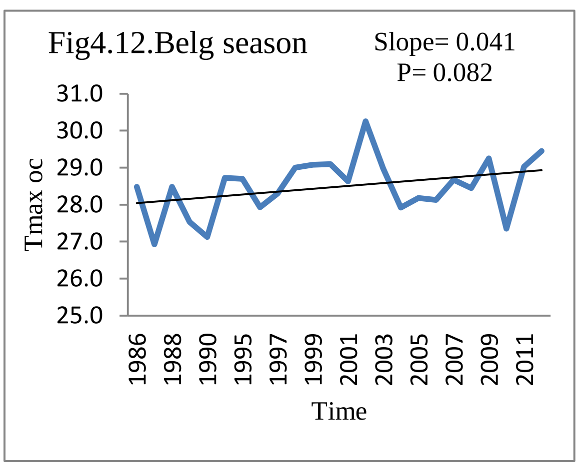
Nazerite station Tmax.

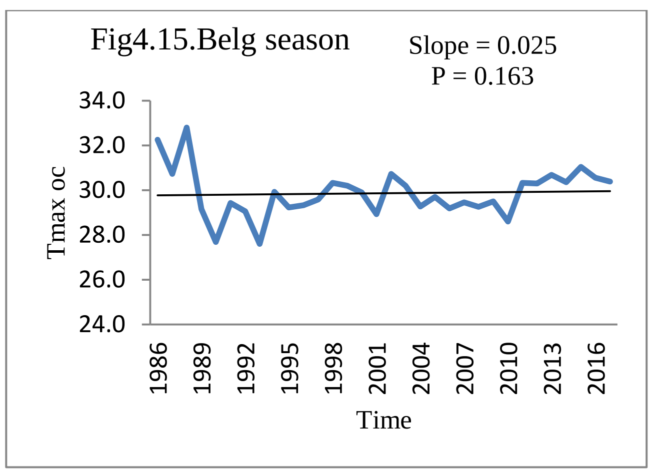


The above Figures show the results of the trend tests for the seasonal mean maximum temperature series for the most selected station in the study area. Dry season maximum temperature series at 50% of the station of considered. Stations are characterized by increasing trend, while the percentage of the station showing increasing trend in small rainy and dry season.

### 4.1.4. Seasonal minimum temperature trend analysis

In the Table 8 below describe the seasonal minimum temperature trends in upper Awash River basin major climatic stations. The results of the Mann-Kendall trend test showed that significantly increasing trends at significant level alpha =0.05. Some stations like Debrezeit and Debrebirhan decreasing trend in seasonal minimum temperature trends. For example in small rainy season in Debrebirhan station with the p-value and slope (P=0.634 and slope =-0.008) and Debrezeit all season which are rainy(kiremt), small rainy(Belg) and dry season(Bega) are showed that negative trends with the p- value and slope (P=0.146, Slope=-0.02, p=0.01,slope=-0.11 and p=0.001,slope=-0.15) respectively .

From the climate variable minimum temperature show more significant increase than the maximum and mean temperature. The increase more marked in small rainy (Belg) and dry (Bega) seasons than during the rainy (Kiremt) season.

Table4.4: Trend results of Mann-Kendall p- value and Sen's slope for seasonal minimum temperature time series. Positive /negative of Sen's slope indicate increasing or decreasing trends respectively.

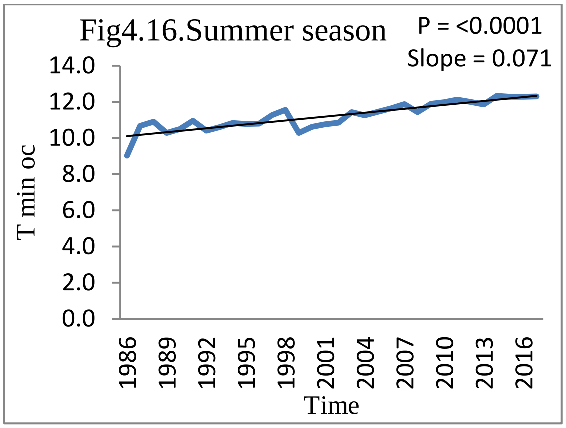
| Station name | Rainy season | | Dry season | | Small rain season | |
|---|---|---|---|---|---|---|
| | P-value | Slop | P-value | Slop | P-value | Slop |
| Abomsa | 0.0001** | 0.027 | 0.927* | -0.009 | 0.0001** | 0.027 |
| Addis Ababa | 0.0001** | 0.071 | 0.0001** | 0.113 | 0.0001** | 0.064 |
| Ambo | 0.000** | 0.049 | 0.014** | 0.047 | 0.000** | 0.055 |
| Debrebirhan | 0.865* | -0.002 | 0.316* | 0.016 | 0.634* | -0.008 |
| Debrezeit | 0.146* | -0.02 | 0.001** | -0.15 | 0.01** | -0.11 |
| Nazerite | 0.0001** | 0.054 | 0.0001** | 0.082 | 0.0001** | 0.078 |

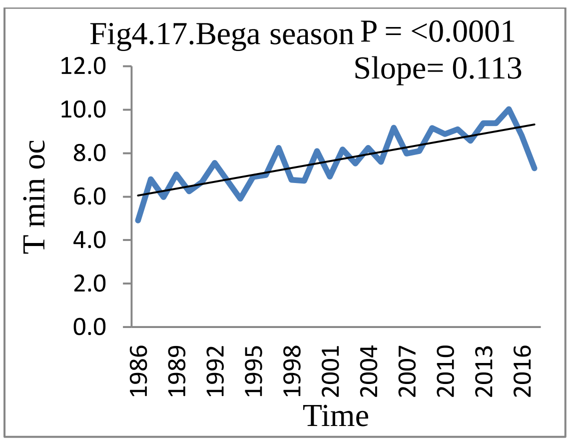
**As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis $H_O$*

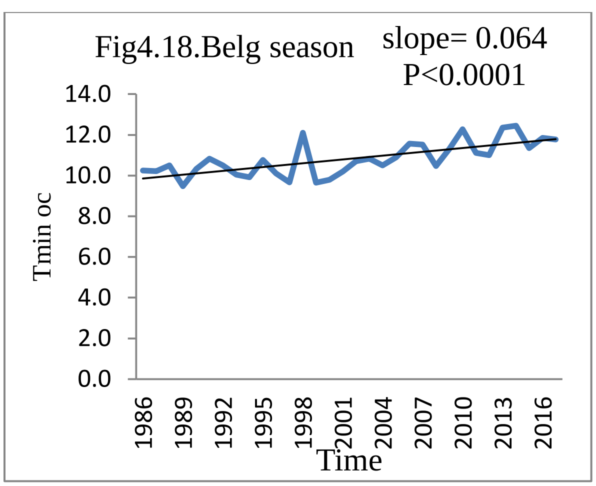
*** As computed P-value is lower than the significance level alpha =0.05 reject the null hypothesis $H_O$*

The figures blow show that the seasonal minimum temperature trends in different climatic station in Upper Awash river basin.

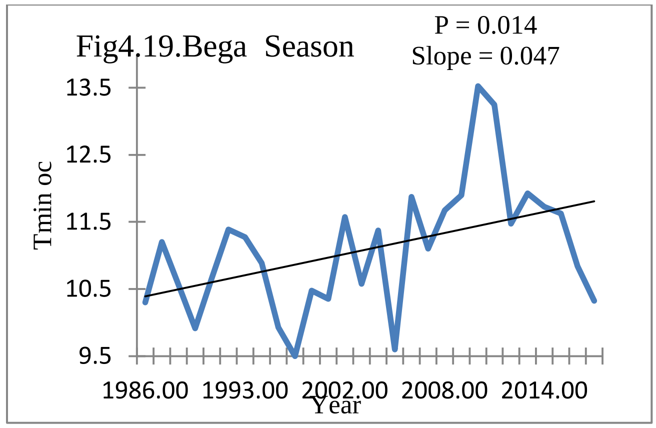
Addis Ababa station Tmin.

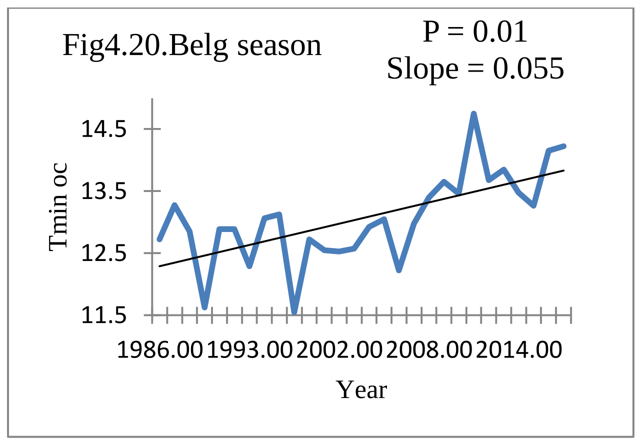


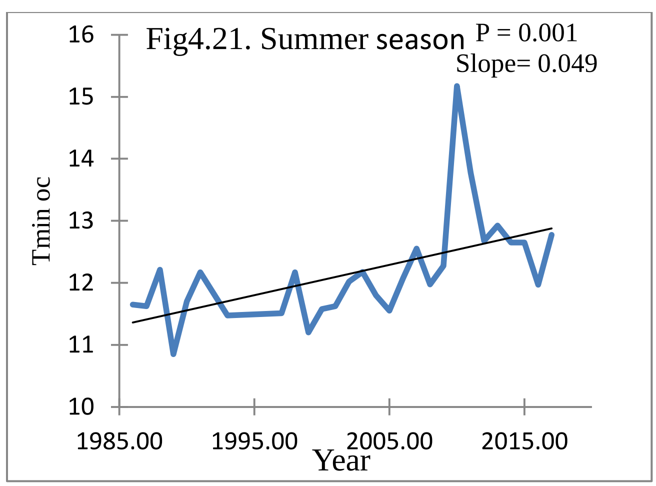



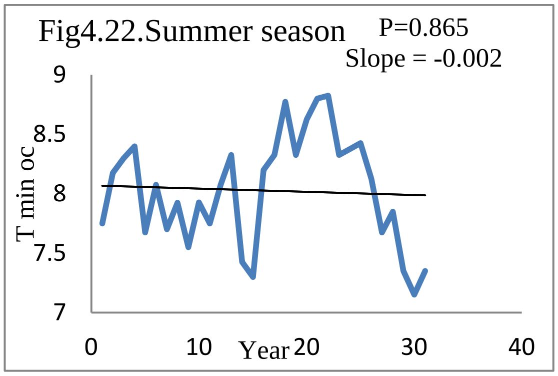

Ambo station Tmin.

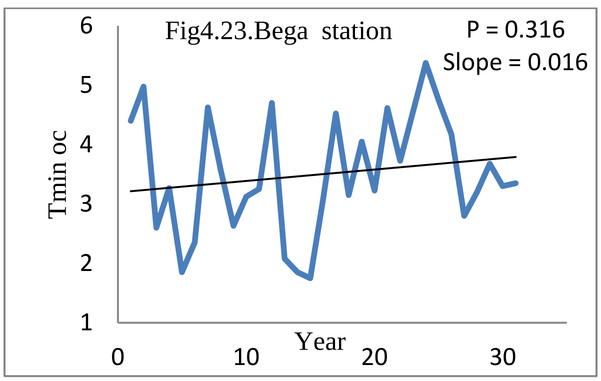


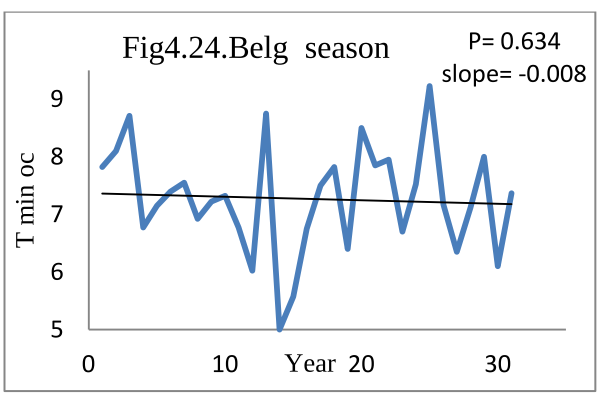



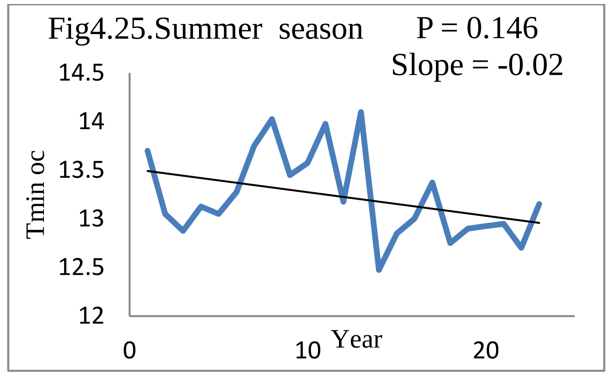
Debrezeit station Tmin.

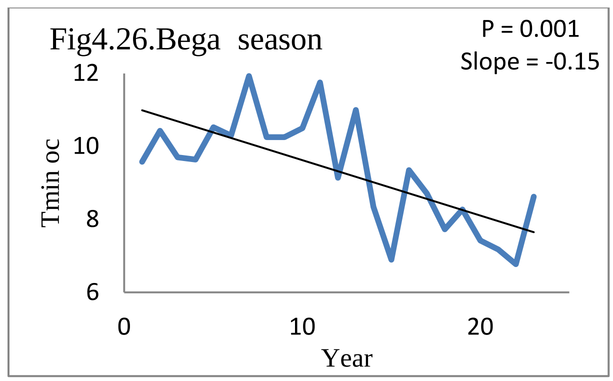


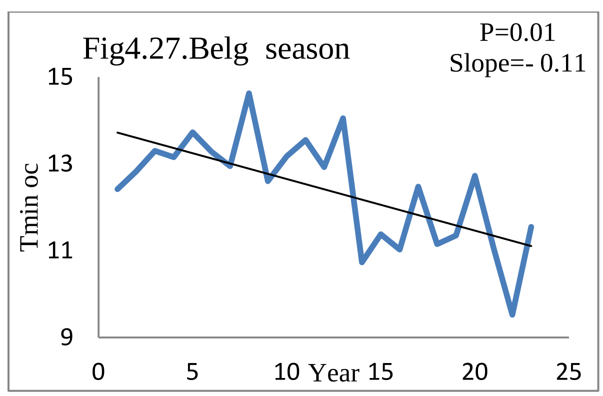




Debrebirhan station Tmin.



### 4.1.4. Annual maximum temperature trend analysis

In Table nine below describe the annual maximum temperature trends of the upper Awash River basin major climatic station. Temperature data from six stations were examined in the upper Awash River basin over different time period. The results of MK tests for the major temperature stations showed that statistically significant increasing trends were observed in annual maximum and minimum temperature for the majority of the station in the basin. However some stations like Addis Ababa stations annually maximum temperature with the p-value and slope (P=0.281, slope=0.00), Debrezeit station annually maximum temperature with the p-value and slope (p=0.308, slope=0.014) and Nazerit station annually maximum with the p-value and slope (P=0.135 and slope =0.023) non-significant increasing trends because the p-values are greater than the significant level alpha=0.05.

The other stations such as Abomsa station annually maximum temperature with the p-value and slope (P=0.001, slope=0.033), Ambo station annually maximum temperature with p-value and slope (P=0.071, Slope =0.00), and Debrebirhan station annually maximum temperature with p-value and slope (P=0.0001, Slope=0.032) are significantly increasing trends at a significant level alpha=0.05.

In Table nine column two describe annually minimum temperature trends in Upper Awash River basin. The result of Mann-Kendall test for the major temperature stations showed that statistically significant increasing trends were observed minimum temperature for the majority of the stations in the basin. But some stations like Abomsa station with the Mann-Kendall test with the P-value and slope (P=0.177, Slope=0.008) and Debrebirhan with the p-value and slope (P=0.825, Slope =0.003) are non-significant increasing trends. While the other stations for example Addis Ababa, Ambo, and Nazerite with the P-value and Slope (P=0.00, slope 0.04, P=0.00, Slope =0.04, P=0.0001 and slope=0.073) respectively are significantly increasing annually minimum temperature at significant level alpha=0.05. In Debrezeit annually temperature significantly decreasing trends with the p=value and the slope (P=0.01and slope =-0.093).

The results of trend analysis in monthly, seasonally, and annually maximum and minimum temperature found in this work are in agreement with the past research work in the some station found in the study area (e.g. Tekleab et al, .2013). They found that monthly, seasonally, and annually maximum and minimum temperature trend increase statically at a significant level alpha=0.05.

Strong increasing trends in temperature are apparent in the majority of the examined stations. Therefore, the increase in temperature particularly during the small rainy season has significant impact on the initial growing stage of crop due to the evaporation. The small rainy season has significant economic importance for Ethiopia, since it triggers the growing season for most of the crops in the country (Slesh and Camberlin, 2006).

Figures below illustrate the annual mean average maximum temperature trend magnitude for the selected temperature station in upper Awash River basin at Abomsa, Addis Ababa, Ambo and Debrebrihan station. The temperature has increased about 0.03, 0.05, 0.016, and 0.032oc/decade respectively. The results from the present study are in agreement with the previous study in the basin who reported increasing trends of temperature (Seleshi and Camberlin, 2006). Caway et al. (2004) reported that over the period 1952-2002 mean annual minimum and maximum temperature from Addis Ababa station showed increasing trend 0.04oc/decayed and 0.02 oc /decayed respectively. This result is line with the research out puts of the national metrological agency. The average mean annual mean minimum temperature thought the country indicated an increase of 0.37oc every decayed (NMA2007). On the global scale, reported an increasing in the annual maximum temperature trend by 0.15 oc per decade

Table4.5: Trend results of Mann-Kendall p- value and Sen's slope for annually maximum and minimum temperature time series. Positive /negative of Sen's slope indicate increasing or decreasing trends respectively.

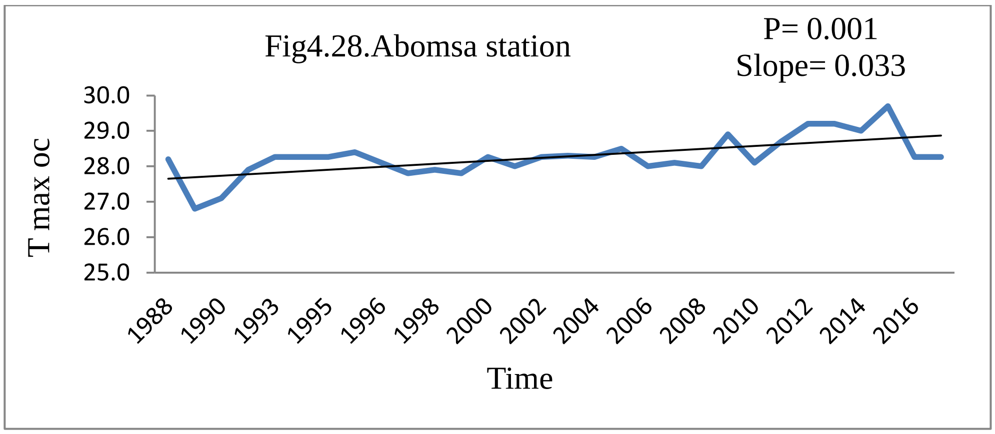
| Station | T max. | | T min. | |
|---|---|---|---|---|
| | p-value | Slope | p-value | Slope |
| Abomsa | 0.001** | 0.033 | 0.177* | 0.008 |
| Addis Ababa | 0.281* | 0.05 | 0.000** | 0.04 |
| Ambo | 0.071* | 0.016 | 0.000** | 0.04 |
| Debrebihain | 0.0001** | 0.032 | 0.825* | 0.003 |
| Debrezeite | 0.308* | 0.014 | 0.01** | -0.093 |
| Nazeret | 0.135* | 0.023 | 0.0001** | 0.073 |

T max. =maximum temperature   T min= minimum temperature

**As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis $H_O$*

*** As computed P-value is lower than the significance level alpha =0.05 reject the null hypothesis $H_O$*

Annually maximum temperature trend figure



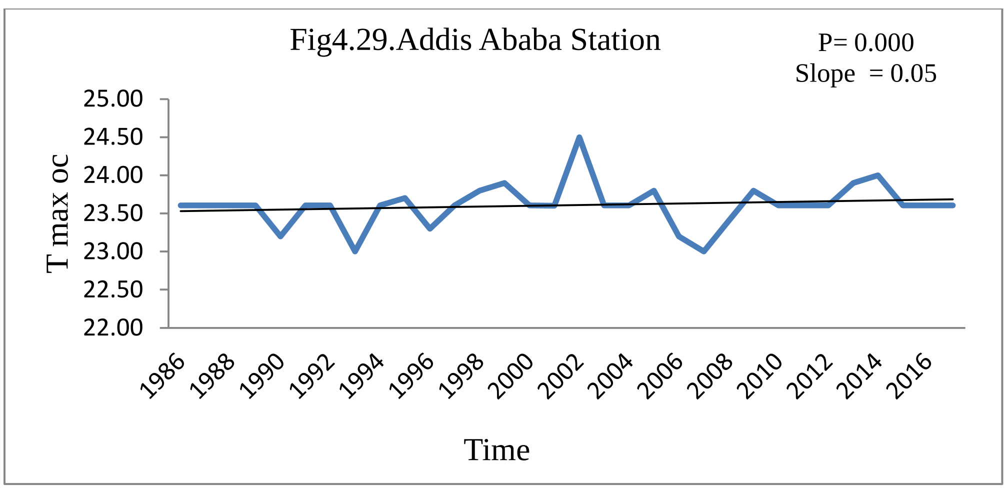



Fig4.30.Abomsa station

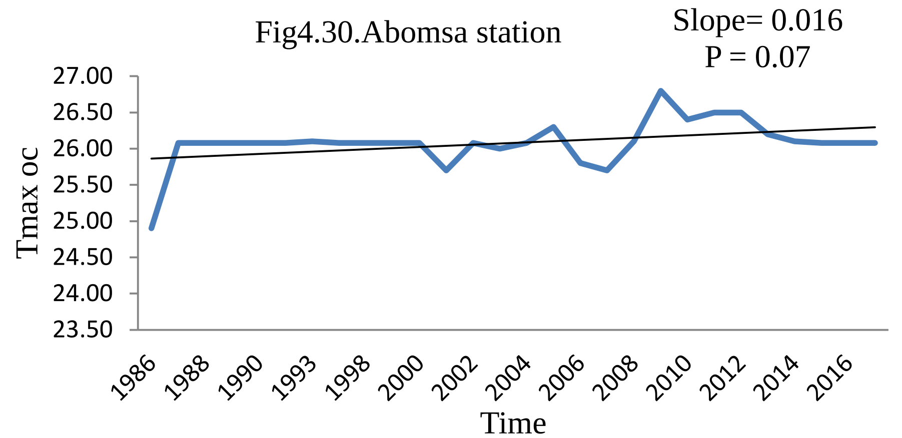
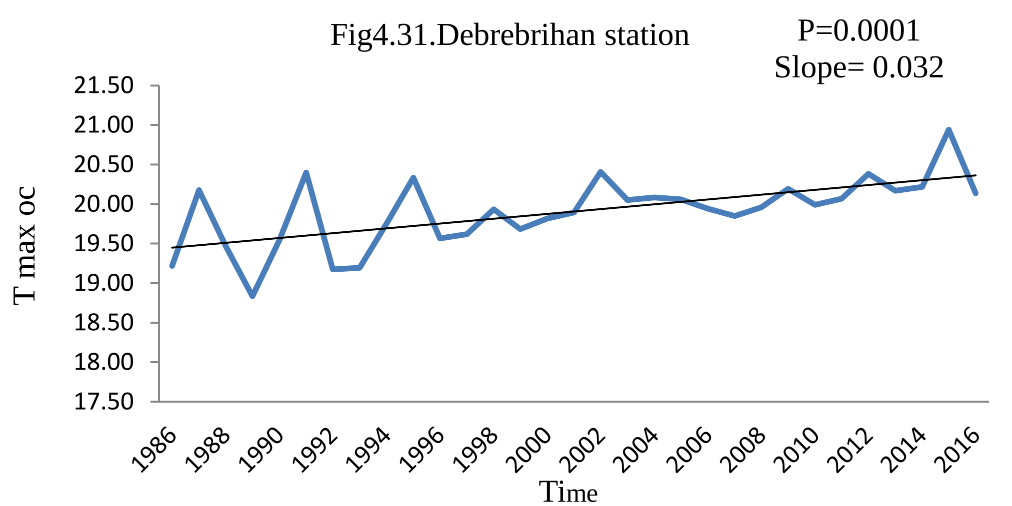



Fig4.31.Debrebrihan station




4.2.1. Monthly precipitation trend analysis

On running the Mann-Kendall's (MK) on monthly rainfall data, the result in Table ten are obtained from the six (6) stations data of the Upper Awash River basin. The Mann-Kendall test is based on the calculation of p-value and slope. The analysis results show that most of stations successive monthly rainfall years are negative related. It is found to be statistically significant monthly rainfall irregularity across the whole record years in the upper Awash River basin at the 5% level of significance. However, for some monthly values statically significant increasing trend were observed. In May at Abomsa station with the p-value and slope (p=0.074 and slope=1.28), at Addis Ababa station with p-value and slope (p=0.05, slope =1.86), in November at Abomsa station with the p-value and slope (p=0.028, slope=0.627), in the same month at Addis Ababa station with the p-value and slope (p=0.05, slope=0.015), Debrebirhan station on November with the p-value and slope (p=0.009,slope=0.125) , and July at Debrebirhan station with the p-value and slope(p=0.007and slope=3.883) significant increasing monthly precipitation at the significant level alpha=0.05.

Table4.6: Trend results of Mann-Kendall p- value and Sen's slope for monthly precipitation time series. Positive /negative of Sen's slope indicate increasing or decreasing trends respectively.

| Month | MK test | Abomsa | Addis Ababa | Ambo | Debrebrihan | Debrezeit | Nazeret |
|---|---|---|---|---|---|---|---|
| Jan. | P-value | 0.205* | 0.894* | 0.675* | 0.703* | 0.513* | 0.801* |
| | Slope | -0.352 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Feb. | P-value | 0.014** | 0.049** | 0.096* | 0.008** | 0.095* | 0.096* |
| | Slope | -0.942 | -0.829 | -1.025 | -0.821 | 0.00 | -0.456 |
| Mar. | P-value | 0.363* | 0.436* | 0.752* | 0.126* | 0.925* | 0.604* |
| | Slope | -1.778 | -1.619 | -0.21 | -0.967 | 0.008 | 0.466 |
| Apr. | P-value | 0.101* | 0.173* | 0.693* | 0.734* | 1.00* | 0.390* |
| | Slope | -1.688 | -1.615 | -0.418 | -0.229 | 0.005 | -0.723 |
| May | P-value | 0.074* | 0.05** | 0.166* | 0.126* | 0.907* | 0.173* |
| | Slope | 1.28 | 1.865 | 1.984 | 1.064 | 0.021 | 0.993 |
| Jun. | P-value | 0.074* | 0.466* | 0.352* | 0.126* | 0.426* | 0.733* |
| | Slope | -0.481 | -0.365 | -0.199 | 0.936 | 0.543 | -0.107 |
| Jul. | P-value | 0.544* | 0.709* | 0.449* | 0.007** | 0.262* | 0.808* |
| | Slope | -0.989 | -0.27 | -0.406 | 3.883 | 2.083 | 0.583 |
| Aug. | P-value | 1.00* | 0.987* | 0.953* | 0.341* | 0.242* | 0.456* |
| | Slope | 0.06 | 0.138 | 0.00 | 1.219 | 1.664 | -0.935 |
| Sep. | P-value | 0.872* | 0.709* | 0.677* | 0.973* | 0.623* | 0.194* |
| | Slope | -0.24 | 0.353 | -0.19 | 0.075 | 0.4 | 1.265 |
| Oct. | P-value | 0.721* | 0.284* | 0.426* | 0.293* | 0.462* | 1.00* |
| | Slope | -0.383 | -0.414 | -0.356 | -0.271 | -0.007 | 0.00 |
| Nov. | P-value | 0.028** | 0.069* | 0.383* | 0.009** | 0.292* | 0.009** |
| | Slope | 0.627 | 0.015 | 0.00 | 0.125 | 0.00 | 0.312 |
| Dec. | P-value | 0.066* | 0.742* | 0.543* | 0.731* | 0.106* | 0.86* |
| | Slope | -0.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis $H_O$*

*** As computed P-value is lower than the significance level alpha =0.05 reject the null hypothesis $H_O$*

4.2.2. Seasonal precipitation trend analysis

The time series mean seasonal precipitation was analyzed across the upper Awash River basin in the same procedure to that of monthly precipitation data. The stations, which are found in upper Awash River basin, mean seasonal precipitation value aggregated and representative single mean value was taken for the upper for the upper Awash River basin analysis. Accordingly, the most seasons mean seasonal for the last 30 years in the upper Awash River basin has stated in Table 11. The slope of most seasons in the station show that negative values implying a decreasing in mean seasonal precipitation. However Debrezeit station show non- significant increasing trends in mean seasonal precipitation.

Table4.7: Trend results of Mann-Kendall p- value and Sen's slope for seasonal precipitation time series. Positive /negative of Sen's slope indicate increasing or decreasing trends respectively.

| Station name | Rainy season | | Dry season | | Small rain season | |
|---|---|---|---|---|---|---|
| | P-value | Slope | P-value | Slope | P-value | Slop |
| Abomsa | 0.568* | -0.38 | 0.695* | -0.2 | 0.239* | -0.529 |
| Addis Ababa | 0.466* | -0.24 | 0.783* | -0.05 | 0.250* | -0.57 |
| Ambo | 0.407* | -0.49 | 0.95* | 0.06 | 0.594* | -0.31 |
| Debrebirhan | 0.089* | 1.12 | 0.683* | 0.048 | 0.341* | -0.275 |
| Debrezeit | 0.129* | 1.16 | 0.591* | 0.089 | 0.907* | 0.107 |
| Nazerite | 0.808* | 0.185 | 0.347* | 0.198 | 0.758* | -0.124 |

**As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis $H_O$*

*** As computed P-value is lower than the significance level alpha =0.05 reject the null hypothesis $H_O$*

The following figures describe the seasonal precipitation trends

Abomsa station

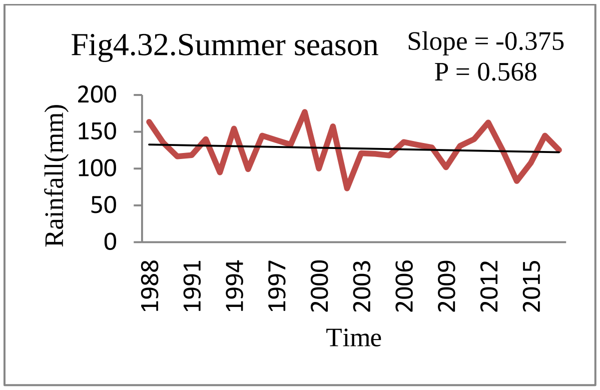



Fig4.32.Summer season

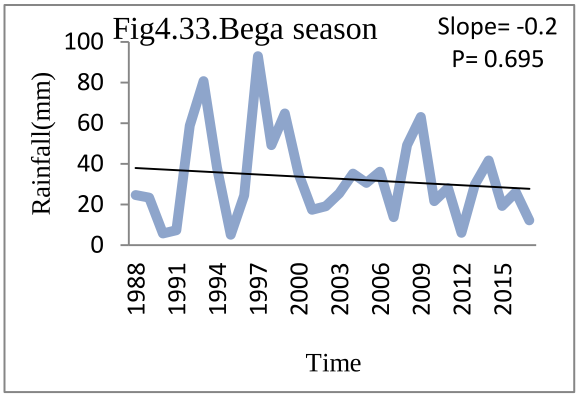



Fig4.33.Bega season

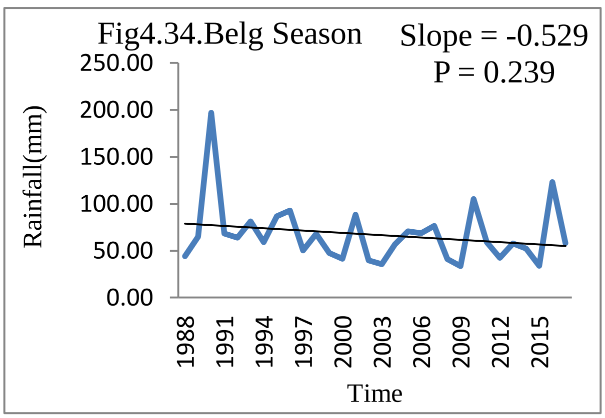



Fig4.34.Belg Season

Addis Ababa station

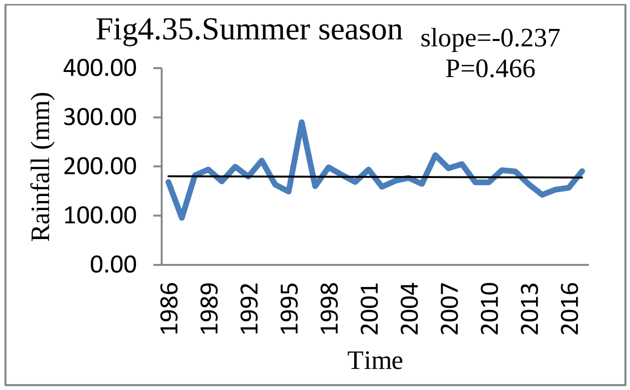



Fig4.35.Summer season

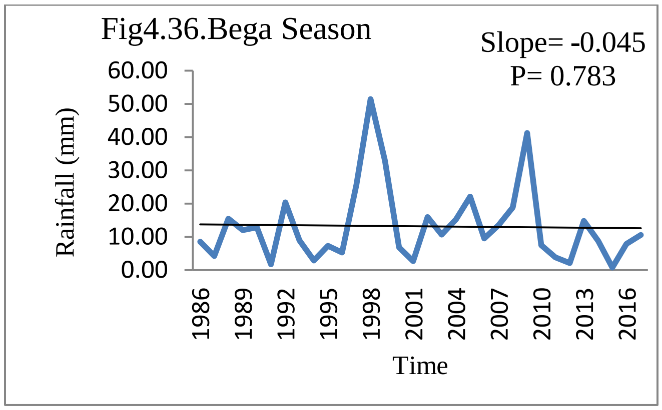



Fig4.36.Bega Season

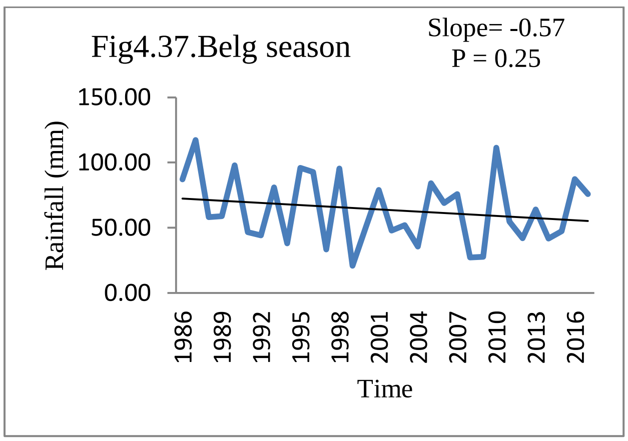
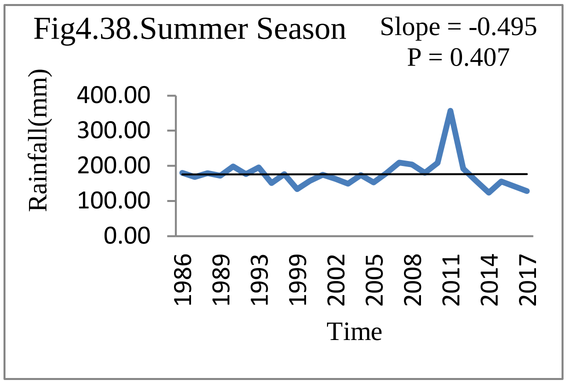
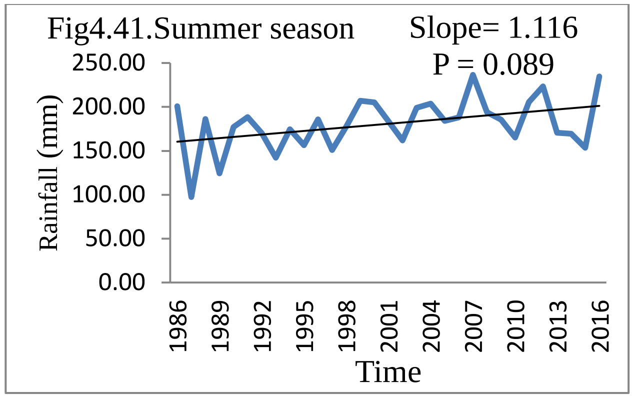


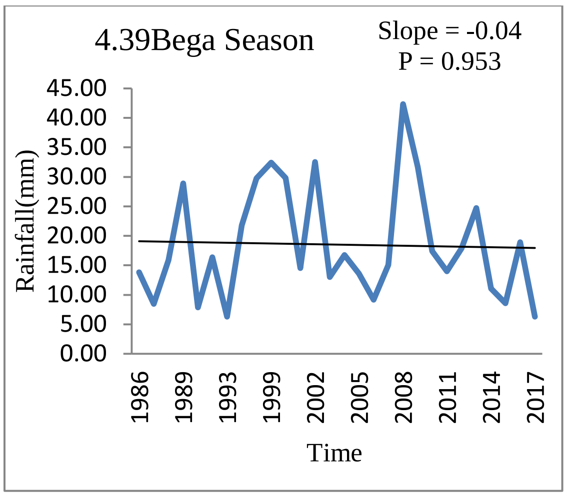

Fig4.37.Belg season

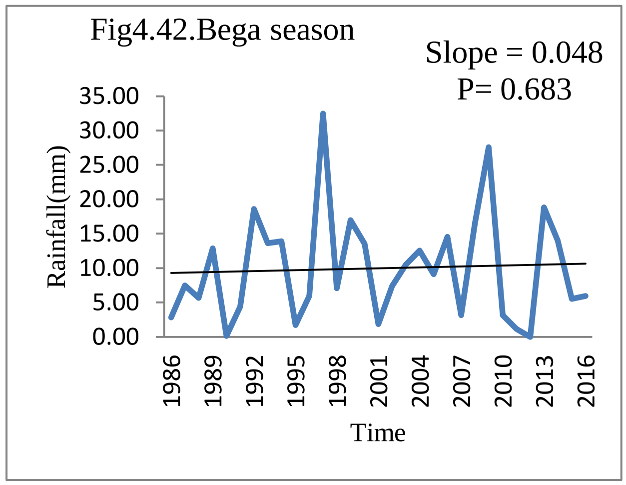
Ambo station

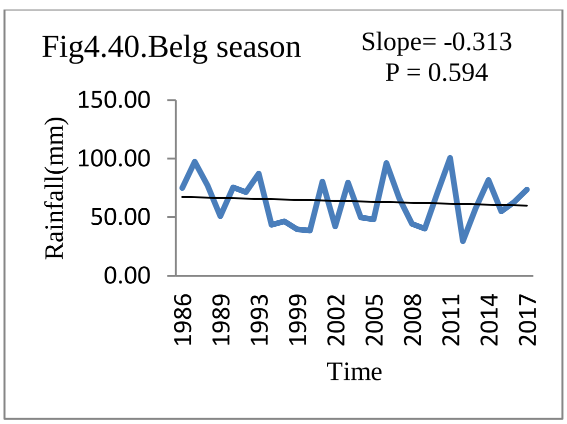
Debrebirhan station

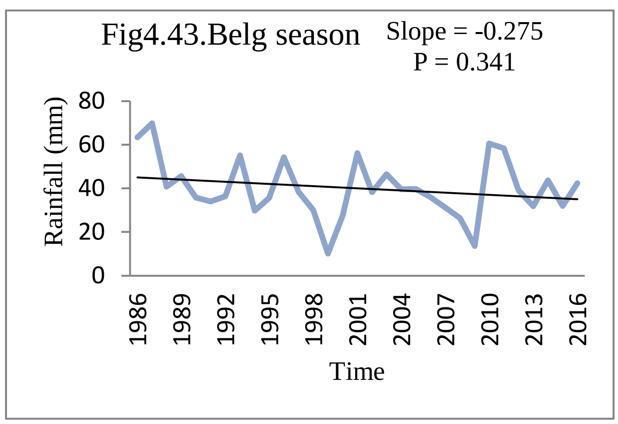


### 4.2.3. Annual precipitation trend analysis

On running the Mann-Kendall's test (MT) on annual precipitation data the result in Table12 are obtained from the six stations data of the upper Awash River basin. The MT is based on the calculation Kendall's (measure of connection between two successive annual precipitation years). The analysis results shows that most of the stations successive annual rainfall years are negatively related. It is found to be statistically significant annual rainfall irregularities across the whole recorded years in upper Awash River basin at 5% level of significance. If p-value is less than the significance level alpha=0.05, $H_O$ (there is no trend), hence the hypothesis is not accepted. Rejecting $H_O$ indicates there is a trend in the time series, while accepting $H_O$ indicated no trend is detected. Rejecting the null hypothesis implies that the result is said to be statistically significant at alpha=0.05. In addition to this slope also indicated the trend of time series, for negative slope indicate the decreasing and positive slope indicate increasing trends. In upper Awash River basin from the selected climatic stations 50% show negative trends and 50% of them are positive (increasing) trends.

Based on the below results, it is of huge importance to discuss the ecological, economical and social impacts that could results if decreasing rainfall trends continue in the future for rural farmers who have been vulnerable to drought, water stress and irregular nature of rainfall , appropriate adaptation strategies should have to be design and implemented. The vulnerability of rural households might further be aggravated if extreme rainfall condition continues in the future and consequently result in drought and surface and ground water losses due to evaporation and consumption.

The magnitude of the significant decreasing trend at Abomsa, Addis Ababa and Ambo stations are -7.4,-1.92, and -5.34 mm/year respectively. The results present study area in agreement with the previous climate change study in the same station, who reported decreasing trends of precipitation in Addis Ababa station (Tekleab et al.,2013 and Taye et al., 2015). Debrebrihan and Debrezeit stations are not in agreement in this study both station show significant increasing trend mean annually precipitation, but the results presented in those stations, who reported significantly decreasing mean annual precipitation trend (Taye et al., 2015).

Tabkle4.8: Trend results of Mann-Kendall p- value and Sen's slope for annually precipitation time series.   Positive /negative of slope indicates increasing or decreasing trends respectively.

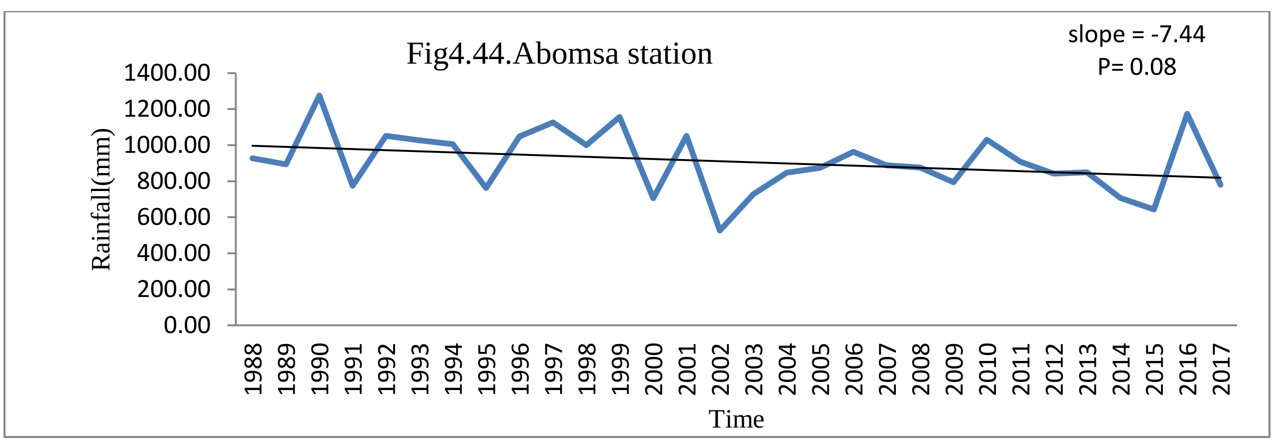
| Station | p-value | Sens slop |
|---|---|---|
| Abomsa | 0.08* | -7.44 |
| Addis Ababa | 0.57* | -1.92 |
| Ambo | 0.213* | -5.36 |
| Debrebihan | 0.049** | 5.09 |
| Debrezeit | 0.097* | 5.9 |
| Nazerite | 0.733* | 1.5 |

**As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis* $H_O$

*** As computed P-value is lower than the significance level alpha =0.05 reject the null hypothesis* $H_O$

Figures below illustrated that the annual precipitation trends at Awash River basin major climatic stations the result show that 50% of the selected station deceasing annual precipitation trend and 50% of the station increasing trends. Abomsa, Addis Ababa and Ambo stations show decreasing trend with the magnitude of -7.44, -1.92, and -5.36 mm/year respectively and the other stations like Debrebrihan, Debrezeit and Nazerite increasing mean annual precipitation trend with the magnitude of 5.09, 5.9 and 1.5 mm/year respectively. These stations are not in agreement with the previous climate change study

The Figures below describe the annual mean precipitation trends



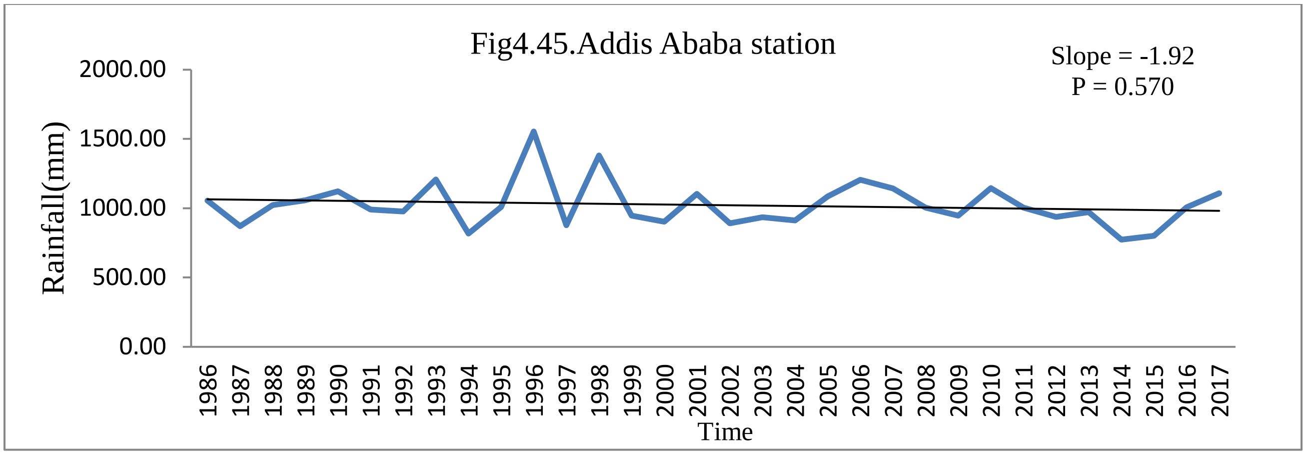


Fig4.45.Addis Ababa station
Slope = -1.92
P = 0.570
Rainfall(mm)
2000.00
1500.00
1000.00
500.00
0.00
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Time

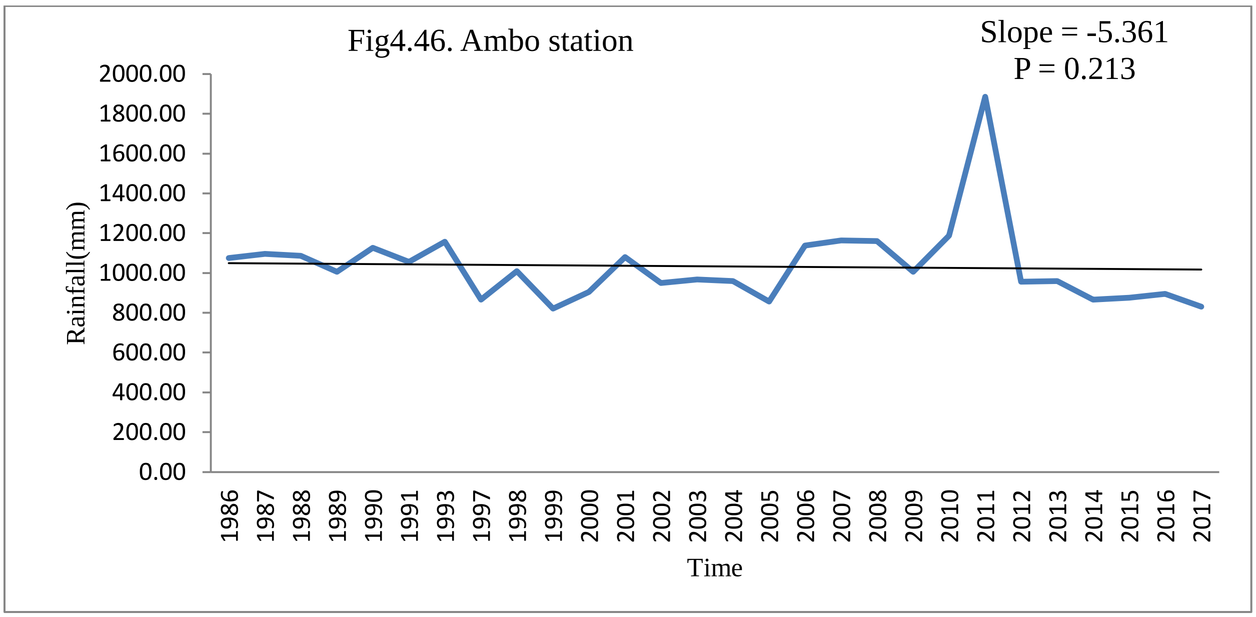


Fig4.46. Ambo station
Slope = -5.361
P = 0.213
Rainfall(mm)
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1986 1987 1988 1989 1990 1991 1993 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Time

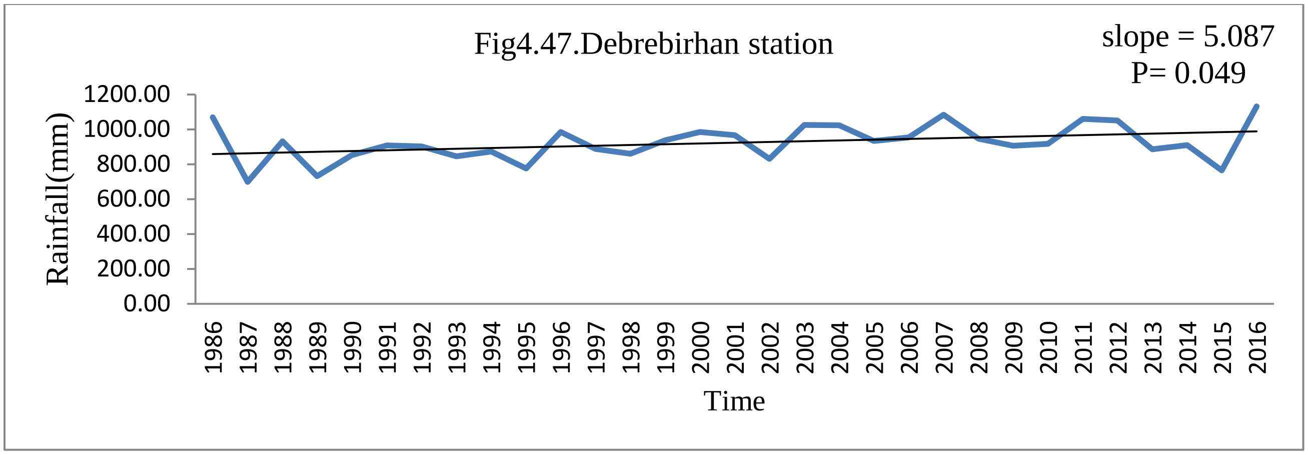


Fig4.47.Debrebirhan station
slope = 5.087
P= 0.049
Rainfall(mm)
Time

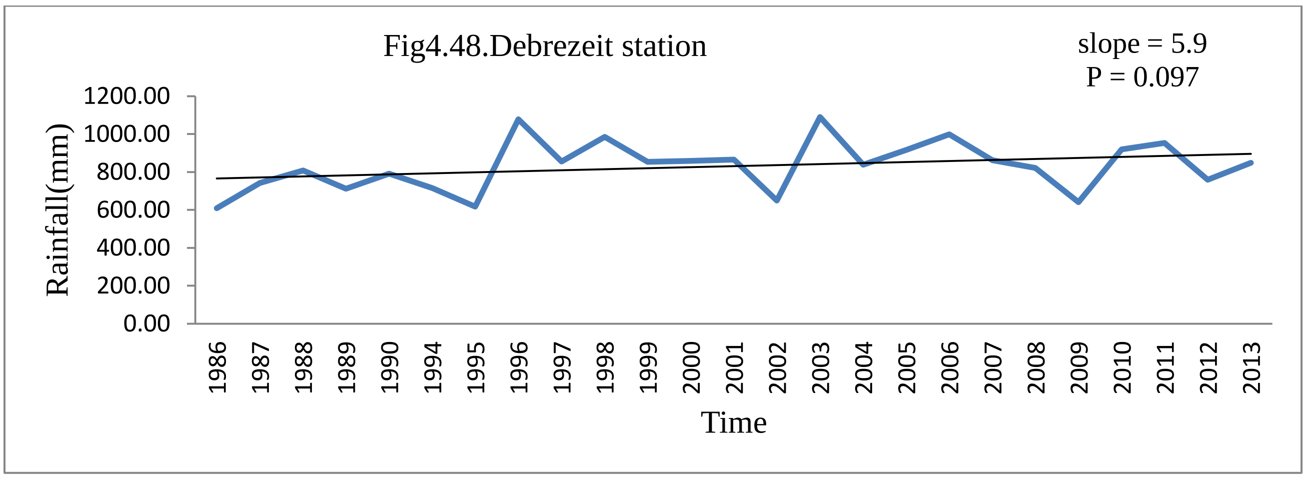


Fig4.48.Debrezeit station
slope = 5.9
P = 0.097
Rainfall(mm)
Time

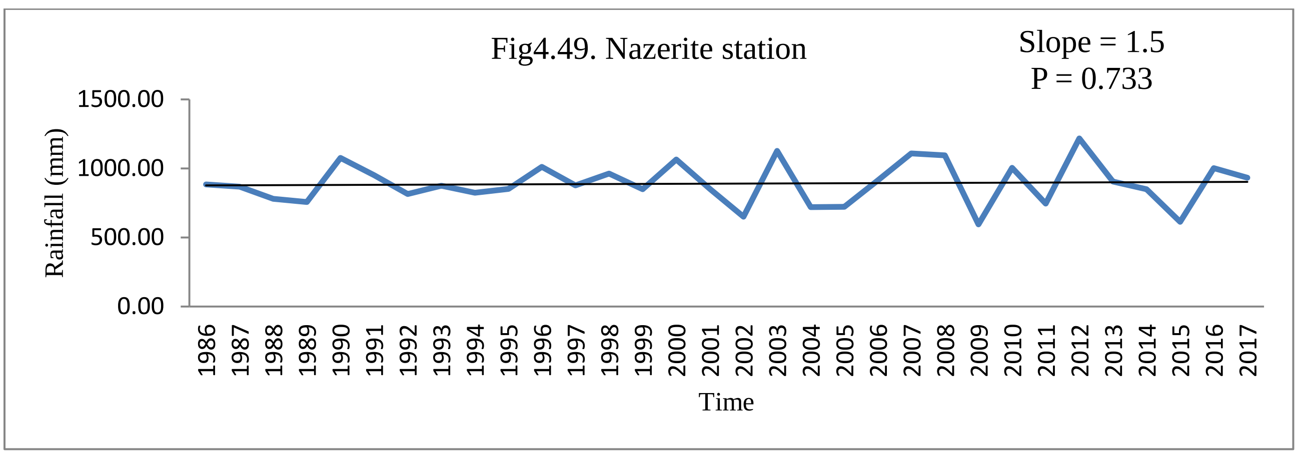


Fig4.49. Nazerite station
Slope = 1.5
P = 0.733
Rainfall (mm)
Time

4.3.1. Season stream flow trend analysis

In the Table 13, below describe selected hydrological stations. The result the Mann-Kendall's p-value and sens slope test showed that rainy seasons the months refers to October, November, December, and January  and small rainy season the months refers to March, April, and may in koka hydrological stations decreasing stream flow  with the p-value and slope (P=0.186,Slope=-0.02) ,and (p=0.386 and slope=-0.01) respectively. Akaki station is one of the major hydrological stations of upper Awash River basin in this stations in rainy season the p-value and the slope (P=0.552 and slope =-0.017) non-significant decreasing stream flow trends

Table4.9: Trend results of Mann-Kendall p- value and Sen's slope for seasonal stream flow time series.  Positive /negative of Sen's slope indicate increasing or decreasing trends respectively.

| Station | Mann-Kendall trend test Result | | |
|---|---|---|---|
| | Season | P-Value | Slope |
| Akaki | Kiremt | 0.373* | 0.206 |
| | Bega | 0.5* | 0.005 |
| | Belg | 0.552* | -0.017 |
| koka | Kiremt | 0.186* | -0.02 |
| | Bega | 0.614* | 0.02 |
| | Belg | 0.386* | 0.01 |
| Hombole | Kiremt | 0.07* | 0.03 |
| | Bega | 0.08* | 0.005 |
| | Belg | 0.09* | 0.01 |

***As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis $H_O$***

***** As computed P-value is lower than the significance level alpha =0.05 reject the null hypothesis $H_O$***

### 4.3.2. Annual streamflow trend analysis

On running the Mann-Kendall's (MK) on annually stream flow data, the results in Table fourteen are obtained from the three (3) stations data of the upper Awash River basin. The Mann-Kendall test is based on the calculation of p-value and slope. From the three selected hydrological station at Akaki station the annual stream flow trend test show that with the p-value and slope (p=0.56 and slope=-0.167)non-significance decrase and also the stations at Koka and Homebole station non- significant increasing trends.

Table4.10: Trend results of Mann-Kendall p- value and Sen's slope for annual stream flow time series. Positive /negative of Sen's slope indicate increasing or decreasing trends respectively.

| Station | Mann-Kendall trend test Result | |
|---|---|---|
| | P-value | Sen's slope |
| Akaki | 0.56* | -0.167 |
| Koka | 0.681* | 0.186 |
| Hombole | 0.055* | 0.02 |

*As the computed P-value is greater than the significance level alpha=0.05, one cannot reject the hypothesis* $H_O$

# Chapter Five

## Conclusion and Recommendation

In this paper, a statistical analysis of monthly, seasonally and annually minimum and maximum temperature, precipitation and stream flow has been performed at six stations for temperature and precipitation trends and three stations for stream flow trends in the upper Awash River basin over the last 30 years time period.

Trends analyses have been conducted by using the non-parametric procedures. Mann-Kendall trend test is one of the non-parametric trend analysis approaches, in this study used the several forms of the Mann-Kendall trend tests. The results indicate significant increasing trends in monthly minimum and maximum temperature at most of the months considered. The Mann-Kendall trend test of seasonal and annually minimum and maximum temperature trends result showed that significantly increase at most of the stations. Out of six precipitations climate stations three stations significantly decreased trends and three stations also insignificant increased trends at significant level alpha 0.05. The selection of stations and records was determined by data availability and quality. From the climate variable the minimum temperature shows more significance increase than the maximum temperature at most climate stations. The more increases are more pronounced in winter and spring seasons than during the summer season.

For the hydrological variables in the Akaki, Koka and Homebole catchments no significant changes are seen on annual and seasonal streamflow trends. All these trend magnitudes reported vary from station to station, and month to month.

These changes are related to the current water shortage problems and are likely to lead to exacerbated problems for agriculture, industry, urban communities and the overall regional environment. This, in turn, will produce serious challenges for water resources management in the region. The results of this study should help governments and decision makers make better informed decision regarding water resources management and economic development planning.

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**APPENDEX ONE**

Temperature data

Abomsa maximum temperature data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | sep | Oct | Nov. | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 27.9 | 30.2 | 32.0 | 29.7 | 31.3 | 30.4 | 27.3 | 26.1 | 25.7 | 26.5 | 26.4 | 25.5 |
| 1989 | 24.9 | 25.3 | 28.0 | 25.6 | 29.4 | 29.9 | 27.5 | 26.9 | 26.3 | 27.0 | 26.4 | 24.6 |
| 1990 | 26.1 | 24.8 | 24.8 | 26.3 | 30.1 | 31.3 | 27.7 | 26.9 | 26.8 | 27.4 | 27.2 | 25.8 |
| 1991 | 27.6 | 27.2 | 28.7 | 28.7 | 29.8 | 31.0 | 27.1 | 26.2 | 27.7 | 28.0 | 26.7 | 25.7 |
| 1993 | 25.3 | 24.9 | 29.9 | 29.4 | 29.8 | 30.8 | 27.2 | 25.7 | 25.3 | 25.6 | 25.5 | 26.0 |
| 1994 | 24.3 | 23.3 | 28.8 | 27.3 | 27.5 | 29.8 | 27.8 | 27.3 | 27.5 | 26.5 | 26.6 | 25.9 |
| 1995 | 26.5 | 28.2 | 29.5 | 29.4 | 30.4 | 31.2 | 27.0 | 26.9 | 27.2 | 27.9 | 25.6 | 24.9 |
| 1992 | 26.3 | 28.6 | 27.5 | 28.2 | 30.3 | 32.0 | 28.4 | 27.6 | 27.5 | 28.5 | 28.3 | 27.7 |
| 1996 | 26.4 | 29.9 | 29.2 | 29.1 | 28.3 | 28.5 | 27.8 | 27.9 | 28.0 | 28.1 | 27.3 | 27.2 |
| 1997 | 26.6 | 27.9 | 30.2 | 28.0 | 30.8 | 30.4 | 27.9 | 27.2 | 28.7 | 26.1 | 24.6 | 25.3 |
| 1998 | 24.9 | 27.4 | 28.1 | 31.0 | 30.1 | 31.7 | 28.4 | 26.7 | 26.9 | 26.6 | 26.4 | 25.9 |
| 1999 | 26.8 | 29.6 | 27.0 | 30.3 | 31.3 | 31.2 | 27.1 | 26.7 | 26.8 | 25.4 | 25.7 | 25.5 |
| 2000 | 26.9 | 28.4 | 30.3 | 29.8 | 30.2 | 31.0 | 28.4 | 26.9 | 27.2 | 27.7 | 26.0 | 25.7 |
| 2001 | 25.3 | 27.9 | 27.6 | 29.7 | 30.7 | 30.0 | 28.1 | 26.4 | 27.5 | 28.4 | 27.7 | 27.1 |
| 2002 | 25.7 | 29.3 | 28.9 | 30.1 | 32.0 | 31.4 | 30.7 | 27.8 | 28.8 | 29.1 | 26.9 | 26.0 |
| 2003 | 25.8 | 29.4 | 29.7 | 29.6 | 32.4 | 30.8 | 27.4 | 26.5 | 27.2 | 28.2 | 27.5 | 25.2 |
| 2004 | 27.2 | 27.1 | 28.4 | 27.3 | 31.1 | 31.0 | 28.2 | 27.2 | 27.5 | 27.7 | 26.9 | 25.8 |
| 2005 | 26.2 | 29.7 | 29.8 | 31.0 | 28.4 | 30.4 | 27.5 | 28.1 | 28.1 | 28.3 | 27.5 | 26.6 |
| 2006 | 27.6 | 29.4 | 28.6 | 28.2 | 31.2 | 31.4 | 27.8 | 26.4 | 26.9 | 27.5 | 26.7 | 24.7 |
| 2007 | 26.3 | 28.6 | 30.7 | 29.0 | 31.3 | 29.7 | 27.5 | 26.4 | 27.1 | 27.7 | 26.7 | 26.0 |
| 2008 | 27.1 | 27.3 | 31.4 | 29.7 | 30.2 | 30.3 | 28.2 | 26.8 | 27.5 | 27.3 | 24.8 | 25.6 |
| 2009 | 26.0 | 28.6 | 31.0 | 29.5 | 32.2 | 32.5 | 29.1 | 27.3 | 28.8 | 27.6 | 28.0 | 26.0 |
| 2010 | 26.6 | 27.1 | 26.8 | 29.5 | 29.8 | 31.4 | 28.6 | 27.9 | 27.4 | 28.9 | 27.5 | 26.0 |
| 2011 | 27.9 | 28.9 | 28.8 | 31.7 | 30.7 | 31.0 | 29.6 | 28.0 | 27.1 | 28.3 | 26.8 | 25.6 |
| 2012 | 27.1 | 28.9 | 32.2 | 30.4 | 31.4 | 32.0 | 28.3 | 27.5 | 28.2 | 28.7 | 29.0 | 27.1 |
| 2013 | 27.4 | 30.3 | 31.3 | 31.3 | 31.3 | 32.0 | 27.7 | 27.5 | 28.6 | 28.8 | 27.2 | 26.7 |
| 2014 | 27.8 | 29.4 | 29.7 | 30.9 | 30.8 | 32.6 | 30.3 | 28.5 | 27.8 | 26.6 | 27.6 | 26.3 |
| 2015 | 26.7 | 30.3 | 31.4 | 31.7 | 30.9 | 31.4 | 30.9 | 29.6 | 29.0 | 29.9 | 28.0 | 26.4 |
| 2016 | 27.1 | 29.1 | 33.5 | 29.2 | 28.9 | 30.4 | 28.2 | 27.9 | 27.5 | 27.7 | 26.9 | 26.9 |
| 2017 | 27.8 | 28.2 | 31.8 | 30.9 | 30.0 | 32.3 | 28.2 | 27.4 | 27.3 | 28.5 | 28.1 | 26.7 |

Abomsa minimum temperature data

| Year | Jan | Feb | Mar | Apr | May | | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 14.7 | 15.9 | 17.0 | 17.4 | 18.4 | 17.8 | 17.3 | 16.1 | 16.4 | 15.1 | 12.0 | 12.4 |
| 1989 | 13.0 | 14.3 | 15.7 | 16.6 | 17.2 | 17.3 | 16.5 | 16.1 | 16.2 | 14.8 | 13.6 | 15.2 |
| 1990 | 13.8 | 15.8 | 15.8 | 16.0 | 17.5 | 17.2 | 15.9 | 16.4 | 16.4 | 14.6 | 13.4 | 12.2 |
| 1991 | 14.8 | 15.6 | 16.9 | 17.4 | 17.8 | 18.5 | 16.8 | 16.4 | 16.8 | 15.3 | 12.9 | 14.2 |
| 1993 | 14.5 | 14.6 | 15.4 | 16.7 | 17.1 | 17.6 | 16.5 | 16.3 | 16.3 | 15.5 | 13.2 | 12.3 |
| 1994 | 13.9 | 14.9 | 16.3 | 17.3 | 18.0 | 17.6 | 16.0 | 15.7 | 15.7 | 13.9 | 13.5 | 11.9 |
| 1995 | 12.0 | 15.1 | 16.2 | 17.2 | 17.6 | 18.0 | 17.0 | 16.5 | 16.3 | 15.7 | 13.4 | 14.1 |
| 1992 | 14.7 | 15.7 | 16.6 | 17.2 | 17.9 | 18.1 | 16.4 | 16.4 | 15.6 | 14.8 | 13.3 | 12.9 |
| 1996 | 14.6 | 14.9 | 16.8 | 17.3 | 16.9 | 16.9 | 16.3 | 15.9 | 16.0 | 13.9 | 13.1 | 12.3 |
| 1997 | 14.2 | 12.9 | 16.0 | 16.8 | 17.3 | 17.0 | 15.9 | 15.9 | 15.9 | 14.8 | 14.5 | 11.9 |
| 1998 | 14.2 | 16.5 | 17.3 | 18.2 | 18.7 | 18.4 | 17.4 | 16.8 | 16.5 | 15.6 | 13.2 | 12.0 |
| 1999 | 13.2 | 14.6 | 15.9 | 17.3 | 18.3 | 17.8 | 16.1 | 15.9 | 15.6 | 15.0 | 12.4 | 11.8 |
| 2000 | 13.1 | 13.3 | 15.3 | 16.8 | 18.0 | 17.8 | 16.2 | 16.2 | 16.3 | 15.1 | 13.9 | 13.3 |
| 2001 | 12.8 | 14.1 | 16.2 | 17.3 | 17.9 | 16.7 | 15.9 | 16.0 | 15.2 | 15.0 | 12.6 | 12.4 |
| 2002 | 13.9 | 13.7 | 16.4 | 16.7 | 18.5 | 17.9 | 17.2 | 16.7 | 16.4 | 16.3 | 13.6 | 12.9 |
| 2003 | 13.8 | 15.6 | 16.7 | 17.5 | 18.4 | 17.1 | 16.6 | 16.2 | 16.3 | 14.4 | 14.0 | 12.9 |
| 2004 | 15.3 | 14.3 | 14.7 | 16.8 | 17.8 | 17.0 | 16.2 | 16.5 | 15.9 | 14.1 | 13.7 | 13.7 |
| 2005 | 14.1 | 14.8 | 16.9 | 17.3 | 17.6 | 17.7 | 16.6 | 16.4 | 16.5 | 14.7 | 13.6 | 11.7 |
| 2006 | 13.6 | 15.4 | 15.8 | 17.3 | 18.2 | 17.9 | 16.7 | 16.5 | 16.4 | 15.9 | 14.0 | 14.3 |
| 2007 | 13.9 | 15.6 | 16.2 | 17.2 | 18.4 | 18.0 | 16.8 | 16.0 | 16.3 | 14.3 | 13.1 | 11.9 |
| 2008 | 13.6 | 13.2 | 14.8 | 17.5 | 18.1 | 17.6 | 16.6 | 16.6 | 16.6 | 15.5 | 13.3 | 11.9 |
| 2009 | 13.7 | 14.6 | 16.3 | 17.5 | 18.4 | 18.9 | 17.0 | 16.6 | 17.0 | 15.3 | 14.0 | 15.3 |
| 2010 | 13.8 | 16.2 | 15.9 | 18.1 | 18.3 | 18.2 | 17.0 | 16.8 | 16.2 | 15.6 | 13.6 | 12.9 |
| 2011 | 13.7 | 15.0 | 15.5 | 18.0 | 17.9 | 18.1 | 17.2 | 16.9 | 16.5 | 14.6 | 15.1 | 12.6 |
| 2012 | 13.6 | 13.6 | 15.6 | 17.5 | 18.2 | 18.3 | 16.4 | 16.2 | 16.5 | 13.9 | 13.3 | 13.6 |
| 2013 | 13.7 | 14.5 | 17.0 | 18.4 | 17.8 | 18.0 | 16.6 | 16.2 | 16.5 | 15.5 | 14.4 | 12.3 |
| 2014 | 14.0 | 15.8 | 16.3 | 17.7 | 18.3 | 18.6 | 17.4 | 16.7 | 16.3 | 15.3 | 14.7 | 12.8 |
| 2015 | 13.1 | 14.9 | 16.7 | 17.5 | 18.5 | 18.9 | 18.1 | 17.0 | 17.2 | 17.1 | 16.0 | 15.0 |
| 2016 | 15.7 | 15.2 | 19.5 | 18.0 | 18.0 | 17.7 | 16.9 | 16.8 | 16.3 | 15.1 | 13.6 | 13.6 |
| 2017 | 12.7 | 15.3 | 16.9 | 17.8 | 18.2 | 18.8 | 16.7 | 17.1 | 16.6 | 16.3 | 13.9 | 11.6 |

Addis Ababa monthly maximum temperature data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 23.5 | 24.1 | 24.1 | 22.5 | 25.4 | 21.9 | 21.4 | 21.1 | 21.6 | 22.8 | 23.1 | 23.1 |
| 1987 | 22.9 | 24.3 | 23.2 | 23.6 | 23.7 | 22.7 | 22.1 | 21.7 | 23.1 | 23.9 | 23.3 | 24.3 |
| 1988 | 24.7 | 25.1 | 27.3 | 25.1 | 25.8 | 23.4 | 21.0 | 21.0 | 21.2 | 21.9 | 22.5 | 22.8 |
| 1989 | 22.7 | 23.2 | 24.5 | 23.0 | 24.9 | 23.6 | 20.7 | 21.2 | 22.0 | 22.8 | 23.1 | 22.8 |
| 1990 | 24.0 | 23.2 | 23.9 | 23.6 | 25.3 | 23.5 | 21.4 | 21.4 | 21.9 | 23.0 | 23.5 | 23.6 |
| 1991 | 25.0 | 24.8 | 25.6 | 25.6 | 25.4 | 23.6 | 21.3 | 21.0 | 22.0 | 23.1 | 22.7 | 22.9 |
| 1992 | 22.5 | 23.4 | 25.7 | 25.8 | 26.2 | 23.6 | 21.1 | 19.7 | 21.0 | 21.9 | 22.2 | 23.1 |
| 1993 | 23.4 | 23.3 | 26.4 | 24.0 | 23.8 | 22.6 | 20.9 | 21.1 | 21.2 | 22.9 | 23.0 | 23.5 |
| 1994 | 23.9 | 25.7 | 25.9 | 26.1 | 26.7 | 23.1 | 21.2 | 20.8 | 22.0 | 23.3 | 23.5 | 23.5 |
| 1995 | 24.2 | 25.4 | 25.1 | 23.9 | 25.2 | 24.5 | 21.0 | 21.5 | 22.3 | 23.8 | 24.0 | 23.9 |
| 1996 | 23.6 | 26.4 | 25.0 | 24.7 | 24.5 | 21.1 | 20.9 | 21.4 | 22.1 | 23.6 | 23.3 | 23.1 |
| 1997 | 23.4 | 25.2 | 26.0 | 24.5 | 26.9 | 24.9 | 21.7 | 21.9 | 23.3 | 23.1 | 23.3 | 24.2 |
| 1998 | 24.3 | 25.0 | 25.4 | 26.6 | 25.2 | 24.7 | 22.3 | 21.9 | 21.9 | 22.2 | 22.8 | 23.2 |
| 1999 | 24.7 | 26.7 | 25.5 | 27.6 | 26.9 | 24.6 | 20.5 | 20.6 | 22.1 | 21.9 | 22.7 | 22.7 |
| 2000 | 23.9 | 25.5 | 27.3 | 25.7 | 25.4 | 23.1 | 21.5 | 20.6 | 21.1 | 22.5 | 22.9 | 23.8 |
| 2001 | 23.5 | 25.2 | 24.0 | 25.5 | 24.3 | 22.5 | 21.5 | 21.0 | 22.9 | 24.7 | 24.2 | 24.2 |
| 2002 | 24.2 | 26.2 | 25.7 | 26.7 | 27.0 | 24.9 | 23.0 | 21.8 | 22.4 | 24.3 | 24.3 | 23.8 |
| 2003 | 24.3 | 26.2 | 26.3 | 25.1 | 26.8 | 24.5 | 21.2 | 20.8 | 21.9 | 23.7 | 23.6 | 23.3 |
| 2004 | 25.1 | 25.1 | 25.6 | 23.9 | 26.8 | 23.6 | 21.5 | 21.5 | 22.2 | 22.3 | 23.7 | 24.0 |
| 2005 | 24.1 | 26.6 | 26.4 | 25.9 | 24.1 | 23.4 | 21.1 | 22.1 | 22.4 | 23.6 | 22.9 | 23.0 |
| 2006 | 23.8 | 25.0 | 24.5 | 24.3 | 25.1 | 23.1 | 20.8 | 20.1 | 21.6 | 24.2 | 23.5 | 22.8 |
| 2007 | 23.6 | 24.7 | 25.9 | 24.4 | 25.0 | 22.4 | 20.7 | 20.2 | 21.0 | 22.4 | 22.9 | 22.6 |
| 2008 | 24.1 | 24.3 | 26.3 | 25.9 | 25.5 | 22.8 | 21.2 | 20.7 | 21.9 | 23.4 | 22.2 | 22.9 |
| 2009 | 23.2 | 25.2 | 26.9 | 25.9 | 26.4 | 26.0 | 20.9 | 20.8 | 22.6 | 22.5 | 23.2 | 22.0 |
| 2010 | 23.4 | 23.7 | 23.6 | 25.1 | 24.1 | 23.3 | 20.9 | 20.9 | 21.9 | 24.1 | 22.9 | 22.8 |
| 2011 | 23.7 | 25.4 | 24.7 | 25.1 | 24.9 | 23.7 | 21.8 | 20.7 | 21.5 | 24.2 | 23.5 | 22.8 |
| 2012 | 24.5 | 25.5 | 26.7 | 24.7 | 26.5 | 24.0 | 21.2 | 20.7 | 22.0 | 23.9 | 24.4 | 23.3 |
| 2013 | 24.5 | 26.3 | 26.3 | 26.0 | 25.1 | 23.3 | 21.3 | 20.8 | 22.8 | 23.2 | 23.9 | 23.4 |
| 2014 | 24.3 | 25.2 | 25.8 | 26.4 | 25.9 | 25.1 | 22.0 | 21.5 | 21.7 | 23.2 | 23.7 | 22.9 |
| 2015 | 23.8 | 26.3 | 26.4 | 25.1 | 25.2 | 24.0 | 22.9 | 22.1 | 23.1 | 24.9 | 24.4 | 24.2 |
| 2016 | 23.9 | 25.1 | 25.6 | 24.5 | 24.1 | 23.6 | 21.5 | 21.7 | 22.7 | 24.0 | 23.3 | 23.2 |
| 2017 | 24.7 | 25.1 | 26.6 | 26.5 | 24.8 | 25.4 | 21.9 | 21.4 | 22.0 | 23.3 | 23.3 | 23.3 |

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 27.2 | 27.4 | 26.0 | 25.5 | 27.0 | 22.8 | 21.9 | 21.7 | 23.0 | 24.8 | 25.9 | 26.1 |
| 1987 | 26.6 | 27.5 | 28.6 | 28.2 | 27.3 | 24.8 | 22.8 | 22.6 | 24.0 | 26.6 | 27.2 | 26.5 |
| 1988 | 27.4 | 28.5 | 28.6 | 28.2 | 27.3 | 24.8 | 22.8 | 21.0 | 24.0 | 25.8 | 26.3 | 26.5 |
| 1989 | 27.4 | 28.5 | 28.6 | 28.2 | 26.6 | 24.8 | 22.8 | 22.6 | 22.4 | 23.8 | 25.0 | 25.6 |
| 1990 | 26.7 | 25.3 | 26.6 | 27.3 | 27.5 | 24.3 | 22.3 | 22.1 | 23.4 | 25.5 | 26.5 | 26.5 |
| 1991 | 27.8 | 27.6 | 27.3 | 28.2 | 27.3 | 24.8 | 22.8 | 22.6 | 24.0 | 25.8 | 26.3 | 26.5 |
| 1993 | 26.7 | 26.3 | 28.7 | 26.8 | 26.6 | 25.3 | 24.4 | 24.1 | 24.3 | 25.7 | 27.5 | 26.3 |
| 1997 | 27.4 | 28.5 | 28.6 | 28.2 | 27.3 | 24.8 | 22.8 | 25.3 | 26.2 | 25.8 | 26.7 | 27.8 |
| 1998 | 27.7 | 29.0 | 28.6 | 30.0 | 27.3 | 24.8 | 22.8 | 22.6 | 24.0 | 25.8 | 26.3 | 26.5 |
| 1999 | 27.4 | 29.6 | 28.3 | 28.7 | 28.0 | 25.0 | 21.4 | 21.9 | 23.7 | 24.2 | 25.3 | 25.9 |
| 2000 | 27.0 | 28.3 | 29.7 | 27.1 | 26.8 | 24.8 | 22.6 | 21.9 | 23.5 | 24.8 | 25.3 | 25.8 |
| 2001 | 26.7 | 28.5 | 26.6 | 28.1 | 26.9 | 23.0 | 22.3 | 22.3 | 24.3 | 26.2 | 26.2 | 26.7 |
| 2002 | 26.1 | 28.2 | 27.7 | 28.5 | 29.3 | 25.2 | 23.9 | 22.6 | 24.3 | 26.5 | 27.0 | 26.8 |
| 2003 | 27.4 | 28.7 | 28.3 | 27.4 | 28.9 | 24.8 | 22.3 | 22.3 | 23.3 | 25.7 | 26.3 | 26.1 |
| 2004 | 27.4 | 28.0 | 28.1 | 27.4 | 28.2 | 24.9 | 22.4 | 22.8 | 23.6 | 25.2 | 26.7 | 26.1 |
| 2005 | 27.0 | 30.1 | 29.2 | 28.4 | 27.0 | 25.3 | 22.4 | 23.2 | 24.3 | 25.7 | 26.4 | 26.7 |
| 2006 | 27.9 | 29.2 | 27.8 | 26.5 | 26.5 | 24.4 | 22.6 | 22.2 | 23.8 | 25.9 | 26.3 | 26.6 |
| 2007 | 27.4 | 27.6 | 28.9 | 27.9 | 26.9 | 23.9 | 22.0 | 22.0 | 23.4 | 25.7 | 26.3 | 26.5 |
| 2008 | 28.0 | 28.7 | 30.1 | 29.0 | 26.6 | 24.3 | 22.5 | 22.3 | 24.2 | 26.0 | 24.9 | 26.5 |
| 2009 | 27.2 | 28.5 | 29.8 | 28.7 | 29.2 | 27.0 | 22.9 | 23.1 | 25.5 | 26.2 | 27.1 | 26.6 |
| 2010 | 28.0 | 29.4 | 28.8 | 28.8 | 27.4 | 25.3 | 22.7 | 22.1 | 23.9 | 27.4 | 27.0 | 26.4 |
| 2011 | 27.5 | 29.7 | 27.8 | 29.3 | 27.3 | 25.2 | 23.6 | 22.8 | 24.4 | 27.0 | 26.3 | 27.3 |
| 2012 | 29.0 | 29.9 | 30.1 | 28.7 | 29.0 | 24.7 | 21.7 | 22.4 | 23.0 | 26.0 | 26.7 | 26.7 |
| 2013 | 27.7 | 29.4 | 29.7 | 29.6 | 26.4 | 24.7 | 22.4 | 21.8 | 24.2 | 25.1 | 26.2 | 26.7 |
| 2014 | 27.7 | 28.0 | 29.0 | 28.2 | 26.4 | 25.6 | 23.4 | 22.7 | 23.7 | 25.7 | 26.7 | 26.6 |
| 2015 | 27.7 | 29.3 | 29.7 | 28.2 | 27.3 | 25.3 | 24.5 | 23.7 | 24.9 | 27.2 | 27.0 | 26.9 |
| 2016 | 27.8 | 29.5 | 30.8 | 28.4 | 26.4 | 24.4 | 23.7 | 23.7 | 24.0 | 25.8 | 26.1 | 26.3 |
| 2017 | 27.6 | 28.5 | 29.4 | 29.3 | 26.3 | 25.1 | 22.7 | 22.3 | 23.9 | 26.3 | 25.9 | 26.5 |

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986.0 | 10.1 | 12.9 | 12.6 | 12.7 | 12.7 | 12.1 | 12.1 | 11.7 | 10.7 | 9.2 | 10.5 | 11.4 |
| 1987.0 | 11.4 | 12.9 | 13.3 | 13.4 | 13.5 | 11.7 | 12.5 | 12.2 | 10.1 | 10.3 | 11.6 | 11.5 |
| 1988.0 | 12.6 | 13.0 | 13.6 | 13.2 | 11.6 | 12.3 | 12.7 | 11.9 | 11.9 | 10.9 | 9.3 | 9.5 |
| 1989.0 | 11.7 | 11.5 | 11.8 | 11.8 | 11.4 | 11.2 | 11.7 | 11.6 | 8.9 | 7.8 | 7.9 | 12.3 |
| 1990.0 | 11.2 | 12.4 | 13.3 | 13.6 | 12.3 | 11.9 | 11.9 | 11.9 | 11.1 | 9.7 | 10.6 | 11.1 |
| 1991.0 | 12.8 | 12.3 | 13.0 | 13.6 | 12.7 | 12.3 | 12.5 | 12.4 | 11.5 | 10.9 | 10.8 | 11.1 |
| 1993.0 | 10.9 | 10.6 | 13.4 | 12.5 | 12.7 | 11.6 | 11.8 | 11.3 | 11.2 | 10.9 | 11.9 | 11.4 |
| 1997.0 | 11.7 | 12.6 | 13.4 | 13.6 | 12.7 | 12.3 | 12.5 | 11.1 | 10.1 | 10.6 | 11.0 | 10.3 |
| 1998.0 | 11.7 | 12.5 | 13.3 | 14.0 | 12.7 | 12.3 | 12.5 | 12.4 | 11.5 | 10.9 | 8.5 | 8.7 |
| 1999.0 | 9.6 | 11.0 | 12.4 | 12.0 | 10.8 | 11.0 | 12.1 | 11.4 | 10.3 | 10.8 | 7.8 | 9.8 |
| 2000.0 | 11.0 | 12.0 | 14.2 | 13.1 | 11.6 | 11.1 | 11.8 | 11.9 | 11.5 | 10.9 | 10.3 | 9.7 |
| 2001.0 | 10.3 | 11.9 | 12.9 | 13.1 | 12.3 | 12.0 | 12.0 | 12.7 | 9.8 | 10.3 | 9.9 | 10.9 |
| 2002.0 | 11.5 | 12.5 | 11.9 | 12.7 | 13.0 | 12.1 | 12.1 | 12.4 | 11.5 | 10.7 | 11.6 | 12.5 |
| 2003.0 | 11.3 | 12.7 | 13.4 | 13.0 | 11.2 | 11.8 | 12.8 | 12.9 | 11.2 | 9.4 | 11.2 | 10.4 |
| 2004.0 | 12.6 | 12.4 | 13.9 | 13.5 | 11.9 | 12.2 | 12.0 | 11.9 | 11.1 | 10.6 | 10.4 | 11.9 |
| 2005.0 | 11.0 | 12.6 | 12.9 | 14.1 | 12.6 | 11.3 | 11.8 | 11.6 | 11.5 | 9.4 | 9.0 | 9.0 |
| 2006.0 | 11.9 | 12.6 | 12.3 | 13.1 | 10.9 | 11.5 | 12.6 | 12.7 | 11.5 | 11.5 | 11.8 | 12.3 |
| 2007.0 | 12.6 | 11.9 | 13.0 | 13.5 | 13.5 | 12.8 | 12.6 | 12.5 | 12.3 | 10.1 | 11.4 | 10.3 |
| 2008.0 | 12.6 | 13.1 | 13.8 | 14.0 | 12.7 | 12.6 | 12.2 | 11.8 | 11.3 | 11.2 | 11.3 | 11.6 |
| 2009.0 | 12.3 | 13.3 | 13.9 | 14.4 | 13.0 | 12.3 | 12.9 | 13.1 | 10.8 | 11.5 | 11.0 | 12.8 |
| 2010.0 | 12.7 | 12.6 | 12.6 | 14.5 | 14.1 | 16.1 | 13.9 | 15.3 | 15.4 | 14.8 | 13.4 | 13.2 |
| 2011.0 | 13.2 | 14.5 | 14.5 | 15.1 | 14.9 | 14.3 | 13.1 | 13.4 | 14.3 | 13.9 | 13.5 | 12.4 |
| 2012.0 | 12.2 | 12.9 | 14.1 | 13.9 | 13.8 | 12.8 | 12.9 | 12.9 | 12.1 | 10.6 | 11.3 | 11.8 |
| 2013.0 | 11.8 | 13.3 | 14.9 | 13.7 | 13.5 | 13.6 | 13.4 | 13.1 | 11.6 | 11.3 | 12.3 | 12.3 |
| 2014.0 | 12.9 | 13.3 | 13.2 | 14.1 | 13.3 | 12.8 | 13.3 | 12.3 | 12.2 | 11.8 | 11.0 | 11.2 |
| 2015.0 | 10.6 | 12.9 | 13.9 | 13.6 | 12.7 | 13.3 | 12.8 | 12.8 | 11.7 | 11.5 | 12.0 | 12.4 |
| 2016.0 | 12.6 | 13.7 | 14.7 | 14.6 | 13.6 | 11.5 | 12.3 | 12.6 | 11.5 | 10.9 | 9.8 | 10.1 |
| 2017.0 | 9.6 | 13.8 | 14.0 | 15.2 | 13.9 | 12.6 | 13.1 | 12.8 | 12.6 | 11.7 | 10.0 | 10.0 |

Debrebirhan monthly maximum temperature data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 20.4 | 19.9 | 19.1 | 19.0 | 20.9 | 19.3 | 18.6 | 18.1 | 18.3 | 18.5 | 19.0 | 19.5 |
| 1987 | 19.5 | 20.9 | 19.5 | 19.7 | 19.5 | 21.9 | 22.4 | 19.5 | 19.8 | 19.5 | 19.8 | 20.1 |
| 1988 | 20.3 | 20.8 | 21.5 | 20.6 | 22.1 | 22.1 | 17.0 | 17.6 | 18.0 | 17.4 | 17.9 | 18.3 |
| 1989 | 19.0 | 18.5 | 19.7 | 18.1 | 20.4 | 21.4 | 18.8 | 17.2 | 18.2 | 18.0 | 18.7 | 18.0 |
| 1990 | 19.0 | 18.5 | 19.9 | 20.1 | 22.6 | 23.0 | 18.6 | 18.9 | 18.4 | 18.2 | 18.5 | 18.8 |
| 1991 | 23.3 | 22.7 | 22.7 | 22.1 | 21.6 | 22.5 | 18.0 | 17.8 | 19.0 | 18.2 | 18.6 | 18.3 |
| 1992 | 18.1 | 18.9 | 21.7 | 21.5 | 21.6 | 22.6 | 18.3 | 16.6 | 17.5 | 17.3 | 17.3 | 18.7 |
| 1993 | 18.9 | 18.7 | 20.6 | 19.4 | 19.9 | 21.9 | 18.5 | 18.9 | 18.4 | 18.0 | 18.2 | 18.9 |
| 1994 | 19.7 | 20.9 | 20.4 | 21.5 | 22.0 | 21.4 | 17.4 | 17.6 | 18.1 | 18.9 | 19.3 | 19.8 |
| 1995 | 20.2 | 20.8 | 21.3 | 20.8 | 22.1 | 23.4 | 18.6 | 18.7 | 19.4 | 19.2 | 19.8 | 19.7 |
| 1996 | 19.1 | 21.8 | 20.7 | 21.2 | 20.1 | 19.2 | 18.5 | 18.6 | 19.6 | 18.9 | 18.7 | 18.4 |
| 1997 | 19.2 | 20.1 | 21.2 | 19.9 | 21.4 | 21.1 | 18.0 | 18.3 | 19.3 | 18.3 | 18.8 | 19.8 |
| 1998 | 19.8 | 21.0 | 20.9 | 22.2 | 22.4 | 23.3 | 17.8 | 17.7 | 18.7 | 18.6 | 18.4 | 18.4 |
| 1999 | 19.3 | 21.5 | 20.5 | 21.8 | 22.6 | 22.4 | 17.1 | 18.1 | 18.6 | 17.9 | 17.8 | 18.6 |
| 2000 | 19.7 | 20.5 | 21.5 | 20.8 | 21.8 | 22.7 | 18.3 | 17.7 | 18.5 | 18.4 | 18.5 | 19.4 |
| 2001 | 19.9 | 20.8 | 19.2 | 21.2 | 22.2 | 21.5 | 17.9 | 17.6 | 19.6 | 19.9 | 19.6 | 19.3 |
| 2002 | 19.5 | 21.2 | 20.7 | 21.4 | 23.0 | 22.8 | 21.5 | 17.5 | 18.6 | 19.6 | 19.8 | 19.3 |
| 2003 | 20.3 | 21.4 | 21.2 | 20.8 | 21.8 | 22.5 | 18.0 | 18.3 | 19.0 | 19.4 | 18.5 | 19.4 |
| 2004 | 20.7 | 20.4 | 21.0 | 20.4 | 23.1 | 21.2 | 18.7 | 18.7 | 19.1 | 18.6 | 19.5 | 19.6 |
| 2005 | 20.1 | 22.1 | 22.0 | 21.3 | 20.4 | 21.6 | 18.3 | 18.9 | 19.3 | 19.0 | 18.8 | 18.9 |
| 2006 | 20.0 | 21.0 | 20.5 | 20.0 | 21.9 | 22.6 | 19.0 | 18.0 | 18.6 | 19.6 | 19.0 | 19.1 |
| 2007 | 19.9 | 20.6 | 21.8 | 20.8 | 22.7 | 21.2 | 18.0 | 18.2 | 18.7 | 19.0 | 18.6 | 18.7 |
| 2008 | 20.0 | 20.2 | 22.0 | 20.8 | 21.3 | 21.2 | 18.9 | 19.0 | 19.4 | 19.2 | 18.4 | 19.1 |
| 2009 | 19.3 | 20.3 | 21.5 | 21.7 | 22.4 | 23.6 | 17.9 | 18.7 | 19.9 | 18.8 | 19.7 | 18.5 |
| 2010 | 19.8 | 20.9 | 20.4 | 20.8 | 21.3 | 22.7 | 18.7 | 18.1 | 19.0 | 19.8 | 19.2 | 19.2 |
| 2011 | 19.5 | 21.6 | 20.1 | 21.9 | 21.2 | 22.2 | 19.1 | 18.2 | 18.8 | 19.4 | 19.4 | 19.4 |
| 2012 | 20.3 | 21.3 | 22.1 | 20.6 | 21.4 | 22.3 | 18.4 | 18.3 | 19.4 | 19.8 | 20.5 | 20.2 |
| 2013 | 20.8 | 21.9 | 22.1 | 22.2 | 22.0 | 22.0 | 17.6 | 17.4 | 19.1 | 18.8 | 19.0 | 19.1 |
| 2014 | 19.7 | 20.9 | 21.3 | 20.9 | 21.3 | 22.8 | 20.0 | 18.4 | 18.7 | 19.0 | 20.0 | 19.6 |
| 2015 | 20.6 | 21.9 | 21.9 | 22.5 | 21.6 | 22.2 | 21.2 | 18.9 | 19.6 | 20.9 | 20.2 | 19.8 |
| 2016 | 20.4 | 22.0 | 21.0 | 20.9 | 21.1 | 21.6 | 18.3 | 18.4 | 19.5 | 20.0 | 19.7 | 18.8 |

Debrebirhan monthly minimum temperature data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 3.8 | 7.4 | 7.6 | 8.6 | 7.7 | 8.6 | 8.3 | 8.0 | 6.1 | 4.5 | 4.3 | 5.0 |
| 1987 | 5.0 | 6.9 | 8.8 | 8.0 | 8.7 | 7.7 | 8.5 | 8.9 | 7.6 | 5.5 | 4.2 | 5.2 |
| 1988 | 6.8 | 6.1 | 13.5 | 8.2 | 7.0 | 6.6 | 9.7 | 9.0 | 7.9 | 3.9 | -1.2 | 0.9 |
| 1989 | 0.3 | 6.2 | 7.4 | 8.0 | 5.5 | 6.3 | 8.7 | 9.2 | 9.4 | 3.6 | 2.5 | 6.7 |
| 1990 | 3.1 | 9.2 | 7.1 | 6.8 | 5.5 | 5.9 | 8.6 | 8.9 | 7.3 | 2.0 | 2.1 | 0.2 |
| 1991 | 5.3 | 6.1 | 8.4 | 7.7 | 7.4 | 7.4 | 9.0 | 8.8 | 7.1 | 1.6 | 1.7 | 0.8 |
| 1992 | 6.8 | 7.9 | 8.5 | 7.3 | 6.5 | 6.9 | 7.9 | 9.0 | 7.0 | 3.6 | 3.9 | 4.2 |
| 1993 | 5.8 | 6.9 | 5.8 | 8.2 | 6.8 | 6.5 | 8.8 | 8.6 | 7.8 | 4.5 | 1.5 | 2.5 |
| 1994 | 3.6 | 5.1 | 8.7 | 8.0 | 7.1 | 7.1 | 8.6 | 7.8 | 6.7 | 3.6 | 0.8 | 2.5 |
| 1995 | 2.8 | 7.5 | 6.7 | 8.7 | 6.4 | 6.7 | 8.8 | 9.2 | 7.0 | 2.7 | 1.2 | 5.8 |
| 1996 | 6.3 | 4.6 | 7.4 | 7.1 | 8.0 | 7.9 | 8.2 | 8.5 | 6.4 | 1.4 | 2.1 | 3.2 |
| 1997 | 6.1 | 2.2 | 8.2 | 7.0 | 6.7 | 8.5 | 8.6 | 8.1 | 7.1 | 6.1 | 4.3 | 2.3 |
| 1998 | 7.7 | 8.4 | 9.3 | 9.6 | 7.7 | 7.2 | 9.3 | 9.5 | 7.3 | 3.7 | -1.0 | -2.1 |
| 1999 | 2.2 | 3.1 | 5.9 | 5.2 | 5.8 | 6.3 | 8.6 | 8.6 | 6.2 | 4.6 | -1.2 | 1.8 |
| 2000 | 1.0 | 3.4 | 4.8 | 7.0 | 7.1 | 5.7 | 8.6 | 8.1 | 6.8 | 3.3 | 1.7 | 1.0 |
| 2001 | 1.5 | 4.5 | 8.3 | 6.0 | 8.2 | 8.0 | 9.2 | 9.2 | 6.4 | 3.3 | 2.9 | 4.6 |
| 2002 | 5.0 | 6.3 | 8.4 | 7.6 | 7.7 | 7.6 | 9.1 | 9.1 | 7.5 | 3.1 | 2.8 | 7.2 |
| 2003 | 5.3 | 6.9 | 7.9 | 9.5 | 7.0 | 8.0 | 9.4 | 9.6 | 8.1 | 3.0 | 2.7 | 1.6 |
| 2004 | 5.0 | 4.4 | 5.6 | 8.9 | 6.7 | 8.1 | 9.2 | 9.0 | 7.0 | 3.3 | 2.7 | 5.2 |
| 2005 | 5.3 | 7.3 | 8.3 | 9.2 | 9.2 | 7.8 | 9.2 | 9.2 | 8.3 | 3.9 | 2.0 | 1.7 |
| 2006 | 5.9 | 8.0 | 7.5 | 8.5 | 7.4 | 8.2 | 9.8 | 9.8 | 7.4 | 5.4 | 2.5 | 4.7 |
| 2007 | 6.6 | 7.5 | 7.7 | 8.5 | 8.1 | 9.0 | 9.6 | 9.2 | 7.5 | 3.4 | 3.9 | 1.0 |
| 2008 | 5.4 | 5.0 | 5.5 | 7.7 | 8.6 | 8.5 | 8.6 | 9.2 | 7.0 | 4.2 | 4.0 | 4.6 |
| 2009 | 6.3 | 7.6 | 8.1 | 7.4 | 7.0 | 8.4 | 9.3 | 9.3 | 6.5 | 4.8 | 3.1 | 7.3 |
| 2010 | 6.4 | 9.3 | 9.2 | 9.2 | 9.2 | 8.1 | 9.1 | 9.3 | 7.2 | 3.7 | 4.1 | 4.8 |
| 2011 | 6.5 | 4.6 | 7.4 | 8.8 | 7.9 | 7.6 | 8.7 | 8.7 | 7.5 | 3.4 | 4.8 | 2.0 |
| 2012 | 3.8 | 3.5 | 6.0 | 8.4 | 7.5 | 7.6 | 8.7 | 7.9 | 6.5 | 1.8 | 1.9 | 3.7 |
| 2013 | 3.6 | 5.2 | 8.6 | 7.5 | 7.2 | 7.9 | 8.7 | 8.5 | 6.3 | 4.2 | 3.7 | 1.3 |
| 2014 | 5.6 | 7.1 | 8.3 | 8.3 | 8.3 | 7.1 | 8.5 | 7.5 | 6.3 | 3.9 | 2.8 | 2.4 |
| 2015 | 1.7 | 5.2 | 6.5 | 4.9 | 7.8 | 7.4 | 7.8 | 7.9 | 5.5 | 3.6 | 3.4 | 4.5 |
| 2016 | 7.1 | 6.9 | 7.7 | 7.9 | 7.0 | 6.8 | 8.1 | 7.6 | 6.9 | 2.8 | 2.0 | 1.5 |

Debrezeit Maximum monthly temperature data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 26.6 | 28.1 | 28.4 | 28.4 | 29.1 | 27.5 | 24.2 | 24.6 | 25.0 | 26.5 | 26.6 | 25.9 |
| 1987 | 25.7 | 27.1 | 26.7 | 26.9 | 27.0 | 26.3 | 26.3 | 25.3 | 26.8 | 27.5 | 26.8 | 26.4 |
| 1988 | 26.6 | 28.1 | 28.4 | 28.4 | 29.1 | 27.3 | 23.2 | 23.7 | 24.3 | 25.4 | 26.1 | 25.9 |
| 1989 | 25.4 | 26.5 | 28.0 | 26.5 | 29.1 | 27.7 | 24.1 | 24.0 | 24.6 | 26.0 | 26.1 | 25.2 |
| 1990 | 26.5 | 26.3 | 26.7 | 26.5 | 29.0 | 27.6 | 24.6 | 23.9 | 24.8 | 26.8 | 26.8 | 26.2 |
| 1994 | 26.6 | 27.8 | 28.4 | 29.1 | 29.6 | 26.9 | 23.8 | 23.1 | 24.4 | 25.5 | 25.0 | 25.5 |
| 1995 | 26.4 | 28.6 | 28.5 | 27.8 | 29.9 | 29.2 | 24.4 | 23.9 | 25.0 | 26.2 | 26.1 | 26.4 |
| 1996 | 26.0 | 28.7 | 28.0 | 27.8 | 27.2 | 24.2 | 24.0 | 24.2 | 25.5 | 26.5 | 25.6 | 25.7 |
| 1997 | 26.1 | 27.3 | 29.0 | 27.2 | 29.7 | 27.7 | 24.8 | 25.2 | 26.9 | 25.9 | 25.3 | 25.9 |
| 1998 | 26.6 | 27.8 | 28.5 | 30.1 | 29.6 | 28.9 | 24.7 | 23.6 | 25.3 | 25.8 | 25.8 | 25.4 |
| 1999 | 26.9 | 28.8 | 27.8 | 29.6 | 30.1 | 28.0 | 23.7 | 24.3 | 25.4 | 26.4 | 25.1 | 25.4 |
| 2000 | 26.7 | 28.2 | 29.7 | 29.4 | 29.1 | 27.5 | 24.8 | 23.8 | 25.0 | 25.2 | 25.5 | 25.8 |
| 2001 | 26.5 | 29.2 | 27.8 | 29.1 | 28.4 | 26.8 | 24.6 | 23.7 | 26.9 | 27.6 | 26.9 | 27.6 |
| 2002 | 27.2 | 29.9 | 29.3 | 30.4 | 31.4 | 29.1 | 26.8 | 25.1 | 26.4 | 27.9 | 27.3 | 26.3 |
| 2003 | 26.9 | 28.9 | 28.9 | 27.9 | 30.2 | 27.6 | 23.6 | 24.0 | 25.0 | 26.6 | 26.3 | 24.7 |
| 2004 | 26.6 | 28.1 | 27.5 | 26.5 | 29.6 | 26.8 | 24.2 | 24.1 | 25.4 | 25.5 | 25.6 | 25.6 |
| 2005 | 26.2 | 29.0 | 27.9 | 28.7 | 27.1 | 27.2 | 23.8 | 25.0 | 25.6 | 26.9 | 25.9 | 25.9 |
| 2006 | 27.1 | 28.3 | 27.8 | 27.3 | 29.1 | 28.0 | 24.6 | 24.1 | 24.9 | 26.7 | 26.2 | 25.6 |
| 2007 | 26.7 | 28.1 | 29.3 | 28.6 | 28.7 | 26.6 | 24.0 | 24.0 | 24.6 | 25.6 | 26.1 | 25.9 |
| 2008 | 26.8 | 26.7 | 29.3 | 28.7 | 29.1 | 26.6 | 24.5 | 23.4 | 25.0 | 26.5 | 25.2 | 26.0 |
| 2009 | 26.3 | 27.9 | 29.7 | 29.2 | 30.2 | 30.1 | 25.4 | 24.5 | 26.3 | 25.9 | 26.8 | 26.0 |
| 2010 | 26.6 | 27.0 | 27.1 | 28.0 | 27.3 | 27.9 | 24.0 | 24.5 | 25.6 | 27.7 | 26.6 | 26.2 |
| 2011 | 27.1 | 28.8 | 28.7 | 29.9 | 28.7 | 27.5 | 25.6 | 23.5 | 24.4 | 26.3 | 26.1 | 25.9 |
| 2012 | 27.4 | 28.7 | 30.0 | 28.7 | 30.4 | 27.9 | 24.0 | 24.2 | 25.4 | 26.4 | 26.1 | 25.9 |

Debrezeit Minimum monthly temperature data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 9.4 | 10.6 | 12.4 | 13.5 | 13.1 | 13.6 | 14.4 | 13.6 | 13.2 | 11.2 | 9.0 | 8.8 |
| 1989 | 9.2 | 11.4 | 13.1 | 13.7 | 13.1 | 12.7 | 13.5 | 13.3 | 12.7 | 10.8 | 9.7 | 12.0 |
| 1990 | 10.0 | 13.8 | 13.6 | 13.2 | 12.6 | 11.2 | 13.5 | 13.6 | 13.2 | 10.4 | 9.8 | 8.6 |
| 1994 | 9.4 | 10.8 | 13.5 | 14.4 | 13.9 | 13.1 | 13.7 | 13.3 | 12.4 | 10.3 | 9.8 | 9.1 |
| 1995 | 9.2 | 12.2 | 13.9 | 14.7 | 14.1 | 12.6 | 13.6 | 13.9 | 12.1 | 11.6 | 9.8 | 11.5 |
| 1996 | 11.8 | 11.4 | 14.3 | 13.7 | 13.7 | 13.7 | 13.2 | 13.7 | 12.5 | 10.7 | 9.8 | 8.9 |
| 1997 | 11.9 | 10.2 | 13.9 | 13.9 | 13.8 | 14.1 | 13.8 | 13.8 | 13.3 | 13.3 | 12.6 | 9.9 |
| 1998 | 12.8 | 14.1 | 14.7 | 15.2 | 14.5 | 13.8 | 14.5 | 14.3 | 13.5 | 12.2 | 8.4 | 7.6 |
| 2000 | 9.0 | 10.3 | 12.5 | 14.3 | 13.3 | 13.0 | 13.7 | 13.7 | 13.4 | 11.6 | 10.5 | 9.9 |
| 2001 | 10.2 | 11.1 | 13.7 | 13.8 | 14.1 | 13.3 | 13.9 | 14.5 | 12.6 | 11.9 | 9.8 | 10.1 |
| 2002 | 11.4 | 11.8 | 14.3 | 14.4 | 13.7 | 14.2 | 14.3 | 14.1 | 13.3 | 12.2 | 10.8 | 12.6 |
| 1999 | 9.8 | 10.2 | 13.5 | 14.3 | 13.7 | 13.2 | 13.4 | 13.5 | 12.6 | 10.1 | 8.1 | 8.5 |
| 2003 | 11.4 | 13.0 | 14.0 | 15.1 | 14.1 | 14.1 | 14.2 | 14.4 | 13.7 | 11.2 | 11.4 | 10.0 |
| 2004 | 9.4 | 10.6 | 10.5 | 11.9 | 9.9 | 11.9 | 13.1 | 13.0 | 11.9 | 8.4 | 7.3 | 8.3 |
| 2005 | 8.1 | 8.0 | 12.1 | 12.3 | 13.1 | 12.2 | 13.0 | 13.6 | 12.6 | 8.2 | 7.4 | 3.9 |
| 2006 | 7.9 | 10.3 | 10.5 | 12.1 | 11.2 | 12.5 | 13.5 | 13.8 | 12.2 | 10.6 | 8.4 | 10.5 |
| 2007 | 10.0 | 11.8 | 11.7 | 13.2 | 13.2 | 13.3 | 13.8 | 13.6 | 12.8 | 7.1 | 9.0 | 8.8 |
| 2008 | 9.0 | 10.1 | 9.3 | 12.7 | 12.5 | 13.2 | 12.9 | 12.9 | 12.0 | 9.0 | 7.8 | 5.1 |
| 2009 | 8.4 | 9.2 | 11.5 | 12.6 | 12.1 | 12.4 | 13.7 | 13.8 | 11.7 | 9.2 | 5.5 | 10.0 |
| 2010 | 7.8 | 12.2 | 11.9 | 13.3 | 13.5 | 12.0 | 13.6 | 13.8 | 12.3 | 8.9 | 6.9 | 6.1 |
| 2011 | 7.5 | 7.8 | 10.6 | 12.5 | 13.3 | 13.1 | 13.4 | 13.6 | 11.7 | 7.4 | 9.1 | 4.7 |
| 2012 | 5.3 | 5.7 | 8.0 | 12.8 | 11.6 | 13.1 | 13.1 | 13.0 | 11.6 | 6.9 | 6.1 | 8.8 |
| 2013 | 6.6 | 7.8 | 12.5 | 12.9 | 13.0 | 12.7 | 13.6 | 13.7 | 12.6 | 10.1 | 9.0 | 8.8 |

Nazerite Monthly maximum temperature data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 29.7 | 31.2 | 29.7 | 33.8 | 34.3 | 29.6 | 27.5 | 28.4 | 30.8 | 27.8 | 28.9 | 29.8 |
| 1987 | 25.0 | 31.7 | 31.2 | 29.8 | 30.2 | 30.1 | 29.0 | 27.0 | 29.8 | 31.1 | 30.7 | 30.6 |
| 1988 | 30.9 | 32.9 | 32.3 | 32.9 | 33.1 | 31.6 | 25.2 | 27.0 | 27.5 | 27.2 | 25.2 | 27.3 |
| 1989 | 28.9 | 29.0 | 28.6 | 27.0 | 32.0 | 30.3 | 24.3 | 24.7 | 27.0 | 28.0 | 28.3 | 28.0 |
| 1990 | 26.8 | 27.5 | 26.1 | 26.8 | 30.3 | 30.0 | 25.6 | 27.5 | 26.1 | 27.3 | 27.3 | 25.9 |
| 1991 | 27.7 | 28.9 | 28.9 | 29.0 | 30.9 | 30.1 | 25.0 | 24.8 | 26.6 | 27.5 | 27.1 | 26.6 |
| 1992 | 25.8 | 26.1 | 29.7 | 29.7 | 30.7 | 30.1 | 25.3 | 24.4 | 25.3 | 25.9 | 26.4 | 25.9 |
| 1993 | 25.3 | 24.9 | 29.5 | 27.9 | 28.1 | 28.6 | 24.8 | 25.1 | 26.5 | 27.7 | 27.1 | 26.4 |
| 1994 | 27.1 | 28.9 | 29.7 | 29.9 | 31.1 | 28.6 | 26.4 | 25.4 | 25.9 | 27.1 | 25.5 | 25.1 |
| 1995 | 26.9 | 29.0 | 28.7 | 28.3 | 30.9 | 31.6 | 25.9 | 25.5 | 26.5 | 27.9 | 27.4 | 27.5 |
| 1996 | 26.8 | 29.6 | 29.5 | 29.0 | 29.2 | 26.5 | 26.3 | 25.5 | 26.9 | 27.9 | 27.5 | 26.2 |
| 1997 | 28.0 | 28.3 | 30.3 | 28.5 | 31.2 | 29.7 | 26.1 | 26.3 | 28.3 | 27.3 | 25.6 | 25.9 |
| 1998 | 26.9 | 29.3 | 28.8 | 31.6 | 31.6 | 29.9 | 26.4 | 25.0 | 26.3 | 26.8 | 26.5 | 25.8 |
| 1999 | 27.1 | 29.9 | 28.3 | 31.1 | 31.5 | 30.5 | 24.7 | 25.2 | 27.1 | 25.6 | 25.9 | 25.4 |
| 2000 | 27.3 | 28.3 | 30.2 | 30.3 | 30.8 | 29.8 | 25.9 | 25.6 | 26.7 | 25.8 | 25.8 | 25.3 |
| 2001 | 24.7 | 27.8 | 28.5 | 29.8 | 29.6 | 28.2 | 25.8 | 25.3 | 27.4 | 28.7 | 27.3 | 26.8 |
| 2002 | 26.2 | 29.2 | 29.9 | 31.0 | 32.8 | 30.9 | 29.7 | 26.6 | 28.2 | 29.8 | 28.6 | 26.5 |
| 2003 | 27.0 | 29.5 | 29.8 | 29.1 | 32.4 | 30.1 | 25.5 | 25.9 | 27.0 | 28.5 | 27.5 | 25.4 |
| 2004 | 27.8 | 28.2 | 29.3 | 28.7 | 30.9 | 29.6 | 26.3 | 26.0 | 27.3 | 26.7 | 26.8 | 26.2 |
| 2005 | 26.6 | 29.6 | 29.9 | 30.2 | 29.1 | 29.6 | 25.6 | 26.7 | 27.6 | 28.9 | 27.5 | 26.3 |
| 2006 | 27.5 | 28.7 | 28.6 | 28.8 | 30.6 | 29.9 | 25.9 | 25.2 | 26.4 | 27.9 | 26.9 | 25.1 |
| 2007 | 26.2 | 28.4 | 29.8 | 28.7 | 30.9 | 28.2 | 25.7 | 25.4 | 26.4 | 26.9 | 26.0 | 25.4 |
| 2008 | 26.8 | 26.9 | 30.4 | 29.6 | 30.1 | 28.5 | 25.4 | 25.1 | 26.9 | 27.3 | 24.7 | 25.1 |
| 2009 | 25.8 | 28.0 | 30.2 | 29.8 | 30.0 | 31.5 | 26.9 | 26.2 | 28.7 | 27.1 | 27.1 | 26.4 |
| 2010 | 26.6 | 27.3 | 27.0 | 29.9 | 30.2 | 29.8 | 27.4 | 26.0 | 26.7 | 28.2 | 27.2 | 26.1 |
| 2011 | 27.3 | 29.4 | 29.4 | 31.7 | 30.8 | 29.7 | 27.4 | 26.2 | 26.7 | 27.9 | 26.6 | 25.8 |
| 2012 | 26.5 | 29.0 | 30.6 | 30.3 | 31.3 | 30.7 | 25.8 | 25.9 | 27.0 | 27.9 | 28.0 | 27.2 |
| 2013 | 27.3 | 29.4 | 31.0 | 31.2 | 31.1 | 30.4 | 26.1 | 26.3 | 28.0 | 28.1 | 27.5 | 26.3 |
| 2014 | 28.1 | 29.5 | 29.8 | 30.7 | 31.4 | 31.6 | 28.3 | 26.7 | 27.3 | 26.9 | 27.5 | 26.2 |
| 2015 | 27.0 | 30.5 | 31.3 | 31.5 | 30.9 | 30.5 | 29.5 | 27.9 | 28.9 | 29.9 | 28.0 | 26.9 |
| 2016 | 28.1 | 29.4 | 32.8 | 30.3 | 29.7 | 29.6 | 27.0 | 27.1 | 28.3 | 27.7 | 27.1 | 26.6 |
| 2017 | 27.9 | 28.9 | 31.5 | 31.3 | 29.8 | 31.6 | 27.5 | 26.8 | 27.3 | 27.7 | 27.4 | 26.0 |

Nazerite Monthly minimum temperature data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 11.2 | 14.7 | 13.3 | 13.5 | 14.8 | 16.1 | 15.7 | 14.2 | 15.8 | 11.2 | 10.7 | 16.2 |
| 1987 | 11.8 | 14.7 | 15.1 | 14.1 | 14.2 | 18.0 | 15.3 | 16.2 | 14.9 | 11.9 | 9.7 | 8.2 |
| 1988 | 11.5 | 15.1 | 12.6 | 12.6 | 14.8 | 17.0 | 11.0 | 14.4 | 15.0 | 10.0 | 7.6 | 8.2 |
| 1989 | 8.5 | 15.5 | 16.2 | 14.1 | 16.7 | 14.8 | 12.0 | 14.9 | 14.6 | 10.7 | 10.3 | 13.7 |
| 1990 | 12.7 | 15.1 | 14.4 | 14.4 | 16.5 | 17.8 | 15.7 | 15.6 | 15.1 | 11.9 | 12.4 | 11.6 |
| 1991 | 14.4 | 14.7 | 15.1 | 14.8 | 16.4 | 18.0 | 15.7 | 15.6 | 14.8 | 13.0 | 12.1 | 11.3 |
| 1992 | 13.6 | 15.4 | 16.1 | 16.0 | 15.8 | 17.0 | 15.4 | 15.5 | 14.0 | 11.8 | 12.2 | 13.9 |
| 1993 | 13.7 | 13.6 | 13.8 | 15.1 | 15.6 | 16.4 | 15.4 | 14.9 | 14.8 | 13.4 | 12.9 | 12.4 |
| 1994 | 13.0 | 14.7 | 15.4 | 15.8 | 15.8 | 16.8 | 15.7 | 15.5 | 13.7 | 11.2 | 12.5 | 11.1 |
| 1995 | 10.5 | 14.3 | 14.4 | 14.8 | 13.2 | 15.3 | 15.6 | 15.2 | 13.5 | 12.9 | 12.7 | 14.1 |
| 1996 | 14.0 | 13.6 | 15.4 | 14.6 | 14.7 | 16.6 | 15.8 | 15.7 | 14.6 | 12.1 | 13.2 | 12.1 |
| 1997 | 12.7 | 15.3 | 15.4 | 15.8 | 16.4 | 17.3 | 15.8 | 15.9 | 15.1 | 15.5 | 14.7 | 12.5 |
| 1998 | 14.0 | 16.2 | 16.1 | 16.3 | 17.0 | 18.0 | 16.4 | 16.1 | 15.0 | 13.5 | 13.0 | 10.6 |
| 1999 | 11.9 | 13.1 | 14.9 | 14.6 | 16.3 | 16.9 | 15.4 | 15.7 | 14.8 | 14.4 | 9.8 | 7.9 |
| 2000 | 9.2 | 13.0 | 15.0 | 16.0 | 16.7 | 17.9 | 15.9 | 16.2 | 15.2 | 13.6 | 12.6 | 11.5 |
| 2001 | 12.2 | 13.3 | 15.1 | 15.3 | 17.1 | 17.3 | 16.1 | 16.5 | 13.9 | 13.5 | 12.9 | 13.0 |
| 2002 | 14.4 | 13.9 | 15.9 | 16.3 | 17.9 | 18.3 | 17.3 | 16.4 | 15.0 | 13.6 | 13.3 | 15.0 |
| 2003 | 13.2 | 14.7 | 13.3 | 16.0 | 14.7 | 16.6 | 15.9 | 15.8 | 15.5 | 13.4 | 13.7 | 12.1 |
| 2004 | 14.8 | 12.9 | 13.3 | 15.9 | 16.5 | 17.6 | 16.3 | 16.3 | 15.4 | 13.6 | 13.6 | 14.0 |
| 2005 | 13.3 | 14.9 | 16.4 | 16.4 | 16.8 | 17.7 | 16.4 | 16.4 | 16.2 | 14.5 | 14.5 | 12.2 |
| 2006 | 14.0 | 15.8 | 15.4 | 15.6 | 16.8 | 17.8 | 16.6 | 16.1 | 16.1 | 15.2 | 14.8 | 14.7 |
| 2007 | 14.0 | 15.8 | 16.1 | 16.5 | 17.9 | 17.6 | 16.7 | 15.6 | 16.5 | 13.1 | 13.9 | 11.6 |
| 2008 | 13.9 | 13.7 | 14.0 | 16.9 | 17.2 | 16.8 | 15.5 | 15.4 | 15.9 | 14.2 | 12.8 | 12.1 |
| 2009 | 13.5 | 15.2 | 16.8 | 17.1 | 17.5 | 17.8 | 16.8 | 16.7 | 16.3 | 14.3 | 12.9 | 12.4 |
| 2010 | 14.1 | 15.4 | 15.3 | 16.2 | 17.4 | 17.8 | 16.6 | 16.9 | 15.2 | 14.5 | 13.9 | 11.6 |
| 2011 | 13.1 | 14.2 | 14.9 | 16.6 | 16.3 | 16.9 | 16.6 | 16.7 | 15.6 | 14.2 | 14.9 | 12.8 |
| 2012 | 14.1 | 14.1 | 16.4 | 16.9 | 17.0 | 18.0 | 15.7 | 16.0 | 15.9 | 13.7 | 13.9 | 14.4 |
| 2013 | 14.3 | 15.1 | 17.3 | 17.4 | 18.3 | 18.2 | 15.6 | 16.7 | 15.9 | 14.8 | 14.2 | 11.9 |
| 2014 | 13.9 | 16.4 | 16.7 | 17.4 | 17.3 | 18.1 | 17.1 | 16.5 | 16.0 | 14.7 | 15.0 | 13.3 |
| 2015 | 12.6 | 15.8 | 17.1 | 16.4 | 16.4 | 18.1 | 17.4 | 16.6 | 16.3 | 17.1 | 15.9 | 15.5 |
| 2016 | 15.7 | 15.4 | 19.0 | 17.7 | 17.3 | 17.5 | 16.6 | 17.0 | 16.1 | 13.4 | 12.9 | 12.7 |
| 2017 | 12.0 | 15.6 | 16.9 | 17.5 | 17.0 | 18.6 | 16.4 | 16.7 | 15.2 | 13.4 | 13.7 | 11.4 |

APPENDIX TWO

PRECIPITATION DATA

Abomsa station monthly precipitation data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 33.8 | 67.2 | 3.1 | 93.6 | 12.1 | 79.0 | 182.8 | 211.4 | 179.2 | 58.6 | 0.0 | 6.4 |
| 1989 | 0.0 | 50.2 | 61.4 | 119.2 | 28.4 | 90.3 | 136.7 | 192.4 | 120.7 | 49.1 | 10.6 | 33.8 |
| 1990 | 7.4 | 347.4 | 186.1 | 183.5 | 70.8 | 22.0 | 220.8 | 115.8 | 106.9 | 8.3 | 3.1 | 4.0 |
| 1991 | 2.0 | 69.6 | 100.2 | 45.3 | 58.3 | 69.8 | 171.0 | 185.1 | 46.1 | 21.0 | 1.1 | 5.2 |
| 1992 | 46.6 | 33.0 | 5.6 | 146.3 | 70.8 | 50.5 | 142.0 | 169.7 | 197.7 | 158.7 | 19.7 | 10.4 |
| 1993 | 189.9 | 38.3 | 0.0 | 204.2 | 82.8 | 19.7 | 118.3 | 128.0 | 112.1 | 120.0 | 4.7 | 8.1 |
| 1994 | 0.0 | 0.0 | 31.0 | 62.7 | 142.6 | 117.1 | 290.0 | 132.7 | 76.3 | 19.0 | 126.0 | 7.6 |
| 1995 | 0.0 | 22.4 | 147.8 | 112.3 | 64.2 | 31.3 | 106.6 | 172.0 | 85.7 | 13.9 | 0.0 | 6.6 |
| 1996 | 66.5 | 3.4 | 144.0 | 80.1 | 143.4 | 121.1 | 107.9 | 214.3 | 135.9 | 22.5 | 8.8 | 0.0 |
| 1997 | 27.5 | 7.3 | 71.5 | 106.0 | 15.4 | 70.6 | 243.7 | 140.2 | 99.5 | 234.4 | 110.0 | 0.2 |
| 1998 | 108.8 | 32.4 | 130.3 | 38.4 | 71.1 | 51.7 | 108.6 | 175.8 | 193.8 | 86.6 | 1.7 | 0.0 |
| 1999 | 25.8 | 1.3 | 162.4 | 4.6 | 21.8 | 82.4 | 275.9 | 204.0 | 144.8 | 229.6 | 3.5 | 0.0 |
| 2000 | 4.8 | 0.0 | 10.5 | 88.1 | 67.1 | 13.4 | 119.4 | 200.6 | 66.2 | 64.7 | 45.8 | 25.0 |
| 2001 | 27.8 | 24.5 | 170.2 | 36.3 | 121.7 | 56.2 | 210.3 | 280.9 | 81.9 | 17.8 | 2.9 | 20.9 |
| 2002 | 37.8 | 0.0 | 102.9 | 37.2 | 18.0 | 48.8 | 65.6 | 125.2 | 52.3 | 0.0 | 28.6 | 10.4 |
| 2003 | 9.4 | 5.9 | 74.4 | 62.2 | 0.0 | 49.9 | 217.9 | 129.8 | 85.3 | 16.4 | 7.0 | 68.8 |
| 2004 | 34.8 | 0.5 | 73.6 | 151.2 | 1.8 | 63.2 | 133.5 | 157.4 | 125.5 | 59.6 | 14.1 | 32.1 |
| 2005 | 52.7 | 0.0 | 78.0 | 103.8 | 100.3 | 38.2 | 174.3 | 154.6 | 103.3 | 21.7 | 47.9 | 0.0 |
| 2006 | 0.0 | 38.8 | 165.8 | 47.4 | 22.4 | 51.8 | 220.9 | 175.6 | 95.5 | 93.0 | 1.4 | 50.1 |
| 2007 | 16.8 | 40.9 | 73.6 | 104.9 | 85.9 | 60.1 | 121.8 | 221.5 | 124.5 | 24.4 | 13.7 | 0.0 |
| 2008 | 5.4 | 2.4 | 1.1 | 74.6 | 85.5 | 42.1 | 193.9 | 176.4 | 102.0 | 143.1 | 48.6 | 0.0 |
| 2009 | 67.7 | 0.0 | 49.3 | 56.3 | 28.7 | 22.4 | 147.8 | 181.9 | 54.5 | 165.0 | 14.5 | 5.2 |
| 2010 | 19.9 | 148.2 | 44.1 | 76.2 | 152.0 | 73.0 | 152.3 | 167.8 | 130.3 | 0.0 | 65.0 | 1.7 |
| 2011 | 0.0 | 18.2 | 61.2 | 27.3 | 130.1 | 106.6 | 56.7 | 176.6 | 218.7 | 3.8 | 108.7 | 0.0 |
| 2012 | 0.0 | 0.0 | 38.0 | 83.6 | 47.4 | 37.2 | 249.6 | 285.4 | 76.7 | 11.4 | 7.0 | 5.8 |
| 2013 | 40.5 | 2.1 | 33.6 | 123.2 | 72.5 | 57.3 | 208.5 | 135.8 | 97.3 | 34.0 | 45.1 | 0.0 |
| 2014 | 0.0 | 0.0 | 79.5 | 46.9 | 82.7 | 9.6 | 94.4 | 107.2 | 119.5 | 153.0 | 13.9 | 0.0 |
| 2015 | 0.0 | 0.0 | 10.6 | 22.5 | 102.8 | 126.4 | 72.5 | 154.0 | 77.4 | 5.5 | 66.8 | 4.9 |
| 2016 | 7.5 | 2.4 | 9.3 | 339.3 | 140.8 | 101.3 | 159.2 | 206.0 | 112.1 | 64.7 | 28.6 | 3.7 |
| 2017 | 0.0 | 33.0 | 90.1 | 26.3 | 82.8 | 39.9 | 162.2 | 156.9 | 140.6 | 40.7 | 8.1 | 0.0 |

Addis Ababa station monthly precipitation data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 0.0 | 37.6 | 56.2 | 216.6 | 37.7 | 175.2 | 167.9 | 222.3 | 107.4 | 31.6 | 0.0 | 2.5 |
| 1987 | 0.0 | 49.1 | 180.1 | 85.7 | 154.6 | 71.9 | 155.9 | 98.1 | 57.0 | 16.6 | 0.0 | 0.4 |
| 1988 | 4.7 | 33.4 | 6.7 | 157.9 | 34.7 | 93.2 | 181.4 | 265.3 | 187.3 | 57.3 | 0.0 | 0.0 |
| 1989 | 3.4 | 33.7 | 58.4 | 143.3 | 0.0 | 88.1 | 218.1 | 318.6 | 150.0 | 36.8 | 0.0 | 7.9 |
| 1990 | 3.2 | 161.1 | 60.4 | 144.5 | 25.2 | 48.3 | 194.2 | 293.6 | 143.0 | 46.1 | 2.1 | 0.0 |
| 1991 | 0.2 | 29.6 | 134.1 | 15.0 | 7.7 | 107.5 | 279.4 | 287.9 | 123.1 | 4.4 | 2.1 | 0.0 |
| 1992 | 14.5 | 28.0 | 35.0 | 58.6 | 55.0 | 82.2 | 254.8 | 223.3 | 157.0 | 64.4 | 2.2 | 0.4 |
| 1993 | 11.7 | 52.1 | 11.6 | 168.3 | 91.5 | 157.2 | 209.5 | 291.7 | 190.1 | 24.1 | 0.0 | 0.0 |
| 1994 | 0.0 | 0.0 | 52.9 | 70.0 | 29.0 | 112.4 | 242.3 | 199.3 | 99.4 | 0.5 | 11.0 | 0.0 |
| 1995 | 0.0 | 81.3 | 73.1 | 133.3 | 95.9 | 77.4 | 165.5 | 256.9 | 97.0 | 0.0 | 0.0 | 29.3 |
| 1996 | 20.5 | 15.8 | 134.4 | 96.0 | 124.6 | 290.2 | 346.3 | 312.7 | 211.4 | 0.2 | 0.4 | 0.0 |
| 1997 | 29.1 | 0.0 | 22.1 | 66.8 | 44.8 | 128.0 | 257.0 | 160.7 | 94.7 | 58.6 | 15.3 | 0.0 |
| 1998 | 66.6 | 40.0 | 43.8 | 99.8 | 197.7 | 111.6 | 270.7 | 236.8 | 173.4 | #### | 0.0 | 0.0 |
| 1999 | 4.4 | 0.0 | 35.0 | 17.8 | 30.5 | 104.6 | 294.0 | 270.5 | 62.8 | #### | 0.0 | 0.0 |
| 2000 | 0.0 | 0.0 | 17.6 | 87.8 | 95.2 | 102.1 | 192.9 | 221.9 | 157.5 | 19.6 | 7.5 | 0.0 |
| 2001 | 0.0 | 10.3 | 174.3 | 14.8 | 116.7 | 166.0 | 289.4 | 207.3 | 113.3 | 10.6 | 0.0 | 0.0 |
| 2002 | 30.6 | 25.9 | 79.4 | 36.6 | 49.6 | 115.5 | 213.9 | 233.6 | 72.6 | 0.5 | 0.0 | 32.8 |
| 2003 | 4.8 | 29.4 | 48.9 | 111.5 | 18.0 | 111.0 | 204.3 | 238.4 | 130.2 | 4.6 | 0.0 | 33.3 |
| 2004 | 10.5 | 11.7 | 32.4 | 91.5 | 7.0 | 114.5 | 240.6 | 230.1 | 122.1 | 50.0 | 0.6 | 0.0 |
| 2005 | 55.4 | 14.1 | 41.8 | 116.2 | 164.6 | 159.1 | 174.3 | 248.0 | 77.6 | 25.8 | 7.2 | 0.0 |
| 2006 | 2.0 | 36.6 | 107.8 | 93.9 | 37.8 | 115.1 | 313.2 | 331.1 | 132.5 | 35.9 | 0.0 | 0.0 |
| 2007 | 9.9 | 21.3 | 61.1 | 86.8 | 134.0 | 157.6 | 191.3 | 305.4 | 130.9 | 37.2 | 0.1 | 7.0 |
| 2008 | 0.0 | 0.0 | 0.0 | 34.0 | 75.3 | 73.1 | 295.1 | 259.1 | 192.7 | 22.2 | 53.1 | 0.0 |
| 2009 | 40.9 | 0.0 | 12.4 | 46.1 | 52.0 | 77.5 | 238.2 | 269.5 | 86.1 | 42.4 | 2.0 | 79.9 |
| 2010 | 0.4 | 115.2 | 75.6 | 159.5 | 94.7 | 107.2 | 320.2 | 138.8 | 105.0 | 0.0 | 13.8 | 15.7 |
| 2011 | 3.4 | 13.6 | 27.9 | 91.5 | 86.0 | 148.0 | 183.1 | 296.5 | 141.3 | 0.0 | 11.9 | 0.0 |
| 2012 | 0.0 | 0.0 | 34.5 | 75.1 | 58.5 | 72.8 | 228.8 | 281.6 | 176.9 | 1.2 | 0.0 | 7.0 |
| 2013 | 10.5 | 0.0 | 63.5 | 114.4 | 78.5 | 101.4 | 157.6 | 270.2 | 126.7 | 45.3 | 3.2 | 0.0 |
| 2014 | 0.0 | 41.7 | 29.7 | 33.7 | 62.1 | 41.8 | 179.7 | 253.6 | 95.1 | 34.8 | 0.0 | 0.0 |
| 2015 | 0.0 | 0.0 | 21.3 | 91.5 | 76.0 | 111.6 | 163.0 | 203.0 | 132.5 | 0.0 | 1.3 | 1.8 |
| 2016 | 10.5 | 29.4 | 58.0 | 137.5 | 124.1 | 104.4 | 162.9 | 226.6 | 132.0 | 17.6 | 3.4 | 0.0 |
| 2017 | 0.0 | 29.4 | 66.1 | 33.1 | 174.3 | 44.1 | 217.0 | 241.7 | 260.5 | 30.8 | 4.4 | 7.0 |

Ambo station monthly precipitation data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 21.2 | 61.6 | 49.5 | 103.7 | 84.3 | 196.8 | 231.1 | 177.5 | 115.3 | 32.8 | 0.4 | 0.9 |
| 1987 | 1.5 | 38.1 | 46.3 | 119.8 | 185.4 | 129.1 | 231.1 | 201.5 | 111.3 | 13.6 | 10.6 | 8.2 |
| 1988 | 21.2 | 232.6 | 8.5 | 31.5 | 35.6 | 161.2 | 213.5 | 169.0 | 171.6 | 34.2 | 0.0 | 8.2 |
| 1989 | 21.2 | 34.3 | 46.3 | 69.8 | 52.9 | 161.2 | 219.2 | 171.7 | 134.5 | 51.8 | 0.0 | 42.7 |
| 1990 | 20.0 | 114.7 | 78.2 | 19.5 | 89.2 | 185.1 | 315.9 | 197.1 | 94.8 | 3.3 | 0.0 | 8.2 |
| 1991 | 12.6 | 58.7 | 52.4 | 69.8 | 104.1 | 161.2 | 231.1 | 201.5 | 111.3 | 34.2 | 10.6 | 8.2 |
| 1993 | 0.0 | 35.6 | 10.5 | 181.9 | 121.2 | 178.3 | 268.5 | 215.4 | 121.3 | 25.1 | 0.0 | 0.0 |
| 1997 | 28.7 | 0.0 | 31.0 | 83.1 | 59.7 | 132.0 | 231.1 | 183.4 | 59.2 | 34.2 | 22.1 | 2.2 |
| 1998 | 74.3 | 10.4 | 40.6 | 30.7 | 104.1 | 161.2 | 231.1 | 201.5 | 111.3 | 34.2 | 10.6 | 0.0 |
| 1999 | 8.4 | 0.1 | 39.5 | 20.1 | 99.2 | 108.4 | 195.9 | 132.9 | 95.9 | 119.9 | 1.3 | 0.0 |
| 2000 | 0.0 | 0.0 | 9.3 | 51.5 | 93.7 | 121.2 | 186.4 | 191.6 | 131.2 | 83.7 | 20.7 | 14.8 |
| 2001 | 0.0 | 12.5 | 60.5 | 70.4 | 177.9 | 148.5 | 197.9 | 243.1 | 110.5 | 41.8 | 5.4 | 11.0 |
| 2002 | 78.7 | 16.9 | 55.6 | 56.3 | 39.5 | 178.0 | 231.1 | 201.5 | 40.3 | 34.2 | 0.0 | 17.2 |
| 2003 | 41.7 | 100.0 | 54.8 | 154.1 | 9.4 | 209.0 | 134.2 | 142.7 | 111.3 | 9.3 | 1.0 | 0.0 |
| 2004 | 39.2 | 16.6 | 46.3 | 108.7 | 26.8 | 137.1 | 203.6 | 215.0 | 138.9 | 19.0 | 0.0 | 8.9 |
| 2005 | 25.2 | 0.0 | 86.8 | 47.5 | 58.1 | 166.3 | 158.0 | 187.1 | 98.4 | 19.0 | 10.2 | 0.0 |
| 2006 | 0.0 | 4.7 | 150.7 | 72.3 | 157.7 | 109.9 | 231.1 | 298.6 | 76.5 | 17.9 | 18.8 | 0.0 |
| 2007 | 49.3 | 54.3 | 40.2 | 38.9 | 131.6 | 275.2 | 232.6 | 218.3 | 111.7 | 11.0 | 0.0 | 0.0 |
| 2008 | 0.0 | 0.0 | 1.0 | 18.7 | 157.3 | 161.8 | 308.0 | 260.2 | 84.0 | 64.8 | 101.8 | 2.7 |
| 2009 | 26.9 | 23.1 | 28.7 | 61.2 | 47.5 | 96.4 | 285.7 | 271.9 | 65.3 | 56.1 | 1.7 | 41.9 |
| 2010 | 22.4 | 48.4 | 76.3 | 33.5 | 126.7 | 166.4 | 315.7 | 235.1 | 116.0 | 0.0 | 22.6 | 24.5 |
| 2011 | 55.9 | 7.0 | 90.0 | 120.0 | 185.8 | 358.7 | 456.4 | 387.1 | 224.2 | 0.0 | 0.0 | 0.0 |
| 2012 | 0.3 | 0.0 | 38.6 | 56.5 | 23.1 | 142.5 | 283.1 | 167.7 | 173.1 | 53.2 | 0.0 | 18.0 |
| 2013 | 0.0 | 3.9 | 18.6 | 88.0 | 119.8 | 158.8 | 226.3 | 172.3 | 73.4 | 94.9 | 4.0 | 0.0 |
| 2014 | 2.8 | 18.2 | 61.5 | 44.8 | 202.9 | 138.8 | 130.1 | 134.2 | 91.3 | 28.2 | 8.9 | 4.4 |
| 2015 | 4.3 | 6.1 | 40.1 | 69.8 | 104.1 | 166.7 | 184.7 | 166.7 | 103.9 | 0.0 | 27.9 | 2.1 |
| 2016 | 37.0 | 29.1 | 21.1 | 104.4 | 97.1 | 113.7 | 185.7 | 156.4 | 111.3 | 34.2 | 0.0 | 4.5 |
| 2017 | 0.0 | 34.3 | 13.4 | 27.5 | 218.9 | 89.0 | 152.3 | 140.9 | 129.6 | 7.6 | 17.6 | 0.0 |

Debrebrihan station monthly precipitation data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 0.0 | 74.7 | 99.2 | 52.5 | 27.0 | 141.9 | 271.3 | 274.7 | 115.7 | 11.3 | 0.0 | 0.0 |
| 1987 | 5.0 | 19.2 | 108.1 | 51.7 | 100.2 | 0.0 | 32.3 | 309.5 | 47.5 | 18.7 | 0.0 | 6.3 |
| 1988 | 10.6 | 18.1 | 45.4 | 83.1 | 16.2 | 16.0 | 286.2 | 290.0 | 153.1 | 12.1 | 0.0 | 0.0 |
| 1989 | 2.3 | 40.5 | 97.6 | 42.7 | 1.4 | 41.1 | 211.4 | 177.4 | 67.7 | 18.6 | 0.0 | 30.7 |
| 1990 | 0.0 | 62.2 | 20.7 | 59.5 | 0.9 | 1.6 | 321.0 | 217.2 | 168.7 | 0.6 | 0.0 | 0.0 |
| 1991 | 4.8 | 8.3 | 64.6 | 21.0 | 41.9 | 63.7 | 215.6 | 387.5 | 86.6 | 6.4 | 0.0 | 6.4 |
| 1992 | 30.3 | 26.7 | 19.4 | 80.2 | 19.3 | 13.3 | 307.6 | 267.6 | 92.9 | 41.9 | 0.5 | 1.8 |
| 1993 | 10.2 | 43.2 | 0.0 | 116.9 | 60.5 | 9.1 | 307.9 | 168.4 | 83.9 | 43.2 | 0.0 | 1.1 |
| 1994 | 0.0 | 0.0 | 95.6 | 0.0 | 23.2 | 92.7 | 281.7 | 222.9 | 101.7 | 19.0 | 36.5 | 0.0 |
| 1995 | 0.0 | 28.5 | 19.1 | 68.4 | 26.3 | 23.3 | 307.9 | 233.8 | 60.4 | 5.1 | 0.0 | 1.7 |
| 1996 | 20.7 | 2.8 | 75.4 | 9.7 | 129.2 | 138.0 | 328.4 | 252.5 | 24.3 | 0.0 | 3.0 | 0.0 |
| 1997 | 29.5 | 4.0 | 41.2 | 82.4 | 25.9 | 96.9 | 272.1 | 200.6 | 34.8 | 89.7 | 6.0 | 4.6 |
| 1998 | 23.1 | 13.2 | 14.9 | 49.3 | 43.0 | 13.5 | 337.3 | 289.0 | 70.6 | 5.2 | 0.0 | 0.0 |
| 1999 | 6.9 | 0.0 | 26.5 | 2.8 | 11.0 | 48.9 | 362.4 | 365.1 | 52.4 | 59.6 | 1.4 | 0.0 |
| 2000 | 0.0 | 0.0 | 25.9 | 47.3 | 37.1 | 45.8 | 352.4 | 317.5 | 105.2 | 28.5 | 18.8 | 6.8 |
| 2001 | 0.0 | 33.8 | 71.2 | 54.7 | 64.6 | 34.9 | 406.7 | 260.4 | 32.2 | 4.1 | 0.0 | 3.4 |
| 2002 | 18.1 | 28.0 | 60.6 | 46.1 | 18.4 | 29.1 | 214.4 | 294.8 | 109.1 | 3.1 | 0.0 | 8.4 |
| 2003 | 15.6 | 36.3 | 60.2 | 85.7 | 3.8 | 99.5 | 334.1 | 288.7 | 74.2 | 19.0 | 0.0 | 7.4 |
| 2004 | 24.4 | 9.7 | 29.7 | 113.3 | 5.6 | 99.7 | 334.7 | 301.3 | 78.9 | 14.1 | 11.8 | 0.0 |
| 2005 | 34.3 | 4.5 | 28.6 | 49.5 | 76.4 | 91.1 | 310.7 | 228.3 | 106.8 | 0.7 | 1.5 | 0.0 |
| 2006 | 17.3 | 24.4 | 61.0 | 38.3 | 19.8 | 35.2 | 432.6 | 224.2 | 59.8 | 8.6 | 6.0 | 26.3 |
| 2007 | 2.0 | 30.4 | 8.9 | 71.8 | 13.6 | 93.2 | 309.9 | 414.6 | 128.5 | 4.9 | 5.7 | 0.0 |
| 2008 | 0.3 | 1.7 | 0.0 | 34.6 | 68.9 | 66.4 | 397.7 | 234.8 | 76.6 | 9.9 | 54.6 | 1.2 |
| 2009 | 47.2 | 0.0 | 8.1 | 31.4 | 14.9 | 13.7 | 423.4 | 273.1 | 31.3 | 36.6 | 1.2 | 25.3 |
| 2010 | 0.0 | 25.2 | 55.7 | 119.3 | 42.2 | 35.4 | 242.3 | 329.2 | 53.8 | 0.3 | 8.5 | 3.9 |
| 2011 | 0.3 | 7.0 | 76.8 | 38.6 | 111.2 | 73.4 | 357.4 | 312.3 | 79.0 | 0.0 | 4.3 | 0.0 |
| 2012 | 0.0 | 0.0 | 5.2 | 93.3 | 57.9 | 56.0 | 351.6 | 394.5 | 92.4 | 0.0 | 0.0 | 0.0 |
| 2013 | 0.8 | 0.0 | 48.8 | 54.2 | 23.9 | 40.1 | 358.5 | 204.4 | 79.6 | 63.1 | 11.5 | 0.0 |
| 2014 | 0.0 | 16.0 | 67.7 | 44.1 | 46.9 | 16.8 | 260.3 | 291.0 | 110.0 | 55.9 | 0.0 | 0.0 |
| 2015 | 0.0 | 0.0 | 24.9 | 0.0 | 102.9 | 95.8 | 117.6 | 248.5 | 151.8 | 6.1 | 8.8 | 7.3 |
| 2016 | 12.7 | 3.4 | 45.4 | 54.7 | 66.1 | 104.3 | 496.5 | 267.1 | 70.5 | 3.9 | 7.2 | 0.0 |

Debrezeit station monthly precipitation data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 9.4 | 16.6 | 53.5 | 55.2 | 42.4 | 101.1 | 81.8 | 116.9 | 120.6 | 11.3 | 0.0 | 0.0 |
| 1987 | 0.0 | 61.4 | 138.2 | 90.1 | 42.4 | 65.0 | 83.3 | 155.9 | 80.9 | 24.0 | 0.0 | 0.0 |
| 1988 | 8.0 | 15.9 | 6.0 | 44.6 | 42.4 | 101.1 | 208.2 | 236.8 | 121.4 | 24.0 | 0.0 | 0.0 |
| 1989 | 0.6 | 12.2 | 35.1 | 47.0 | 42.4 | 59.0 | 183.7 | 171.5 | 135.2 | 21.2 | 0.0 | 3.3 |
| 1990 | 0.0 | 16.6 | 58.2 | 55.2 | 36.5 | 76.0 | 208.2 | 205.5 | 104.6 | 24.0 | 5.4 | 0.0 |
| 1994 | 9.4 | 0.0 | 53.5 | 19.5 | 19.6 | 74.5 | 232.8 | 187.3 | 108.6 | 0.0 | 10.2 | 0.0 |
| 1995 | 0.0 | 2.4 | 7.8 | 34.0 | 5.5 | 92.5 | 188.4 | 169.6 | 104.6 | 0.0 | 0.0 | 11.9 |
| 1996 | 16.4 | 0.0 | 103.1 | 55.3 | 105.4 | 261.5 | 164.1 | 275.6 | 90.0 | 0.1 | 5.9 | 0.0 |
| 1997 | 27.8 | 0.0 | 26.7 | 74.8 | 13.6 | 121.7 | 235.8 | 171.8 | 71.4 | 99.9 | 10.9 | 0.0 |
| 1998 | 32.0 | 51.4 | 13.9 | 77.2 | 41.8 | 77.7 | 206.3 | 293.5 | 97.6 | 93.3 | 0.0 | 0.0 |
| 1999 | 0.5 | 0.0 | 36.6 | 0.0 | 10.0 | 176.8 | 298.7 | 258.6 | 48.7 | 24.0 | 0.0 | 0.0 |
| 2000 | 0.0 | 16.6 | 8.6 | 50.4 | 65.4 | 77.4 | 244.3 | 205.5 | 139.4 | 24.0 | 23.4 | 3.4 |
| 2001 | 0.0 | 4.6 | 166.4 | 21.8 | 104.0 | 79.5 | 242.3 | 143.4 | 64.3 | 38.2 | 0.0 | 0.0 |
| 2002 | 8.6 | 0.0 | 48.0 | 34.6 | 11.0 | 109.1 | 179.3 | 178.0 | 58.4 | 0.0 | 0.0 | 21.3 |
| 2003 | 38.3 | 55.4 | 64.4 | 100.3 | 21.1 | 81.4 | 277.9 | 285.5 | 120.0 | 6.0 | 3.6 | 35.4 |
| 2004 | 9.4 | 16.6 | 67.8 | 119.9 | 2.0 | 133.5 | 172.5 | 209.1 | 73.6 | 22.6 | 10.3 | 0.0 |
| 2005 | 21.8 | 0.0 | 122.1 | 77.3 | 86.5 | 96.7 | 168.0 | 186.7 | 153.3 | 0.0 | 2.9 | 0.0 |
| 2006 | 5.0 | 108.8 | 0.0 | 52.2 | 32.2 | 108.2 | 329.0 | 141.4 | 122.8 | 78.3 | 5.2 | 16.1 |
| 2007 | 5.8 | 0.0 | 0.0 | 57.9 | 92.0 | 77.4 | 326.8 | 155.1 | 123.2 | 13.2 | 5.4 | 5.1 |
| 2008 | 0.0 | 0.0 | 0.0 | 41.1 | 47.6 | 55.5 | 226.3 | 253.5 | 148.6 | 3.2 | 45.2 | 0.0 |
| 2009 | 40.9 | 0.0 | 13.9 | 26.9 | 16.8 | 38.0 | 125.1 | 243.9 | 45.5 | 67.5 | 0.6 | 20.9 |
| 2010 | 0.0 | 36.2 | 87.0 | 129.7 | 37.2 | 100.7 | 197.9 | 204.9 | 125.5 | 0.0 | 0.0 | 0.0 |
| 2011 | 0.0 | 0.0 | 85.2 | 25.2 | 64.8 | 101.1 | 239.9 | 287.7 | 147.3 | 0.0 | 1.6 | 0.0 |
| 2012 | 0.0 | 0.0 | 110.2 | 39.2 | 26.9 | 101.1 | 175.6 | 193.7 | 104.6 | 1.6 | 0.0 | 5.1 |
| 2013 | 0.0 | 0.0 | 32.3 | 51.2 | 50.8 | 161.9 | 208.2 | 205.5 | 104.6 | 24.0 | 5.4 | 5.1 |

Nazerite station monthly precipitation data

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 0.0 | 96.5 | 41.0 | 6.2 | 54.4 | 152.4 | 263.3 | 212.1 | 20.4 | 37.7 | 0.0 | 0.0 |
| 1987 | 0.0 | 11.2 | 80.2 | 81.1 | 259.6 | 0.0 | 161.6 | 243.4 | 30.8 | 0.0 | 0.0 | 0.0 |
| 1988 | 34.0 | 31.3 | 6.8 | 50.9 | 9.4 | 50.3 | 185.4 | 171.4 | 186.9 | 52.9 | 0.0 | 0.0 |
| 1989 | 0.0 | 29.9 | 21.7 | 95.4 | 0.0 | 54.7 | 182.5 | 281.2 | 80.3 | 5.7 | 0.0 | 3.5 |
| 1990 | 0.7 | 183.9 | 83.0 | 114.7 | 13.3 | 12.0 | 337.8 | 168.7 | 153.7 | 7.0 | 0.0 | 0.0 |
| 1991 | 0.0 | 27.9 | 111.0 | 13.5 | 53.6 | 61.7 | 322.0 | 232.8 | 89.0 | 37.7 | 0.0 | 1.7 |
| 1992 | 41.2 | 27.8 | 0.0 | 53.5 | 8.6 | 61.7 | 243.9 | 212.1 | 108.1 | 37.7 | 11.9 | 6.7 |
| 1993 | 15.5 | 51.9 | 0.0 | 102.6 | 53.6 | 64.1 | 345.2 | 142.4 | 79.3 | 20.0 | 0.0 | 0.0 |
| 1994 | 0.0 | 0.0 | 2.6 | 49.1 | 26.5 | 70.1 | 229.6 | 171.5 | 173.8 | 13.8 | 35.6 | 51.0 |
| 1995 | 0.0 | 36.5 | 46.9 | 127.2 | 33.0 | 46.5 | 203.1 | 251.4 | 88.2 | 14.7 | 0.0 | 2.8 |
| 1996 | 27.2 | 0.0 | 111.5 | 65.1 | 115.2 | 120.2 | 220.2 | 250.0 | 93.9 | 0.0 | 7.9 | 0.0 |
| 1997 | 14.4 | 0.0 | 75.3 | 28.5 | 6.9 | 94.0 | 193.1 | 240.9 | 75.5 | 116.5 | 31.5 | 0.0 |
| 1998 | 11.8 | 25.6 | 105.2 | 19.8 | 49.3 | 55.3 | 196.5 | 220.6 | 144.7 | 132.8 | 0.0 | 0.0 |
| 1999 | 9.2 | 0.0 | 34.6 | 1.2 | 18.6 | 74.0 | 283.2 | 194.4 | 66.3 | 164.7 | 3.1 | 0.0 |
| 2000 | 0.0 | 0.0 | 20.2 | 16.1 | 51.5 | 60.8 | 355.1 | 269.0 | 133.6 | 85.7 | 57.8 | 12.9 |
| 2001 | 0.0 | 6.2 | 108.3 | 28.7 | 177.0 | 51.2 | 216.8 | 145.3 | 107.8 | 1.7 | 0.0 | 6.6 |
| 2002 | 20.9 | 11.1 | 57.1 | 51.3 | 22.5 | 50.2 | 129.9 | 205.7 | 65.3 | 1.1 | 0.0 | 34.5 |
| 2003 | 46.5 | 69.1 | 151.2 | 88.9 | 3.6 | 75.2 | 235.6 | 279.7 | 122.8 | 0.0 | 5.3 | 48.8 |
| 2004 | 28.8 | 3.3 | 77.4 | 53.1 | 1.9 | 63.3 | 114.4 | 227.3 | 77.1 | 58.6 | 12.8 | 1.6 |
| 2005 | 72.5 | 6.3 | 90.1 | 41.3 | 71.1 | 50.2 | 144.3 | 165.0 | 68.4 | 6.0 | 5.3 | 0.0 |
| 2006 | 17.6 | 88.4 | 64.6 | 88.7 | 27.8 | 58.7 | 173.5 | 225.0 | 128.8 | 10.1 | 0.5 | 28.5 |
| 2007 | 23.1 | 31.6 | 82.1 | 101.7 | 64.7 | 62.8 | 225.7 | 344.4 | 138.0 | 25.6 | 7.5 | 0.0 |
| 2008 | 9.6 | 0.0 | 0.0 | 79.9 | 69.5 | 71.3 | 353.1 | 302.2 | 100.3 | 37.5 | 69.5 | 0.0 |
| 2009 | 62.6 | 0.0 | 3.1 | 2.3 | 22.1 | 50.0 | 156.1 | 113.3 | 34.0 | 132.7 | 11.9 | 6.7 |
| 2010 | 0.0 | 97.3 | 57.1 | 27.4 | 68.1 | 100.6 | 227.8 | 242.9 | 164.7 | 0.0 | 17.6 | 0.3 |
| 2011 | 0.0 | 0.0 | 10.4 | 17.6 | 68.7 | 54.8 | 215.1 | 155.8 | 192.1 | 0.0 | 30.2 | 0.0 |
| 2012 | 56.0 | 0.0 | 39.8 | 78.2 | 48.8 | 33.0 | 508.9 | 313.0 | 130.2 | 1.4 | 0.5 | 6.7 |
| 2013 | 4.4 | 0.2 | 69.2 | 35.1 | 36.0 | 38.9 | 443.2 | 105.2 | 132.8 | 34.0 | 5.2 | 0.0 |
| 2014 | 0.0 | 4.8 | 123.0 | 7.1 | 62.3 | 7.7 | 211.7 | 180.0 | 150.6 | 91.7 | 8.9 | 0.0 |
| 2015 | 0.0 | 0.0 | 11.0 | 3.6 | 53.6 | 74.9 | 131.3 | 207.9 | 78.6 | 2.7 | 47.0 | 1.5 |
| 2016 | 1.3 | 23.0 | 21.7 | 146.0 | 52.5 | 122.2 | 345.4 | 103.9 | 135.0 | 37.7 | 11.9 | 0.0 |
| 2017 | 0.0 | 27.9 | 121.8 | 36.4 | 110.6 | 31.9 | 250.0 | 207.5 | 108.1 | 37.7 | 0.0 | 0.0 |