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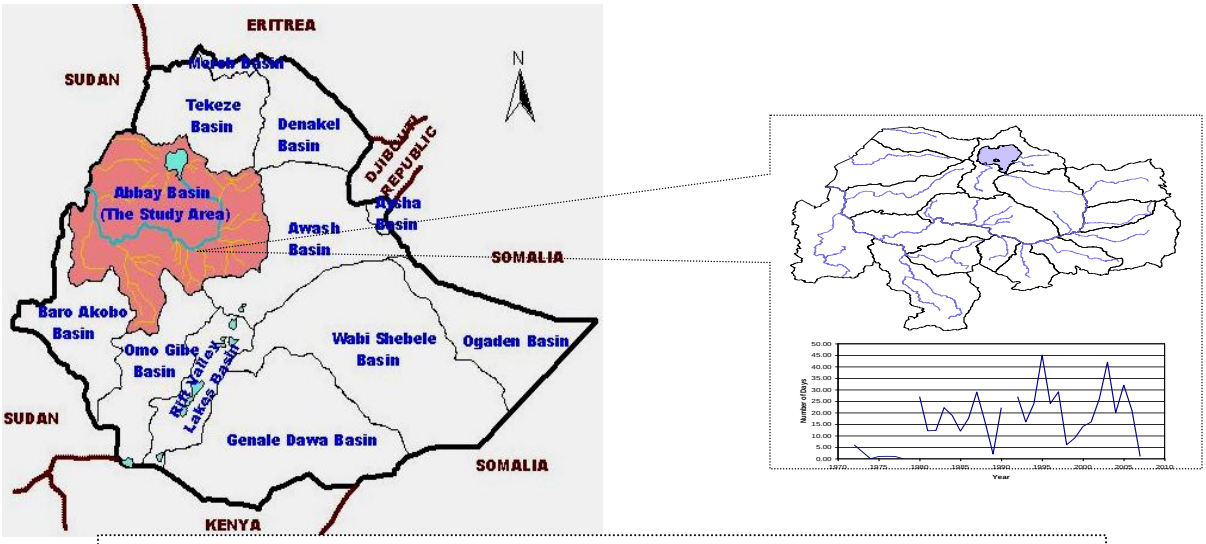
DEPARTMENT OF CIVIL ENGINEERING



Evaluation of Extreme Rainfall and Temperature Variability (In Upper Blue Nile, Ethiopia)

Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of

Master of Science

In

Civil Engineering

By
MILLION TAMIRU MEKASHA

July 2011

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Approved by board of examiners

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CERTIFICATION

I, the undersigned, certify that I read and here by recommend for acceptance by Addis Ababa University a dissertation entitled ***"Evaluation of Extreme Rainfall and Temperature Variability (In Upper Blue Nile, Ethiopia)"*** in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

_____

Semu Ayalew (PhD)

Supervisor

_____

Date

DECLARATION AND COPYRIGHT

I, Million Tamiru Mekasha, declare that this is my own original work and that it has not been presented and will not be presented to any other University for similar or any degree award.

_____

Signature

ACKNOWLEDGEMENTS

First I would like to thank my advisor, Dr. Semu Ayalew Moges, for his support throughout this project, with his professional guidance, invaluable comments, discussion, constant inspiration and encouragement that all inspired me to work continuously and enthusiastically throughout this study.

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Last but certainly not the least; I would especially like to thank my family whose support, for remembering me in all their praying and affection that encourage me to complete this research.

Finally, my last words of appreciation and respect are reserved to my few valuable Friends for their encouragement, advice and keeping in touch during the research period.

Above all, I owe everything to the Almighty God who gave me strength and good health throughout the entire period of my study. There is no loss in believing in him.

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LIST OF ABBREVIATIONS

CCI ----------Climate Change Index

CLIVAR ---------- Climate Variability

CTMs ----------Chemical Transport models

ETCCDI ---------- - Expert Team on Climate Change Detection

GCM ----------General Circulation Model

IPCC ---------- Intergovernmental Panel on Climate Change

Max.T---------- Maximum Temperature

Min.T ----------Minimum Temperature

MoWR ----------Ministry of Water Resources

NCDC ---------- -National Climate Data Centre

NMSA ----------National Meteorological Service Agency

NRC----------National Research Council

Prcp ----------precipitation

SGCM ----------Simple General Circulation model

UNEP ---------- United Nations Environmental Program

WMO ---------- World Meteorological Organization

ABSTRACT

Climate is perceived to be changing worldwide and there has been growing concern as to the direction and effects of these changes. The upper Blue Nile river basin is one of the potential river basins in the country where many development projects are undergoing currently with out having detail climate change situational analysis. As a trans-boundary river basin, this area attracts the attention of some neighboring countries.

For sound water resources planning and safeguarding of structures it is important to detect the possible climate change and variability of decisive metrological events like temperature, and precipitation. Therefore the concern of this research is to evaluate the variability of extreme events with regard to climate change for the upper Blue Nile river basin using climate indices. A suite of climate change indices derived from daily temperature and precipitation data, with a primary focus on extreme events, were computed and analyzed with specially designed computer Software. ClimeDex Version 1.3 Software is designed to analyze daily metrological data input and generates climate indices which intern indicates how temperatures and precipitation are varying in the upper Blue Nile River basin.

The whole trend analysis result of the basin showed no change over days having a rainfall amount 10mm/day or above. Only 3 days per decade join the upper rainfall extremes in the basin. Unlike precipitation, there is consistent increase in both minimum and maximum temperatures extremes. The result showed that 46 days per decade joins the upper extremes of maximum temperature and 43 days per decade leave the bottom extremes and join the next intermediate category. There is an increase of 38 days per decade in the upper extremes and surprisingly 68 days per decade leave the bottom extremes of minimum temperature and appear above the 5^{th} percentile of the base period. Further research can improve the accuracy of the results.

Generally the over all trend analysis result showed there are slight and non-consistence variability in precipitation extremes and significant variability in temperature extremes.

1. INTRODUCTION

1.1 Back ground

A better understanding of the nature of hydrologic/metrological events variability due to climate changes is needed to advance the ability to predict extreme flows arising from extreme rainfall events. Large scale climate indices are considered as an important source of inter-annual variability in weather and climate change detection.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP) to provide an assessment of all aspects of Climate Change including how human activities can cause such changes and can be impacted by them.
Most studies of changes in extreme rainfall have focused on linear trends in the indices. The aim of these studies has been to determine whether there has been a statistically significant shift in such indices of extremes.

Much of the analysis of climate and water impacts looks at how changes in various means will affect water and water systems, such as mean temperatures, average precipitation patterns, mean sea-level, and so on. While many factors of concern are affected by such average conditions, some of the most important impacts will result, not from changes in averages, but from changes in local extremes. Water managers and planners are especially interested in extreme events and how they may change with climate change. (*Peter H. Gleick, 2000):*

Extreme climatic phenomena are the subject of investigation both because of their current impacts on society and the threat of their possible increases in frequency, duration and severity in the climate troubled by enhanced concentrations of greenhouse gases in the atmosphere. Impacts of climate change would result rather from changes in climate variability and extreme event occurrence than from an increase in mean temperature (Houghton et al., 1996; Watson et al., 1996)

ClimDex is a Microsoft Excel based program that provides an easy-to-use software package for the calculation of indices of climate extremes for monitoring and detecting climate change. This paper uses this analysis Software to detect the variability of extreme rainfall and temperature events using daily data in the Blue Nile river basin.

Assessing & evaluating the impacts of climate changes cannot be a static activity. New information is constantly being made available, new methods and models are being developed and tested, policies related to water management and planning are dynamic and changing. This thesis must therefore be considered a snapshot in time, and would like to provide about climate change and the consequence variability of extreme rainfall and temperature events in the basin.

1.2 Statement of the Problem

The upper Blue Nile river basin is one of the river basins in the country where many development projects are undergoing currently with out having detail climate change situational analysis. These projects are important for hydropower generation and irrigation schemes for food security and national economic growth. Prior assessment in existence of uncertain phenomenon like extreme rainfall and temperature variability due to climate change will help to minimize risks, taking into account during planning stage.

Alterations in the hydrological cycle induced by rainfall and temperature variability can affect electricity production and may affect the country's ability to meet electricity demand. Physical damage to hydroelectric generation facilities may happen as a result of extreme weather events variability related to global Climate change. Extreme rainfall results in landslides, flash floods, and crop damage that have major impacts on society, the economy, and the environment. Although prediction of such extreme weather events is still fraught with uncertainties, a proper assessment of likely future trends would help in setting up infrastructure for disaster preparedness.

The Intergovernmental Panel on Climate Change concluded in 1996, *(Peter H. Gleick, 2000)* that: "the flood related consequences of climate change may be as serious and

widely distributed as the adverse impacts of droughts" and "there is more evidence now that flooding is likely to become a larger problem in many regions, requiring adaptations not only to droughts and chronic water shortages, but also to floods and associated damages, raising concerns about dam and levee failure."

Climate changes have the potential to alter water quality significantly by changing temperatures, runoff rates and timing. Global and regional increases in air temperature, and the associated increases in water temperature, are likely to lead to adverse changes in water quality, even in the absence of changes in precipitation.

Lakes are known to be sensitive to a wide array of changes in climate. Even small changes in climate can produce large changes in lake levels and salinity. As air temperatures increase, fewer lakes and streams in high-latitude areas will freeze to the bottom and the number of ice-free days will increase, leading to increases in nutrient cycling and productivity. Other effects of increased temperature on lakes could include higher thermal stress for cold-water fish, improved habitat for warm-water fish, increased productivity and lower dissolved oxygen, and degraded water quality.

Blue Nile river basin is shared watersheds and any change against its water resources potential may lead to local and international political disputes. International agreements covering these shared waters usually do not include provisions for explicitly addressing the risks of climate-induced changes in water availability or quality.

For sound water resources planning and safeguarding of structures, it is important to know the possible variability of decisive metrological events like temperature and precipitation. Therefore the concern of this research is to evaluate the variability of extreme events with regard to climate change for the upper Blue Nile river basin using climate indices derived from daily precipitation and temperatures data using ClimDex Version 1.3 Computer program specifically designed to climate change detection.

1.3 Objectives

The main objective of this thesis is to detect any climate change through evaluation of extreme rainfall and temperature variability on the basis of climate indices in the upper Blue Nile river basin.

The specific objectives of this thesis include

- To generate many climate indices for lower and upper extremes of precipitation and temperatures
- To evaluate and detect the potential extreme rainfall and temperature variability due to climate change based on the indices generated

1.4 Description of the study area

The Ethiopia part of Blue Nile also called Abay Basin in Ethiopia is located in the northwestern region of Ethiopia between 7^0 40' N and 12^0 51' N latitude, and 34^0 25' E and 39^0 49' E longitude. It covers an area of approximately 199,812 sq km. It shares a boundary with the Tekeze basin to the north, the Awash basin to the east and south east,the Omo-Gibe basin to the south, and the Baro-Akobo basin to the south west. The country's largest freshwater lake, Lake Tana, the source of the Blue Nile (Abbay) river is located to the north of the basin.

The Abbay basin accounts for a major share of the country's irrigation and hydropower potential. It has an irrigation potential of 815,581 ha and a hydro potential of 78,820 GWH/yr. The basin has an average annual run-off estimated to 54.8 BCM (Awlachew, et.al., 2007).

The basin is subdivided into 16 sub basins based on the major rivers in the basin, the Abbay River and its tributaries.

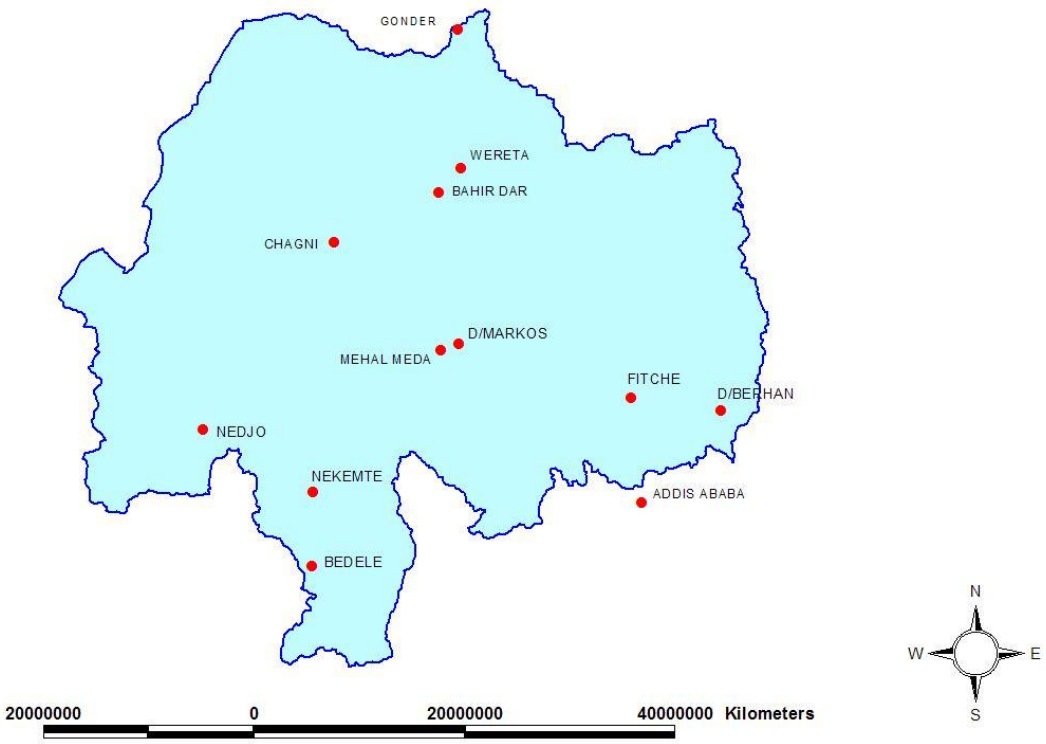

Fig 1.1: Upper Blue Nile (Abay) River Basin and selected stations

1.4.1. Climate

1.4.1.1. Rainfall

Rainfall ranges between 787 mm and 2200 mm per year; The Ethiopian highlands having highest rainfall ranging from 1500 to 2200 mm, whereas lowlands having rainfall less than 1500 mm. The lowest rainfall recorded less than 1000 mm per annum in the Beshelo, Welaka, Jemma, Muger, Guder, and parts of Dinder and Rahad.

1.4.1.2. Temperature

The highest temperature observed in the north western part of the basin, in parts of Rihad, Dinder, Beles and Dabus, the maximum temperature being 28°C - 38°C and minimum

temperature 15 °C – 20 °C. Lower temperature observed in the highlands of Ethiopia in the central and eastern part of the basin. The maximum and minimum temperature ranges from 12 °C – 20 °C and -1°C to 8°C respectively.

1.5 Structure of Dissertation

This thesis is divided into six chapters. Chapter one provides brief introduction of the study. Chapter two presents the previous works done related to climate change detection, and the technical capabilities of the Software used during the research. Chapter three presents the methodology of application of each set of tools used in this research, including ClimeDex Version 1.3 Software, Statistical data analysis tools, and MS Excel functions. Chapter four deals with the sources of data, availability of data, and data analysis. Chapter five deals with details of the results obtained and their discussion using both tabulated and graphical outputs of the Software.

Conclusion and recommendation part will be in the final chapter, six. In addition to the six chapters described above, the appendices are provided at the end of the paper.

2. LITERATURE REVIEW

2.1 Importance of Climate Indices in Climate Change Study

The term climate variability denotes the natural characteristic of climate that manifests itself within the changes of climate with regards to time. It refers to variations in the mean state of climate on all temporal and special scales beyond that of individual metrological events.

On the other hand, climate change has a much distinct meaning compared to climate variability. It is the change within the statistical distribution of the metrological events over certain periods of time. This can range from centuries, decades or even millions of years. It refers to shifts in the mean of the climate or in its variability, persisting for an extended period.

Climate indices are internationally standardized and coded indicators resulted from the analysis of daily rainfall and temperature data. Now a days researchers working on climate change detection are using climate indices generated by Software as a tool for trend analysis. International and regional studies focusing on climate change detection suggest that use of these indices derived from daily data of precipitation, maximum and minimum temperatures are suitable for analyzing extreme events. Climate indices have unique codes, values, and interpretations. Indices have been chosen primarily for assessment of the many aspects of a changing global climate which include changes in intensity, frequency and duration of temperature and precipitation events.

The advantages of using indices for climate change detection includes

(a) They can be applied to different climate parameters such as maximum & minimum temperatures and precipitation.

(b) They enable an easy comparison of trends between different climate regions and

(c) They are easily understandable and manageable for impact studies.

ClimDex is a Microsoft Excel based program that provides an easy-to-use software package for the calculation of indices of climate extremes for monitoring and detecting

climate change. It was developed by Byron Gleason at the National Climate Data Centre (NCDC), USA and generates (sometimes dependent on data quality &homogeneity) 18 climate indices for trend analysis. How ever, all indices may not be responsive and applicable for all areas in the world.

List of Climate Indices

INDEX NO.	ABBREVATION	TITLE	UNITS
125	FD	Number of Days with Frost (Tmin < 0 deg C)	days
141	ETR	Intra-Annual Extreme Temperature Range (Th-Tl)	days
143	GSL	Growing Season Length (when T>5 deg C for >5 days and: T<5 deg C for >5 days)	days
144	HWDI	Heat Wave Duration Index	days
191	**Tx10**	**Percent of Time Tmax < 10$_{th}$ Percentile of Daily Maximum Temperature**	**% of time**
192	**Tx90**	**Percent of Time Tmax > 90$_{th}$ Percentile of Daily Maximum Temperature**	**% of time**
193	**Tn10**	**Percent of Time Tmin < 10$_{th}$ Percentile of Daily Minimum Temperature**	**% of time**
194	**Tn90**	**Percent of Time Tmin > 90$_{th}$ Percentile of Daily Minimum Temperature**	**% of time**
606	**R10**	**No. of days with Precipitation >= 10.0 mm/day**	**days**
641	**CDD**	**Maximum Number of Consecutive Dry Days (Rday < 1 mm)**	**days**
644	**R5d**	**The Greatest 5-day Rainfall Total**	**mm**
646	**SDII**	**Simple Daily Intensity Index**	mm / day
695	R95T	Fraction of Annual Total Rainfall due to Events Above the 95$_{th}$ Percentile	
001	TxGE	**Number of Days Tmax >= user defined threshold**	**days**
002	**TxLE**	**Number of Days Tmax <= user defined threshold**	**days**
003	**TnGE**	**Number of Days Tmin >= user defined threshold**	**days**
004	**TnLE**	**Number of Days Tmin <= user defined threshold**	**days**
005	**Prcp**	**Number of Days Prcp >= user defined threshold**	**days**

2.2 Types of Climate Indices

Climate indices can be divided into four different categories:

a) Percentile-based indices giving information about the temperature of cold nights, warm nights, cold days and warm days. They sample the coldest and warmest deciles for both maximum and minimum temperatures. The precipitation indices in this category represent the amount of rainfall falling above the 95th (R95T) percentiles. However percentile indices are highly dependent on data quality and homogeneity. When compared with threshold indices these indices have less strength of expressing extreme events due to the fact that they don't allow the user to extend any more towards the lower and upper percentiles.

- (191Tx10)Percent of Time Max.T < 10^{th} Percentile of Daily Maximum Temperature shows the percent of time that the value of maximum temperature declines the tenth percentile of the data. It is an indicator of cold days

- (192Tx90) Percent of Time Max.T > 90^{th} Percentile of Daily Maximum Temperature shows the percent of time that the value of maximum temperature exceeds the 90^{th} Percentile of daily maximum temperature data. It is an indicator of warm days
- (193Tn10) Percent of Time Min.T < 10th Percentile of Daily Minimum Temperature shows the percent of time that the value of minimum temperature declines the 10^{th} percentile of daily minimum temperature data. It is an indicator of cold nights
- (194Tn90) Percent of Time Min.T > 90th Percentile of Daily Minimum Temperature shows the percent of time that the value of minimum temperature exceeds the 90^{th} percentile of all daily minimum temperature data. It is an indicator of warm nights
- (695R95T) Fraction of Annual Total Rainfall due to Events above the 95th Percentile shows the proportion of total annual rainfall from events above the 95^{th} percentile of daily precipitation data. It is an indicator for frequency and duration of upper extreme events

b) Threshold indices are defined as the number of days on which a temperature or precipitation value falls above or below a fixed threshold

- (125 FD) Number of Days with Frost (Min.T < 0 deg C), count of days having minimum temperature records less than 0 deg. C. less likely occur in the study area
- (606 R10) No. of days with Precipitation >= 10 mm/day, count of days having precipitation record >=10mm in any given year of records
- (001 TxGE) Number of Days Max.T >= user defined threshold, count of days having maximum temperature record >= 95^{th} percentile of the entire data set of a station in analysis for this study It indicates the variability of upper extremes.

- (002TxLE)Number of Days Max.T <= user defined threshold, count of days having maximum temperature record<= 5th percentile of the entire data set of a station in analysis for this study .It indicates the variability of lower extremes.
- (003 TnGE) Number of Days Min.T >= user defined threshold, count of days having minimum temperature record >= 95th percentile of the entire data set of a station in analysis for this study. It indicates the variability of upper extremes.
- (004 TnLE) Number of Days Min.T <= user defined threshold, count of days having minimum temperature record<= 5th percentile of the entire data set of a station in analysis for this study It indicates the variability of lower extremes.
- (005 Prcp) Number of Days Prcp >= user defined threshold, count of days having precipitation record >= 95th percentile of the entire data set of a station in analysis for this study.

c) Duration indices define periods of excessive warmth, cold, wetness or dryness or in the case of growing season length, periods of mildness.

- (143 GSL) Growing Season Length (when T>5 deg C for >5 days and: T<5 deg C for >5 days) commonly meaningful in northern hemisphere
- (144 HWDI) Heat Wave Duration Index ,count of days (at least 3 days)exceeding 95th percentile of maximum temperature and it can be expressed better by threshold maximum temperature index (003 TnGE)
- (641 CDD) Maximum Number of Consecutive Dry Days (Rday < 1 mm)

d) Other indices

- (141 ETR) Intra-Annual Extreme Temperature Range (Th-Tl),is the difference of the highest and the lowest temperature records of any given record year
- (644R5d) The Greatest 5-day Rainfall Total ,
- (646SDII) Simple Daily Intensity Index ,is the quotient of total annual precipitation and wet days of the same year (days having record value> 1mm)

2.3 Previous studies

The symptoms of global warming can be observed and felt throughout the world. Floods in certain areas of the globe are mainly caused by melting glaciers in the polar region and extreme rainfall events in different regions of the world. Droughts and heat waves are widespread amongst the places of the world where rains, temperatures, and humidity levels were once normal. These are some of the evidences for the existence of climate variability.

Rainfall variability was observed in the north central Ethiopia highlands that include upper Blue Nile river basin. The variability observed is mainly on monthly basis and there is a decline of annual rainfall due specific reduction of rainfall amount in the months June to September. The consequence of this annual rainfall decline was fluctuation of Blue Nile river flow where more than 50% of its catchment is found in north central Ethiopia highlands (Yilma and Demaree, 1995).

Caribbean region study on climate change detection and variability based on climate indices generated from daily data using ClimeDex Software was one of the series studies taken place so far. Participants from almost all countries in the region organized in the research team with their own available data.

The individual indices provided insights into recent climate change in individual countries and some clearly highlighted dramatic changes in the climate of the region as a whole or parts of the region. For example, since the late 1970s, stations from the southern Caribbean showed strong, nearly linear increases in the number of warm nights.
The rising interest in Climate Change detection and its impacts is a consequence of human activities mainly through the release of greenhouse gases. Many studies in Europe and North America showed an increasing trend in regional air and surface temperatures.

Interest in the climate system of Africa has been increasing in recent years. The social and economic characteristics of most African countries depend on the seasonal and inter

annual variability of temperature and rainfall patterns. Experts and representatives from 22 African countries undergone climate change study based on indices developed from daily temperature and precipitation data.

It has been found a negative trend in the number of very cold minimum temperatures and a positive trend in warm night-time temperatures over most countries, including Madagascar and the Seychelles. Exceptions were northern Eritrea and the extreme eastern coast of Tanzania. These coherent patterns of change were also found for maximum temperature. The evidence of warming in almost all the countries was statistically significant in many cases.

The precipitation indicators show a much more mixed pattern of change than the temperature indicators. Neighboring stations can sometimes show opposite signs of change or variability.

From climate change detection studies conducted on the basis of indices generated from daily precipitation and temperature data, it can be concluded that most of the selected indices seem to be very relevant for temperature and give a regional overview of climate change. However the precipitation indices seem to be highly dependent on location and regional studies may therefore need to consider other regionally dependant indices.

The results of the simulation studies in USA *(Peter H. Gleick, 2000)* support the conclusion that relatively small changes in temperature and precipitation can have large effects on runoff. In every one of these studies, an increase in temperature and no change in precipitation resulted in decreases in runoff. A 10% reduction in precipitation and a 2^0C increase in temperature reduces estimated runoff by between 13 to 40% in most studies. Increasing precipitation by 10% approximately balances evaporative losses resulting from an increase in temperature of 4C ^{o}. These results are not comprehensive, but are suggestive as to the possible magnitude and uncertainty surrounding the hydrologic implications of a greenhouse warming. In contrast to these variable results, shifts in runoff timing in basins with snowfall and snowmelt are consistent in all studies

that looked at daily or monthly runoff. These studies show with very high confidence that increases in winter runoff, decreases in spring and summer runoff, and higher peak flows will occur in such basins if temperatures rise.
A study of a semi-arid basin in Africa concluded that a 15% reduction in rainfall could lead to a 45% reduction in groundwater recharge (Sandstrom, 1995).

Data from a network of ground and ocean-based sites suggest that the average surface temperature of the Earth has increased by over a degree Fahrenheit (around 0.6 degree Celsius) over the past century (NRC, 2000). The fifteen warmest years this century have all occurred since 1980, the 1990s were the warmest decade of the entire millennium, and 1998 was the warmest year on record (Mann et al. 1999). Seven of the ten warmest years on record occurred in the 1990s. These changes appear to be outside the range of natural variability (IPCC 1996a, b; Mann et al. 1999).

3. METHODOLOGY

The methodology applied for the evaluation of variability of extreme metrological events is utilizing of ClimeDex version 1.3 software and statistical annual data analysis.

3.1 ClimDex Software Version 1.3

ClimDex is a Microsoft Excel based program that provides an easy-to-use software package for the calculation of indices of climate extremes for monitoring and detecting climate change. It was developed by Byron Gleason at the National Climate Data Centre (NCDC), and has been used in different climate change detection studies. ClimDex (Version 1.3) is a Microsoft Excel (Version 97 or higher) program designed to assist researchers in the analysis of climate change and detection using daily metrological data. More specifically, ClimDex guides a user through a four-step analysis process:

- Quality Control
- Homogeneity Testing
- Calculate Indices
- Region Analysis

The first three steps are performed on a single station's data whereas the last step compiles the results calculated in step 3 for multiple stations.

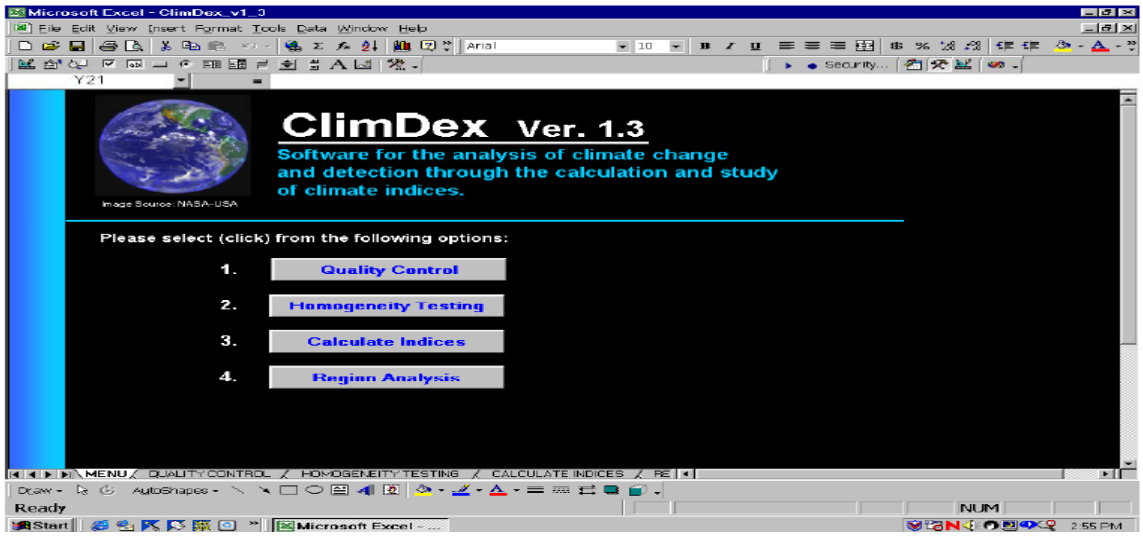

Fig 3.1: ClimeDex V.1.3 Main Menu (ClimeDex Manual)

3.1.1 Quality Control

The first step in the analysis process consists of the application of routine quality control procedures to a user's station data. The quality control checks performed are:

- Min.T > Max.T
- PRCP < 0.0 mm
- Identifying outliner values > or < a specified number of standard deviations.

Daily values for both maximum and minimum temperature are evaluated using this technique against sigma value or standard deviation value of 7. Therefore, for all 365 of the same day values (leap years excluded) a standard deviation is calculated for each day and if it is > or < 7, it is set equal to the missing value designated by the user (-99.9).

In addition, values that meet the criteria of the quality control steps (e.g. Min.T > Max.T , PRCP < 0.0mm) are also set to missing. The quality control procedure is not meant to be comprehensive but rather to assist a user in identifying common gross errors that may exist within daily station data.
The data quality is assessed by visual inspection before the Software is self manages at the quality control step. Dramatic errors, sometimes misplacing a point, are found and corrected accordingly.

3.1.2 Homogeneity Testing

ClimDex provides users with a way to detect maximum and minimum temperatures inhomogeneities. These values can be thought of as discontinuities or shifts in the data record or time series of maximum or minimum temperature. These abrupt or sometimes gradual changes can be traced to both natural and artificial (human induced) changes. Users are generally more interested in eliminating or mitigating the effects of the latter (artificial) and trying to detect and/or explain the former (natural).

Poor homogeneities in the available datasets, even after primary corrective measures, were a problem. Due to having large number of missing, data in most of the stations have been found having poor homogeneity.

Most long-term time series are affected by inhomogeneities caused by changes in instrumentation, site displacements, changes in the local environment such as urbanization, or the introduction of different observing practices (Wijngaard, 2003).

The homogeneity test provides the probability result after accomplishing a t-test against each station using user defined "window size" taken 10 in this case. However it is the user's mandate to utilize or reject the station due to poor homogeneity for indices calculation. This test is important at times when there are plenty of stations for analysis and to choice the best ones. But the writer decided to utilize even stations with poor homogeneity for further analysis as there are limited numbers of stations.

3.1.3 Region Analysis

It is possible to summarize a single index for many stations by combining the results into a single data file. A user can then use a variety of mapping/analysis software packages to plot the results for a specified region. This step is commonly applicable for plotting of results from analysis of data that covers vast region or even a continent where significant variations in between stations of sub areas are expected. ClimeDex is not equipped with any mapping tools operating under Windows environment. Therefore, it is not possible to plot directly the results found from the analysis. However for this specific study GIS mapping tools have been utilized to show the variability among stations in the basin based on annual data analysis result.

The following points were considered for the selection of ClimeDex Software:

- Moderate data requirements
- Applied and tested in various international climate changes detection workshops and provided good performance in evaluating extreme rainfall and temperature events variability.
- The availability of the Software freely from website
- Results could be easily understood and used in policy decisions made by non-specialists in the field

3.2 Selection of Stations

The investigation made into the collected time series data of the Abbay (Blue Nile) River Basin revealed that in many of the gauging stations there are significant discontinuities in the daily data series. And it is difficult if not impossible to get concurrent rainfall, minimum and maximum temperature data in the basin. Most of the stations have several years of missing records that some of them are continuous which makes the analysis difficult.

Improved studies of climate extreme trends, on high quality and consistent data, are needed if we are to be able to determine whether climate extremes are varying (M.Haylock &N.Nichols, 2000). Filling of missed data is not recommended while using this analysis methodology to avoid errors that lead to wrong conclusion. Therefore the first step for data analysis should be station selection based on their data quality and length of years of records. Percentage of missing data of rainfall and temperatures data was calculated for each of the stations.

In order to select stations having comparatively better quality data record, the following criterions are developed and applied:

- Those stations having more than 30 years of records for all three events, the percentage of missing should be less than or equal to 25%.
- Those stations having 25-29 years of records for all three events, the percentage of missing should be less than 15%.
- Those stations having 21-24 years of records for all three events are expected to have percentage of missing data value of less than or equal to 5%.

Most researchers are using criterions more tightened than this one but difficult to apply here due to poor data quality of our stations. These criterions are set on the basis that at least a station should have a net data record of 20 years. Unless otherwise it will be difficult to fit a trend of generated indices and observe variability in short period of time as climate change is evolutional phenomenon. Still there are stations with continuous missing months of records but the total percentage of missing lies with in the listed criterions.

Percentage of missing data has been calculated by re-arranging the given raw data into sequential order (year, month, and day) and assign the value -99.9 for those cells don't have any record or missed data. Then applying *find* and *replace* editing tools of MS.EXCEL program, the number of days with missed data are calculated.

3.3 Indices selection

The data format obtained from the national metrological service agency (NMSA) is not compatible with the format that the analysis Software demands. Therefore the input data has been prepared according to the format. This study is focusing mainly on extreme events variability and to address this issue, the minimum and maximum user defined thresholds are decided to be the 5^{th} and 95^{th} percentile of each station data respectively. For formulation of indices, these values are calculated by sorting the available data of the given station and applying PERCENTRANK function of MS.EXCEL program.

ClimeDex Software generates, dependent on data quality and homogeneity, 18 indices for trend analysis. How ever, all indices may not be responsive for all areas in the world.
The detection of trends in weather extremes remains a challenge because of the rare occurrence of extreme events. Moreover, the detection likelihood decreases with increasing rarity of the event (Frei and Schär, 2001; Klein Tank and Können, 2003). Therefore, the assessment of trends is often based on indices describing extreme events. To notice if changes are already evident and to reduce the climate variability it is of remarkable interest to analyze the occurrence of past extremes (Moberg et al., 2006).

Therefore selection of indices according to the exact study area situation, data type, and expected out put is indispensable. Those stations more indicative for extreme events and responsive to study area are selected. Some indices like "number of days with frost" are not applicable as very few days have temperature record less than zero degrees Celsius in the study area. Having this in mind, the following indices are selected for this specific trend analysis work.

Indices for rainfall trend analysis

For the study of the extreme events variability and possible climate changes, the precipitation indices that are selected to be developed from the analysis of the daily data of the precipitation, with the help of the climdex software are:

(a) Number of days with precipitation equal or greater than 10mm/day.

(b) Maximum number of consecutive dry days (Rday<1mm).

(c) Maximum quantity of precipitation in 5 days. The greatest 5-day Rainfall Total

(d) Simple daily intensity Index.

(e) Number of Days Prcp >= user defined threshold (95^{th} percentile)

f) Fraction of Annual Total Rainfall due to Events above the 95th Percentile

Indices for temperatures trend analysis

For the study of the extreme events variability and possible climate changes detection, the temperatures indices are selected based on the capacity of expressing the most extreme events and relatively less sensitive to data quality and homogeneity.

a) Number of Days Max.T >= (95^{th} percentile)

b) Number of Days Max.T <= (5^{th} percentile)

c) Number of Days Min.T >= (95^{th} percentile)

d) Number of Days Min.T <= (5^{th} percentile)

e) Intra-Annual Extreme Temperatures range (Th-TI)

3.4 Statistical Data Analysis

Originally analysis of data using statistical data analysis tools was not the aim of this study. However the number of stations selected for analysis found less that expected and to strengthen the conclusions using results from statistical data analysis tools that have similar detection out puts, no doubt, maximizes the realty of the findings. Therefore having this constructive idea, annual historical data linear trend analysis has been made for all stations. Annual data having more than one month missing have been omitted.

4. DATA AVAILABILITY AND ANALYSIS

4.1 Metrological Data

The office in charge of collecting and disseminating metrological data is the National Meteorological Service Agency (NMSA). In the NMSA record there are about 173 stations in the Basin and few around the basin boundaries. With such an important number of stations, the pluviometric network for the whole basin reaches a global density of about 1 station for each 1,200 km^2 which is more than satisfactory according to international standards (BCEOM, 1999). Yet the Metrological data network exhibits limitations because of uneven distribution of the stations over the basin, short record period, almost all stations experience considerable percentage of missing data, and some stations are incapable of recording temperature data.

Daily rainfall, maximum & minimum temperatures data probably with the long years of records for 21 stations have been collected in the entire Abbay (Blue Nile) river basin. The length of record of the data made available for this analysis varies from 9 to 37 years. Although daily climate data are essential for societally-sensitive extremes, most analyses have focused on changes in mean values due to the lack of the availability of high quality daily data required for monitoring, detecting and attributing changes in climate extremes (Jones, 1999).

4.2 Data Analysis

Percentage of missing data values of precipitation and temperatures for all stations have been calculated and tabulated below.

Table 4.1: Rainfall stations and corresponding % of missing values

Station ID	length of years of records	Missing years of records	Max.consecutive missing months	%missing	Remark
Addis Ababa	50	0	0.6	0.2	
Ambo	25.8	1992,94,95,96	36	24.47	
Arjo	34.8	0	3	6.85	
Assosa	35.9	1990,91,92,93,97,98,99	48	21.90	
Bahirdar	36	0	3	1.44	
Bedele	36.8	1982	20	10.19	
Chagni	33	1993-97	69	21.91	
Debark	35.8	1976,77,78,79,90,91,08	58	31.00	
Debirebirhan	34	0	3	3.44	
D/Marikos	35	0	3	1.29	
Fiche	34.8	0	8	6.21	
Gimbi	35.8	1976,77,82	31	19.04	
Gonder	37	0	9	4.32	
Kutaber	9				
Mehalmeda	33.75	0	16	7.46	
Nedjo	33.5	1976,84	19	12.58	
Nefasmewcha	22.5	1990	25	14.80	
Nekemte	36	0	2	4.68	
Shambu	27.9	1983	23	15.66	
Wereta	34.3	1979	27	19.45	
Yetmen	30	1978	17	12.68	
D/Tabore	15				

Table 4.2: Max.Tempreture stations and corresponding % missing values

Stations	length of years of records	Missing years of records	Max.consecutive missing months	%missing	Remark
Ambo	12.4	2007	12	16.20	
Arjo	35.5	1995,96,97,98,00,01,02	61	29.43	
Assoa	35.9	1990,91,92,93,97,98,99,	53	29.94	
Bahirdar	36	1990	12	4.06	
Bedele	36.8	1982,93	20	17.46	
Chagni	33.4	1993-97	69	21.76	
Debark	35.8	1976,77,78,79,89,90,91,08	58	40.12	
D/Birhan	31	0	1	2.32	
D/Marikos	35	0	3	2.07	
Fiche	34.8	0	8	8.47	
Gimbi	35.8	1976,77,82,94,95,96,97,98,99,01	77	40.26	
Gonder	35	0	5	5.61	
Kutaber	0				
Mehalmeda	34.8	0	16	9.37	
Nedjo	33.4	1976,99,00	32	19.56	
Nefasmewcha	19.5	1990	25	17.22	
Nekemte	35.9	0	5	9.14	
Shambu	23.6	1987,94,95,96,97	54	32.19	
Wereta	34.2	1979	27	20.34	
Yetemen	25.2	1994,95,96,97	59	28.82	
D/Tabore	15				

Table 4.3: Min. Temperature stations and corresponding % missing values

Stations	length of years of records	Missing years of records	Max.consecutive missing months	%missing	Remark
Ambo	26	1992,94,95,96	43	30.83	
Arjo	35.5	1995,96,97,98,01,02,03	61	37.94	
Assoa	35.9	1990,91,92,93,97,98,99	53	27.06	
Bahirdar	36	0	3	2.82	
Bedele	36.8	1982,93	20	16.11	
Chagni	33.4	1993,94,95,96,97	69	21.76	
Debark	35.8	1976,77,78,79,86,89,90,91,08	63	38.34	
D/Birhan	31	0	1	2.84	
D/Marikos	35	0	3.5	2.83	
Fiche	34.8	0	13	8.26	
Gimbi	35.8	1976,77,82,94,95,96,97,98,99	77	36.83	
Gonder	35	1998	20	10.15	
Kutaber	0				
Mehalmeda	34.8	0	16	7.81	
Nedjo	33.5	1976,99,00	32	20.16	
Nefasmewcha	19.7	1990	25	19.26	
Nekemte	35.9	0	5	8.83	
Shambu	23.6	1987,94,95,96,97	54	32.87	
Wereta	33.8	1979	27	22.96	
Yetemen	25.2	1994,95,96,97	62	37.28	
D/Tabore	15				

Table 4.4: Shows Criterions and Selected Stations

Stations	Rainfall		Max. Temperature		Min.Tempereture		Selected(yes/No)
	Record yrs	% missing	Record yrs	% missing	Record yrs	% missing	
AMBO	25.8	24.47	12.4	16.20	26	30.83	No
ARJO	34.8	6.85	35.5	29.43	35.5	37.94	No
ASSOSA	35.9	21.90	35.9	29.94	35.9	27.06	No
BAHIRDAR	36	1.44	36	4.06	36	2.82	**Yes**
BEDELE	36.8	10.19	36.8	17.46	36.8	16.11	**Yes**
CHAGNI	33	21.91	33.4	21.76	33.4	21.76	**Yes**
DEBARK	35.8	31.00	35.8	40.12	35.8	38.34	No
DEBRBIRHAN	34	3.44	31	2.32	31	2.84	**Yes**
DEBRMARIKOS	35	1.29	35	2.07	35	2.38	**Yes**
FICHE	34.8	6.21	34.8	8.47	34.8	8.26	**Yes**
GIMBI	35.8	19.04	35.8	40.26	35.8	36.83	No
GONDER	37	4.32	35	5.61	35	10.15	**Yes**
KUTABER	9						No
MEHALMEDA	33.75	7.46	34.8	9.37	34.8	7.81	**Yes**
NEDJO	33.5	12.58	33.4	19.56	33.5	20.16	**Yes**
NEFASMEWHCA	22.5	14.80	19.5	17.22	19.7	19.26	No
NEKEMETE	36	4.68	35.9	9.14	35.9	8.83	**Yes**
SHAMBO	27.9	15.66	23.6	32.19	23.6	32.87	No
WERETA	34.3	19.45	34.2	20.34	33.8	22.96	**Yes**
YETEMEN	30	12.68	25.2	28.82	25.2	37.28	No
DEBRETABOR	15		15		15		No

After the analysis made to select the better stations among 21 stations, 11 stations are selected as per the criterions listed above. Even though the number of stations selected is few, fortunately their location is at different zones of the basin. In addition to these stations Addis Ababa station rainfall data has been included as a nearby station to incorporate the information obtained.

Table 4.5: Selected Stations and their agro-ecological zones in the basin

Selected Stations	Altitude (m)	Agro-ecological zone
Mehalmeda	3040	Wirch (Altitude >3000m)
Debrebirhan	2750	Dega (Altitude, 2301-3000m)
Debremarikos	2515	
Fiche	2750	
Bahirdar	1770	Woyna Dega (Altitude ,1500-2300m)
Bedele	2030	
Chagni	1620	
Gondar	1967	
Nedjo	1800	
Nekemte	2080	
Wereta	1810	

Finally the prepared input data of all selected stations are analyzed and the resulted graphical and tabulated indices' trends have been summarized and discussed.

Like wise the annual data series of Rainfall, Maximum, and Minimum Temperatures of each of selected station has been fitted with linear trend and the results are summarized in tables.

5. RESULTS AND DISCUSSION

5.1 Precipitation Indices

Six indices for precipitation have been selected and calculated for each of the stations. The results have been summarized and tabulated. It has been observed that for the same indices, the result from different stations may vary each other. Significant trends are highlighted to give attention during observation.

The sampled graphical results are also presented to show how trends are fitted and looks like as an out put of the analysis Software. The tabulated result shows stations having increment trend value under positive trend column and station having decrement trend value under negative trend column. The significance level under 95% level of confidence of each value is indicated under the significance column.

The tabulated result tells an increase/decrease of trend value (as per the unit indicated) per year incase of ClimeDex analysis result and per decade incase of annual historical data analysis. For example there is 0.257 days increment per year at Debremarikos station regarding rainfall index 606R10.

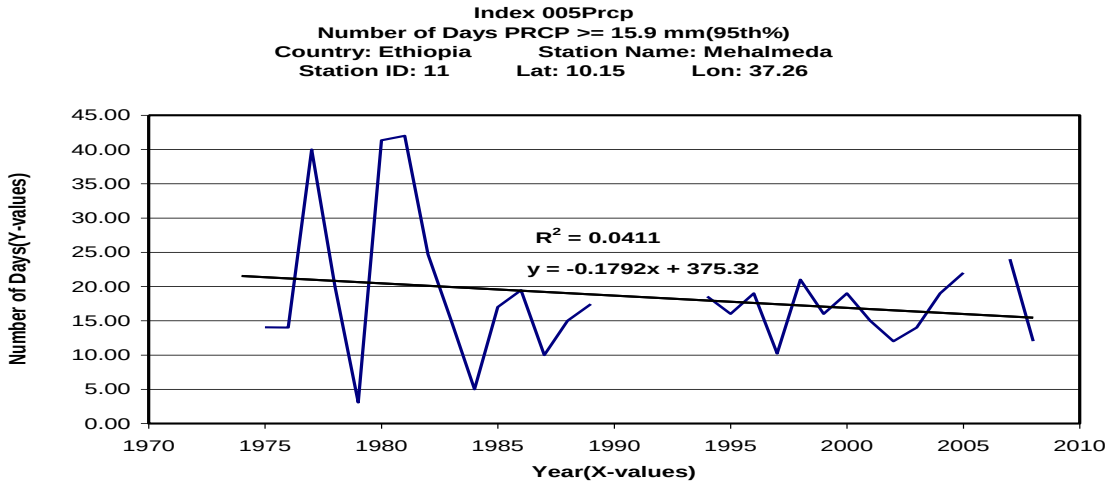

Fig 5.1: Shows trend line of single precipitation index for Mehalmeda station

Table 5.1: Rainfall Indices & their trend values of each station

Stations	005Prcp(No of Days)			606R10(No. of Days)			641CDD(No. of Days)			644R5D (mm)		
	Trend(+)	Trend(-)	Signif.	Trend(+)	Trend(-)	Signif.	Trend(+)	Trend(-)	Signif.	Trend(+)	Trend(-)	Signif.
Addis A.		0.01	0.7985		0.135	0.0824	0.007		0.9716		0.302	0.1621
Bahirdar		0.113	0.1925		0.019	0.8567		0.139	0.7319	0.000	0.000	0.999
Bedele	0.065		0.4652		0.147	0.4472	0.088		0.6588		0.839	0.1535
Chagni		0.036	0.6654	0.087		0.4921	0.177		0.6737	0.001		0.9992
D/Birhan	0.124		0.1889	0.187		0.1958		0.550	0.1505	0.311		0.4693
D/ Marikos	0.061		0.2985	0.257		0.0385		0.217	0.4554	0.653		0.0643
Fiche	0.067		0.4133	0.024		0.885		0.281	0.4566		0.073	0.8331
Gonder	0.057		0.6162	0.187		0.3059		0.232	0.4849	0.374		0.3818
Mehalmeda		0.179	0.2446		0.246	0.2323		0.717	0.0466		0.355	0.5277
Nedjo	0.158		0.0954		0.127	0.5449	0.203		0.6897	0.132		0.7693
Nekemete	0.084		0.2007		0.121	0.4409	0.270		0.1740	0.653		0.1439
Wereta	0.056		0.6815	0.063		0.7891		0.070	0.8689		0.452	0.5220

005Prcp –Number of days precipitation >= 95^{th} %
606R10 - Number of days with precipitation >= 10mm/day
641CDD -Maximum Number of consecutive dry days (Rday< 1mm)
644R5D - The greatest 5-day rainfall total

Table 5.1: Continued …..

Stations	646SDII (mm/day)			695R95T (%)		
	Trend(+)	Trend(-)	Signif.	Trend(+)	Trend(-)	Signif.
Addis A.	0.006		0.4884	0.048		0.542
Bahirdar		0.028	0.3689	0.017		0.9198
Bedele		0.031	0.2003	0.071		0.4583
Chagni		0.031	0.3676		0.215	0.2036
D/Birhan	0.002		0.9281	0.161		0.3084
D/Marikos	0.018		0.1436	0.104		0.2812
Fiche		0.044	0.1213		0.061	0.7012
Gonder	0.034		0.3085	0.244		0.1518
Mehalmeda		0.144	0.0009		0.204	0.2235
Nedjo		0.019	0.359		0.162	0.2107
Nekemete		0.004	0.8309		0.014	0.8745
Wereta		0.007	0.8344	0.091		0.6748

646SDII -Simple Daily intensity Index
695R95T- Fraction of Annual Total Rainfall due to Events Above the 95th Percentile

5.2 Discussion on Precipitation Indices

The main objective of this study was to evaluate the variability of extreme metrological events in Blue Nile river basin. Analysis of Software generated indices is the main methodology for this specific study.

The number of days with precipitation greater than or equal to 10mm (606R10) index shows a positive trend for six stations out of which one station (Debremarikos) is significant at 95% level of confidence and negative trend for the same number of stations. This indicator shows balanced variability regarding number of stations.

The maximum number of consecutive dry days (641CDD) index, an indicator of drought, shows a positive trend for five stations and a negative trend for seven stations out of which Mehalmeda is significant one at 95% level of confidence. This indicator shows there is an indication of decreasing in the number of consecutive dry days means, according to literatures, the number of wet days who have rainfall amount greater than or equal to 1mm are increasing.

The greatest 5 day rainfall total (644R5d), an indicator of flood producing events, shows positive trend for six stations, no change for one station (Bahirdar), and negative trend for the other five stations. Generally it shows no considerable change in the basin.

Simple Daily intensity index (646SDII) is defined as the mean daily intensity for events greater than or equal to 1mm per day. This index show positive trends in four stations and negative trends in eight stations .This result reflects there is variability, decreasing trend, among stations in daily rainfall intensity index in the basin. The decrease in this index reflects an increase in the number of rain days rather than a decrease in rainfall (Hennessy et al. 1999).This idea also supported by the decreasing trend for the consecutive number of dry day.

The fraction of annual total precipitation from events wetter than the 95th percentile for the whole record (**695R95T**) shows that increasing trend for seven stations and a decreasing trend for five stations. The 95th percentile is the average of the 95th percentiles calculated for each year. Therefore this is the average rank event. But for the purposes of this study to calculate the next index, the upper threshold value has been chosen the 95thpercentile of the whole data set not averaged. The **695R95T** index examines the contribution to total precipitation of a given station with high value events. A year with more events above the threshold will almost always show a larger proportion of the total rainfall from these events. Generally the result indicates there is a slight increase in the occurrence of higher value precipitation events in the basin.

The number of days precipitation is greater than or equal to the 95thpercentile of the whole data set of each station (**005prcp**) showed positive trend for eight stations and negative trends for five stations. Both rainfall indices that are a measure of upper extremes variability showed similar trend analysis results.

Generally the rainfall indices did not show a significant variability when we evaluate the results. However indices like 646SDII simple daily intensity indicated the increase of wet days (days having rainfall amount >= 1mm).This result is supported by the decreasing trend of consecutive dry days in the river basin. The increasing trend for number of days having precipitation greater than 95th percentile of the data set, upper extremes, in the river basin indicates that there is a tendency of existence for flash flood due to presence of more extreme events. However most of the results are not supported by significant out puts in 95% level of confidence. Mean while the results are not dependent on the agro-climatic zone of the stations analyzed.

5.3 Results of Temperature Indices

Those generated maximum and minimum temperature indices are tabulated with their respective trend out puts. Sampled Graphical out puts are presented to show how line fitting trend looks like. The tabulated result shows stations having increment trend value under positive trend column and station having decrement trend value under negative trend column. The significance level under 95% level of confidence of each value is indicated under the significance column.

The tabulated result tells an increase/decrease of trend value (as per the unit indicated) per year incase of ClimeDex analysis result and per decade incase of annual historical data analysis. For example there is 0.562 days increment per year at Bahirdar station regarding minimum temperature index 003TnGE.

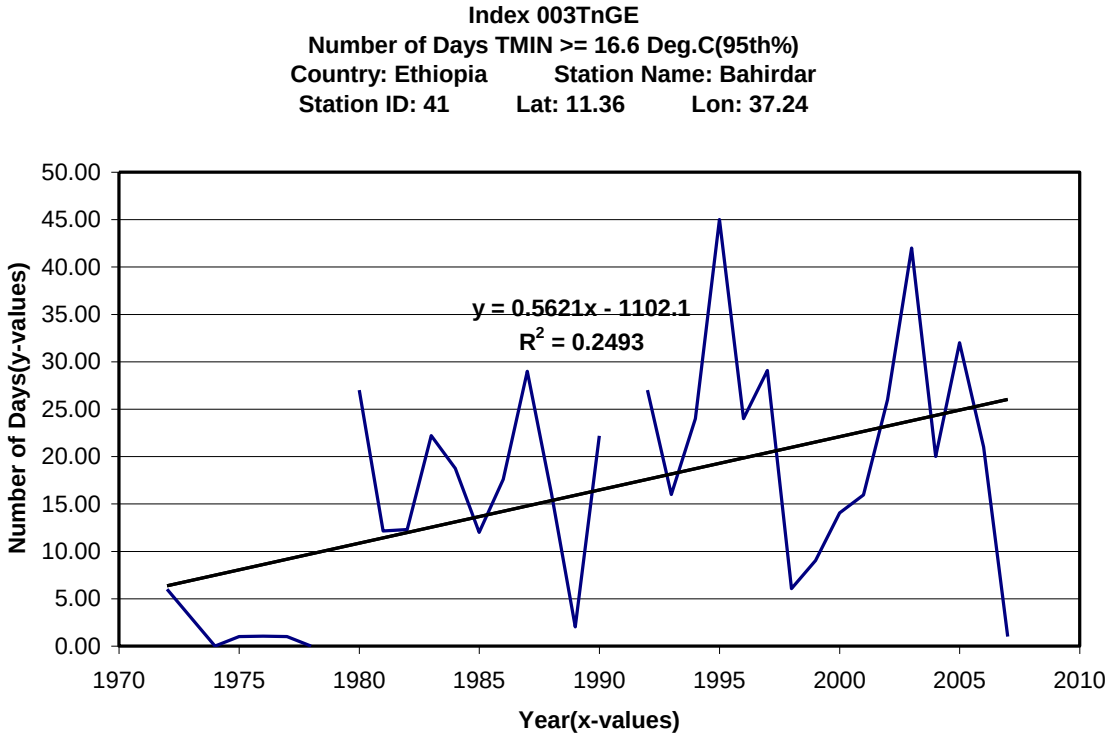

Fig 5.2: Shows trend line of single Minimum Temperature index for Bahirdar station

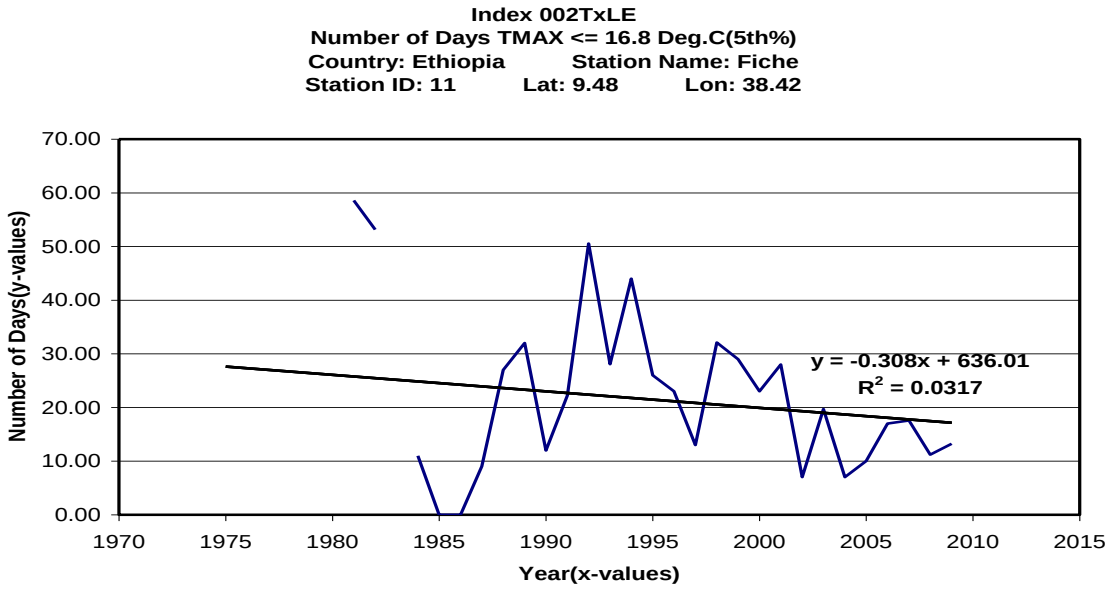

Fig 5.3: Shows trend line of single Maximum Temperature index for Fiche station

Table 5.2: Tempreture indices and their trend values of each station

Stations	003T_nGE(No. of Days)			004T_nLE(No. of Days)			001T_XGE(No. of Days)			002T_XLE(No. of Days)		
	Trend(+)	Trend(-)	Signif.	Trend(+)	Trend(-)	Signif.	Trend(+)	Trend(-)	Signif.	Trend(+)	Trend(-)	Signif.
Bahirdar	0.562		0.0022		1.636	0.0002	0.080		0.8036		0.437	0.0380
Bedele	0.179		0.5760		2.271	0.0001		0.004	0.9895		0.208	0.2160
Chagni	0.716		0.0002		0.027	0.9264	0.676		0.0372		0.840	0.0014
D/Birhan	0.679		0.0450		0.894	0.0822	0.598		0.0342	0.023		0.9340
D/Marikos	0.782		0.0004		1.005	0.0002		0.309	0.1889		0.155	0.3696
Fiche	0.497		0.0013		0.612	0.0153		0.106	0.7554		0.280	0.289
Gonder	0.279		0.0985		0.489	0.1285	0.533		0.0276		0.149	0.4016
Mehalmeda		0.348	0.3683	0.266		0.4135	0.897		0.0001		0.376	0.2124
Nedjo		0.907	0.0001	1.867		0.0000	0.637		0.0042		0.486	0.0015
Nekemete	0.606		0.0026		1.355	0.0141	0.349		0.2251		0.597	0.0006
Wereta	0.821		0.0539		0.658	0.2711	1.304		0.0005		0.875	0.0293

Stations	141ERT(days)		
	Trend(+)	Trend(-)	Signif.
Bahirdar		0.089	0.0321
Bedele		0.109	0.0454
Chagni	0.052		0.0715
D/Birhan	0.074		0.1879
D/Marikos		0.034	0.2632
Fiche		0.03	0.3917
Gonder		0.003	0.9041
Mehalmeda	0.152		0.0167
Nedjo	0.221		0.0000
Nekemete		0.019	0.4096
Wereta		0.070	0.3350

001T_XGE- Number of days Tmax >= (95^{th} percentile)
002T_XLE –Number of days Tmax <= (5^{th} percentile)
003T_nGE-Number of days Tmin >= (95^{th} percentile)
004T_nLE- Number of days Tmin <= (5^{th} percentile)
141ERT – Intra-Annual Extreme Temperature Range

5.4 Discussion on Temperature Indices

Those generated maximum and minimum temperature indices are discussed in this section.

Intra-Annual Extreme Temperature range (141ERT) index an indicator for the gap between the highest and the lowest temperatures of a given year showed increasing trend in four stations out of which Mehalmeda &Nedjo are significant and negative trend in seven stations with significant trend value of Bedele and Bahirdar stations. This index indicates how the gap between the annual maximum and minimum temperatures of a station varies. Negative trend implies there is a decrease in the gap of annual maximum and minimum temperatures means approaching each other. Consequently tells that though variability exists, not in the same scale for maximum and minimum temperatures.

Number of days maximum temperature greater than or equal to 95^{th} percentile of the data ($001T_xGE$) showed a positive trend in eight stations out of which six of them are significant in 95% level of confidence and a negative trend in three stations. This index indicates there is a clear increase in number of days that records maximum temperature value greater than the 95^{th} percentile of the station data set. This variability clearly shows the warming effect in the basin.

Number of days maximum temperature less than or equal to the 5^{th} percentile ($002T_xLE$) showed a positive trend in one station and a negative trends in ten stations out of which five of them are significant in 95% level of significance. This result indicates that there is an increase in number days having maximum temperature record values greater than the 5^{th} percentile .This variability again indicates there is an increase of warm days in the basin.

Number of days minimum temperature greater than or equal to 95^{th} percentile ($003T_nGE$) showed a positive trend in nine stations of the basin out of which six of them are significant and negative trend only in two station. This indicates the record of maximums

of minimum temperature values is increasing from the 1970's to the first decade of the 21st century in the Blue Nile river basin.

Number of days minimum temperature less than 5th percentile ($004T_nLE$) showed a positive trend in two stations and negative trend in nine stations out of which five of them are significant in the same level of significance. This indicates that the minimums of the minimum temperature records are increasing in the study area.

The variability in temperature extremes have been occurred for all trend analysis methodologies in a similar way. The whole investigation period was characterized by a strong increase of $001T_xGE$, and $003T_nGE$ indices accompanied by almost a complete decrease of $002T_xLE$ and $004T_nLE$. Overall, the maximum and minimum temperature extremes showed consistent trend magnitudes variability than precipitation related indices. This is quite the same conclusion with the one made during the African region climate change detection work shop held in Morocco.

The findings of this research work clearly justifies that there is variability in both maximum and minimum temperatures. Therefore it contributes considerable share to make clear the ambiguity of existence of variability of extreme temperature events in Blue Nile river basin. This variability is characterized by warming effect of the basin.

5.5 Historical Annual Data Analysis Result

The historical annual data have been arranged and used to draw a chart for trend analysis. A linear trend line is fitted and the results are tabulated. The positive and negative trends represent increment and decrement of annual values respectively that are calculated on decadal basis to show the changes in a cumulative way.

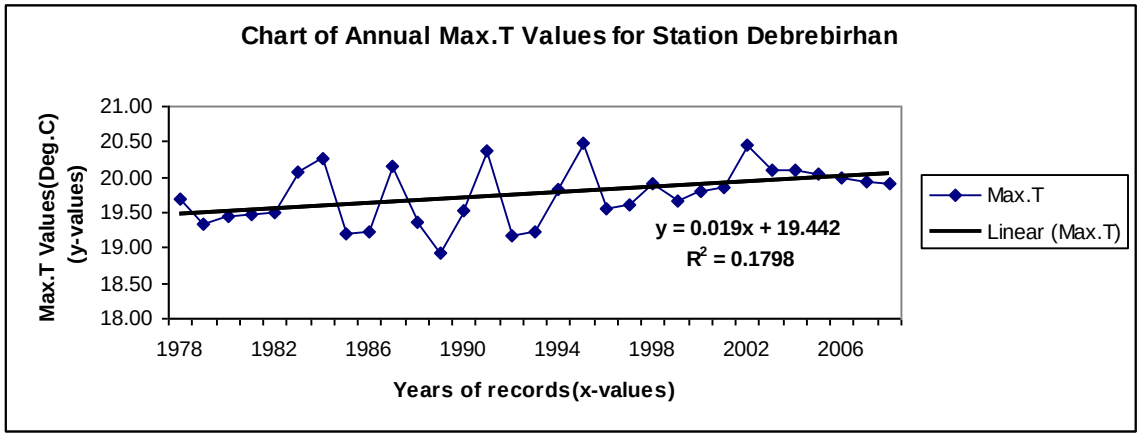

Fig 5.4: Historical annual Max.Temperature data series and trend fitting for Debre birhan Station

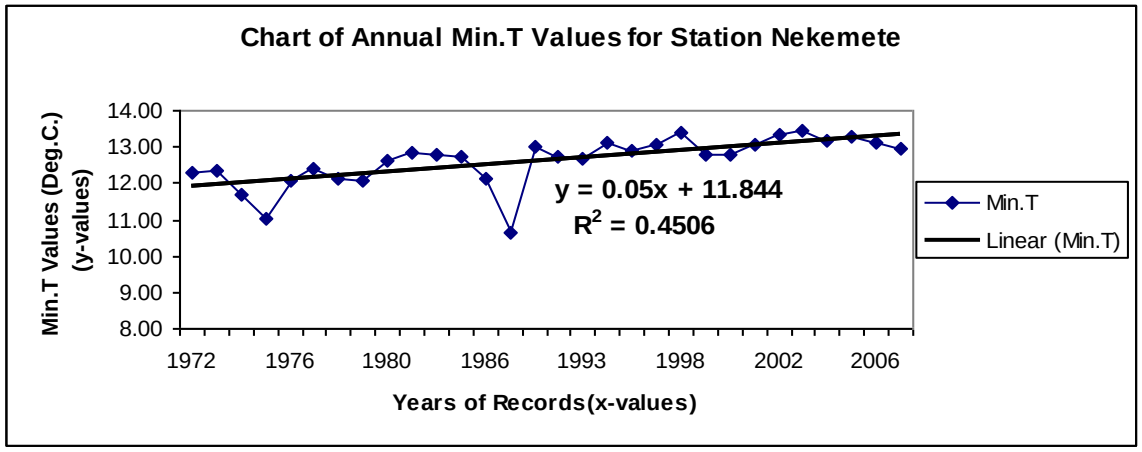

Fig 5.5: Historical annual Min.Temperature data series and trend fitting for Nekemte Station

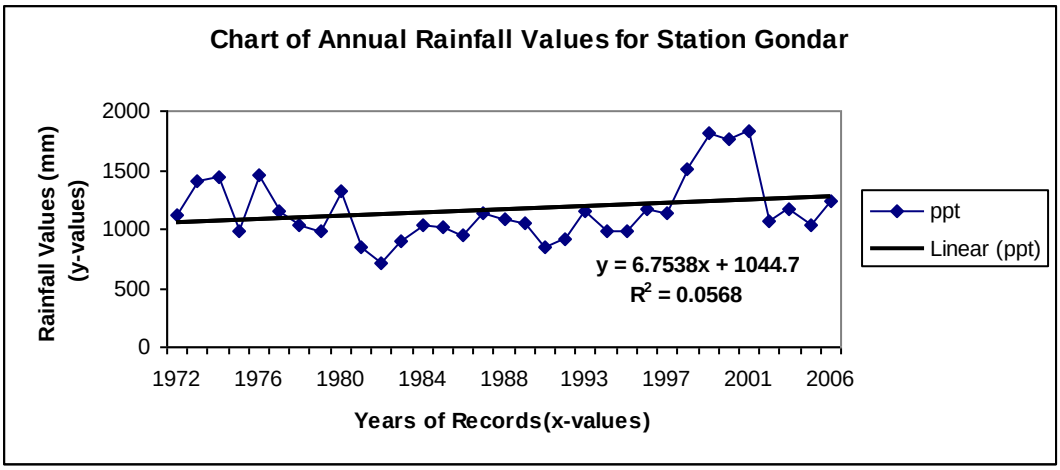

Fig 5.6: Historical Annual Rainfall Data series and trend fitting for Gonder Station

Table 5.3: Annual Historical Data Trend Analysis Result

Stations	Rainfall(mm) Trend Value/Decade		Max.T(Deg.C) Trend Value/Decade		Min.T(Deg.C) Trend Value/Decade		Remark
	(+)	(-)	(+)	(-)	(+)	(-)	
Addis Ababa		10.8					
Bahirdar		34	0.2		1.01		
Bedele	16		0.02		0.61		
Chagni		3.6	0.54		0.33		
D/Birhan	55.7		0.19		0.13		
D/Marikos	42.7		0.14		0.46		
Fiche	8.1			0.09	0.37		
Gondar	67		0.26		0.27		
Mehalmeda		41.3		0.05	0.07		
Nedjo		37.9	0.17			1.2	
Nekemete		4		0.42	0.5		
Wereta	86		0.31		0.91		
Total No of Stations	6	6	8	3	10	1	

Finally GIS mapping tools used to show the net variability of each event with in the stations. Those stations showed a positive trend (increase) have given red color and for

those negative (decrease) trends a blue colored circles have been utilized. The size of the circle represents the magnitude of the trend value means the greater the size the bigger the magnitude of the trend value.

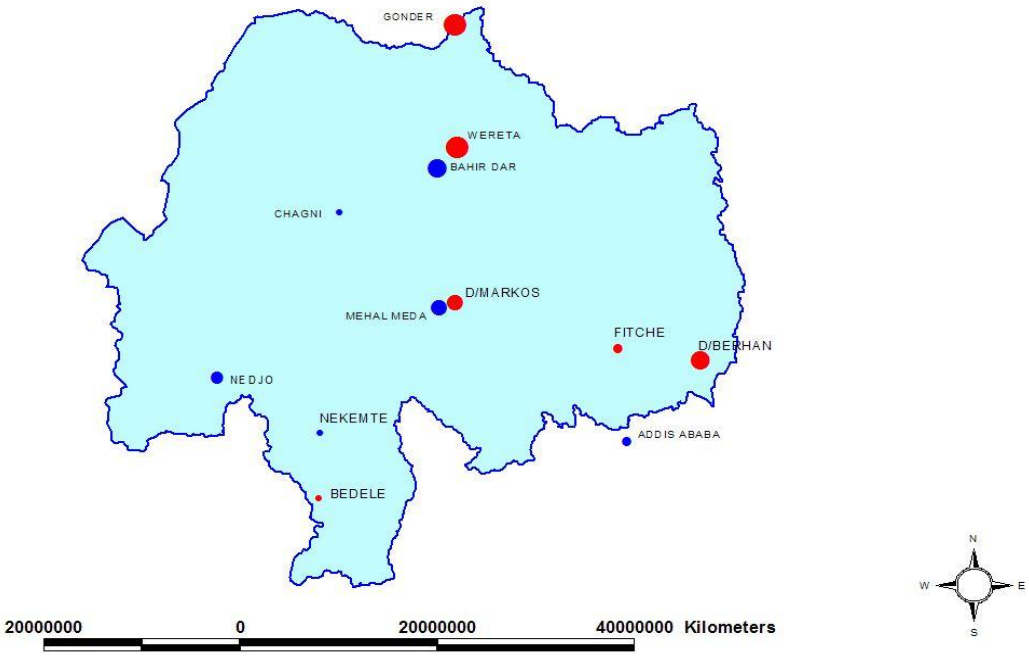

Fig. 5.7 Rainfall variability among stations in the study area

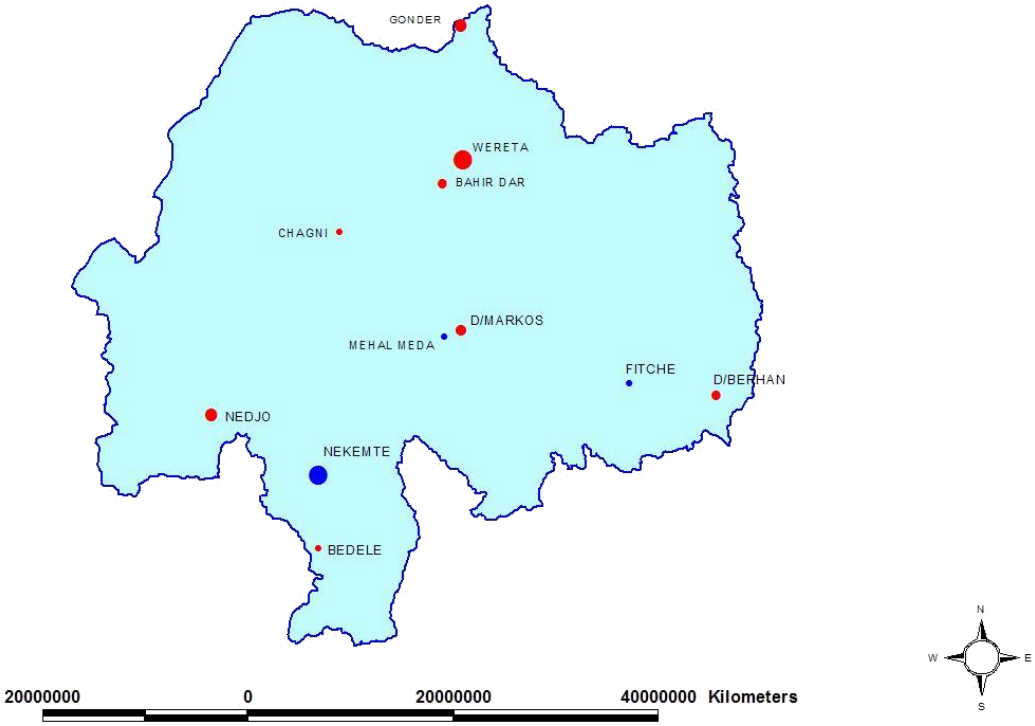

Fig. 5.8: Maximum Temperature variability among stations in the study area

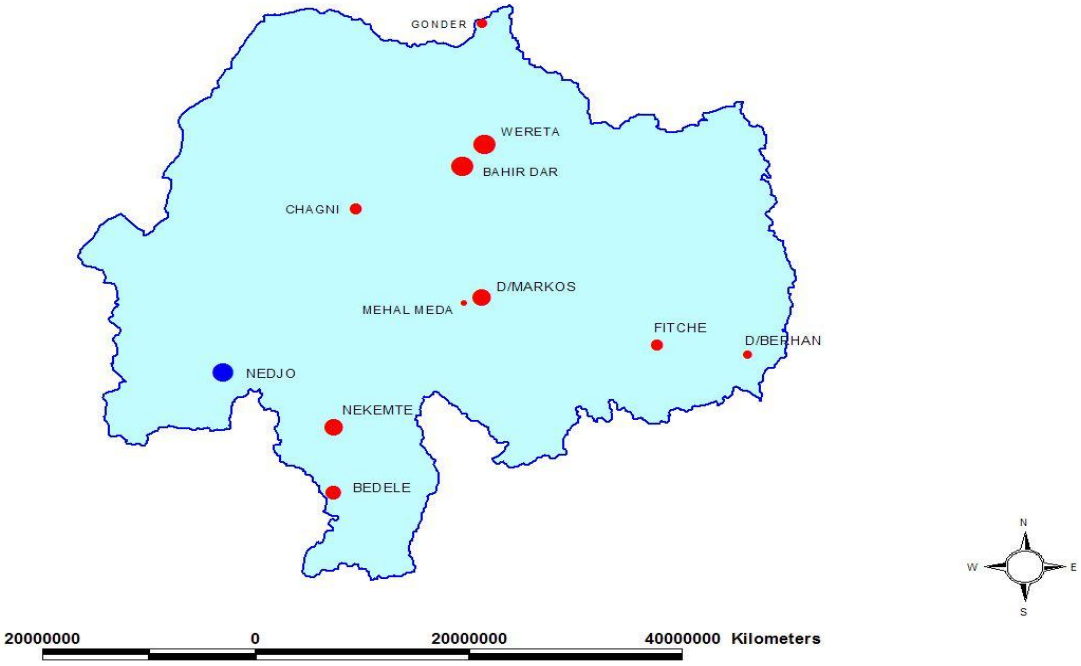

Fig. 5.9: Minimum Temperature variability among stations in the study area

5.6 Discussion of Annual Data Trend Analysis Results

The results and findings of this work are discussed and interpreted below.

From that of historical data trend analysis, half of the analyzed precipitation stations showed a positive trend or increment in annual rainfall amount that Wereta scored the highest value of 86mm/Decade and the other half showed a negative trend among which Mehalmeda scored the higher magnitude 41.3mm/Decade.

The linear trend analyses of annual data from eleven stations in the basin for both maximum and minimum temperatures are utilized for this specific research. Eight stations for maximum temperatures showed increasing trend for the whole historical data set. The values of increments may vary in each stations but it can be seen that there is maximum temperature increase in the Blue Nile river basin.

Consequently, regarding minimum temperature historical data trend analysis except nedjo station all of the rest are on the increasing track.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

This study was carried out to evaluate the variability of extreme metrological events in upper Blue Nile river basin. Indices developed from daily data of precipitation, maximum temperature and minimum temperature are the main tools for analysis.

From precipitation indices:

- 58% of the stations showed a decrease in the number of continuous dry days that inter indicates there is an increase of wet days
- There is slight variability in the greatest 5 day rainfall total and Simple intensity index
- From the combined results of indices **695R95T** and **005Prcp** there is a moderate chance for the occurrence of variability in extreme rainfall events in the basin
- From historical annual data linear trend analysis result, 50% of the stations indicated an increase of annual rainfall and the other 50% showed a decrease of rainfall amount.

From temperatures indices:

- 63% of the stations showed a decrease in inter-annual temperature range (the difference between the highest maximum temperature record of any given calendar year and the lowest minimum temperature record of the same year). This indicates there is variability in extreme events of both minimum and maximum temperatures.
- Again from the above and historical data analysis results, it can be concluded that the change is decreasing due to the fact that the absolute trend magnitude of minimum temperature (**Index 004T_nLE**) is higher than the absolute trend magnitude of maximum temperature (**Index 001T_xGE**). This means the variability of minimum temperature is more incremental than maximum temperature. Consequently this indicates minimum temperature is more likely sensitive to climate change.

- 73% of the stations showed an increase in the number of days having maximum temperature record value of greater than or equal to 95^{th} percentile (upper threshold selected for this study). This indicates there is variability in the upper extremes of maximum temperature events in the basin and warming up of the basin due to effects of climate change.
- 90% of the stations showed a decrease in the number of days whose maximum temperature record values are less than or equal to the lower threshold (5^{th} percentile for this specific study).This indicates there is great variability in the lower extremes of maximum temperature records and warming up of the basin due to climate change.
- 81 % of stations showed an increase in the number of days having minimum temperature record values greater than or equal to 95^{th} percentile of the data set (upper threshold for this study). There is variability in the upper extremes of minimum temperature records and again warming up of the basin due to climate change.
- In the same fashion 81% of stations indicated that there is a decrease in the number of days whose minimum temperature record value is less than the 5^{th} percentile of data. This variability in the lower extremes of minimum temperature records in the basin shows the warming effect of the basin.
- From statistical data analysis tools used in this research work, it can be conclude that there is incredible increase in both maximum and minimum temperatures in the basin. These results strongly tally with and strengthen the findings from developed indices.

Generally it can be concluded that the variability of maximum and minimum temperatures is on the basis of many significant trend values unlike rainfall having only three significant trend values in 95% level of confidence. The result obtained is not dependent on the agro-climatic zones of the stations in the basin.

Nevertheless, the presented results need to be considered with some *limitations* due to data inhomogeneities and missing of data. Hence, with the information available it is not

possible to draw any accurate conclusions to what extent inhomogeneities and missing values affected the trends in the investigated extreme indices. Moreover, there is a need for more and longer daily observational records to allow a better spatial analysis covering the whole basin.

6.2 Recommendations

- For better findings best quality and long years of daily data plays an important role, there fore the data record system should be given more attention in a national level.
- Most of the selected indices seem to be very relevant for temperature and give a regional overview of climate change. However the precipitation indices shows less consistency in detecting variability and studies in different approach may therefore need to address more precisely.

- There should be a systematic incorporation of engineering design criteria for civil engineering structures and operating rules of existing dams and reservoirs under conditions of climate change & extreme events Variability.

- There is a significant body of international law addressing transboundary water problems, but very little law addressing climate change-related activities that affect water quality, quantity, or distribution. Ultimately, this will be of importance for Ethiopia as blue Nile river basin is shared watersheds lead to local and regional political disputes. If conflict is to be avoided, new and effective legal instruments addressing climate change-related activities will have to be developed and implemented in Nile river basin as a whole.

- Researches on climate change detection should be done in various approaches in collaboration with world wide concerned bodies.

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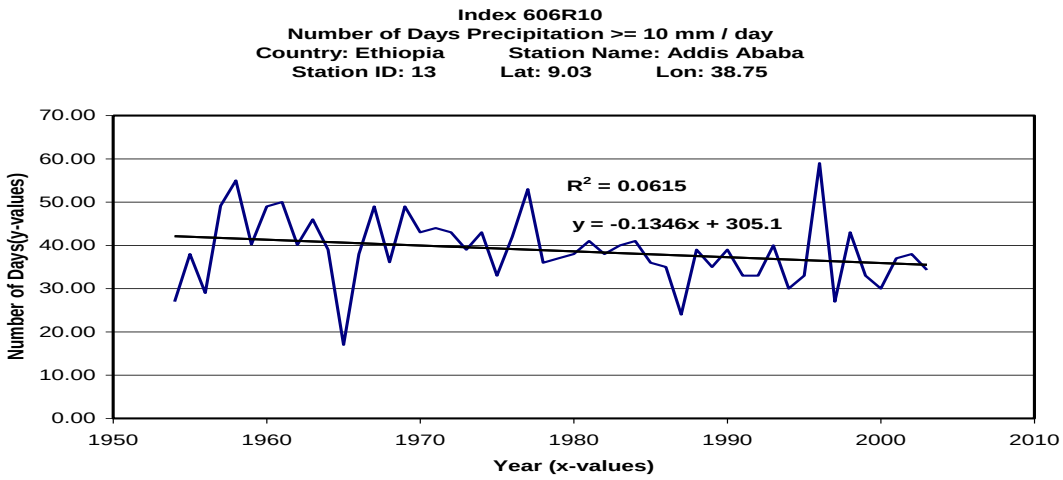
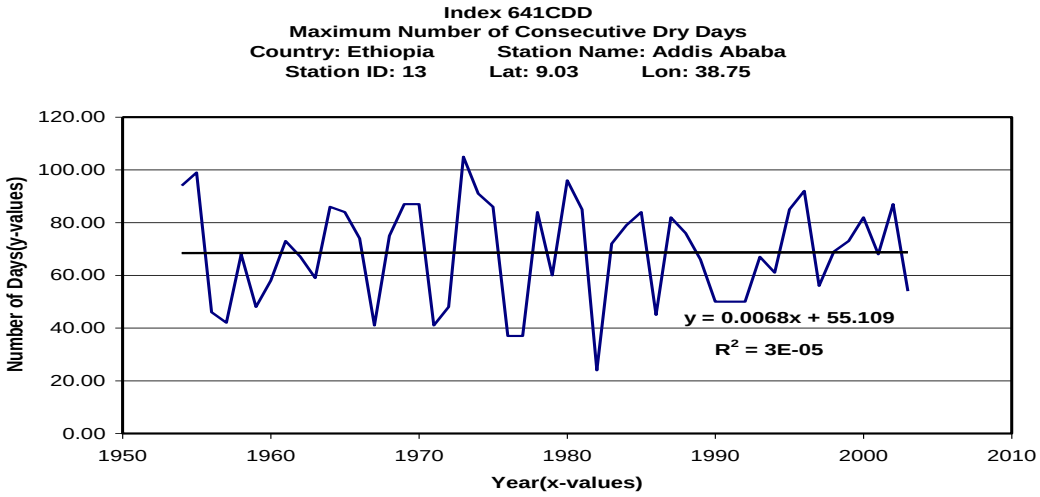
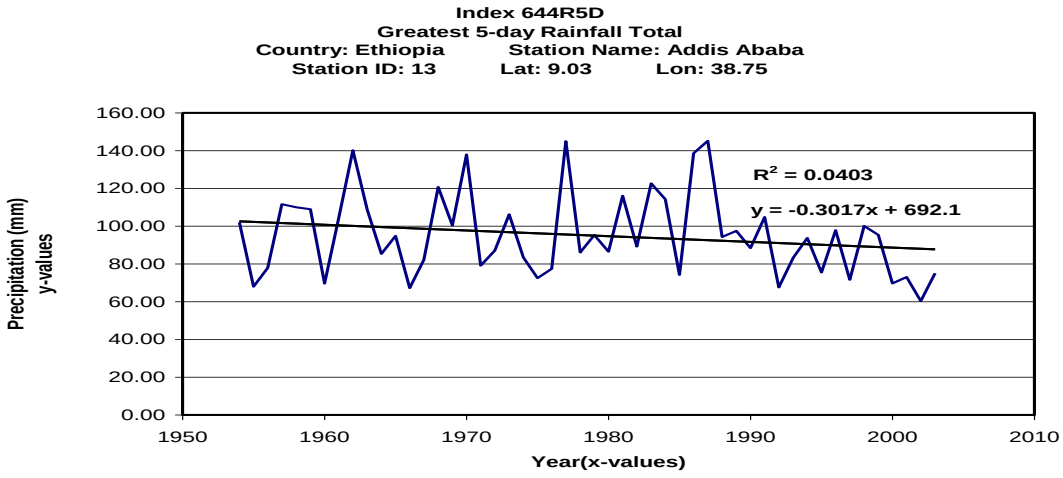
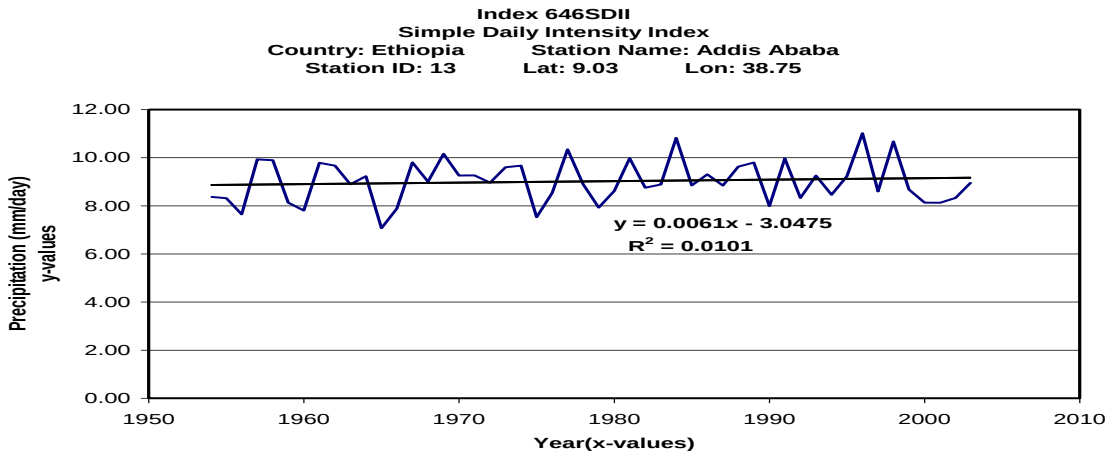
APPENDICES

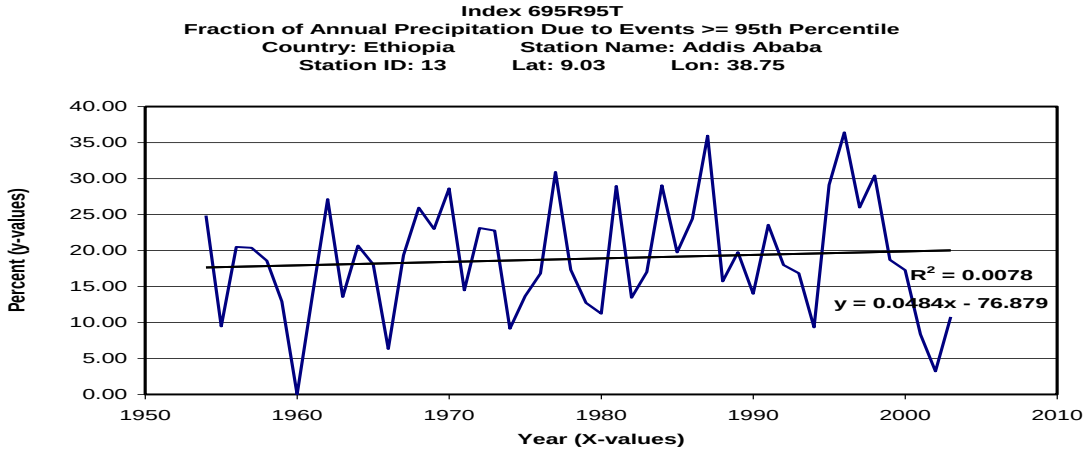
APPENDIX A: GRAPHICAL RESULTS OF PRECIPITATION INDICES

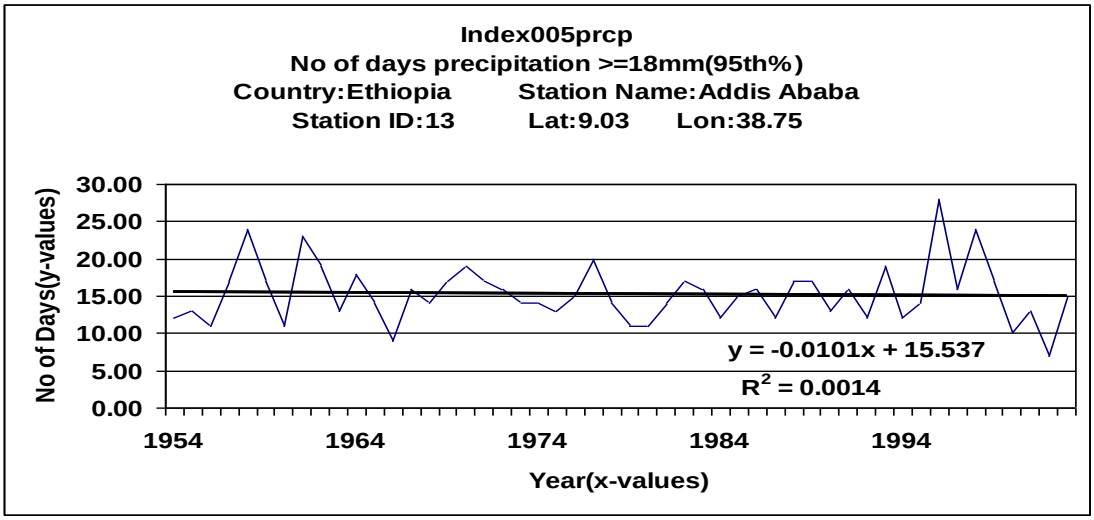

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Addis Ababa
Station ID: 13 Lat: 9.03 Lon: 38.75
R² = 0.0615
y = -0.1346x + 305.1
Number of Days(y-values)
Year (x-values)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1950
1960
1970
1980
1990
2000
2010

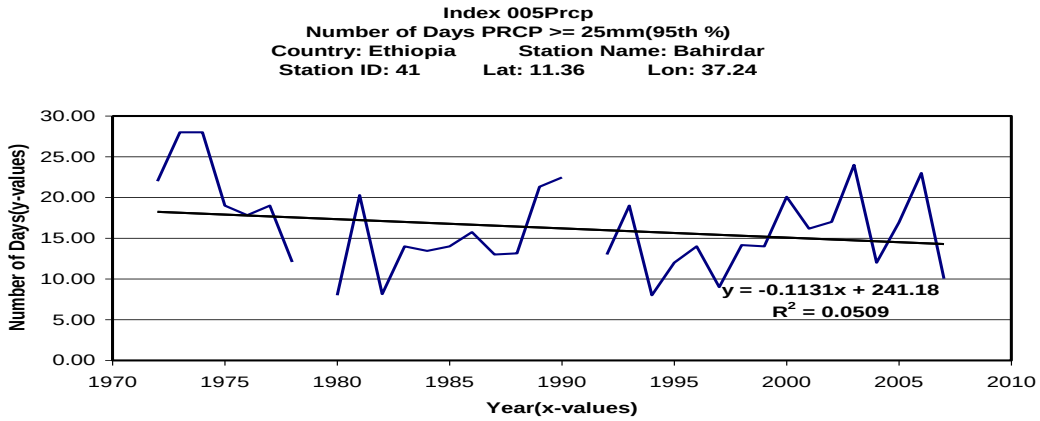

Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Addis Ababa
Station ID: 13 Lat: 9.03 Lon: 38.75
y = 0.0068x + 55.109
R² = 3E-05
Number of Days(y-values)
Year(x-values)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1950
1960
1970
1980
1990
2000
2010

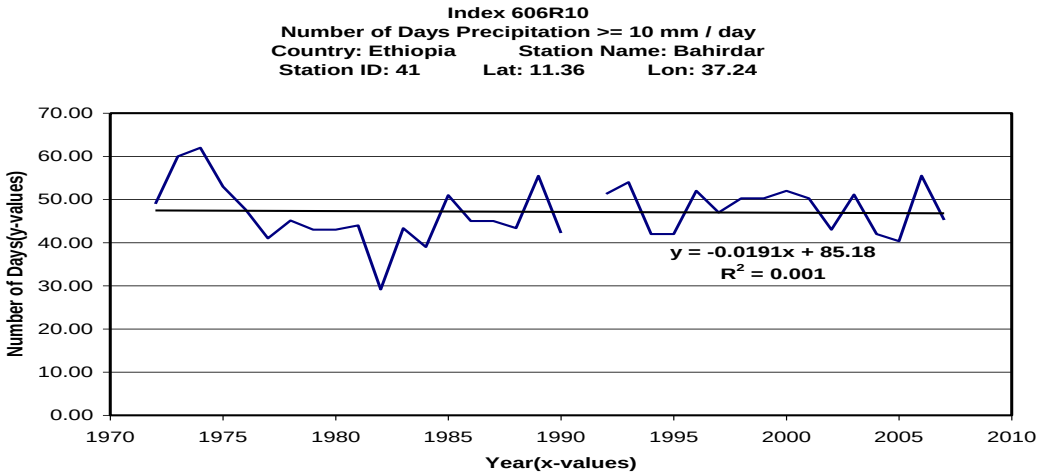

Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Addis Ababa
Station ID: 13 Lat: 9.03 Lon: 38.75
R² = 0.0403
y = -0.3017x + 692.1
Precipitation (mm)
y-values
Year(x-values)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1950
1960
1970
1980
1990
2000
2010

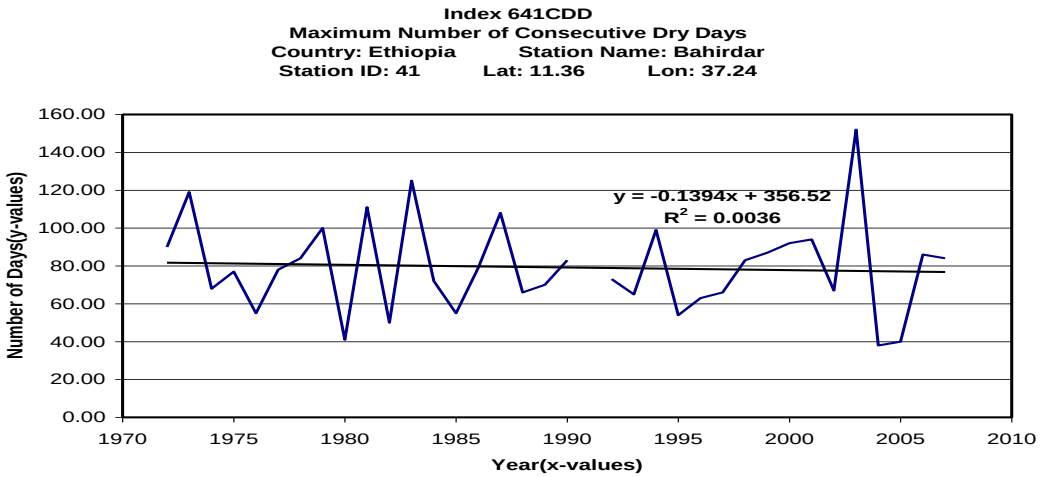

Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Addis Ababa
Station ID: 13 Lat: 9.03 Lon: 38.75
Precipitation (mm/day)
y-values
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1950
1960
1970
1980
1990
2000
2010
y = 0.0061x - 3.0475
R² = 0.0101
Year(x-values)


Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Addis Ababa
Station ID: 13 Lat: 9.03 Lon: 38.75
Percent (y-values)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1950
1960
1970
1980
1990
2000
2010
R² = 0.0078
y = 0.0484x - 76.879
Year (X-values)

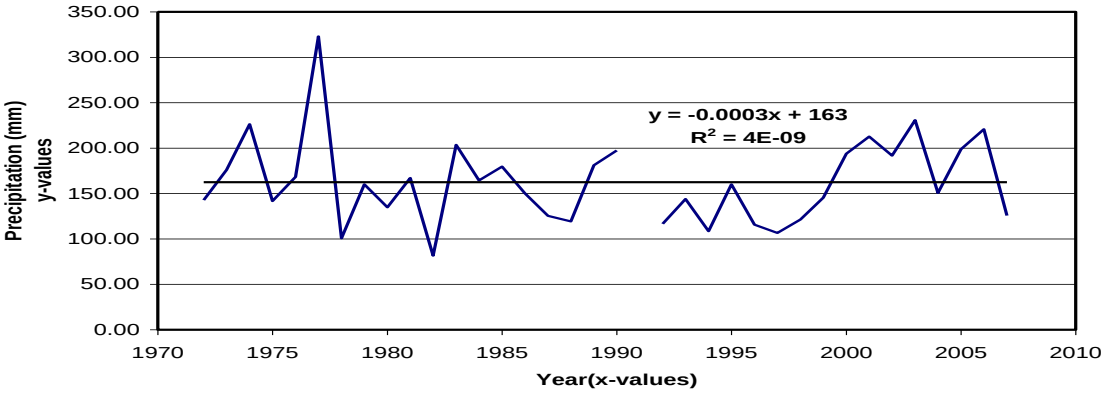

Index005prcp
No of days precipitation >=18mm(95th%)
Country:Ethiopia Station Name:Addis Ababa
Station ID:13 Lat:9.03 Lon:38.75
No of Days(y-values)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1954
1964
1974
1984
1994
y = -0.0101x + 15.537
R² = 0.0014
Year(x-values)


Index 005Prcp
Number of Days PRCP >= 25mm(95th %)
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24
Number of Days(y-values)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = -0.1131x + 241.18
R2 = 0.0509

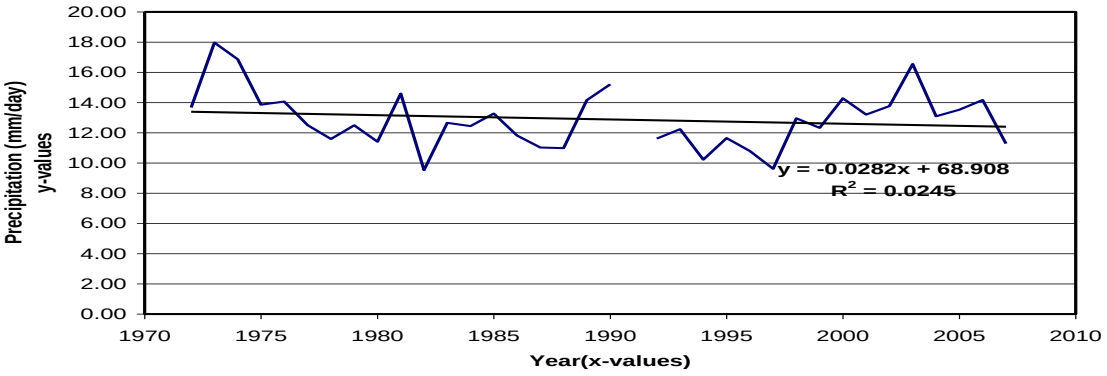

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24
Number of Days(y-values)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = -0.0191x + 85.18
R2 = 0.001


Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24
Number of Days(y-values)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = -0.1394x + 356.52
R2 = 0.0036

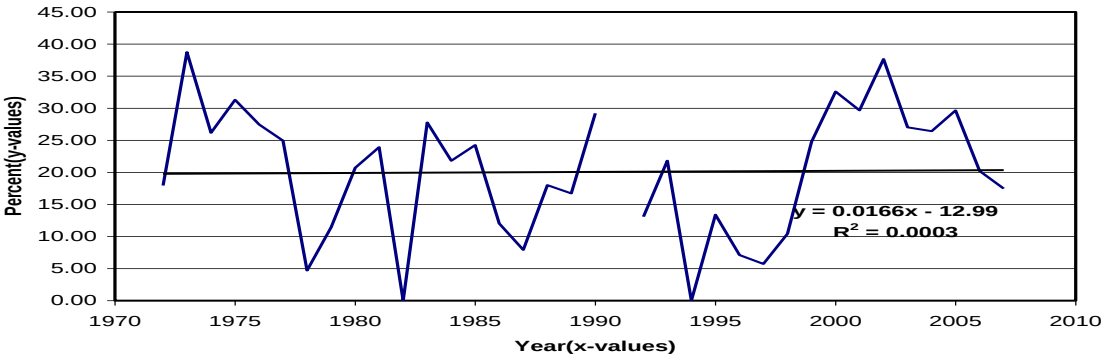
Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24

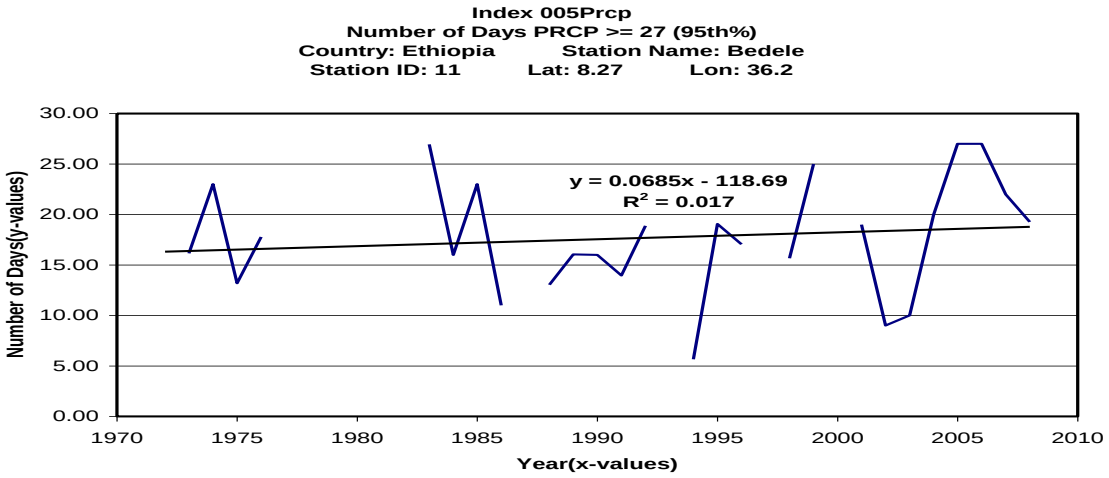


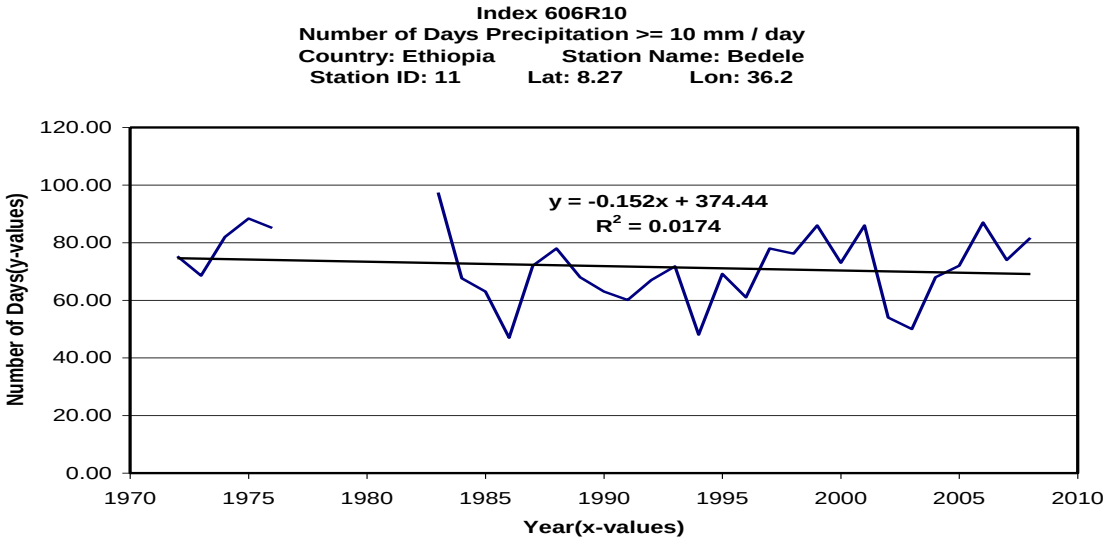
Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24

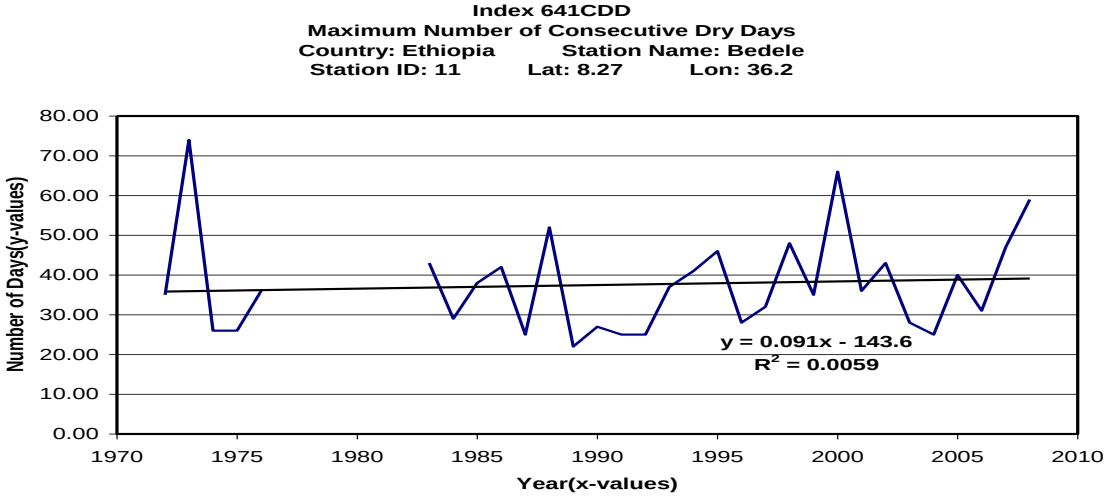


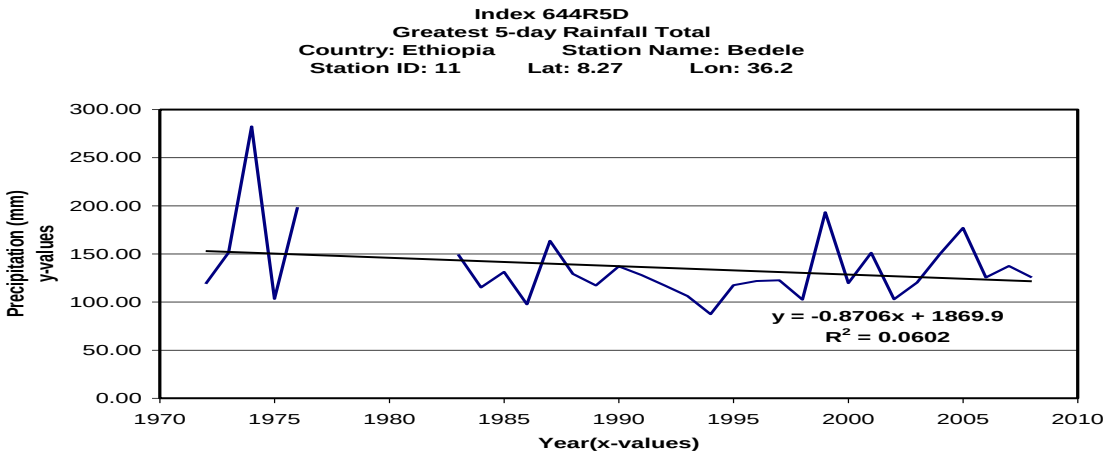
Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24

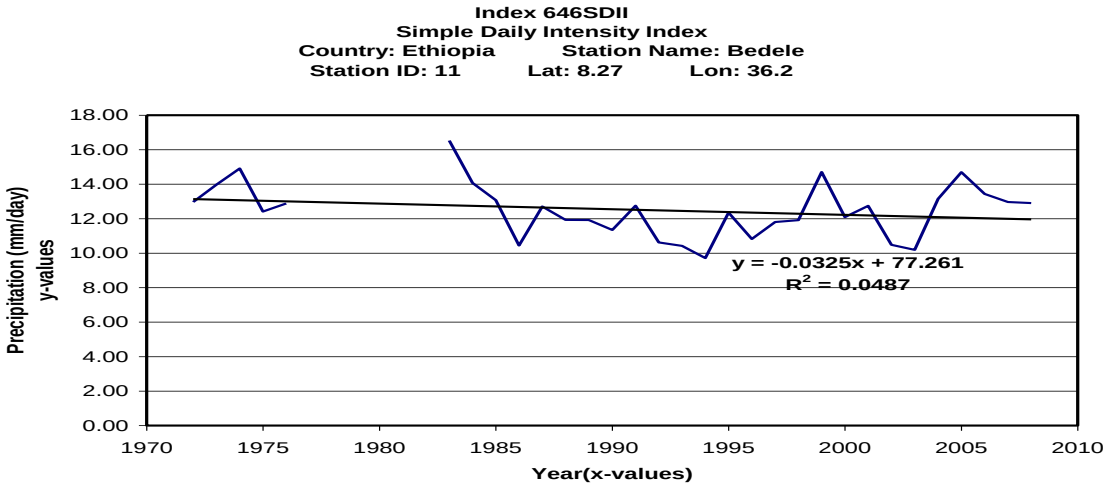


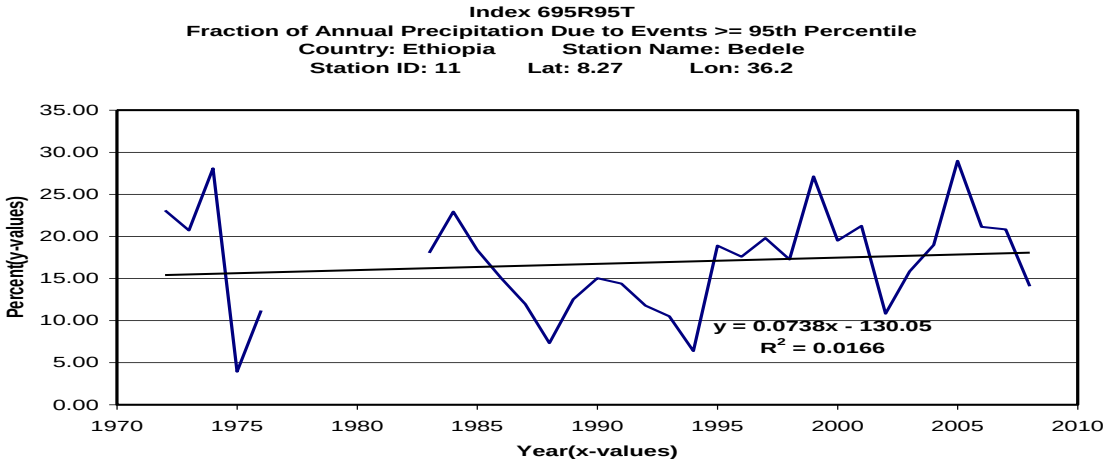

Index 005Prcp
Number of Days PRCP >= 27 (95th%)
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2
y = 0.0685x - 118.69
R² = 0.017
Number of Days(y-values)
Year(x-values)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010

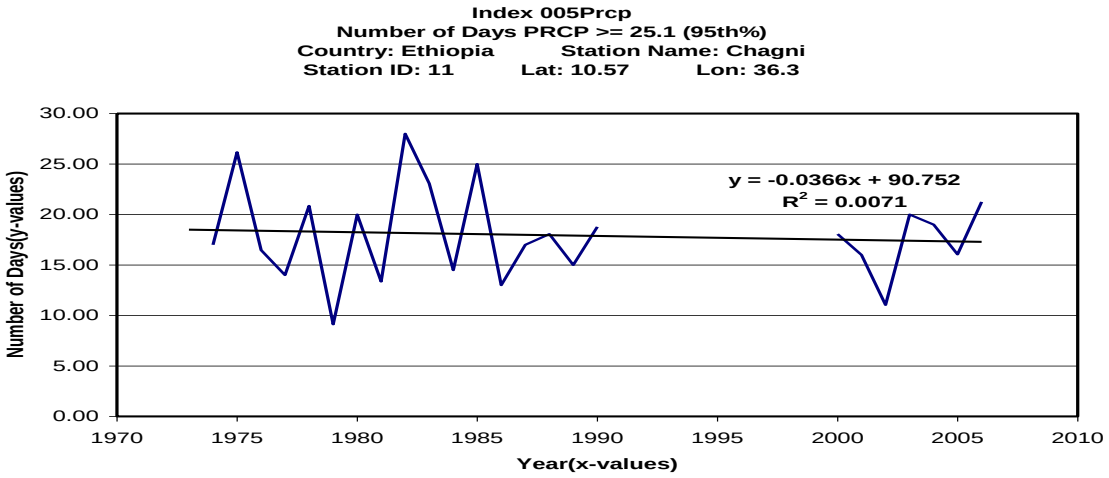

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2
y = -0.152x + 374.44
R² = 0.0174
Number of Days(y-values)
Year(x-values)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010

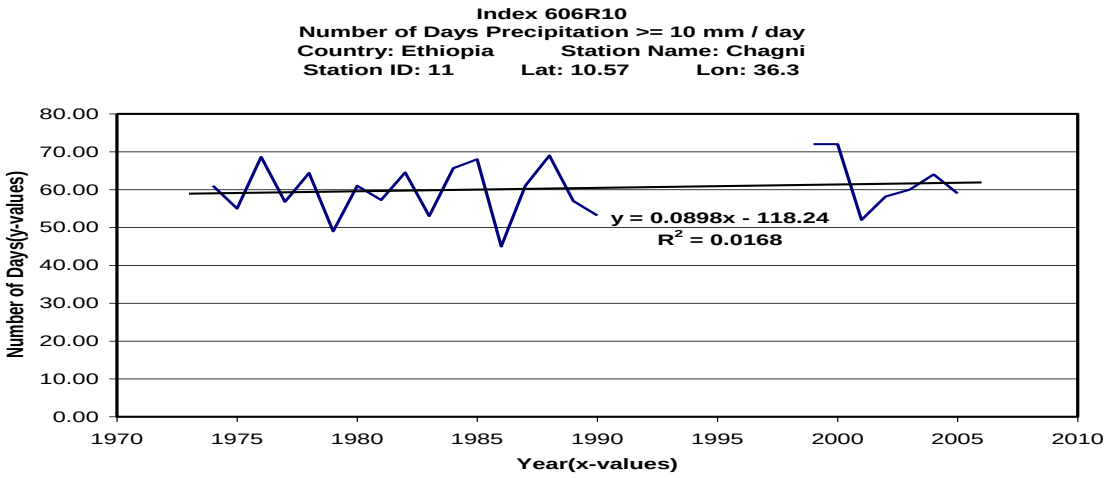

Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2
y = 0.091x - 143.6
R² = 0.0059
Number of Days(y-values)
Year(x-values)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010

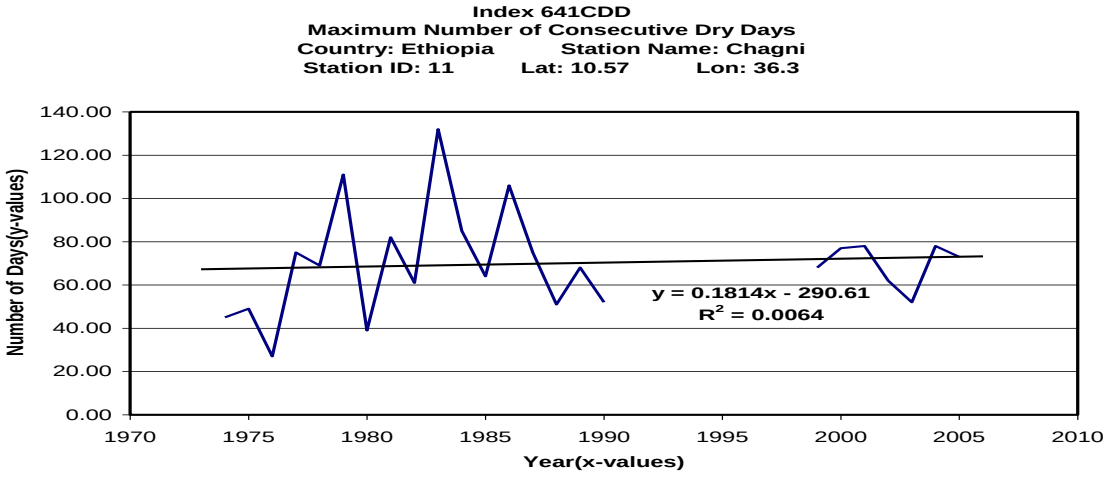

Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2
Precipitation (mm)
y-values
300.00
250.00
200.00
150.00
100.00
50.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = -0.8706x + 1869.9
R² = 0.0602


Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2
Precipitation (mm/day)
y-values
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = -0.0325x + 77.261
R² = 0.0487

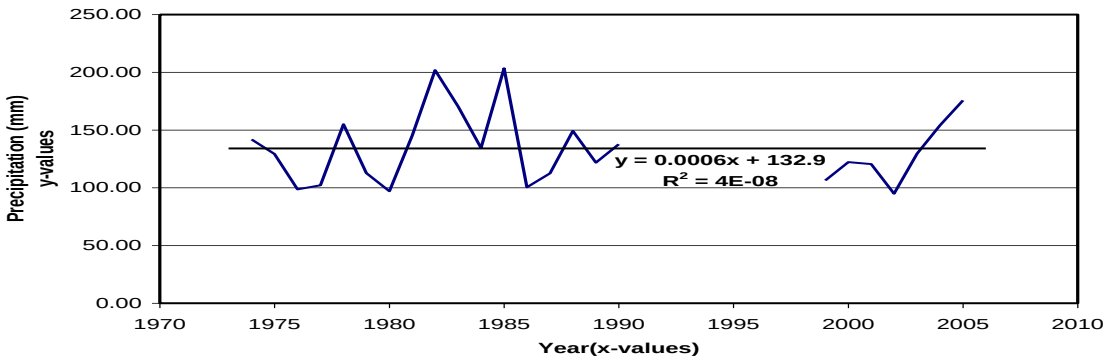

Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2
Percent(y-values)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = 0.0738x - 130.05
R² = 0.0166


Index 005Prcp
Number of Days PRCP >= 25.1 (95th%)
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3
y = -0.0366x + 90.752
R2 = 0.0071
Number of Days(y-values)
Year(x-values)

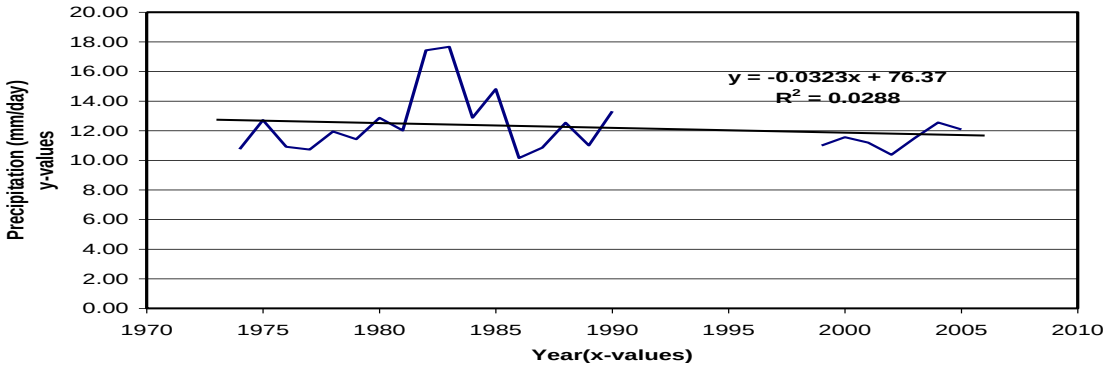

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3
y = 0.0898x - 118.24
R2 = 0.0168
Number of Days(y-values)
Year(x-values)


Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3
y = 0.1814x - 290.61
R2 = 0.0064
Number of Days(y-values)
Year(x-values)

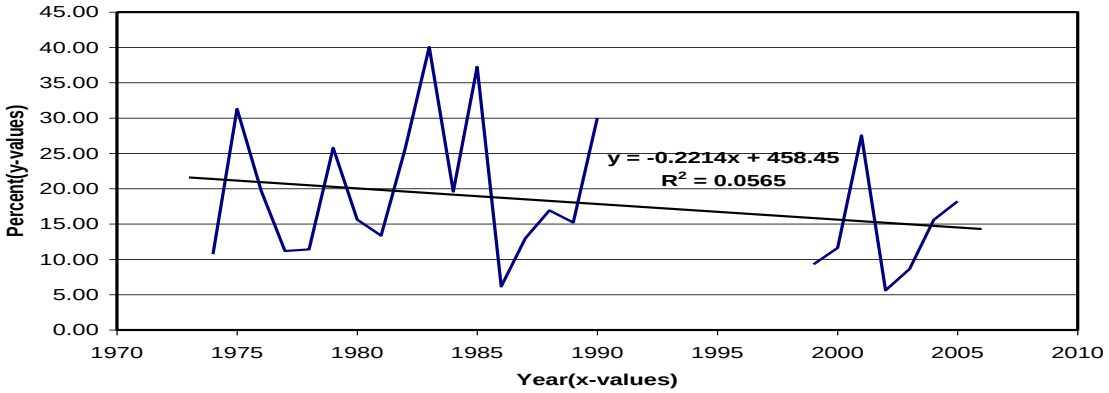
Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3



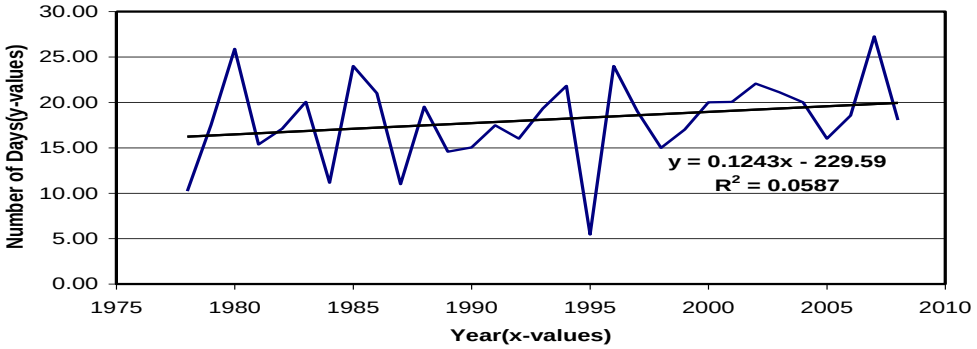
Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3



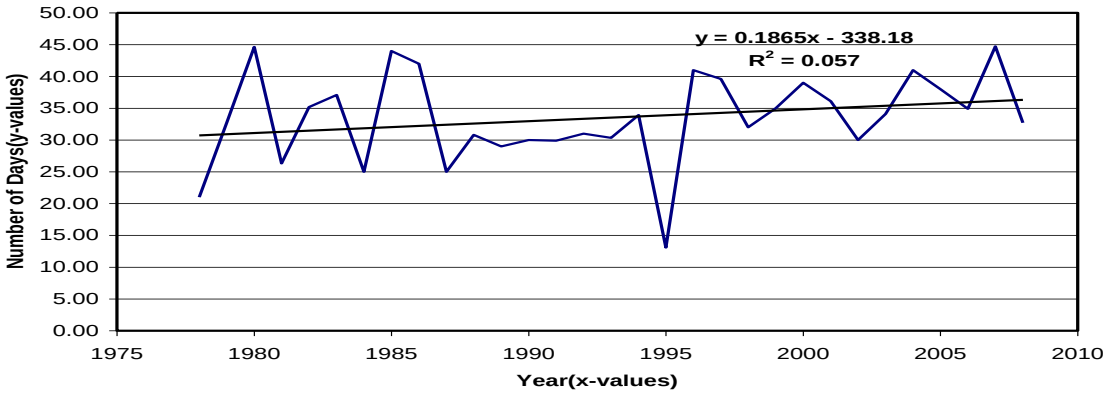
Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3



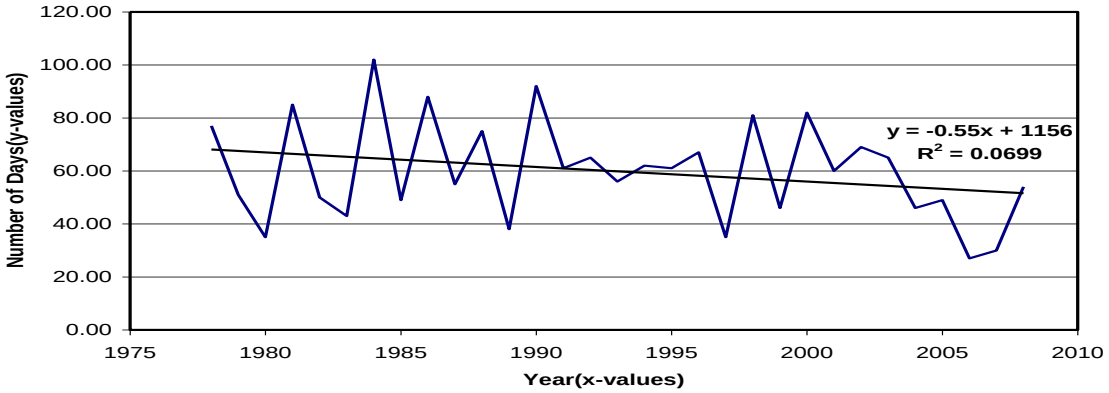
Index 005Prcp
Number of Days PRCP >= 16mm(95th%)
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3

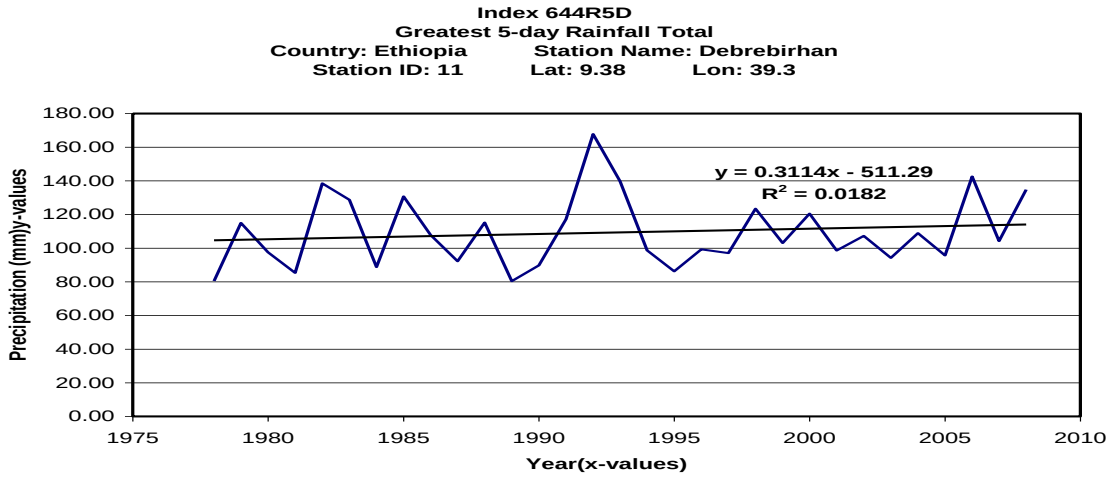


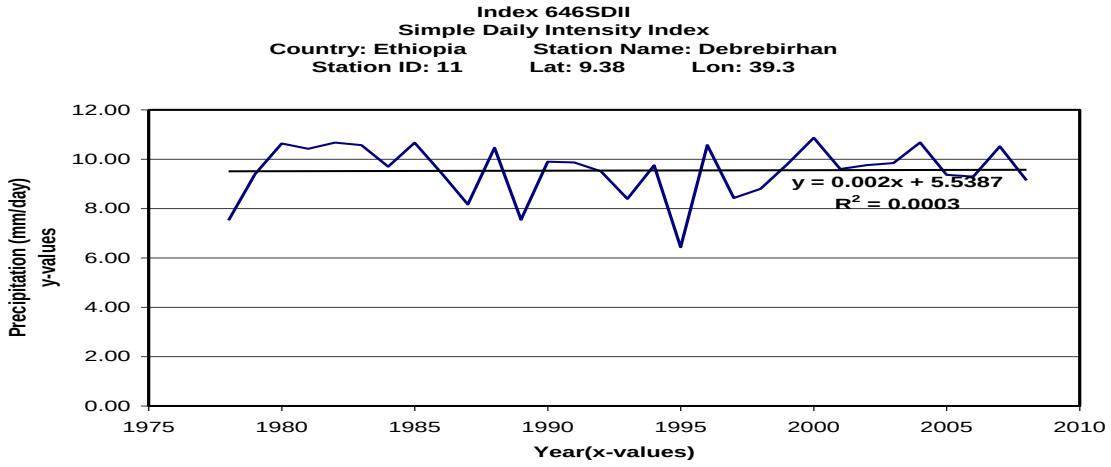
Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3

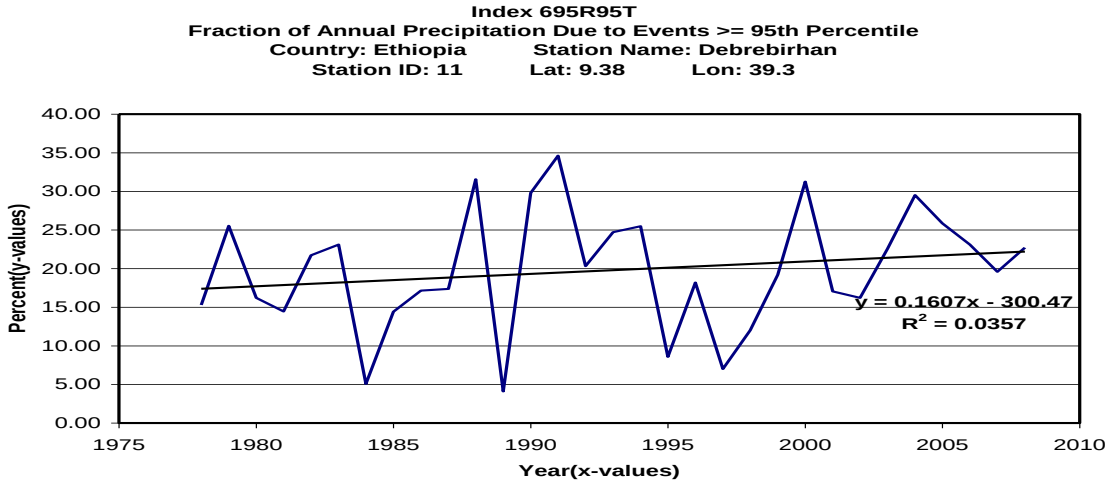


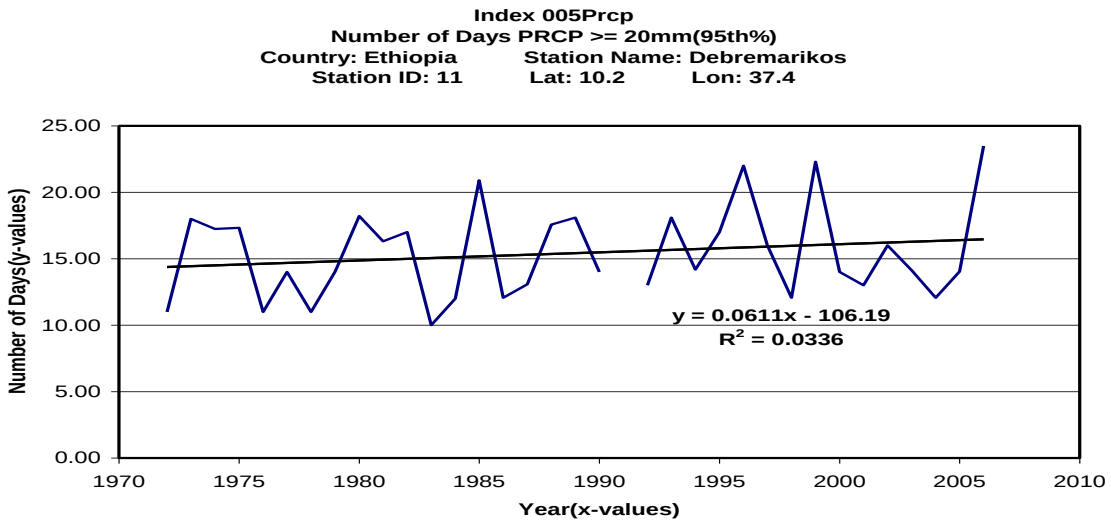
Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3

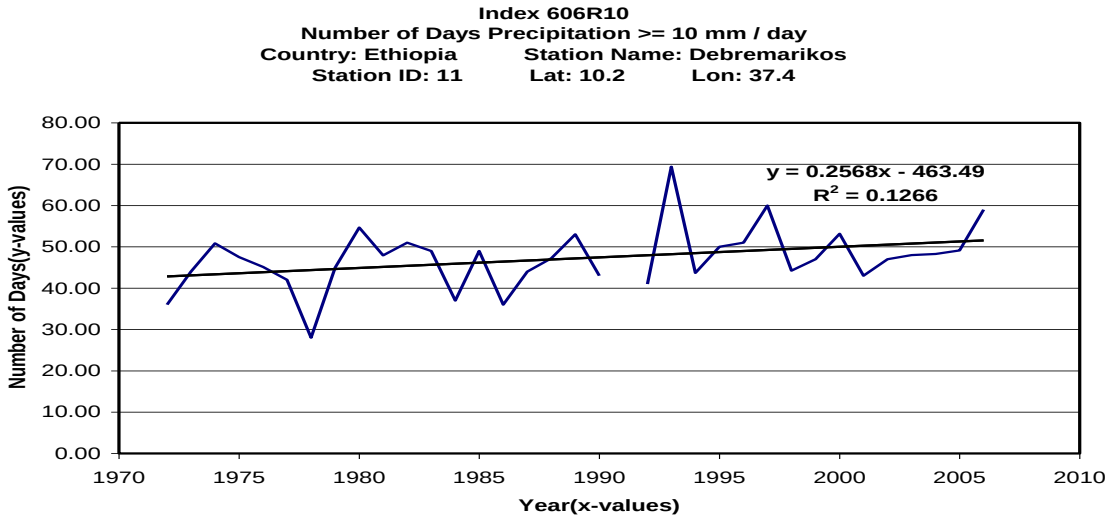


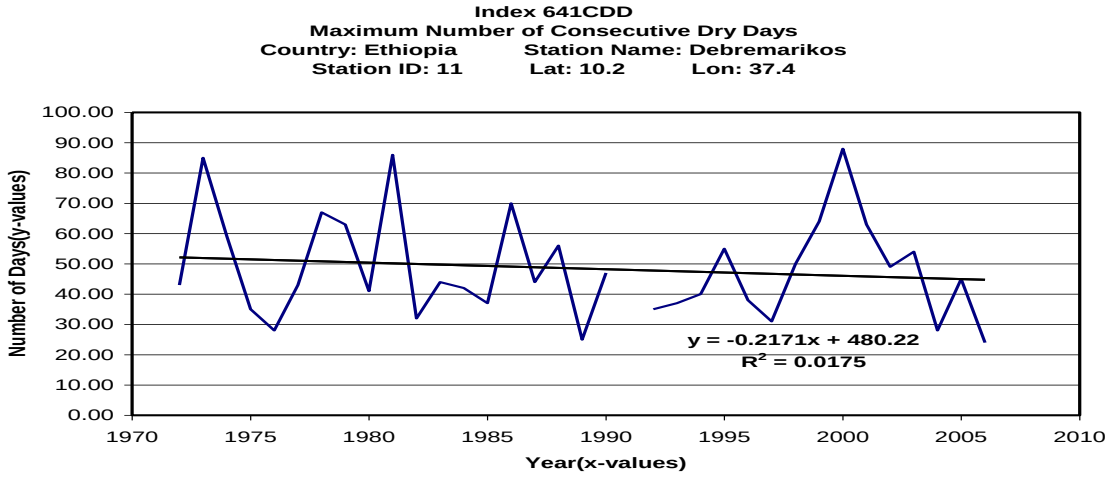

Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3
Precipitation (mm)y-values
y = 0.3114x - 511.29
R² = 0.0182
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)

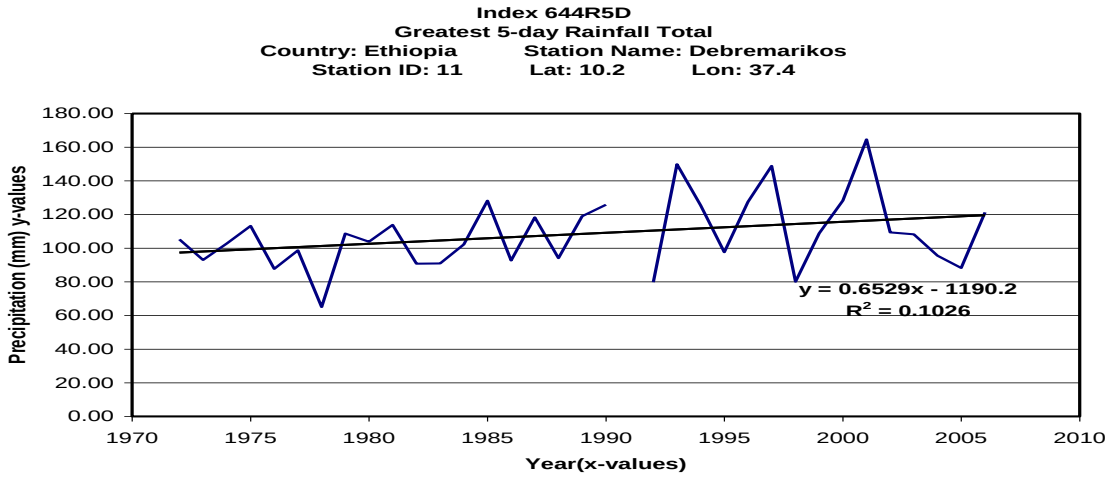

Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3
Precipitation (mm/day)
y-values
y = 0.002x + 5.5387
R² = 0.0003
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)

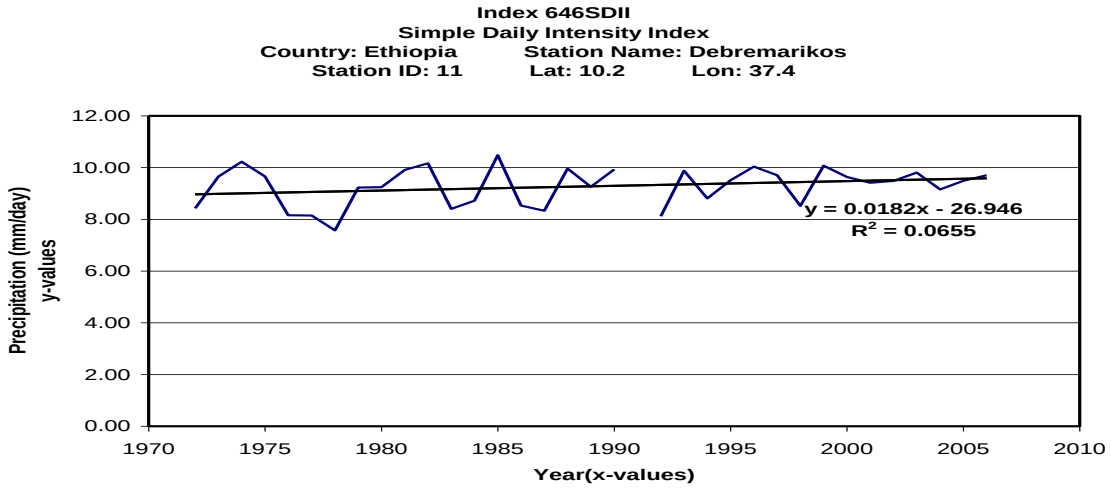

Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3
Percent(y-values)
y = 0.1607x - 300.47
R² = 0.0357
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)

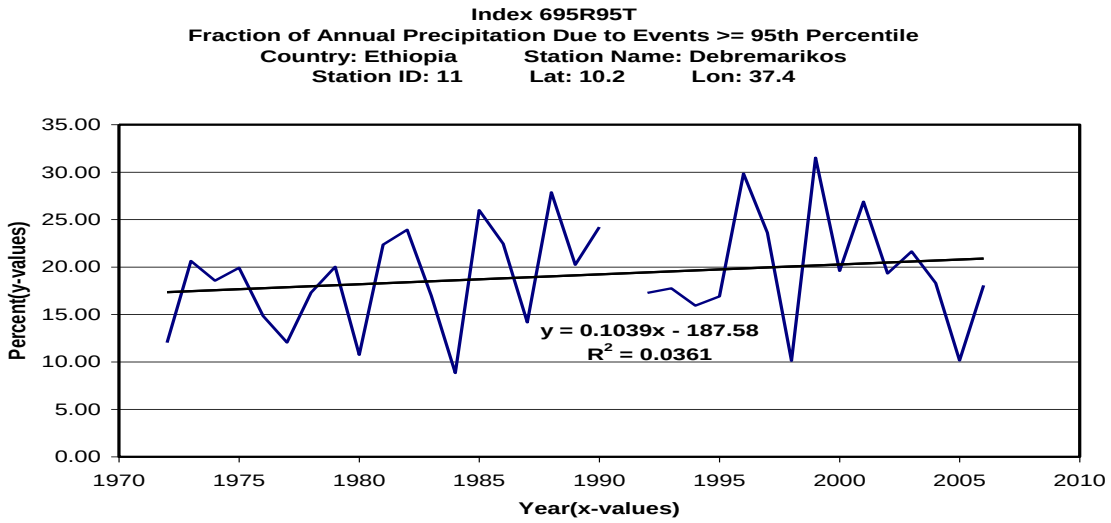

Index 005Prcp
Number of Days PRCP >= 20mm(95th%)
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4
Number of Days(y-values)
Year(x-values)
y = 0.0611x - 106.19
R2 = 0.0336

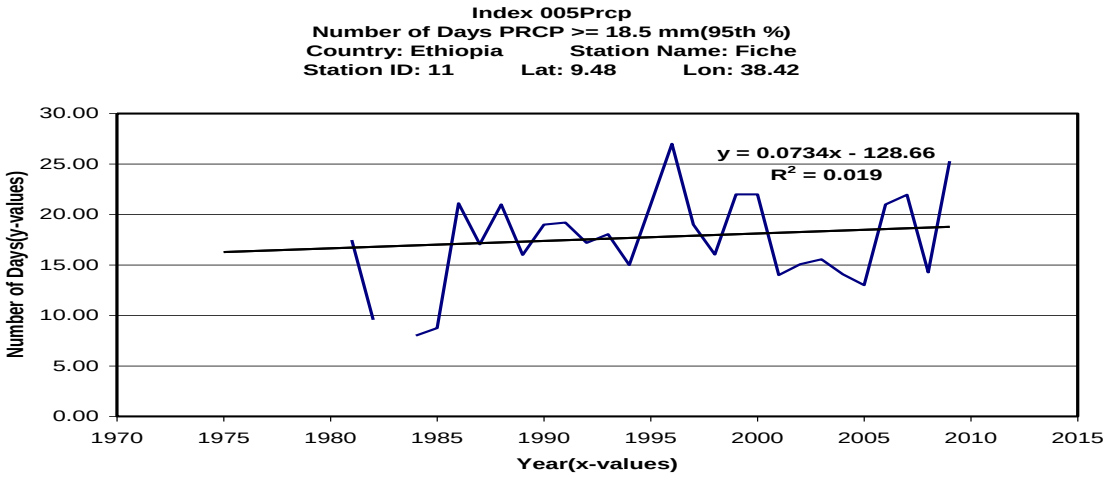

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4
Number of Days(y-values)
Year(x-values)
y = 0.2568x - 463.49
R2 = 0.1266

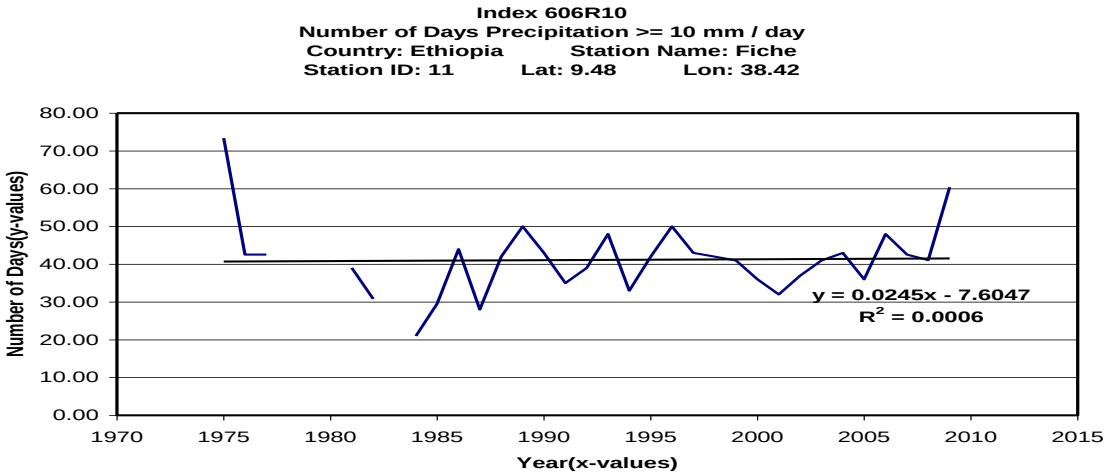

Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4
Number of Days(y-values)
Year(x-values)
y = -0.2171x + 480.22
R2 = 0.0175

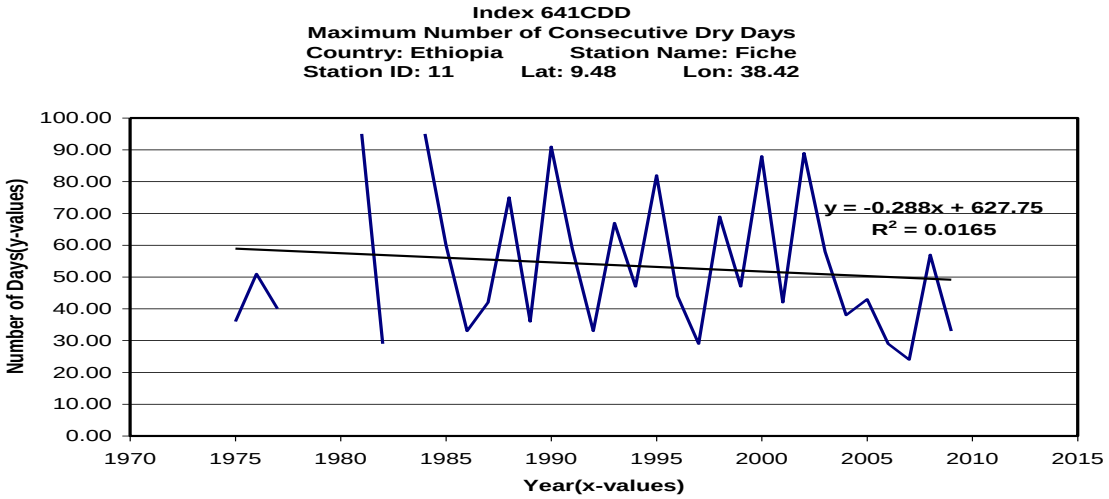

Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4
Precipitation (mm) y-values
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = 0.6529x - 1190.2
R² = 0.1026


Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4
Precipitation (mm/day)
y-values
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = 0.0182x - 26.946
R² = 0.0655

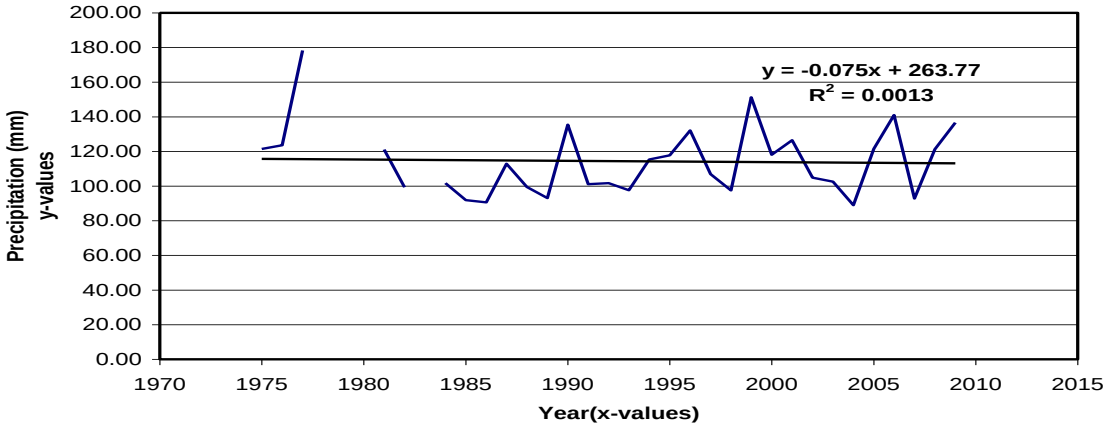

Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4
Percent(y-values)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = 0.1039x - 187.58
R² = 0.0361


Index 005Prcp
Number of Days PRCP >= 18.5 mm(95th %)
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42
y = 0.0734x - 128.66
R² = 0.019
Number of Days(y-values)
Year(x-values)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

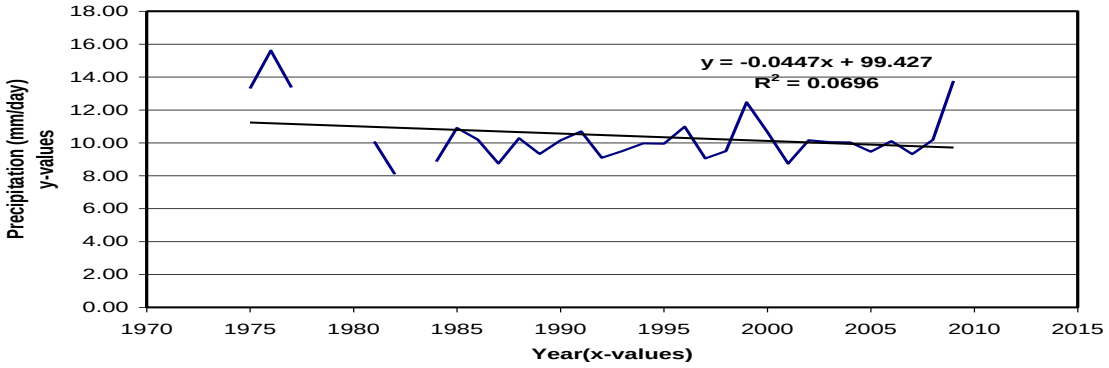

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42
y = 0.0245x - 7.6047
R² = 0.0006
Number of Days(y-values)
Year(x-values)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015


Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42
y = -0.288x + 627.75
R² = 0.0165
Number of Days(y-values)
Year(x-values)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

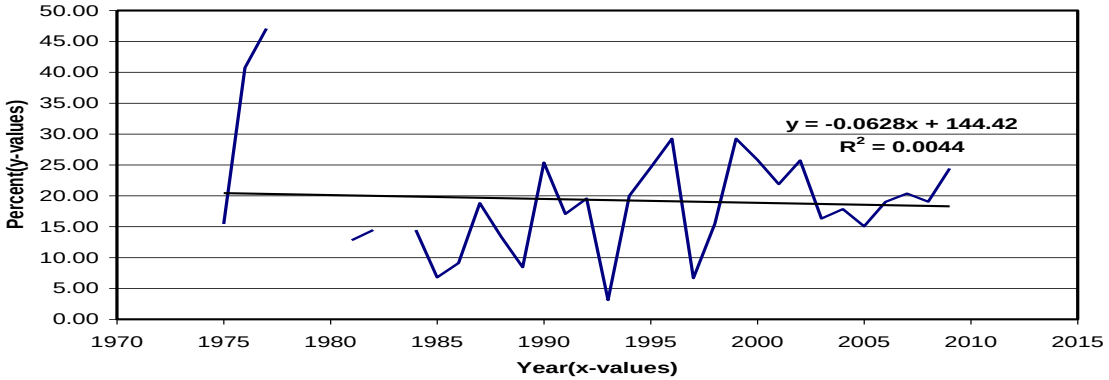
Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42



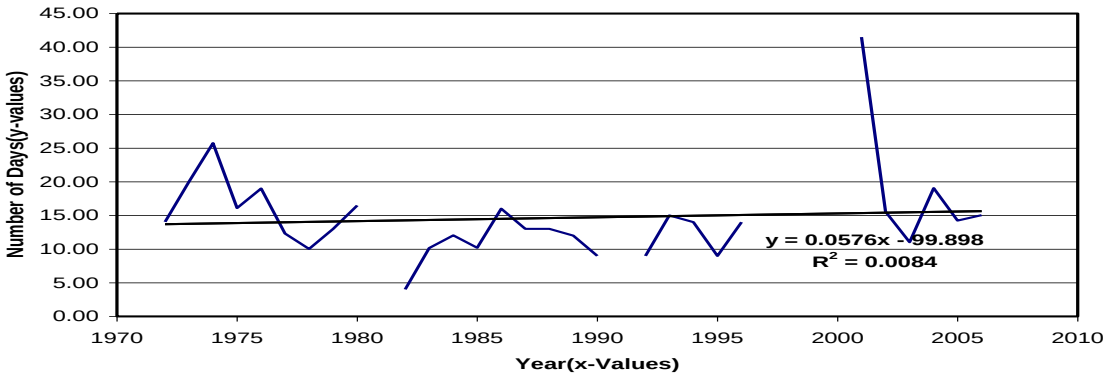
Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42



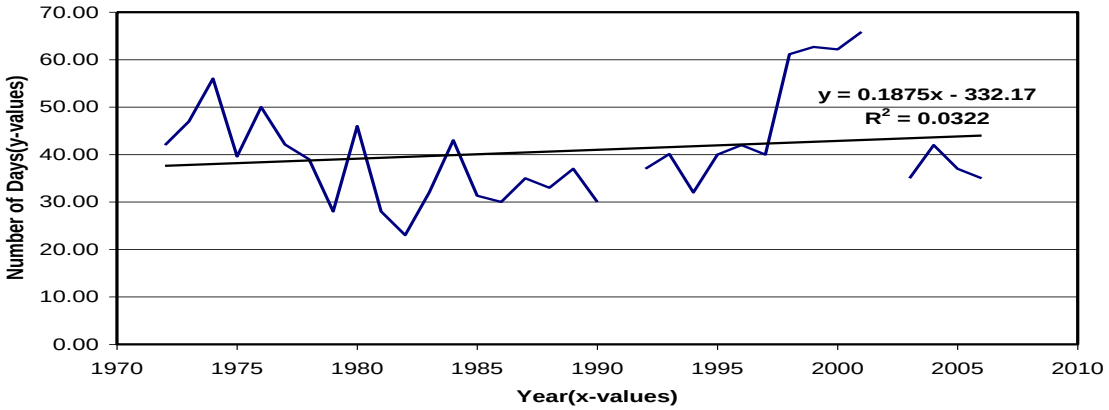
Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42



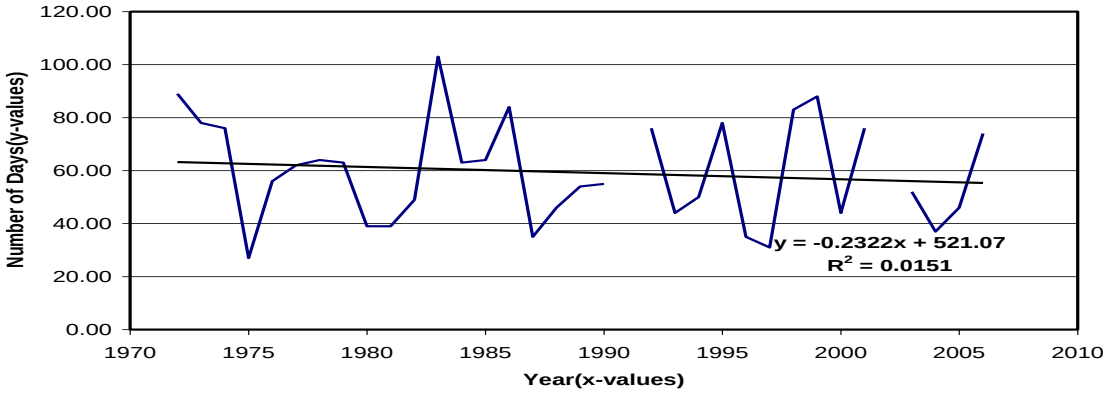
Index 005Prcp
Number of Days PRCP >= 20mm(95th%)
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25



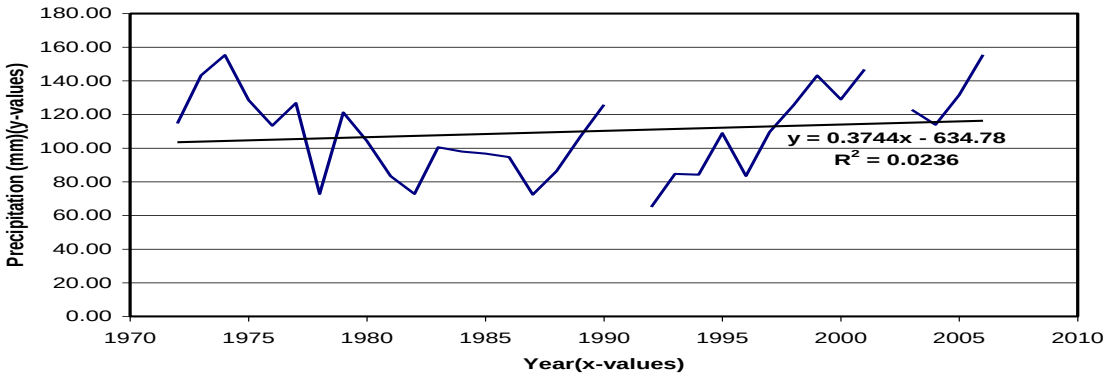
Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25



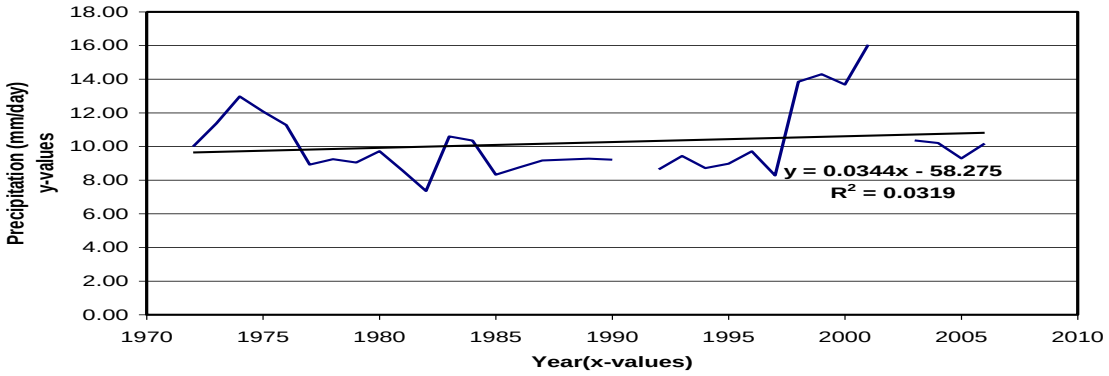
Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25



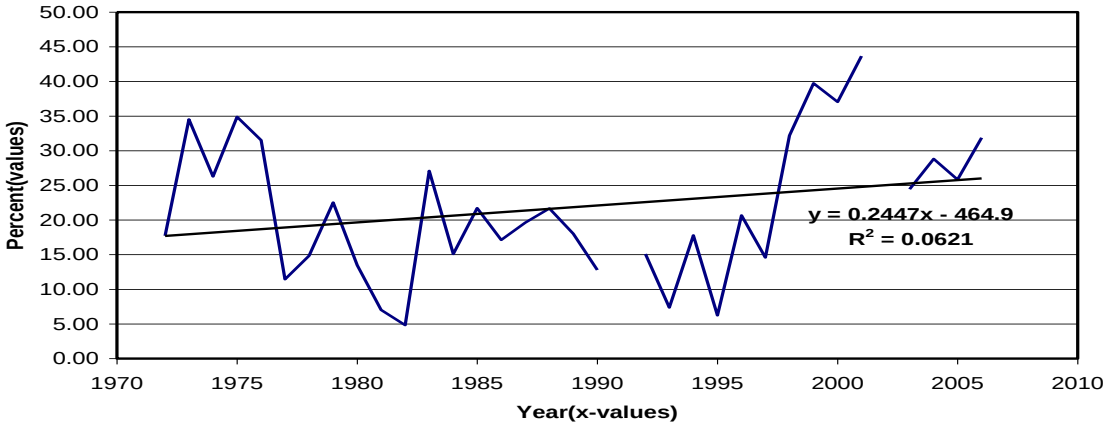
Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25

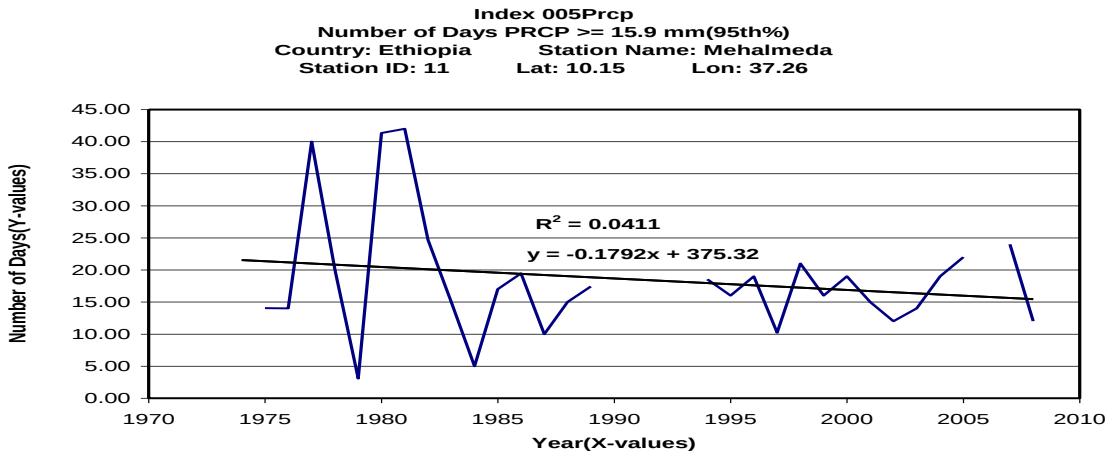


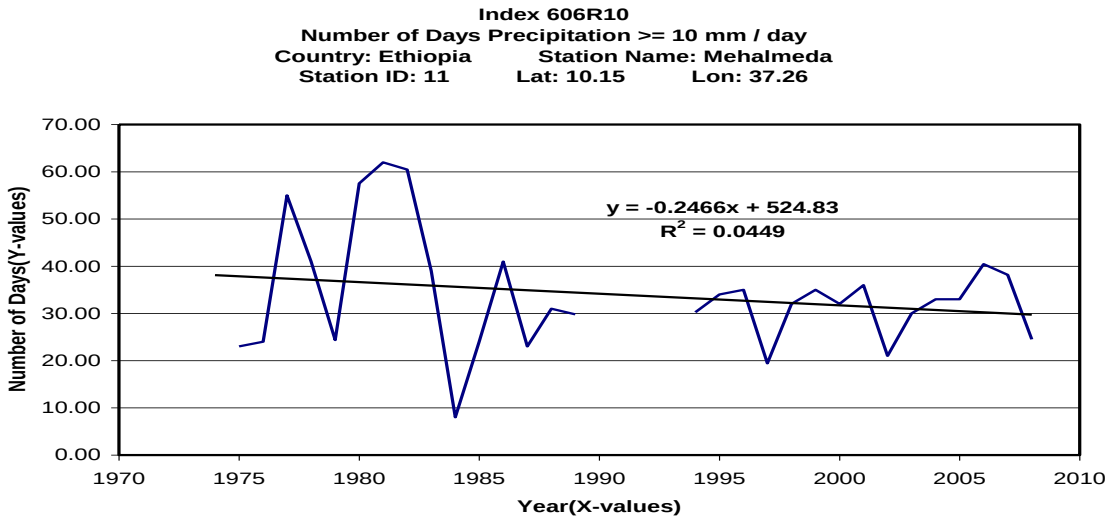
Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25

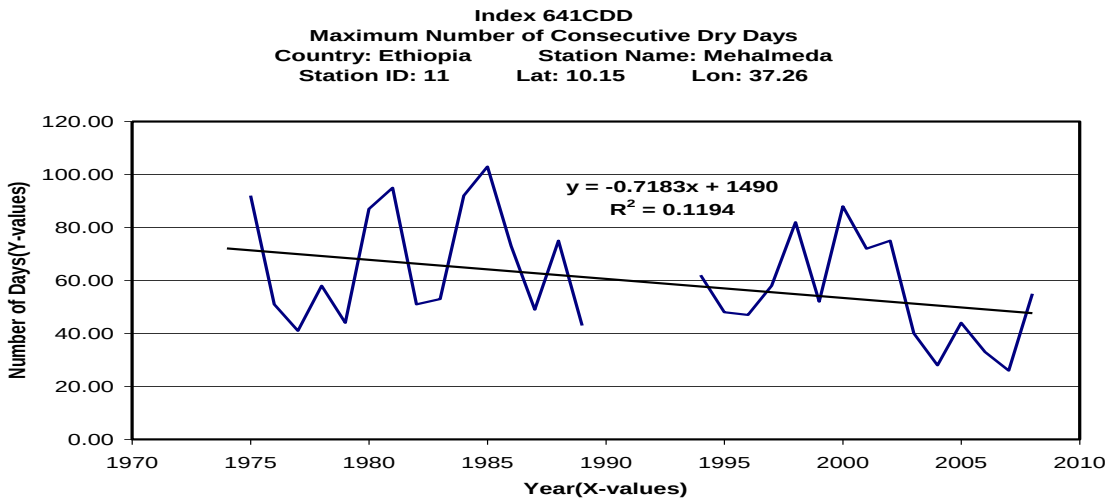


Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25

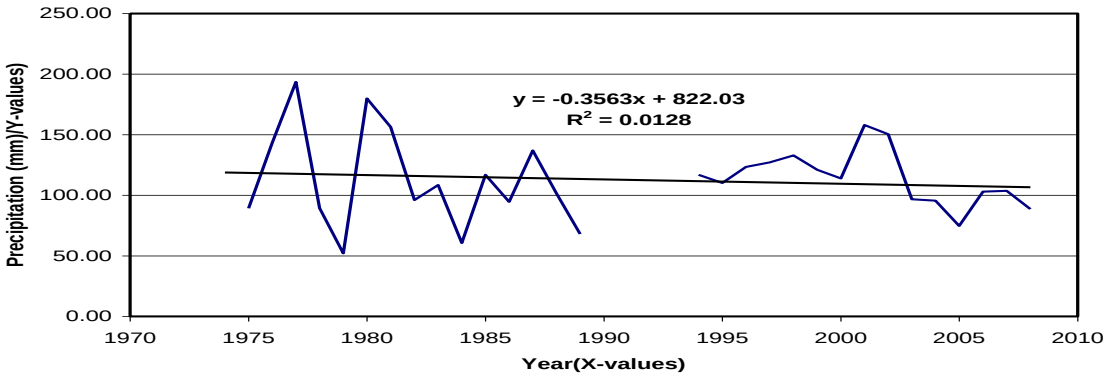



Index 005Prcp
Number of Days PRCP >= 15.9 mm(95th%)
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26
R² = 0.0411
y = -0.1792x + 375.32
Number of Days(Y-values)
Year(X-values)

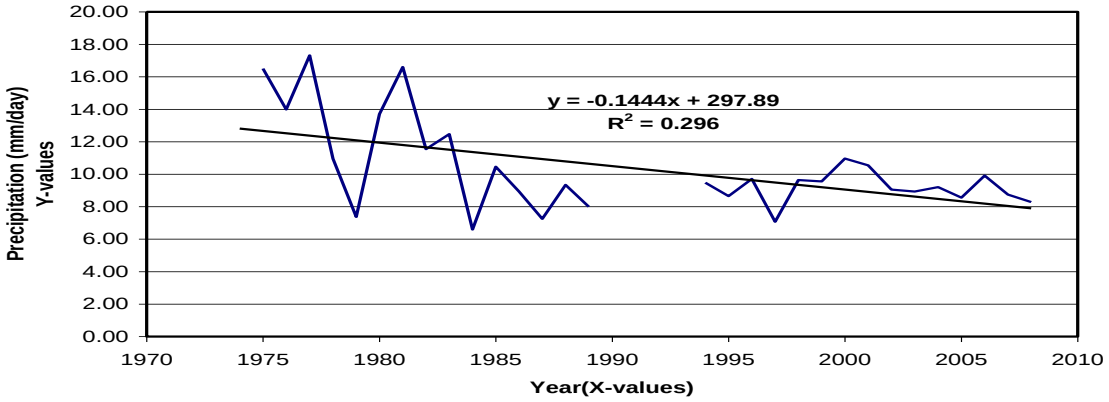

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26
y = -0.2466x + 524.83
R² = 0.0449
Number of Days(Y-values)
Year(X-values)


Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26
y = -0.7183x + 1490
R² = 0.1194
Number of Days(Y-values)
Year(X-values)

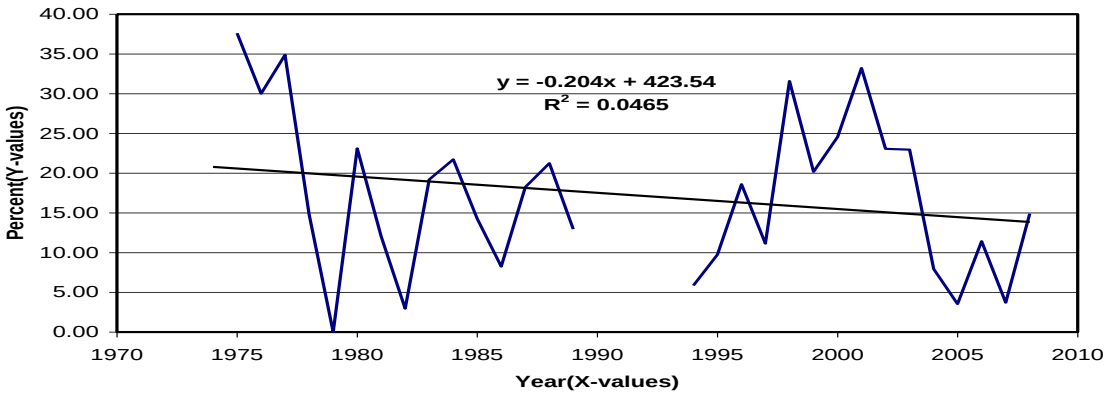
Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26

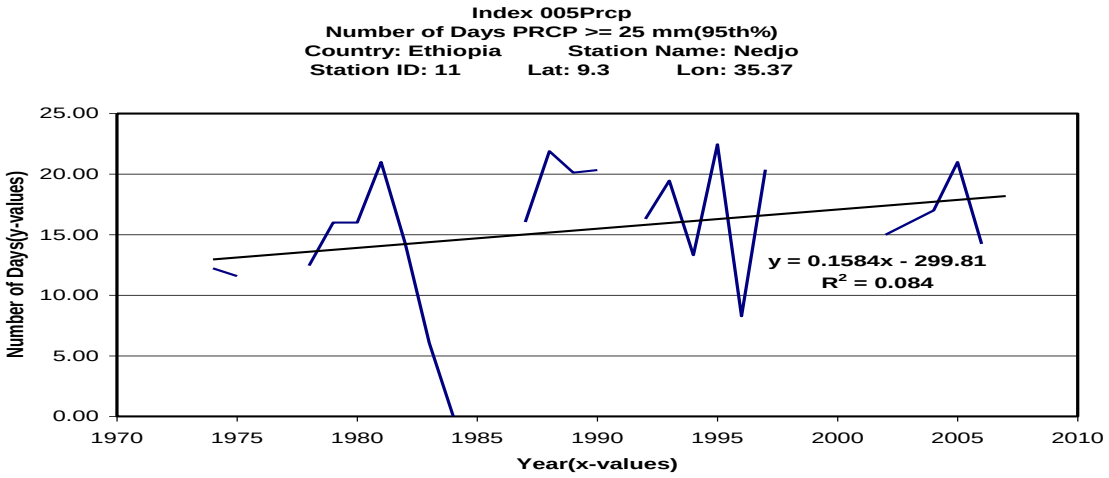


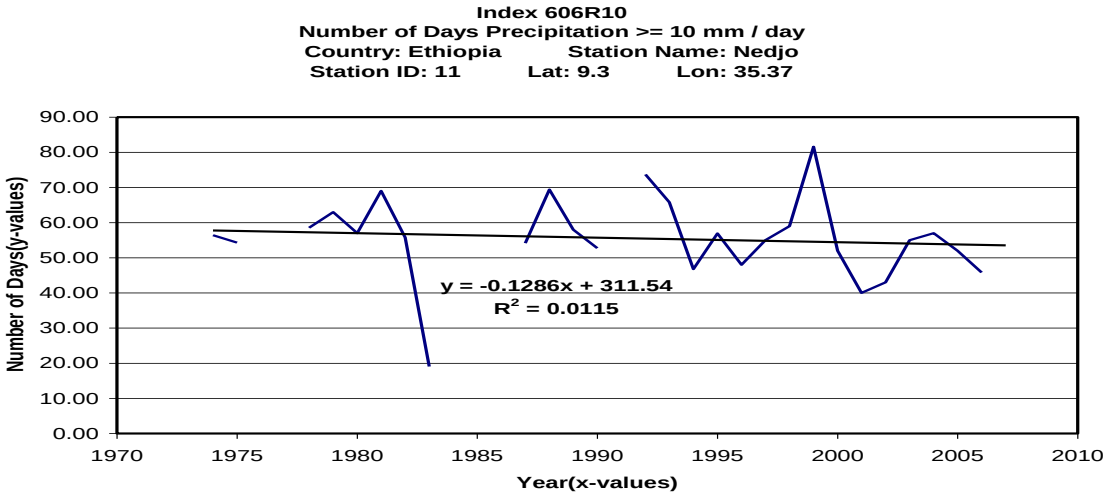
Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26

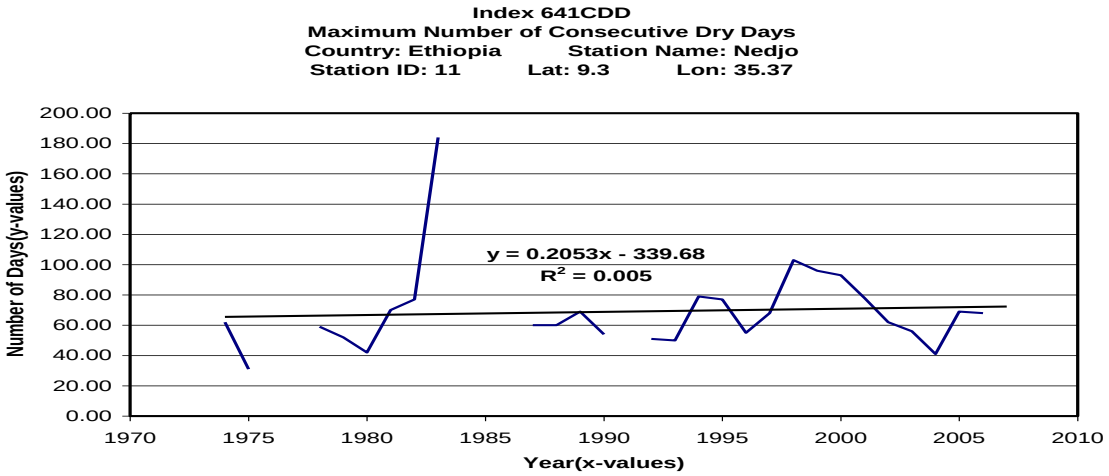


Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26

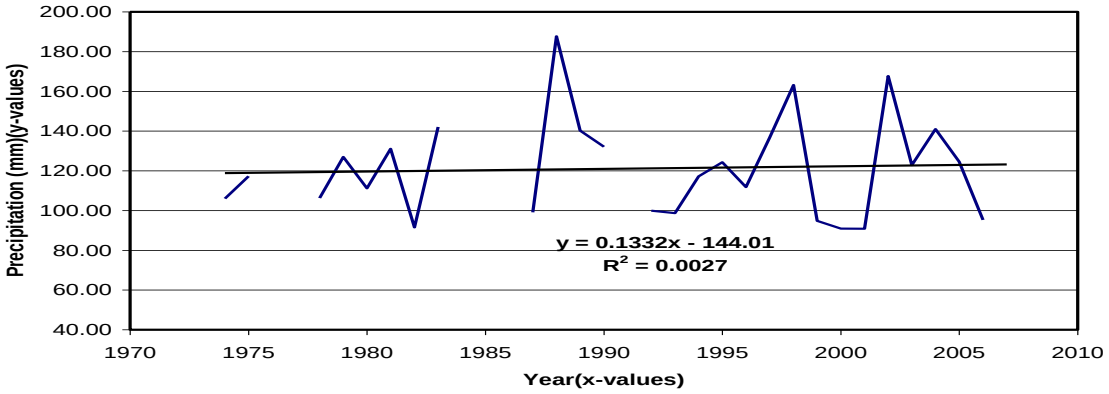



Index 005Prcp
Number of Days PRCP >= 25 mm(95th%)
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37
Number of Days(y-values)
Year(x-values)
y = 0.1584x - 299.81
R² = 0.084

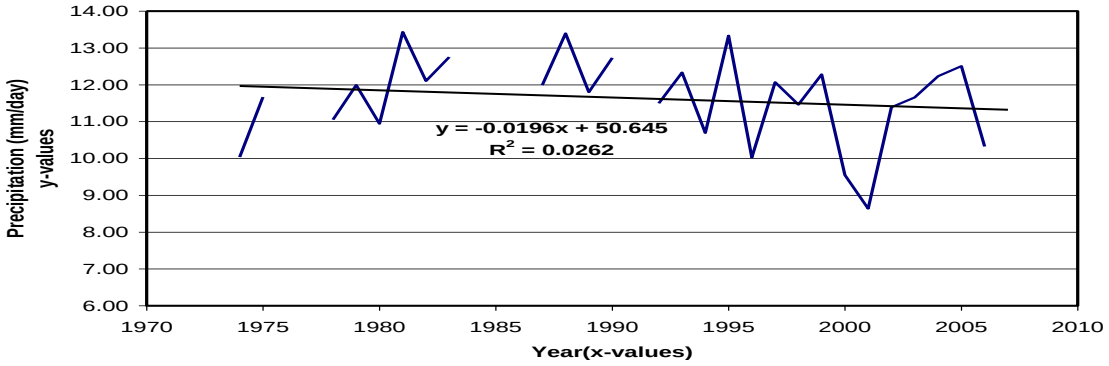

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37
Number of Days(y-values)
Year(x-values)
y = -0.1286x + 311.54
R² = 0.0115


Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37
Number of Days(y-values)
Year(x-values)
y = 0.2053x - 339.68
R² = 0.005

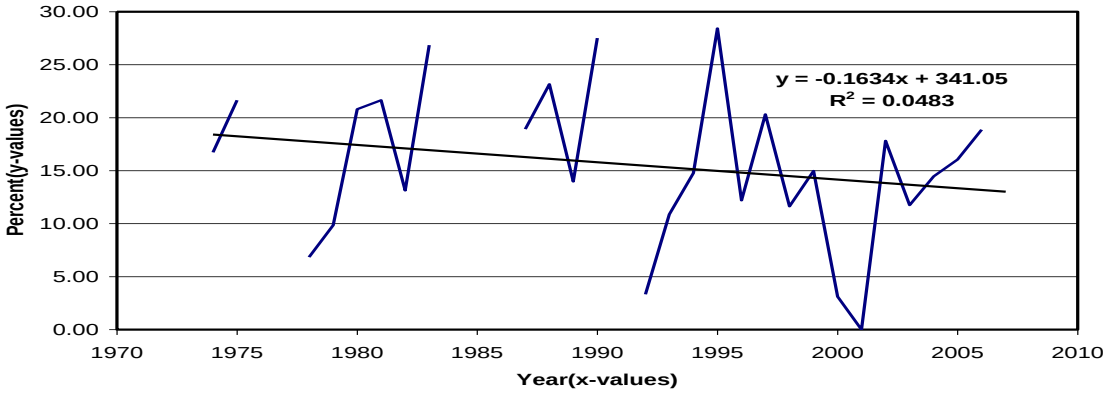
Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37

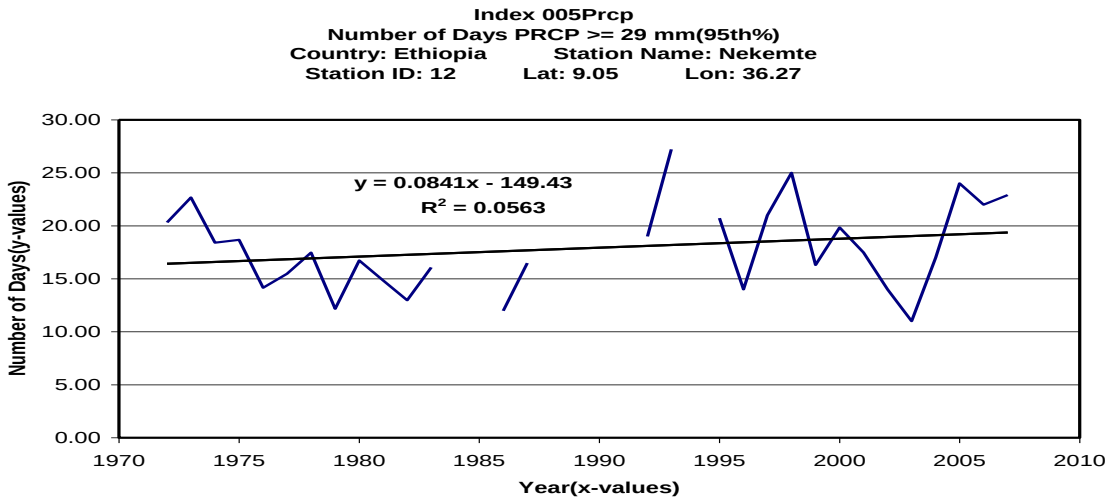


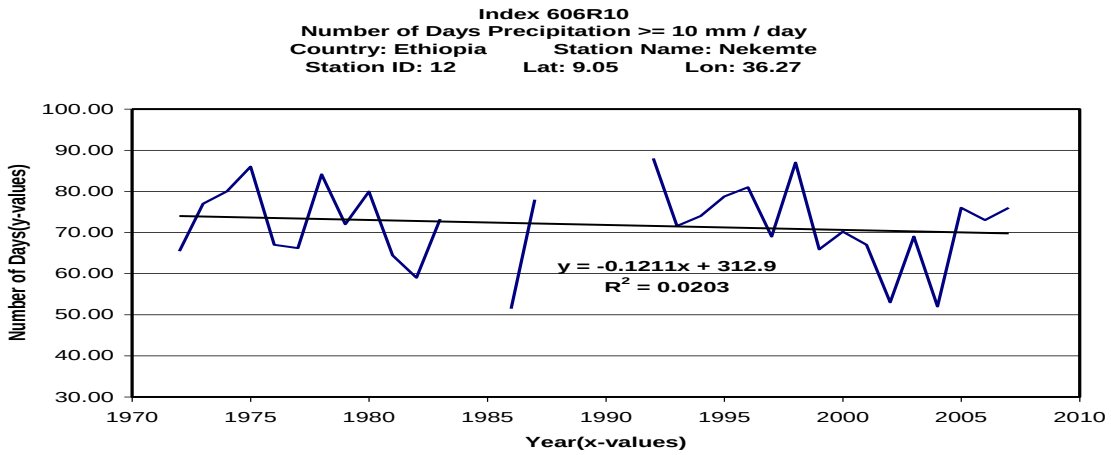
Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37

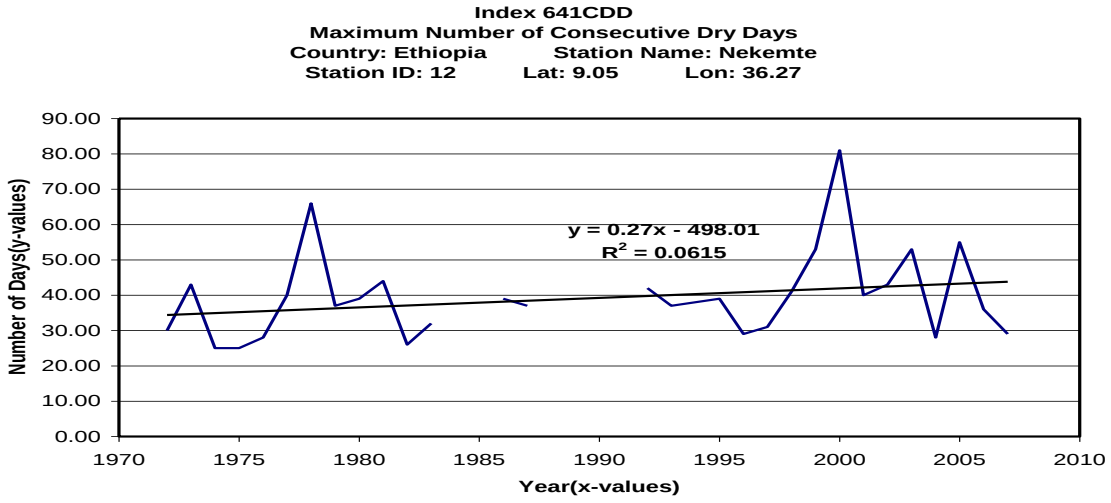


Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37

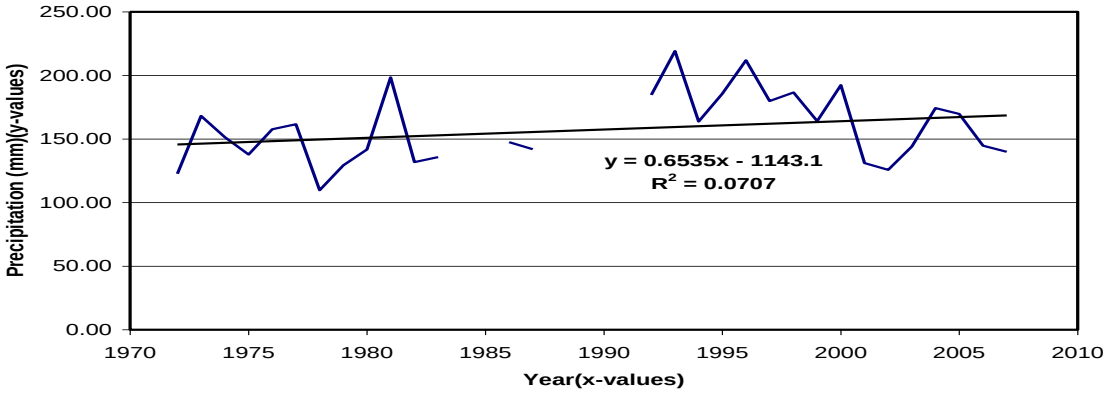



Index 005Prcp
Number of Days PRCP >= 29 mm(95th%)
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27
y = 0.0841x - 149.43
R² = 0.0563
Number of Days(y-values)
Year(x-values)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010

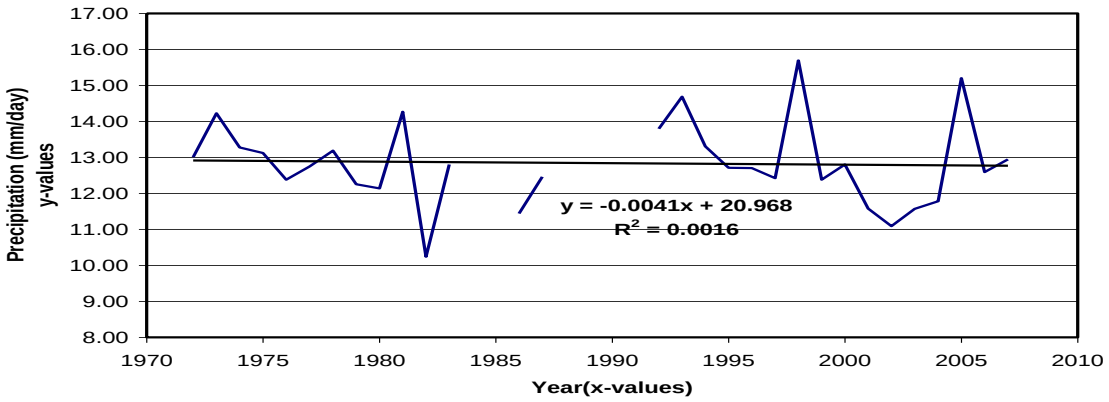

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27
y = -0.1211x + 312.9
R² = 0.0203
Number of Days(y-values)
Year(x-values)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
1970
1975
1980
1985
1990
1995
2000
2005
2010


Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27
y = 0.27x - 498.01
R² = 0.0615
Number of Days(y-values)
Year(x-values)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1970
1975
1980
1985
1990
1995
2000
2005
2010

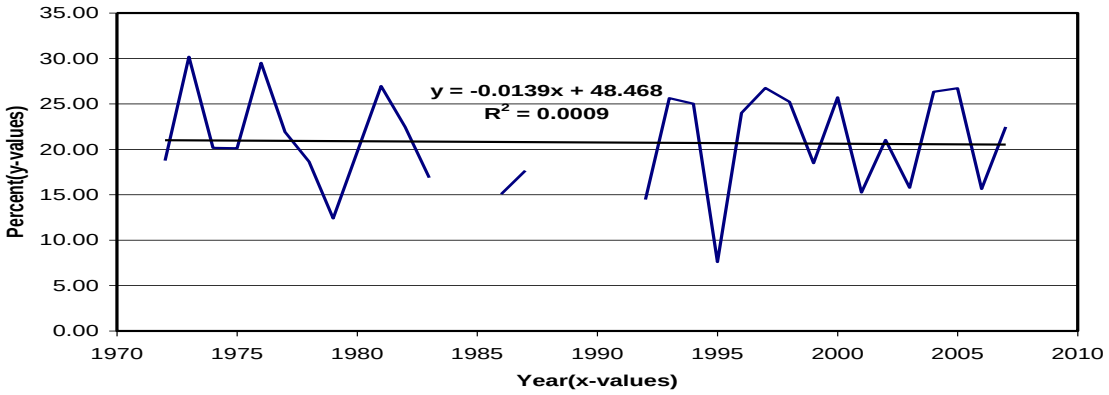
Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27

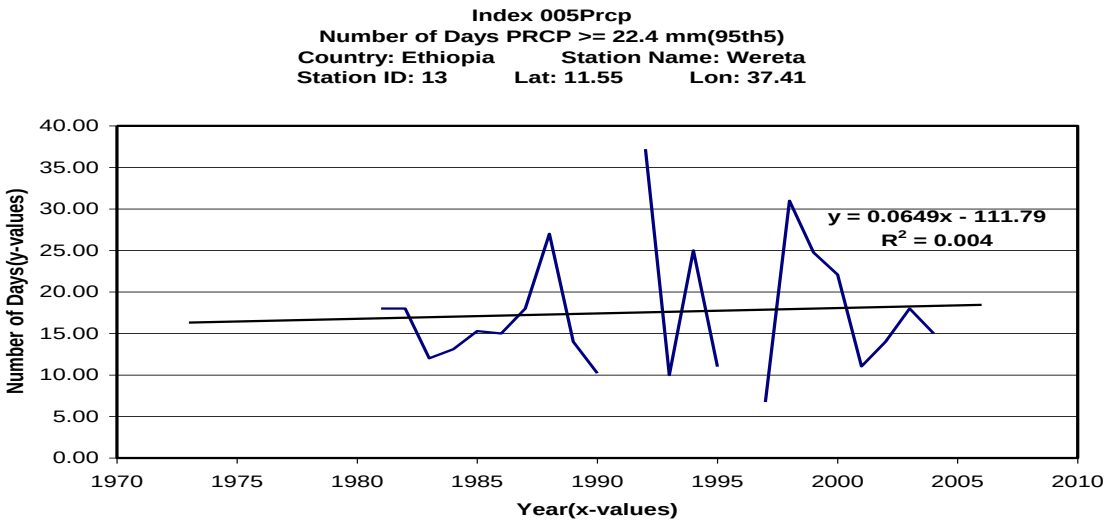


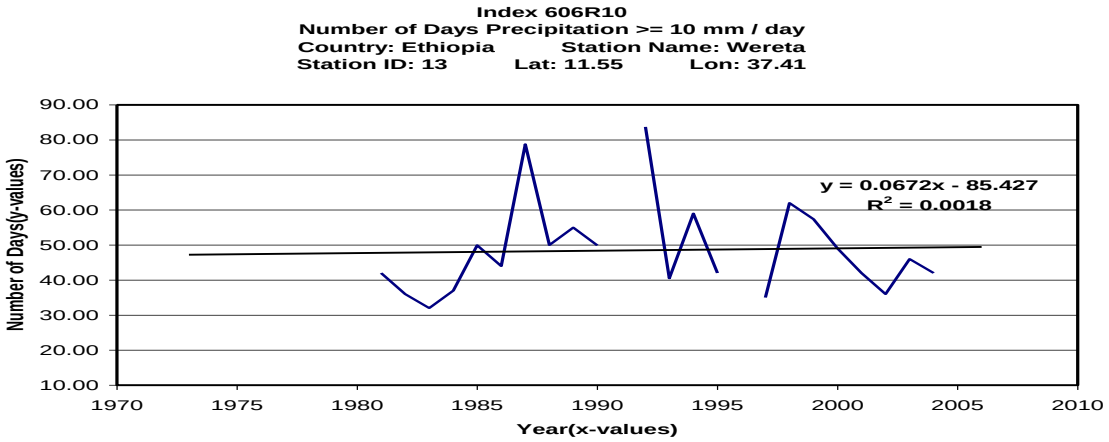
Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27

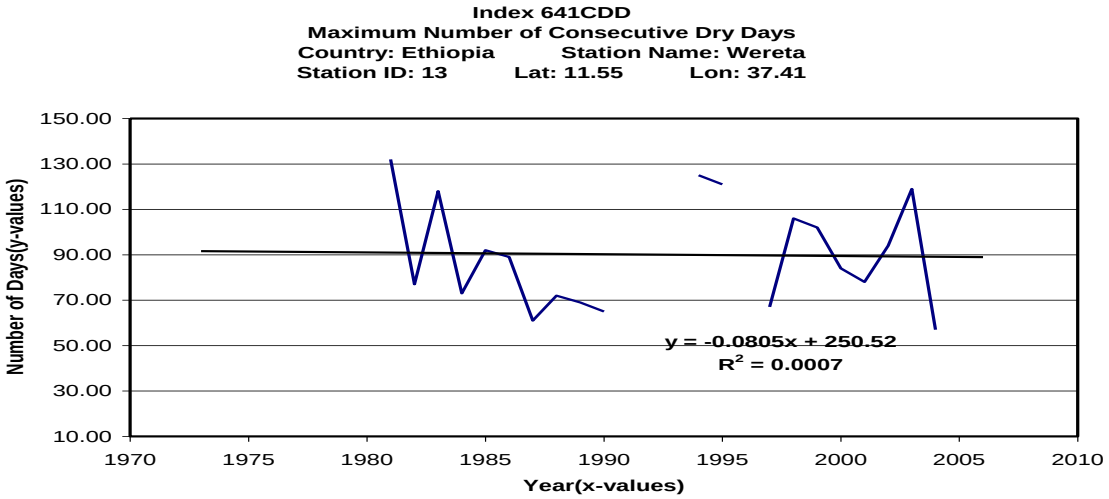


Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27

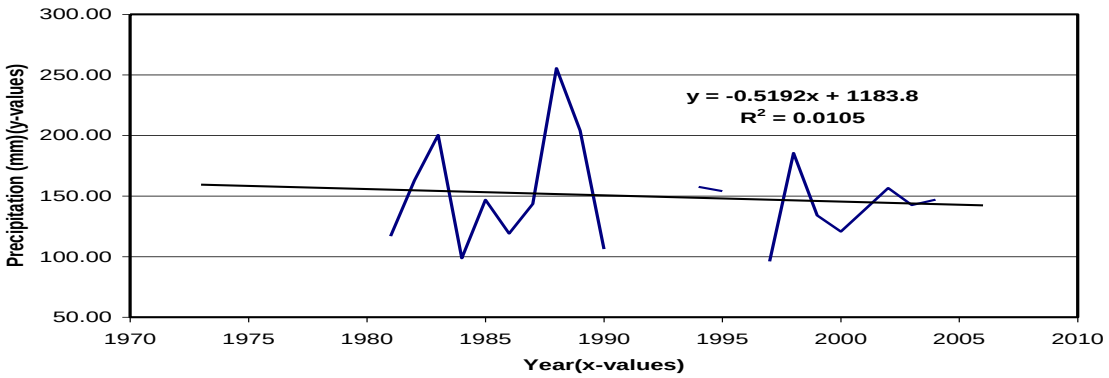



Index 005Prcp
Number of Days PRCP >= 22.4 mm(95th5)
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41
y = 0.0649x - 111.79
R2 = 0.004
Number of Days(y-values)
Year(x-values)

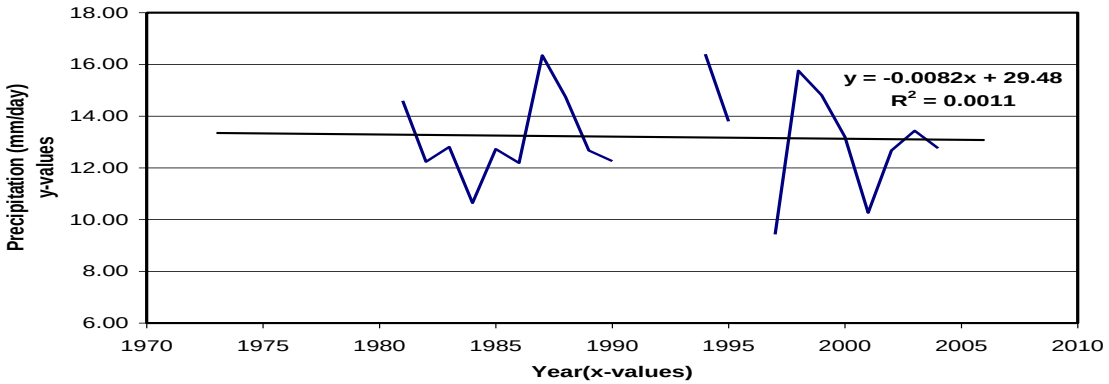

Index 606R10
Number of Days Precipitation >= 10 mm / day
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41
y = 0.0672x - 85.427
R2 = 0.0018
Number of Days(y-values)
Year(x-values)


Index 641CDD
Maximum Number of Consecutive Dry Days
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41
y = -0.0805x + 250.52
R2 = 0.0007
Number of Days(y-values)
Year(x-values)

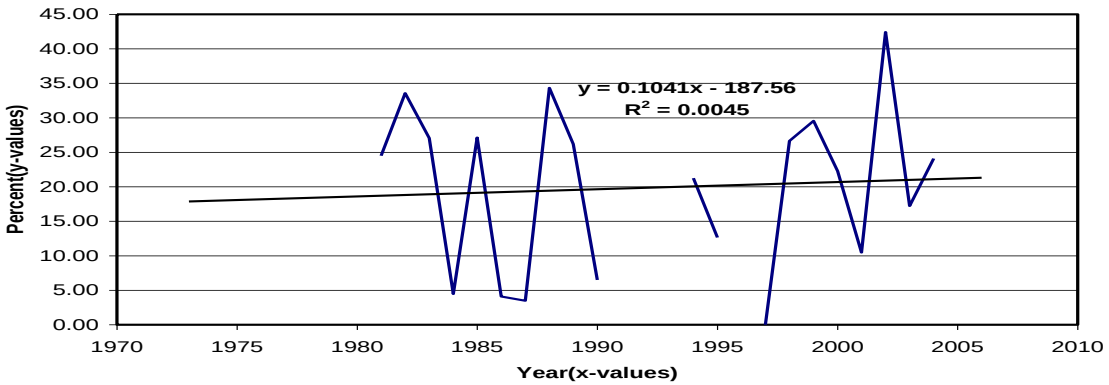
Index 644R5D
Greatest 5-day Rainfall Total
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41



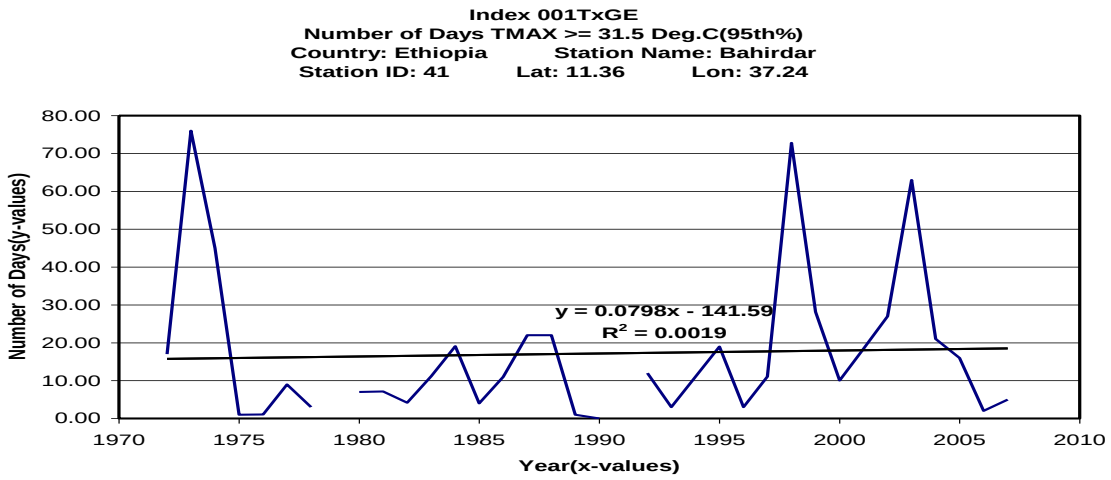
Index 646SDII
Simple Daily Intensity Index
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41

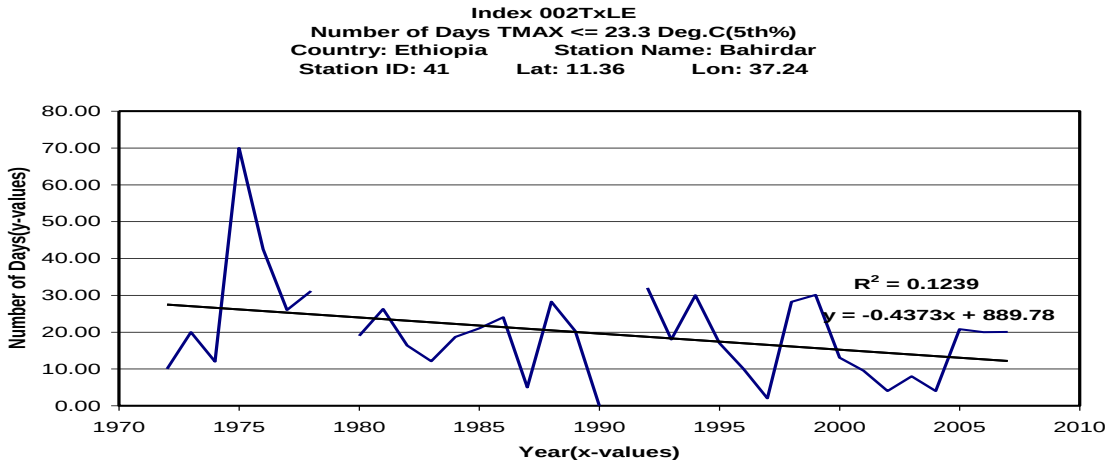


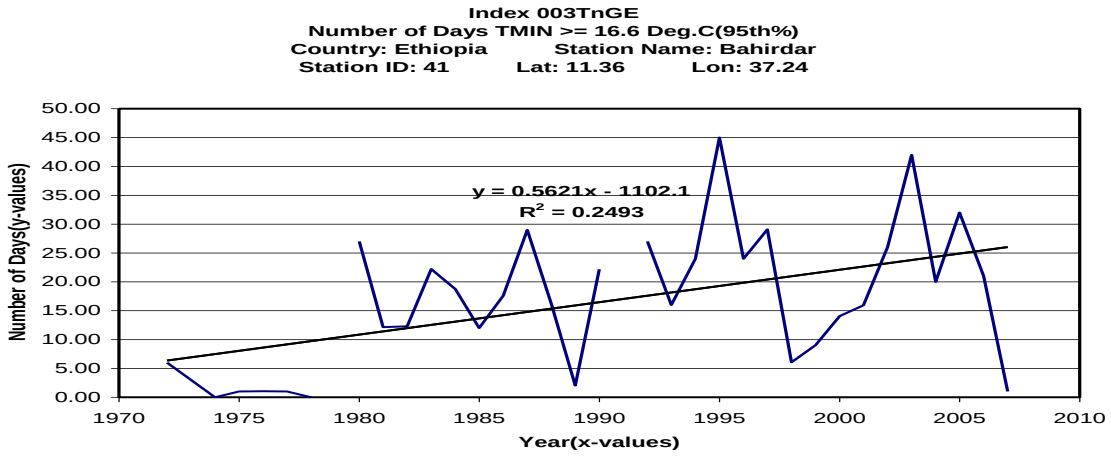
Index 695R95T
Fraction of Annual Precipitation Due to Events >= 95th Percentile
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41



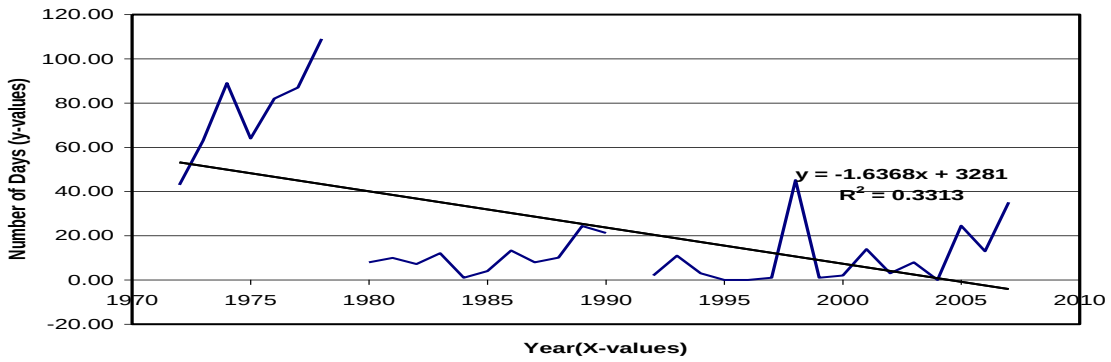
APPENDIX B: GRAPHICAL RESULTS OF TEMPERATURES INDICES


Index 001TxGE
Number of Days TMAX >= 31.5 Deg.C(95th%)
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24
y = 0.0798x - 141.59
R2 = 0.0019
Number of Days(y-values)
Year(x-values)

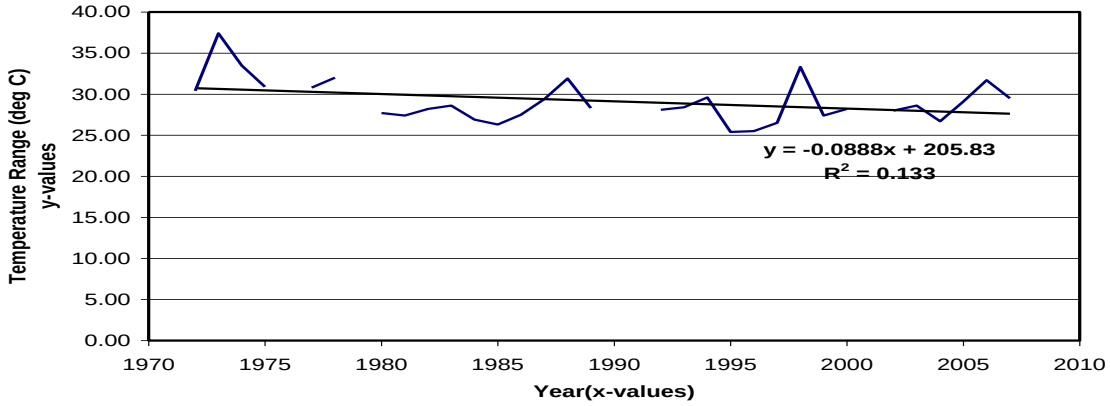

Index 002TxLE
Number of Days TMAX <= 23.3 Deg.C(5th%)
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24
R2 = 0.1239
y = -0.4373x + 889.78
Number of Days(y-values)
Year(x-values)


Index 003TnGE
Number of Days TMIN >= 16.6 Deg.C(95th%)
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24
y = 0.5621x - 1102.1
R2 = 0.2493
Number of Days(y-values)
Year(x-values)

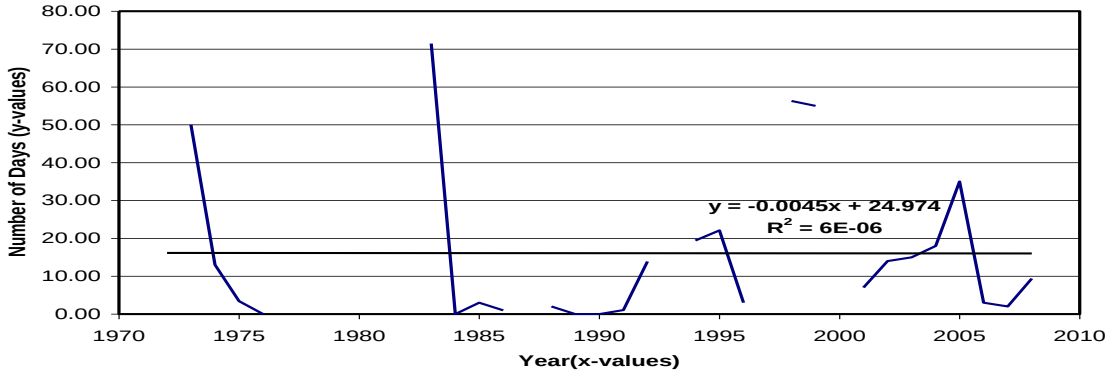
Index 004TnLE
Number of Days TMIN <= 6 Deg.C(5th%)
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24

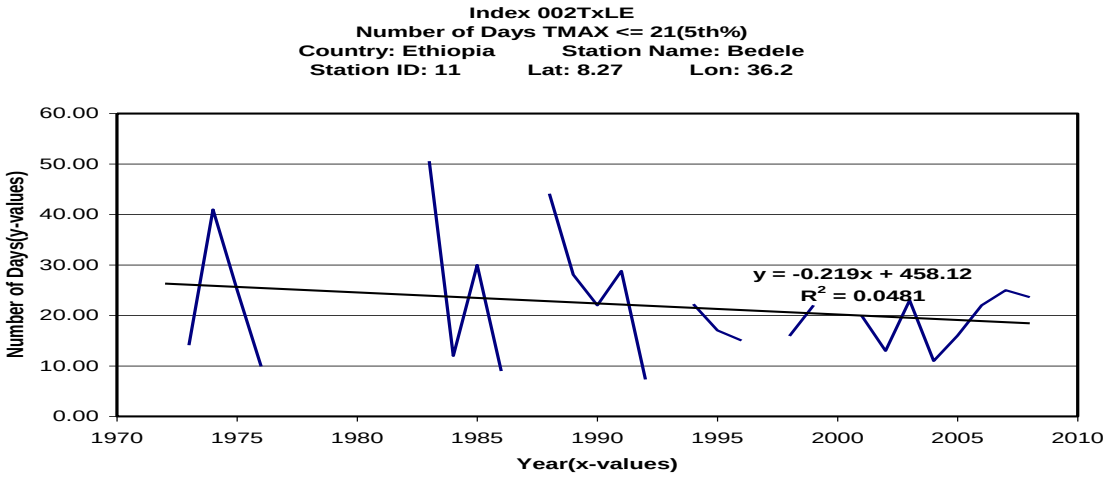


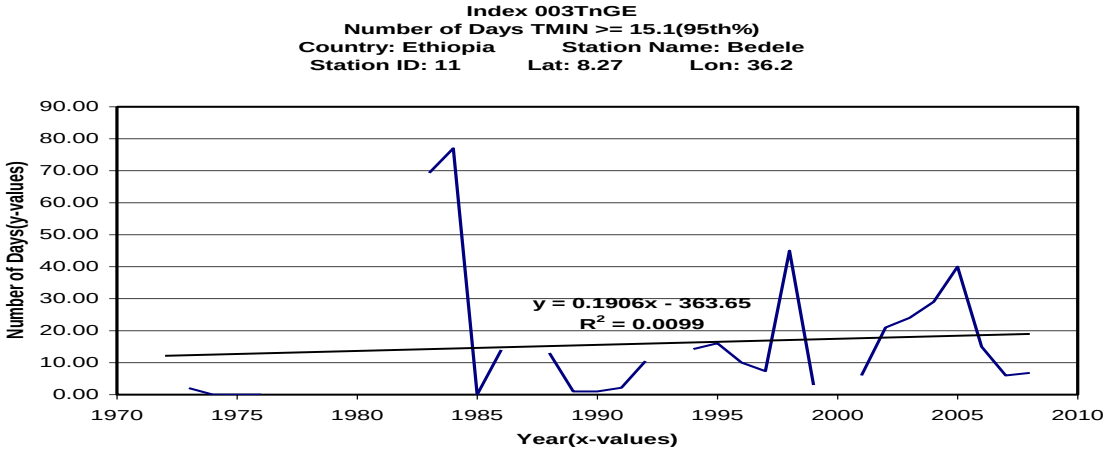
Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Bahirdar
Station ID: 41 Lat: 11.36 Lon: 37.24

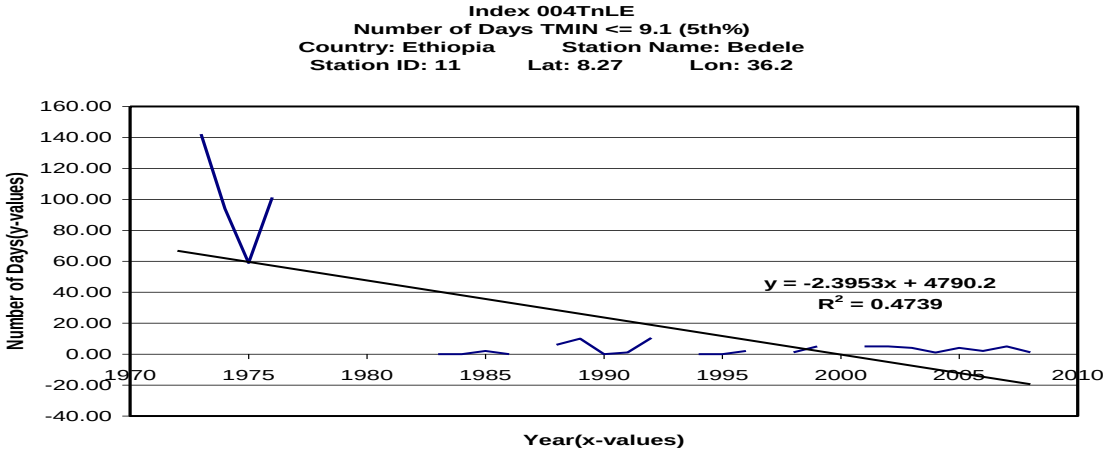


Index 001TxGE
Number of Days TMAX >= 30.1(95th%)
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2

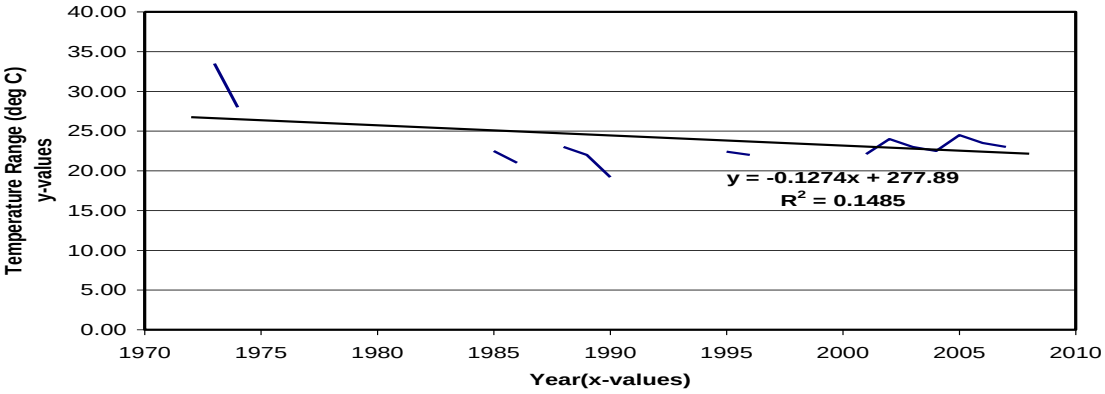



Index 002TxLE
Number of Days TMAX <= 21(5th%)
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2
Number of Days(y-values)
Year(x-values)
y = -0.219x + 458.12
R2 = 0.0481

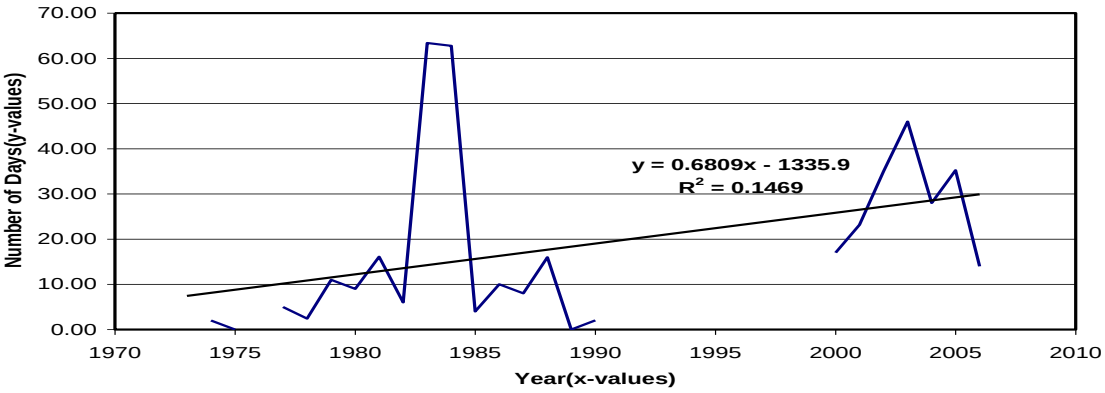

Index 003TnGE
Number of Days TMIN >= 15.1(95th%)
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2
Number of Days(y-values)
Year(x-values)
y = 0.1906x - 363.65
R2 = 0.0099


Index 004TnLE
Number of Days TMIN <= 9.1 (5th%)
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2
Number of Days(y-values)
Year(x-values)
y = -2.3953x + 4790.2
R2 = 0.4739

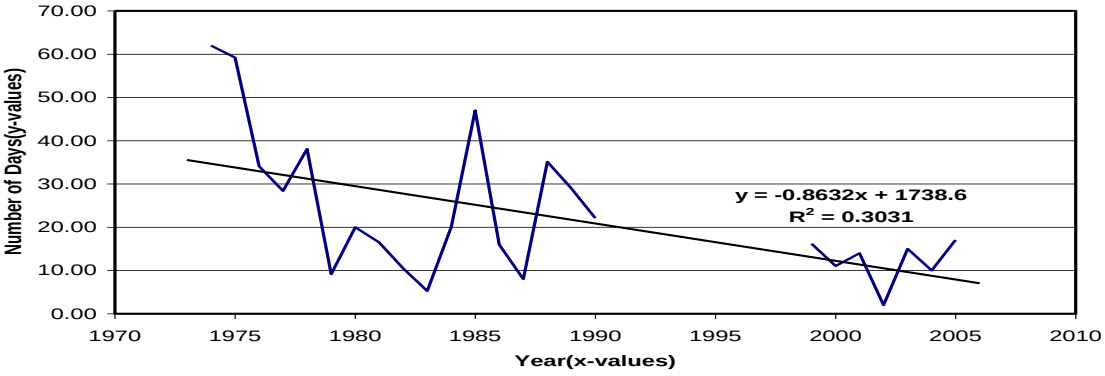
Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Bedele
Station ID: 11 Lat: 8.27 Lon: 36.2



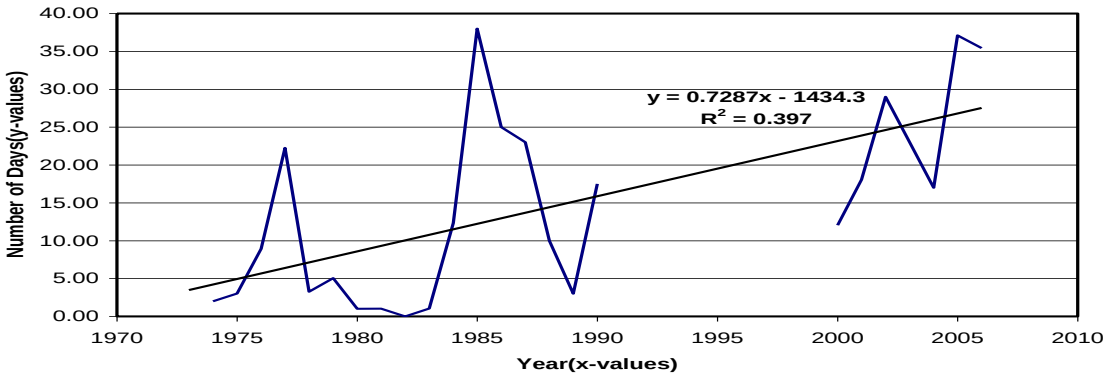
Index 001TxGE
Number of Days TMAX >= 33.6 (95th%)
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3



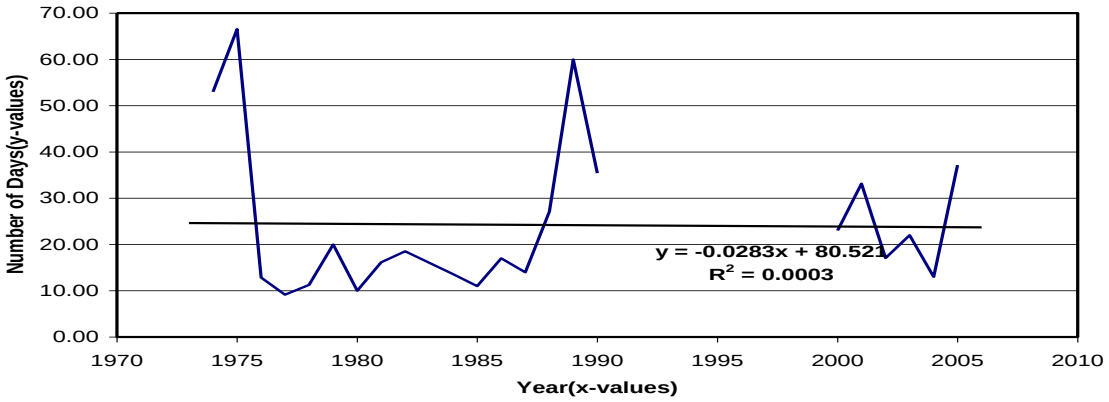
Index 002TxLE
Number of Days TMAX <= 23 (5th%)
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3



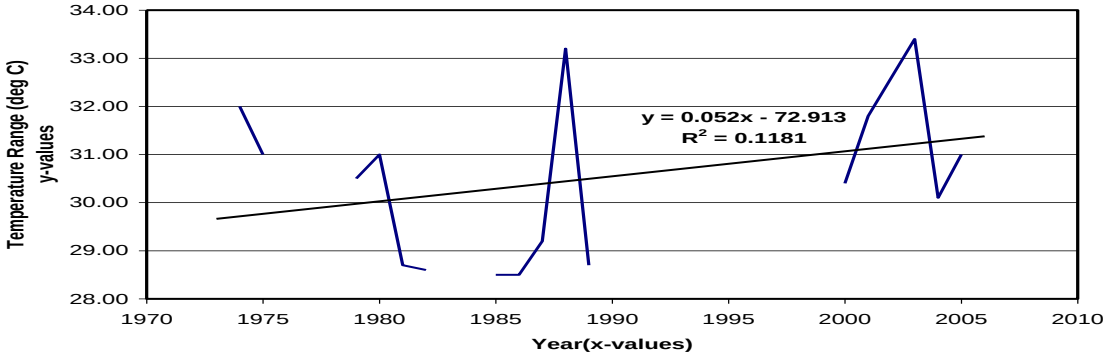
Index 003TnGE
Number of Days TMIN >= 16.6 (95th%)
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3

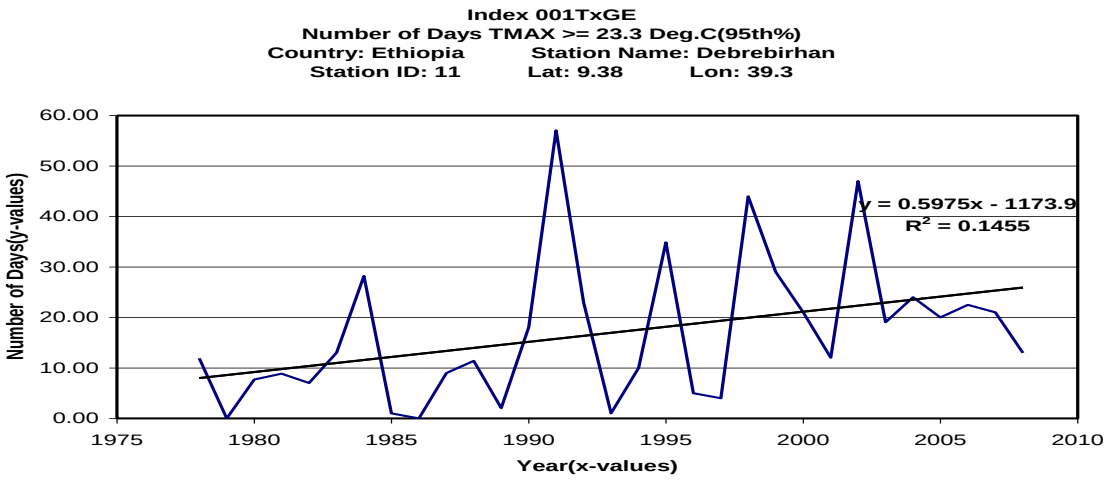


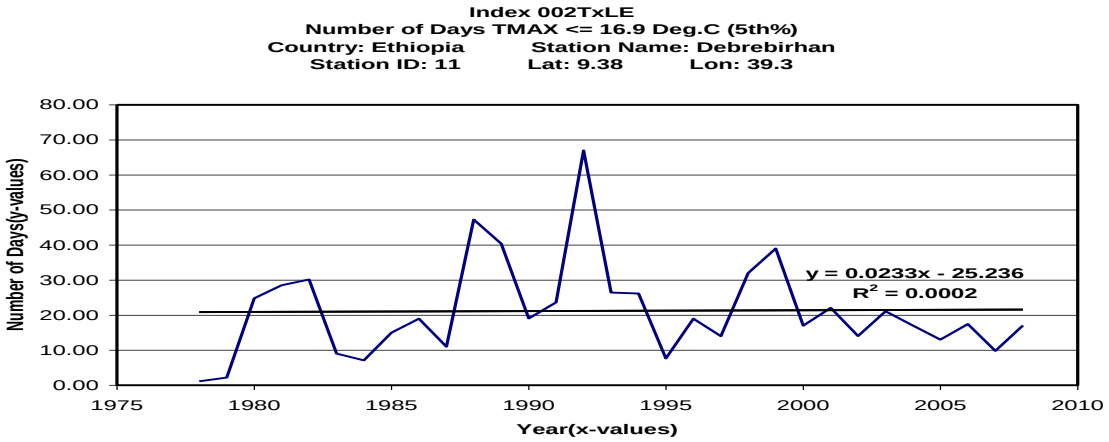
Index 004TnLE
Number of Days TMIN <= 7.5 (5th%)
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3

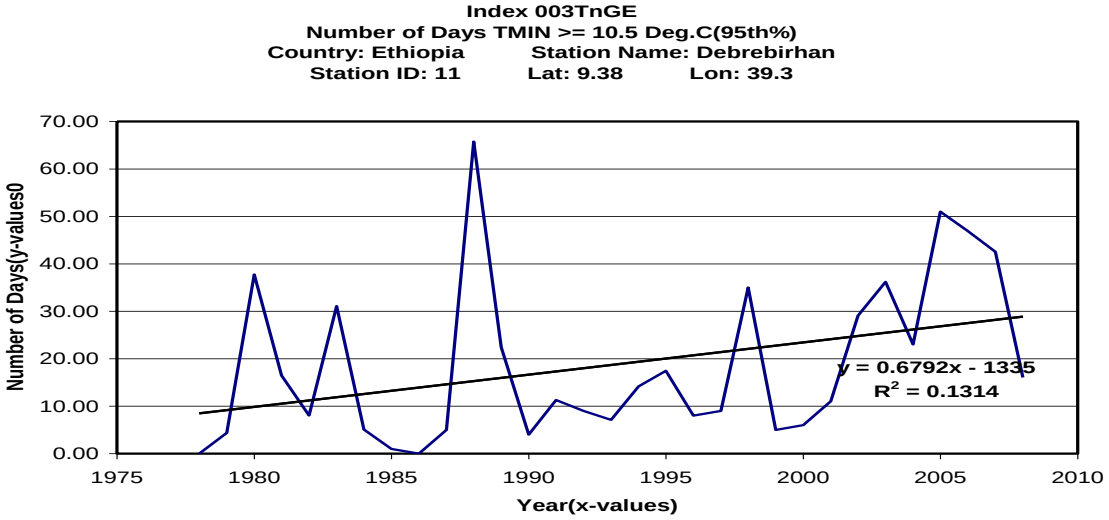


Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Chagni
Station ID: 11 Lat: 10.57 Lon: 36.3

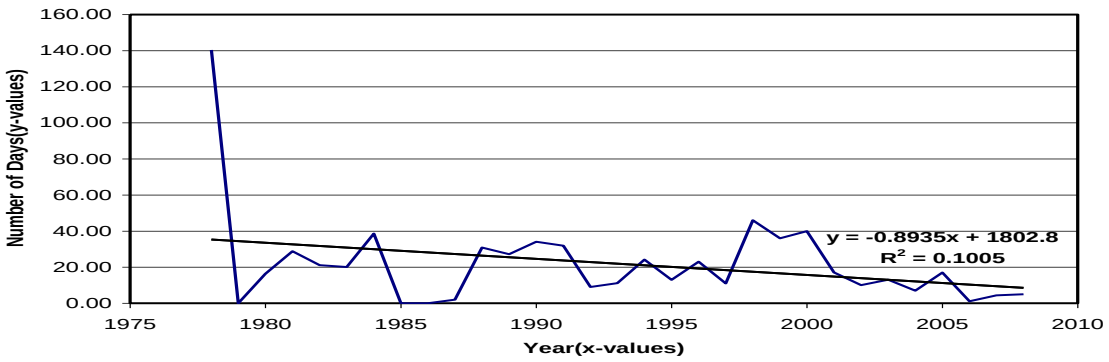



Index 001TxGE
Number of Days TMAX >= 23.3 Deg.C(95th%)
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3
Number of Days(y-values)
Year(x-values)
y = 0.5975x - 1173.9
R² = 0.1455
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1975
1980
1985
1990
1995
2000
2005
2010

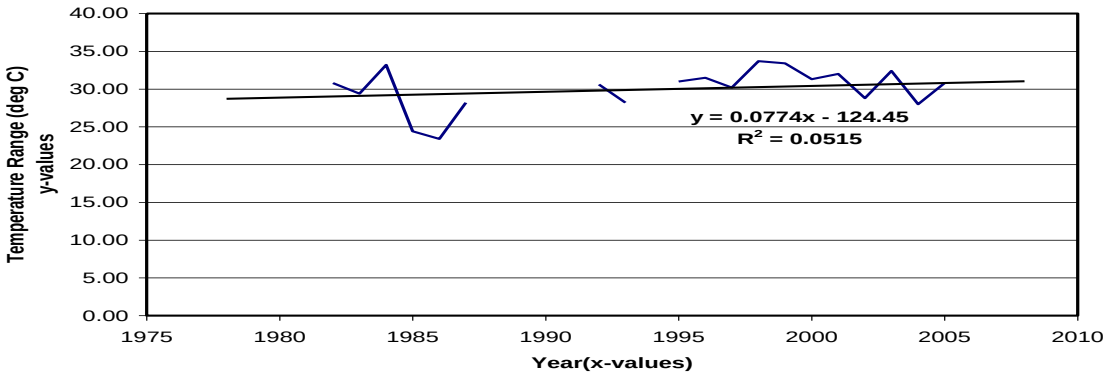

Index 002TxLE
Number of Days TMAX <= 16.9 Deg.C (5th%)
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3
Number of Days(y-values)
Year(x-values)
y = 0.0233x - 25.236
R² = 0.0002
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1975
1980
1985
1990
1995
2000
2005
2010


Index 003TnGE
Number of Days TMIN >= 10.5 Deg.C(95th%)
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3
Number of Days(y-values0
Year(x-values)
y = 0.6792x - 1335
R² = 0.1314
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1975
1980
1985
1990
1995
2000
2005
2010

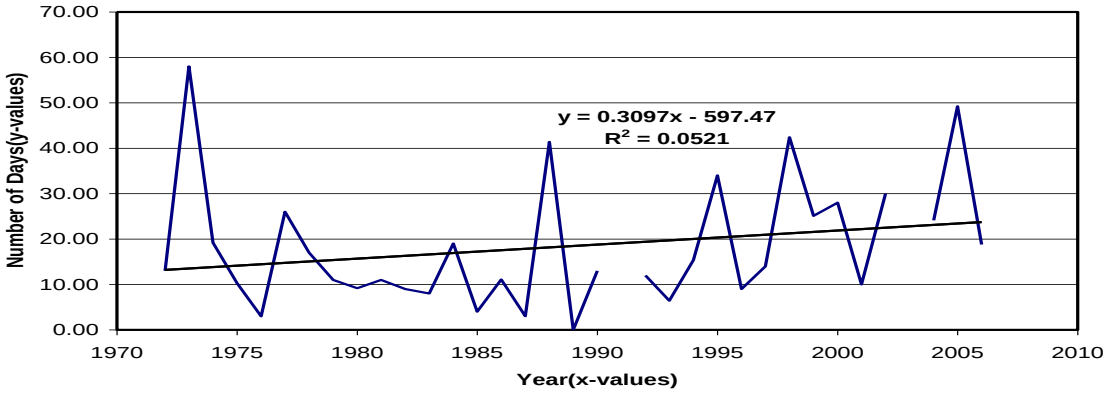
Index 004TnLE
Number of Days TMIN <= -0.8 Deg.C(5th%)
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3

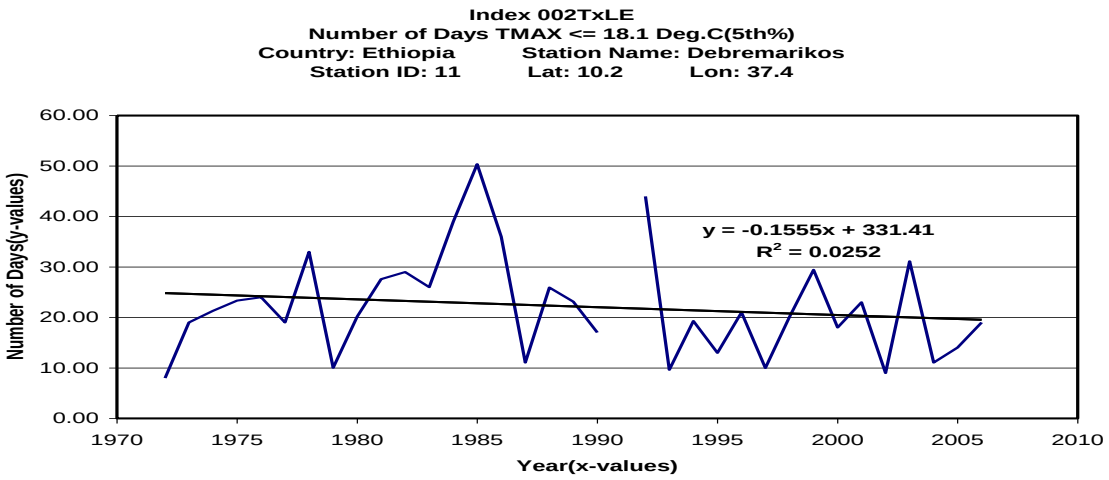


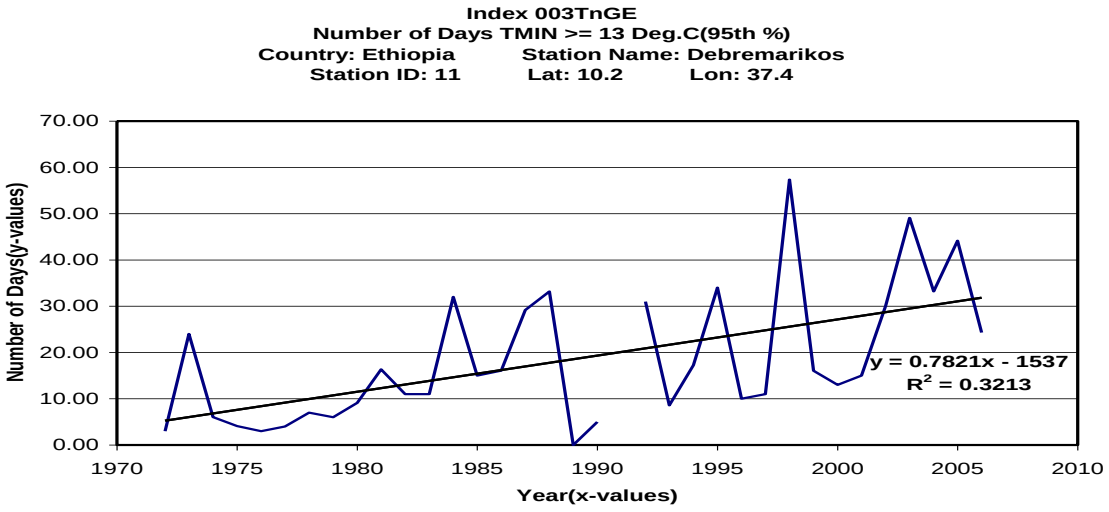
Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Debrebirhan
Station ID: 11 Lat: 9.38 Lon: 39.3

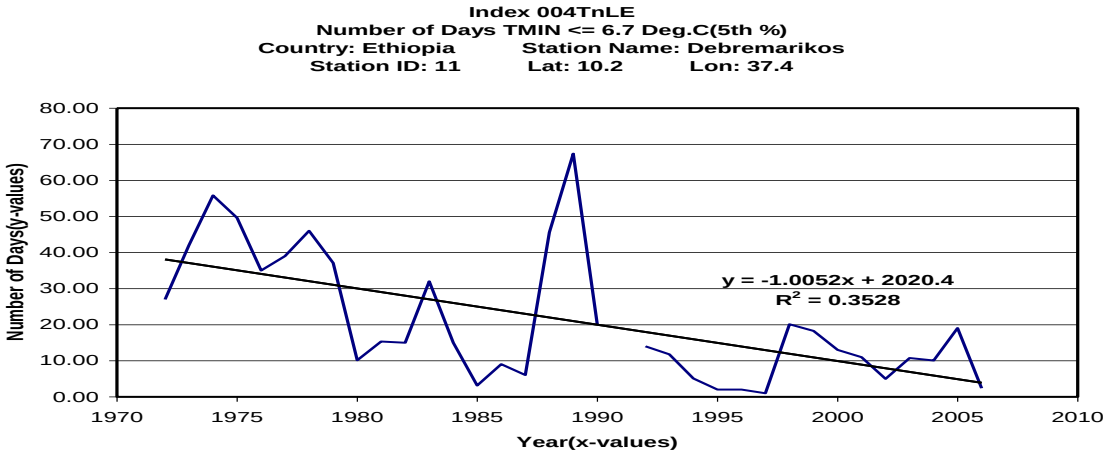


Index 001TxGE
Number of Days TMAX >= 27 Deg.C(95th%)
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4

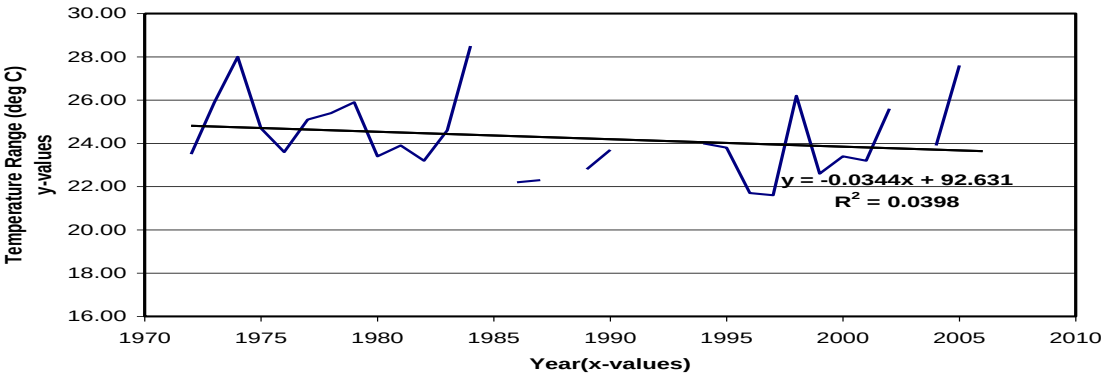



Index 002TxLE
Number of Days TMAX <= 18.1 Deg.C(5th%)
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4
y = -0.1555x + 331.41
R2 = 0.0252
Number of Days(y-values)
Year(x-values)

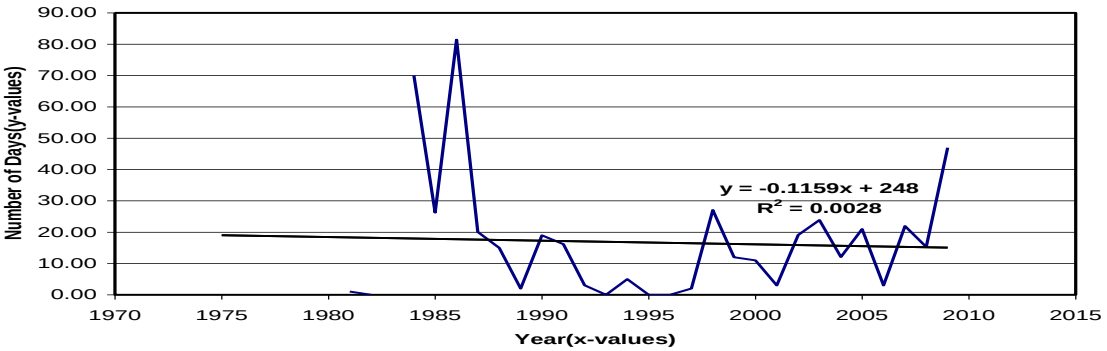

Index 003TnGE
Number of Days TMIN >= 13 Deg.C(95th %)
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4
y = 0.7821x - 1537
R2 = 0.3213
Number of Days(y-values)
Year(x-values)


Index 004TnLE
Number of Days TMIN <= 6.7 Deg.C(5th %)
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4
y = -1.0052x + 2020.4
R2 = 0.3528
Number of Days(y-values)
Year(x-values)

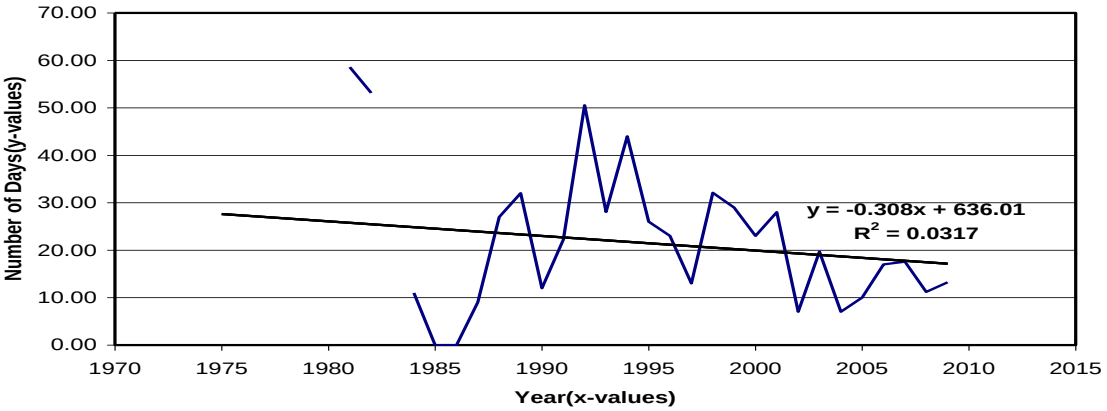
Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Debremarikos
Station ID: 11 Lat: 10.2 Lon: 37.4

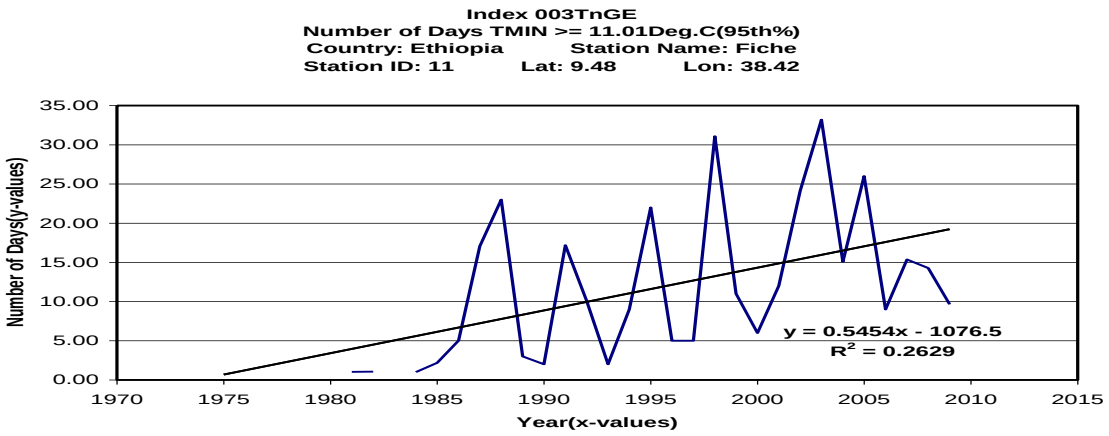


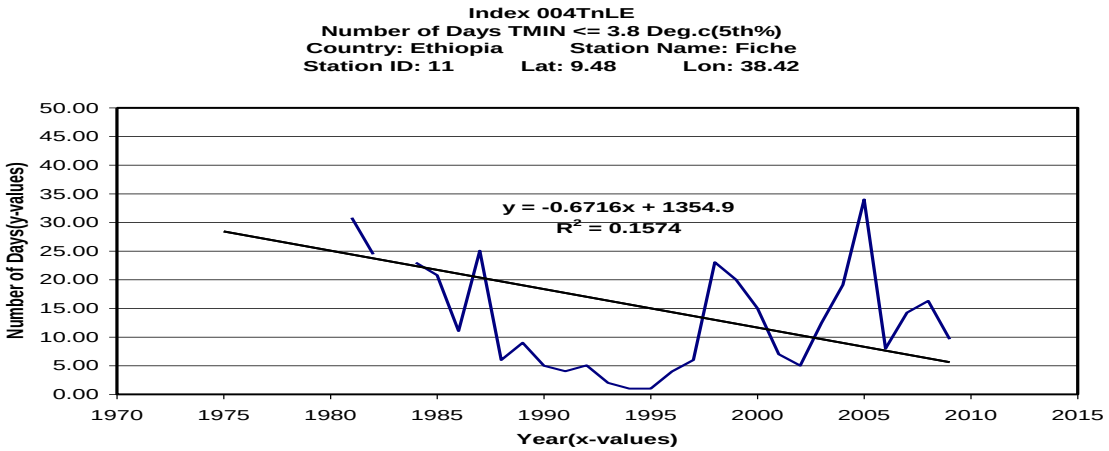
Index 001TxGE
Number of Days TMAX >= 24.5 Deg.C(95th%)
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42

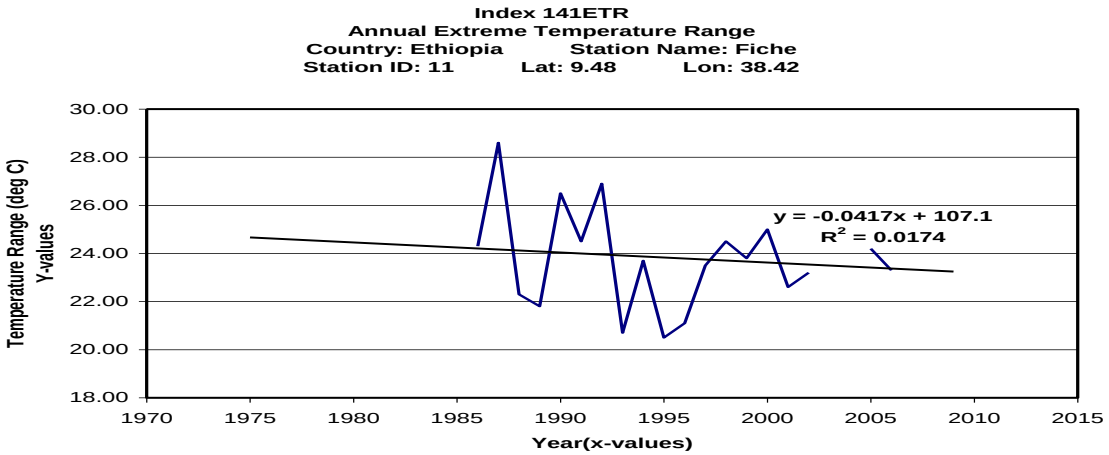


Index 002TxLE
Number of Days TMAX <= 16.8 Deg.C(5th%)
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42

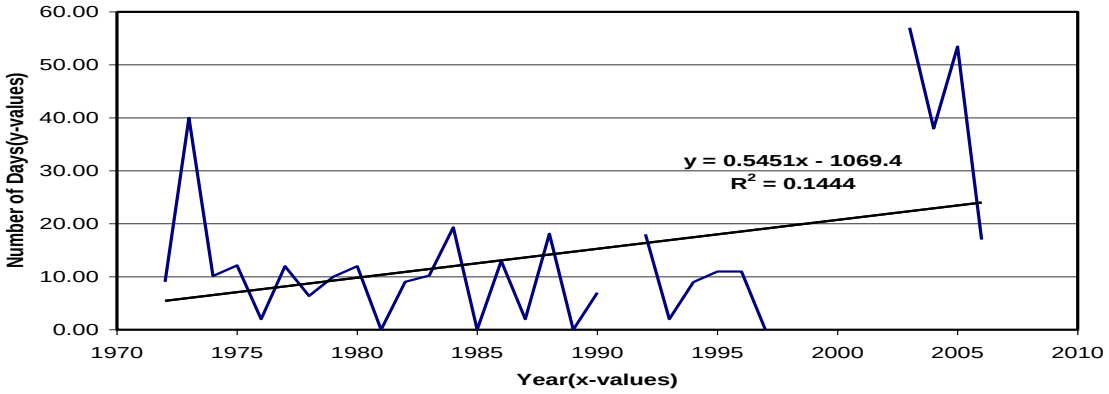



Index 003TnGE
Number of Days TMIN >= 11.01Deg.C(95th%)
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42
Number of Days(y-values)
Year(x-values)
y = 0.5454x - 1076.5
R² = 0.2629

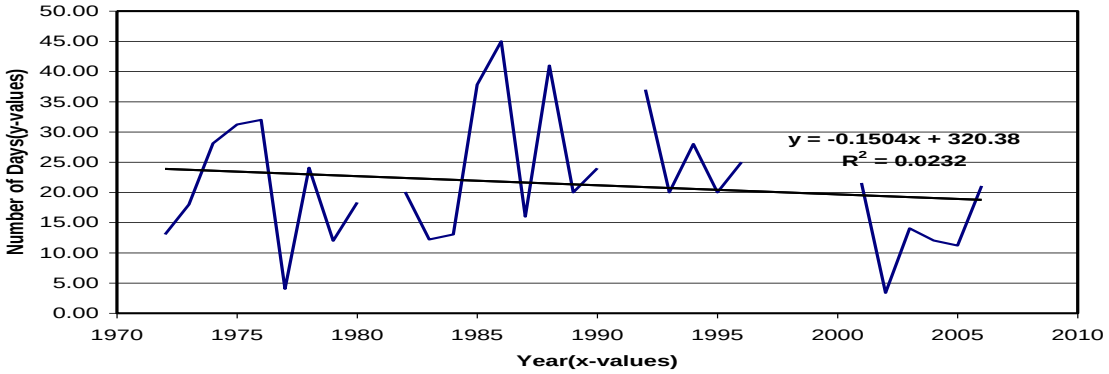

Index 004TnLE
Number of Days TMIN <= 3.8 Deg.c(5th%)
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42
Number of Days(y-values)
Year(x-values)
y = -0.6716x + 1354.9
R² = 0.1574


Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Fiche
Station ID: 11 Lat: 9.48 Lon: 38.42
Temperature Range (deg C)
Y-values
Year(x-values)
y = -0.0417x + 107.1
R² = 0.0174

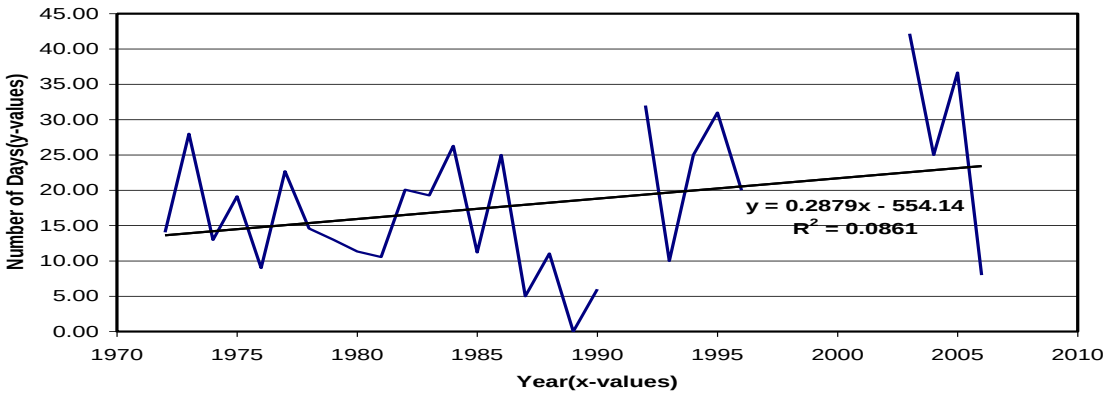
Index 001TxGE
Number of Days TMAX >= 31.5 Deg.C(95th%)
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25



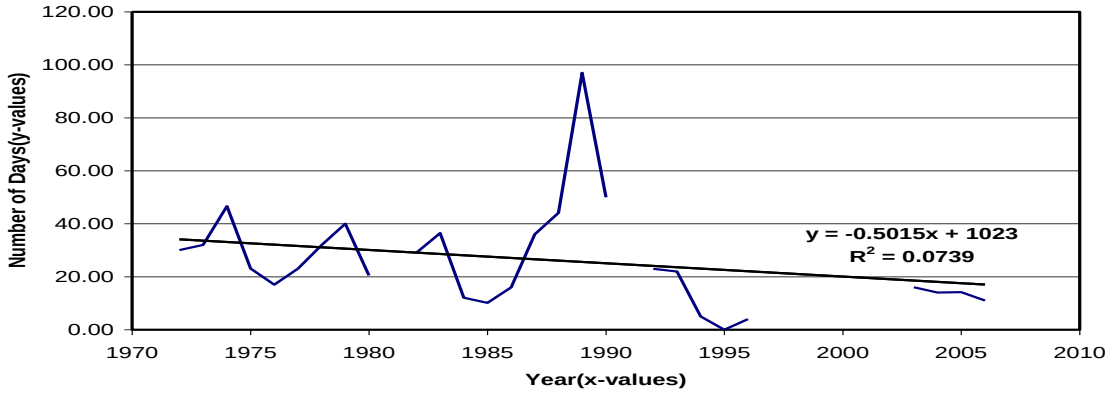
Index 002TxLE
Number of Days TMAX <= 22.1 Deg.C(5th%)
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25



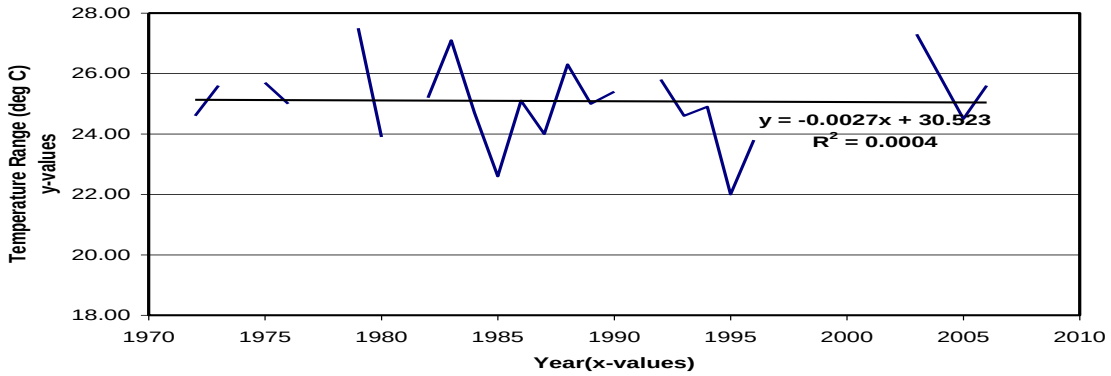
Index 003TnGE
Number of Days TMIN >= 17.1 Deg.c(95th%)
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25



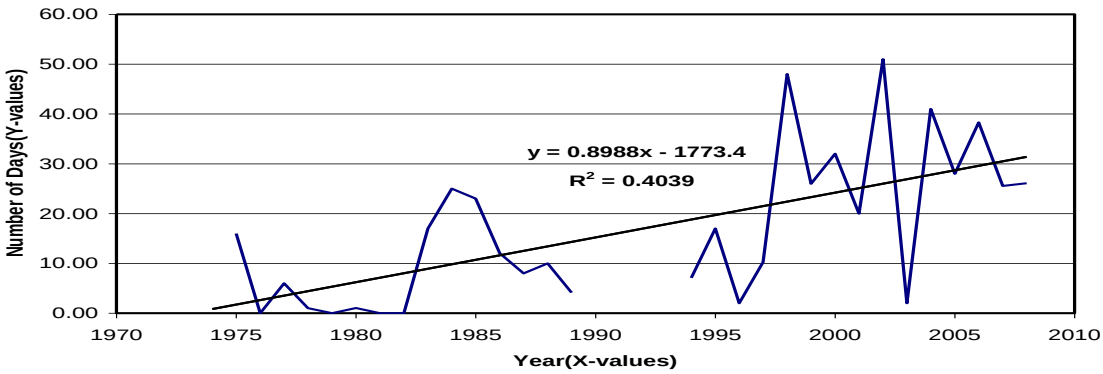
Index 004TnLE
Number of Days TMIN <= 10 Deg.C(5th%)
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25

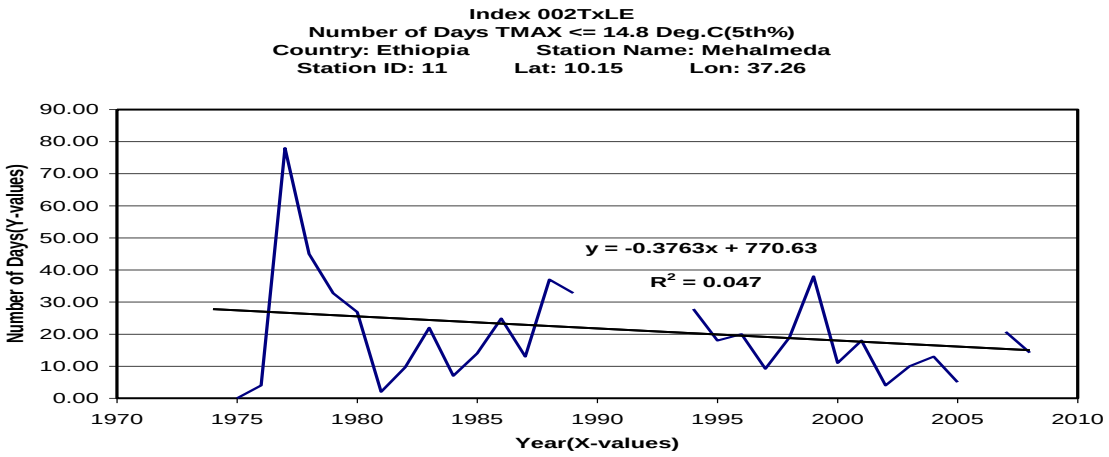


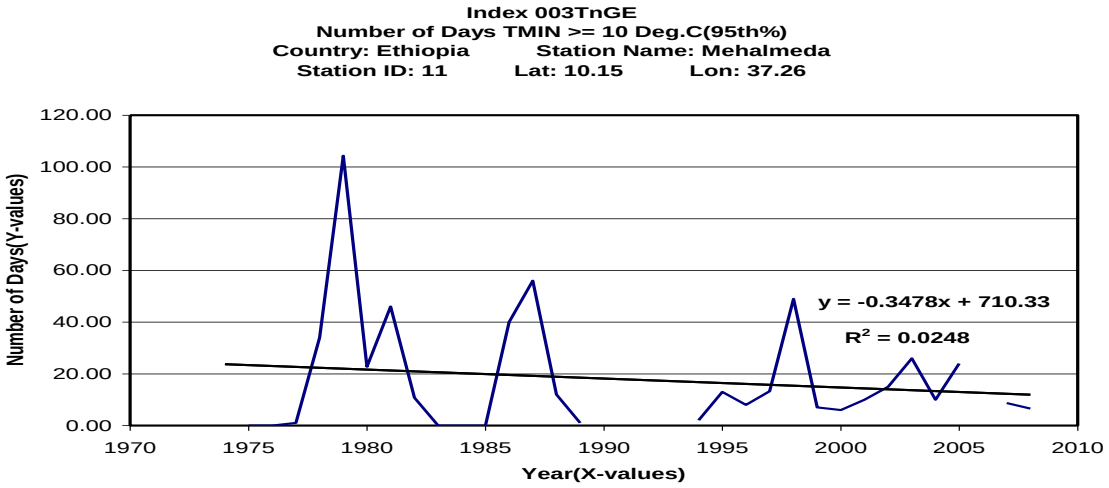
Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Gonder
Station ID: 12 Lat: 12.33 Lon: 37.25

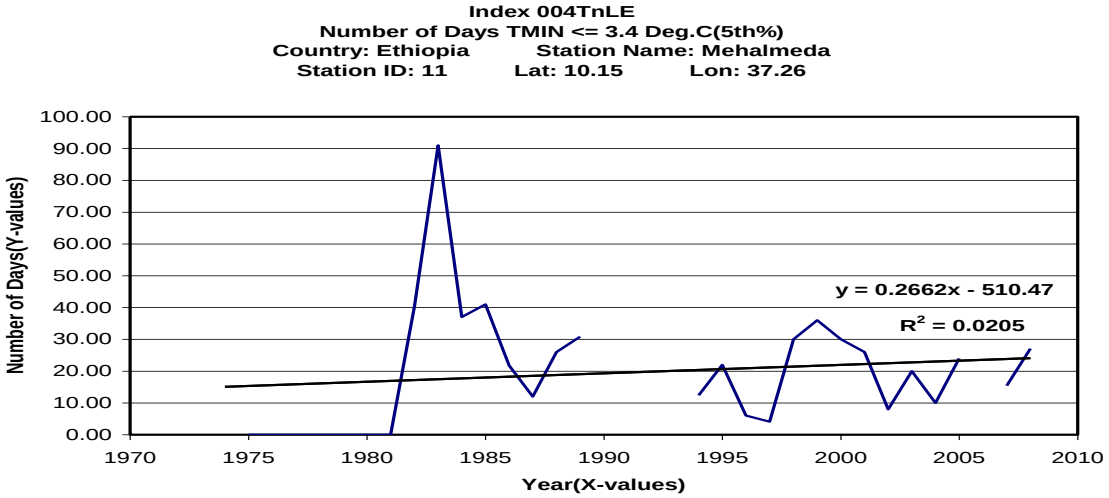


Index 001TxGE
Number of Days TMAX >= 21.1 Deg.C(95th%)
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26

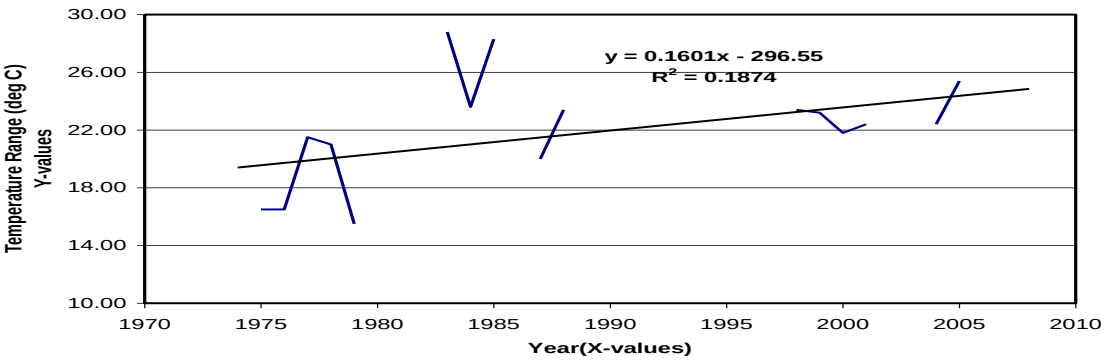



Index 002TxLE
Number of Days TMAX <= 14.8 Deg.C(5th%)
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26
y = -0.3763x + 770.63
R² = 0.047
Number of Days(Y-values)
Year(X-values)

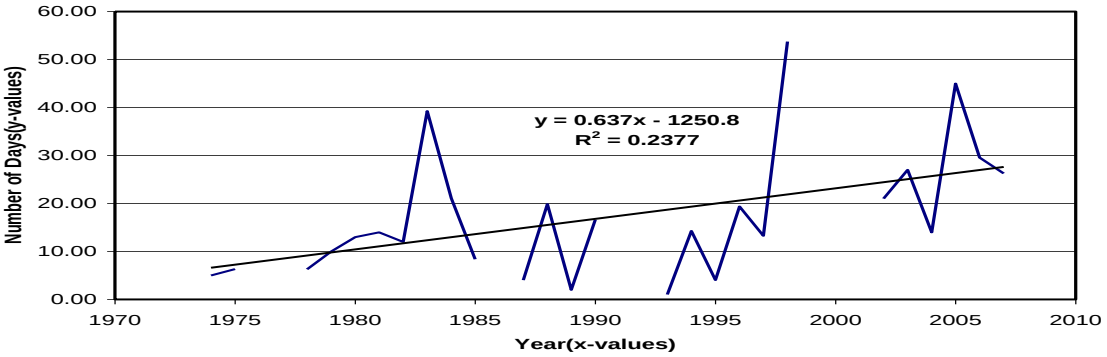

Index 003TnGE
Number of Days TMIN >= 10 Deg.C(95th%)
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26
y = -0.3478x + 710.33
R² = 0.0248
Number of Days(Y-values)
Year(X-values)


Index 004TnLE
Number of Days TMIN <= 3.4 Deg.C(5th%)
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26
y = 0.2662x - 510.47
R² = 0.0205
Number of Days(Y-values)
Year(X-values)

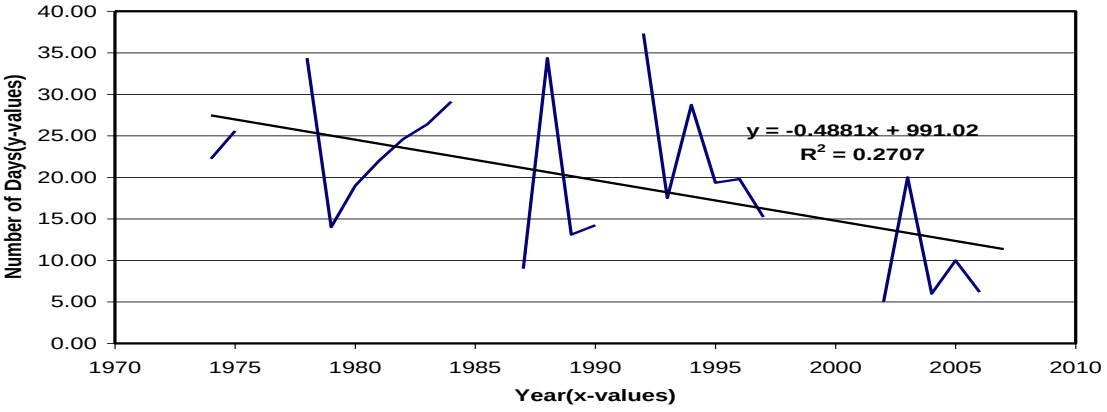
Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Mehalmeda
Station ID: 11 Lat: 10.15 Lon: 37.26



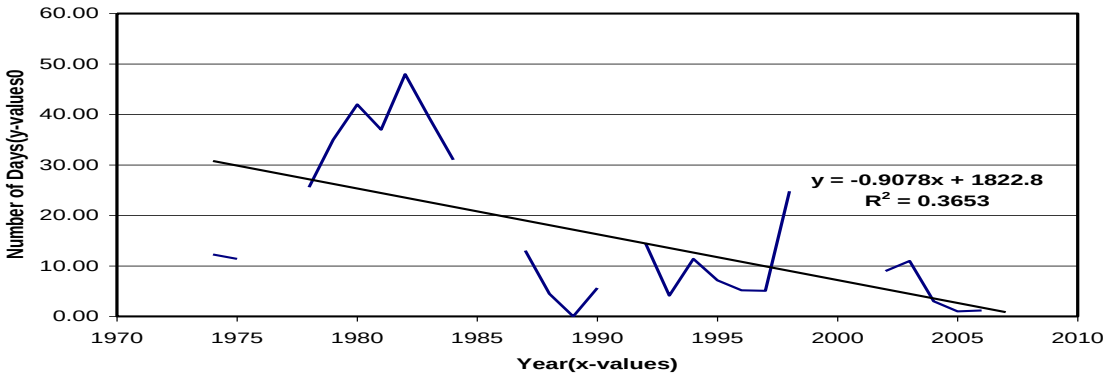
Index 001TxGE
Number of Days TMAX >= 30.51 Deg.C(95th%)
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37



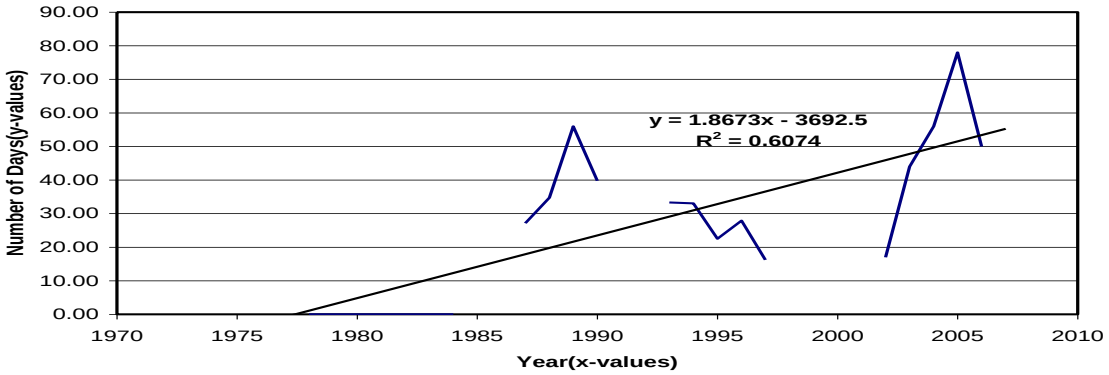
Index 002TxLE
Number of Days TMAX <= 21.1 Deg.C.(5th%)
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37



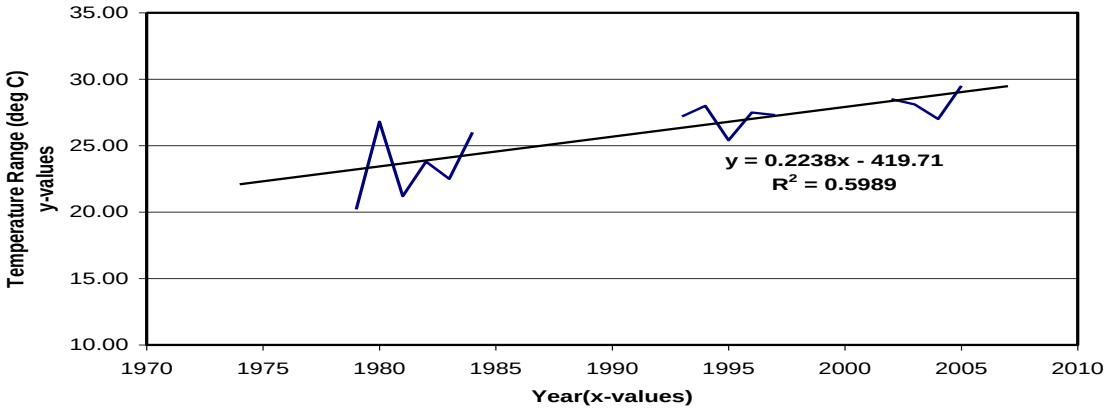
Index 003TnGE
Number of Days TMIN >= 15.8 Deg.C(95th%)
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37

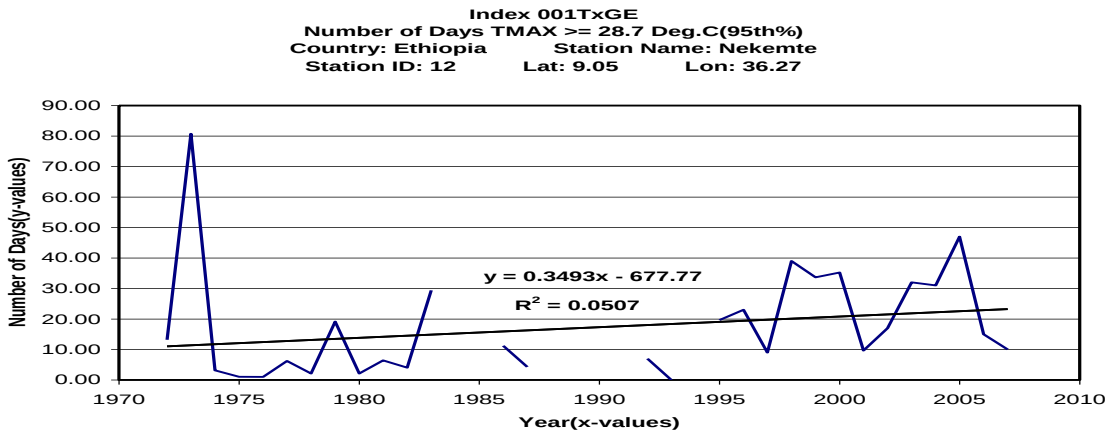


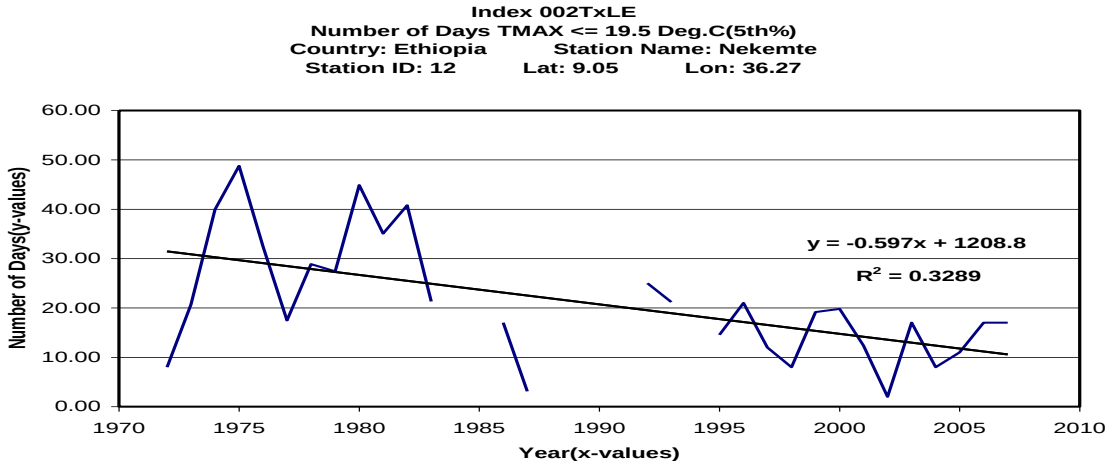
Index 004TnLE
Number of Days TMIN <= 8 Deg.C(5th%)
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37

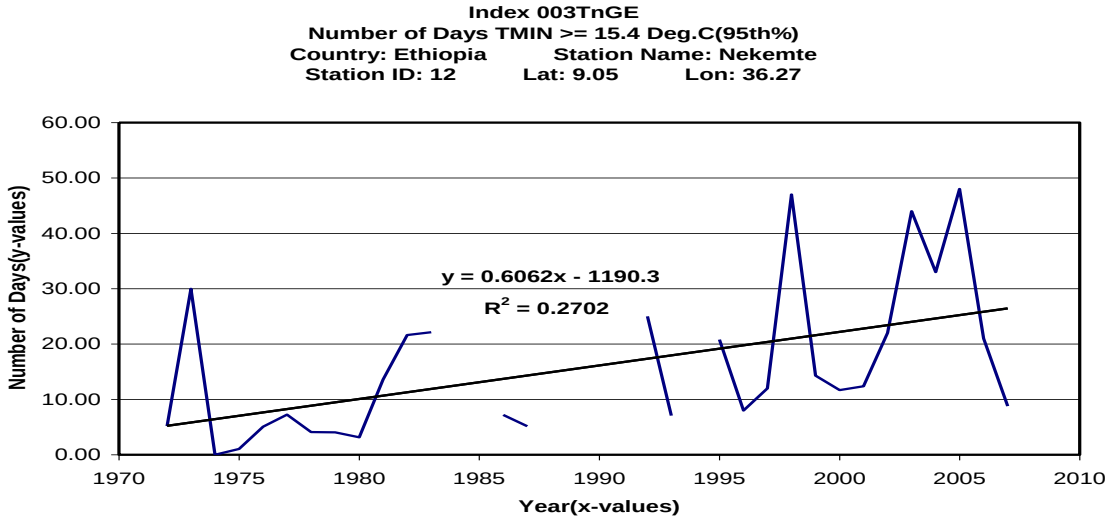


Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Nedjo
Station ID: 11 Lat: 9.3 Lon: 35.37

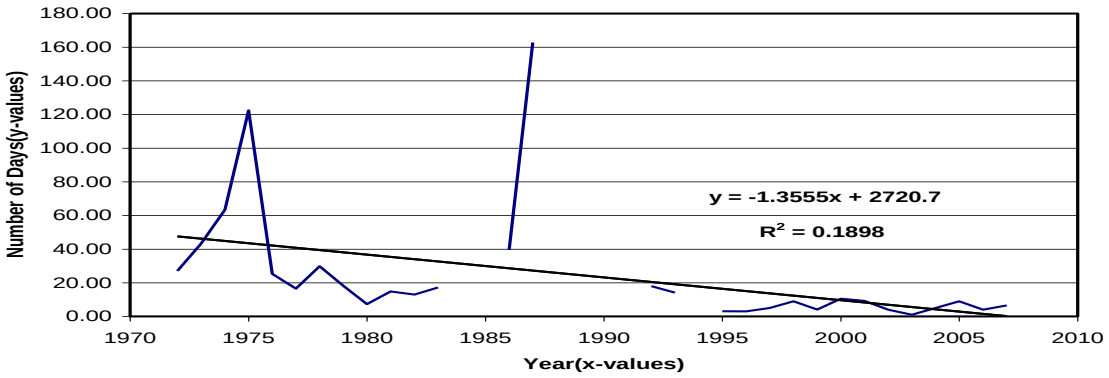



Index 001TxGE
Number of Days TMAX >= 28.7 Deg.C(95th%)
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27
y = 0.3493x - 677.77
R² = 0.0507
Number of Days(y-values)
Year(x-values)

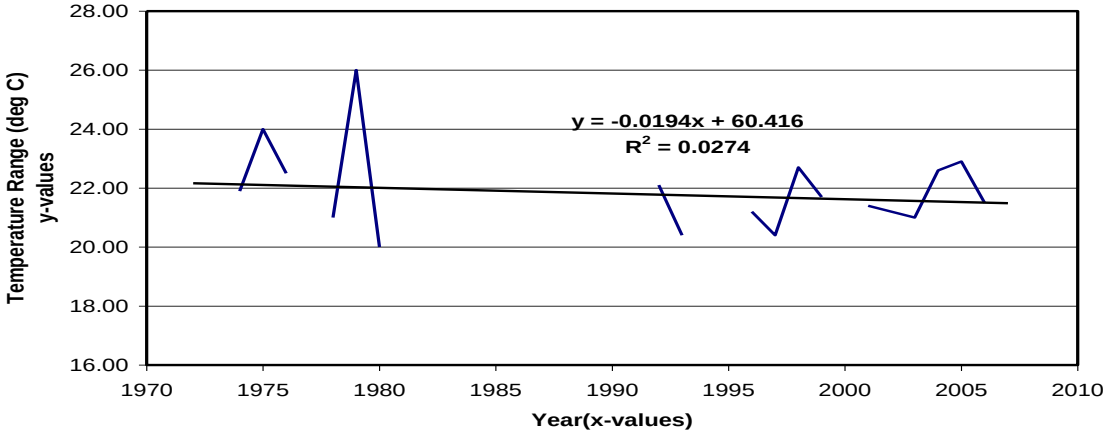

Index 002TxLE
Number of Days TMAX <= 19.5 Deg.C(5th%)
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27
y = -0.597x + 1208.8
R² = 0.3289
Number of Days(y-values)
Year(x-values)


Index 003TnGE
Number of Days TMIN >= 15.4 Deg.C(95th%)
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27
y = 0.6062x - 1190.3
R² = 0.2702
Number of Days(y-values)
Year(x-values)

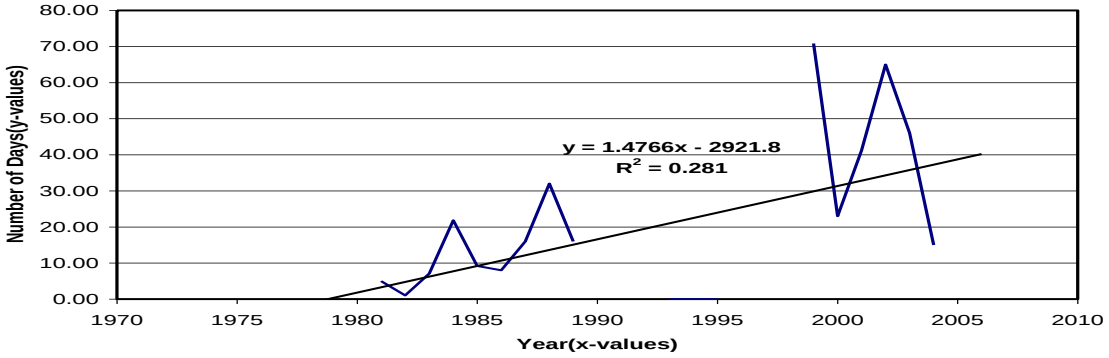
Index 004TnLE
Number of Days TMIN <= 10.2 Deg.C(5th%)
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27

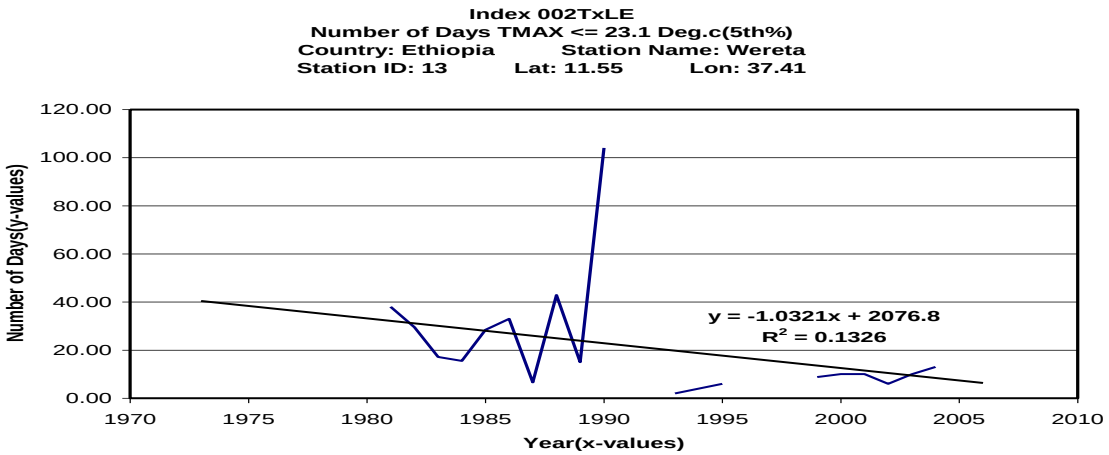


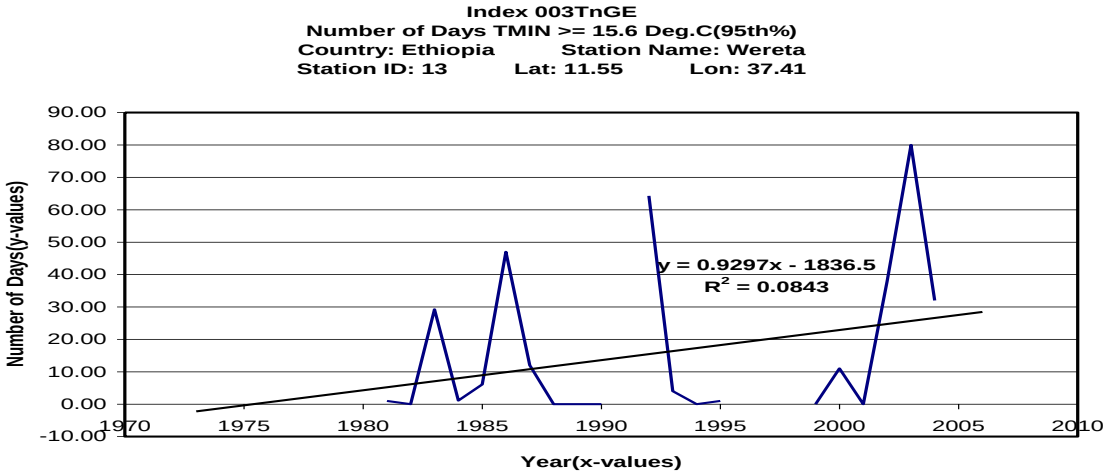
Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Nekemte
Station ID: 12 Lat: 9.05 Lon: 36.27

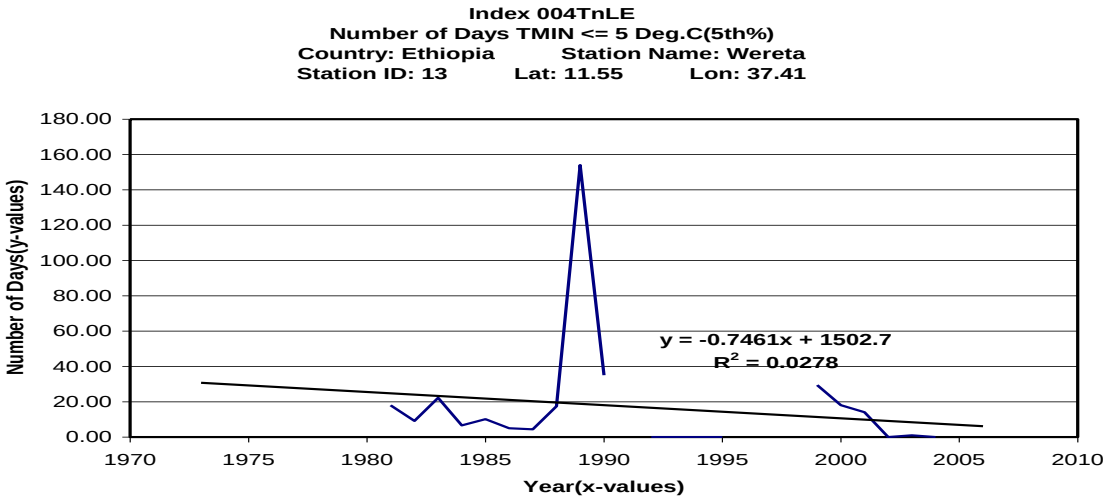


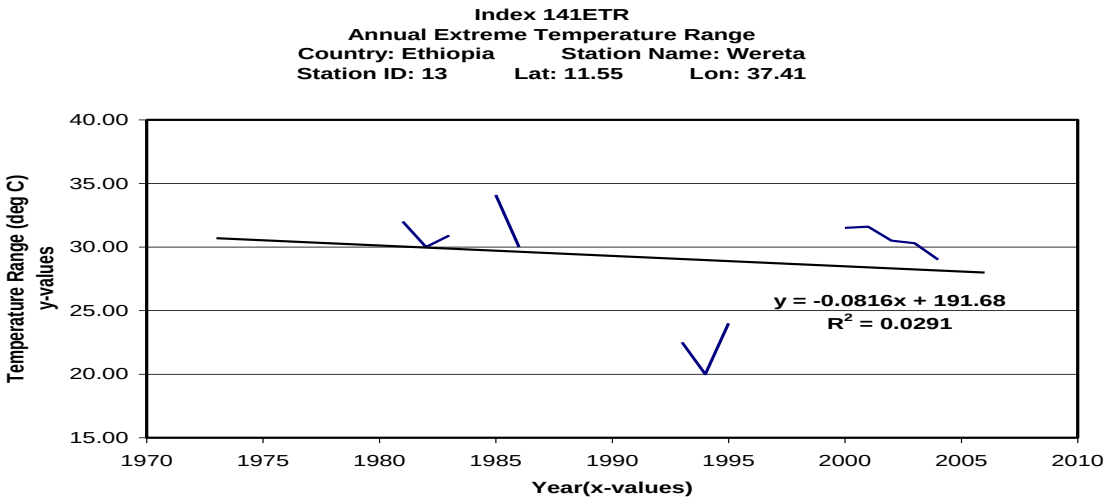
Index 001TxGE
Number of Days TMAX >= 32.5 Deg.C(95th%)
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41




Index 002TxLE
Number of Days TMAX <= 23.1 Deg.c(5th%)
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41
Number of Days(y-values)
Year(x-values)
y = -1.0321x + 2076.8
R² = 0.1326


Index 003TnGE
Number of Days TMIN >= 15.6 Deg.C(95th%)
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41
Number of Days(y-values)
Year(x-values)
y = 0.9297x - 1836.5
R² = 0.0843


Index 004TnLE
Number of Days TMIN <= 5 Deg.C(5th%)
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41
Number of Days(y-values)
Year(x-values)
y = -0.7461x + 1502.7
R² = 0.0278


Index 141ETR
Annual Extreme Temperature Range
Country: Ethiopia Station Name: Wereta
Station ID: 13 Lat: 11.55 Lon: 37.41
Temperature Range (deg C)
y-values
40.00
35.00
30.00
25.00
20.00
15.00
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year(x-values)
y = -0.0816x + 191.68
R² = 0.0291

APPENDIX C: GRAPHICAL RESULTS OF ANNUAL RAINFALL ANALYSIS

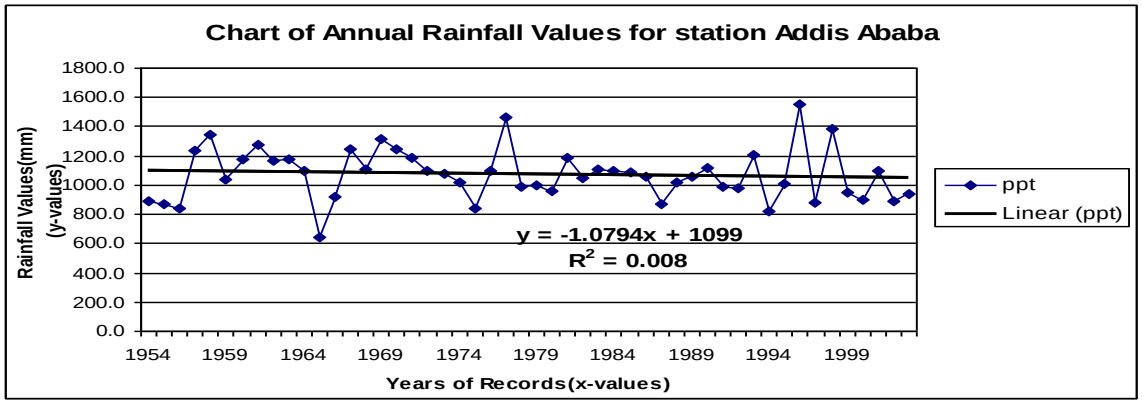


Chart of Annual Rainfall Values for station Addis Ababa
Rainfall Values(mm) (y-values)
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
1954
1959
1964
1969
1974
1979
1984
1989
1994
1999
Years of Records(x-values)
y = -1.0794x + 1099
R2 = 0.008
ppt
Linear (ppt)

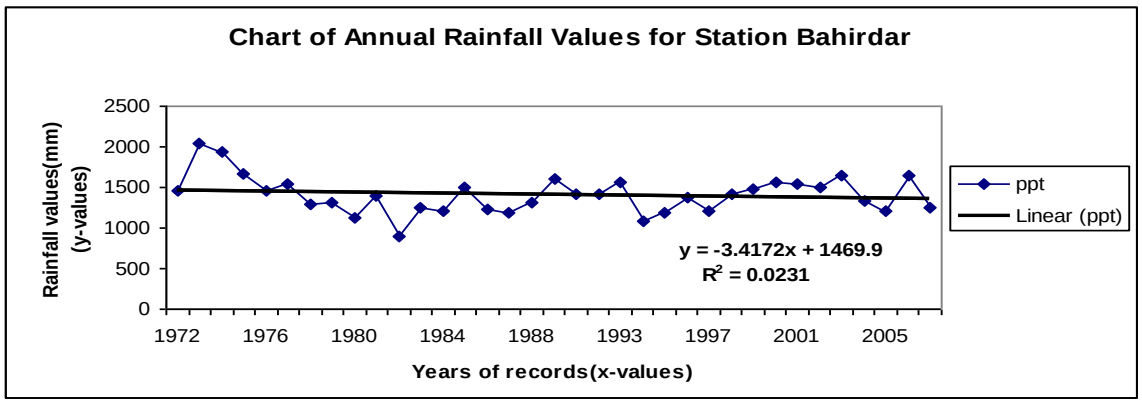


Chart of Annual Rainfall Values for Station Bahirdar
Rainfall values(mm) (y-values)
2500
2000
1500
1000
500
0
1972
1976
1980
1984
1988
1993
1997
2001
2005
Years of records(x-values)
y = -3.4172x + 1469.9
R2 = 0.0231
ppt
Linear (ppt)

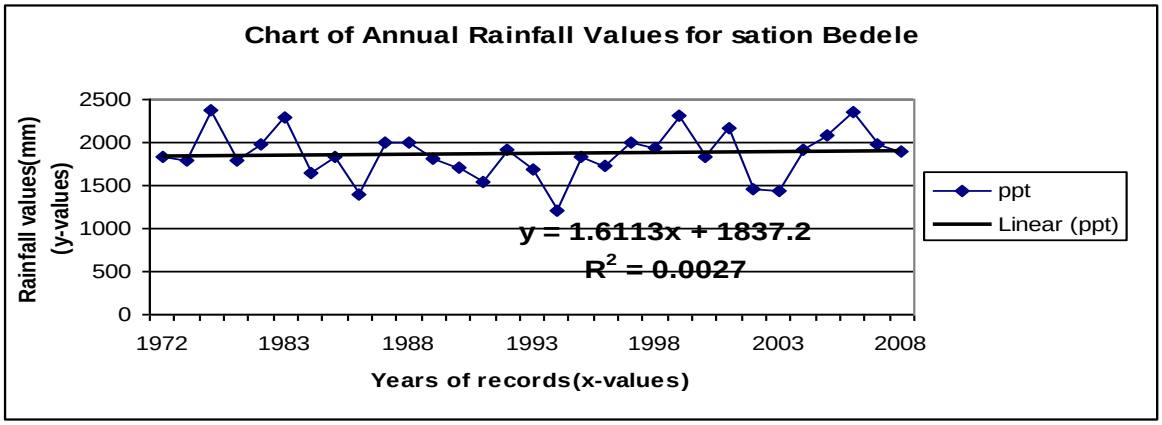


Chart of Annual Rainfall Values for sation Bedele
Rainfall values(mm) (y-values)
2500
2000
1500
1000
500
0
1972
1983
1988
1993
1998
2003
2008
Years of records(x-values)
y = 1.6113x + 1837.2
R2 = 0.0027
ppt
Linear (ppt)

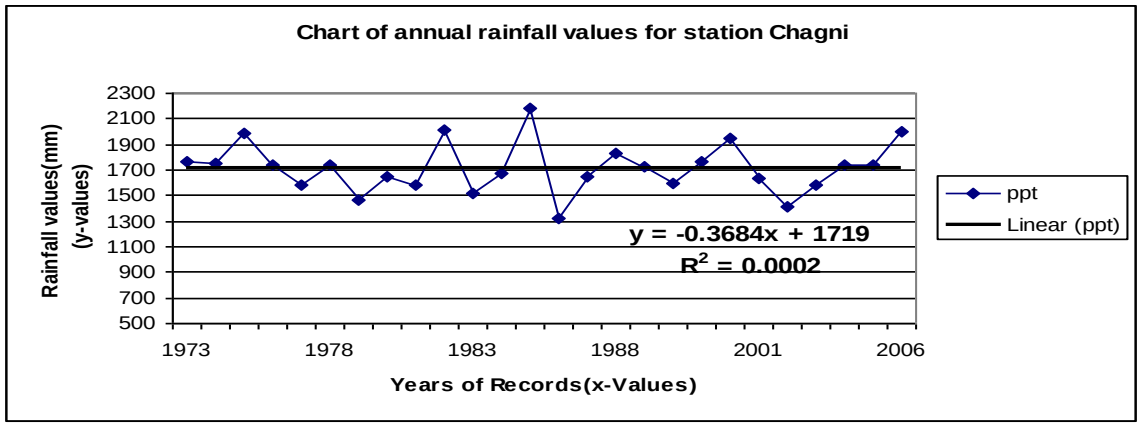


Chart of annual rainfall values for station Chagni
Rainfall values(mm) (y-values)
2300
2100
1900
1700
1500
1300
1100
900
700
500
1973
1978
1983
1988
2001
2006
Years of Records(x-Values)
y = -0.3684x + 1719
R2 = 0.0002
ppt
Linear (ppt)

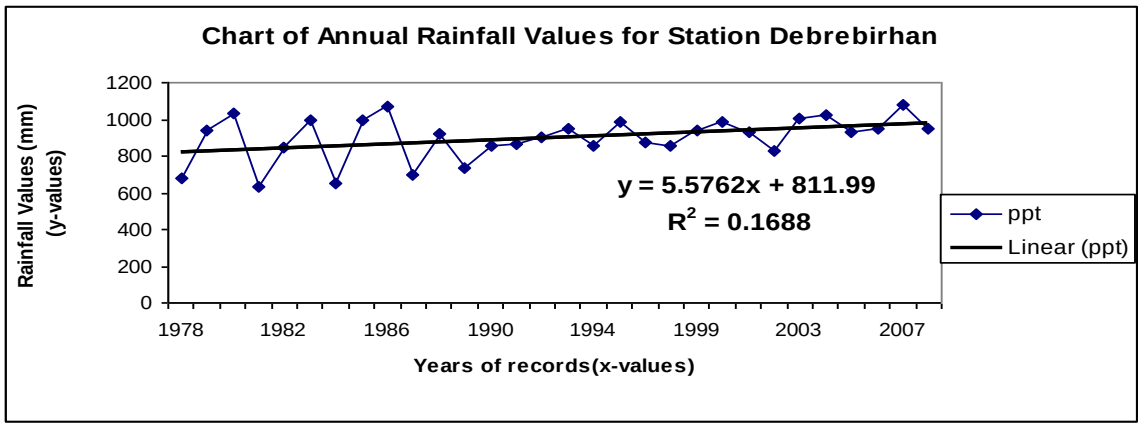


Chart of Annual Rainfall Values for Station Debrebirhan
Rainfall Values (mm) (y-values)
1200
1000
800
600
400
200
0
1978
1982
1986
1990
1994
1999
2003
2007
Years of records(x-values)
y = 5.5762x + 811.99
R2 = 0.1688
ppt
Linear (ppt)

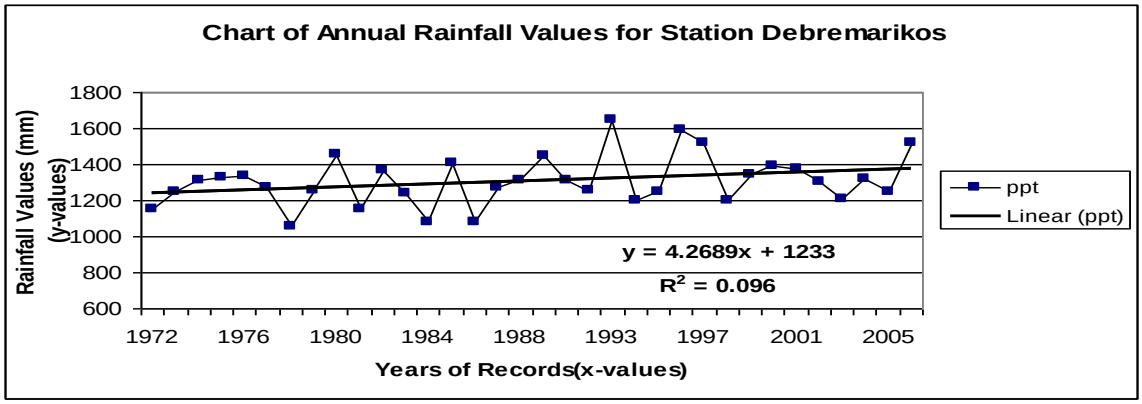


Chart of Annual Rainfall Values for Station Debremarikos
Rainfall Values (mm) (y-values)
1800
1600
1400
1200
1000
800
600
1972
1976
1980
1984
1988
1993
1997
2001
2005
Years of Records(x-values)
y = 4.2689x + 1233
R2 = 0.096
ppt
Linear (ppt)

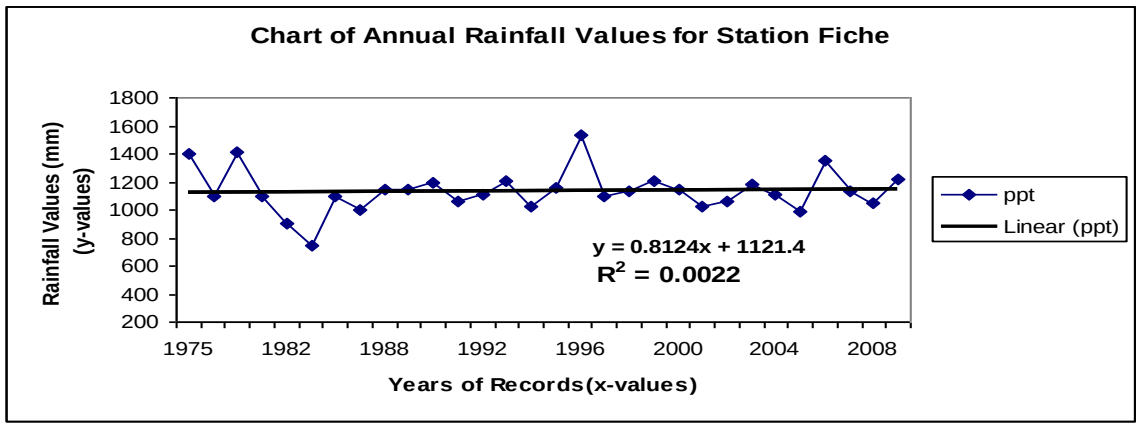


Chart of Annual Rainfall Values for Station Fiche
Rainfall Values (mm) (y-values)
1800
1600
1400
1200
1000
800
600
400
200
1975
1982
1988
1992
1996
2000
2004
2008
Years of Records(x-values)
y = 0.8124x + 1121.4
R2 = 0.0022
ppt
Linear (ppt)

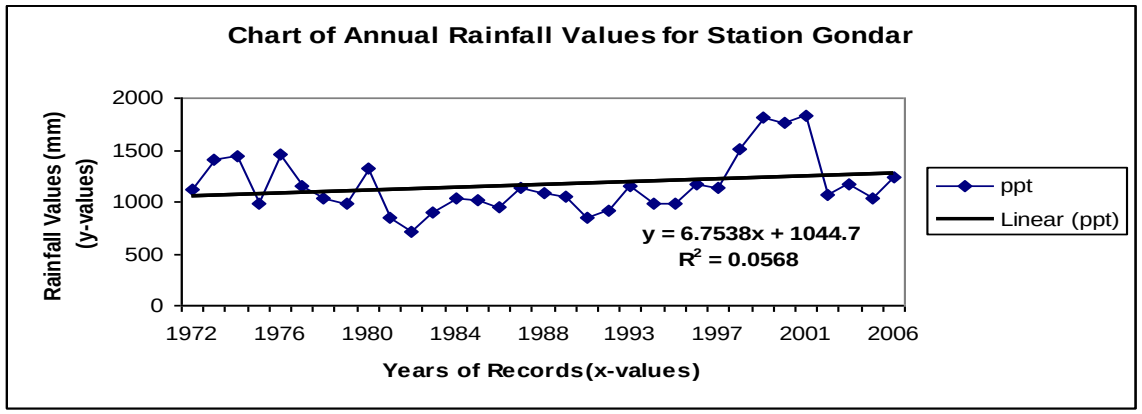


Chart of Annual Rainfall Values for Station Gondar
Rainfall Values (mm) (y-values)
2000
1500
1000
500
0
1972
1976
1980
1984
1988
1993
1997
2001
2006
Years of Records(x-values)
y = 6.7538x + 1044.7
R2 = 0.0568
ppt
Linear (ppt)

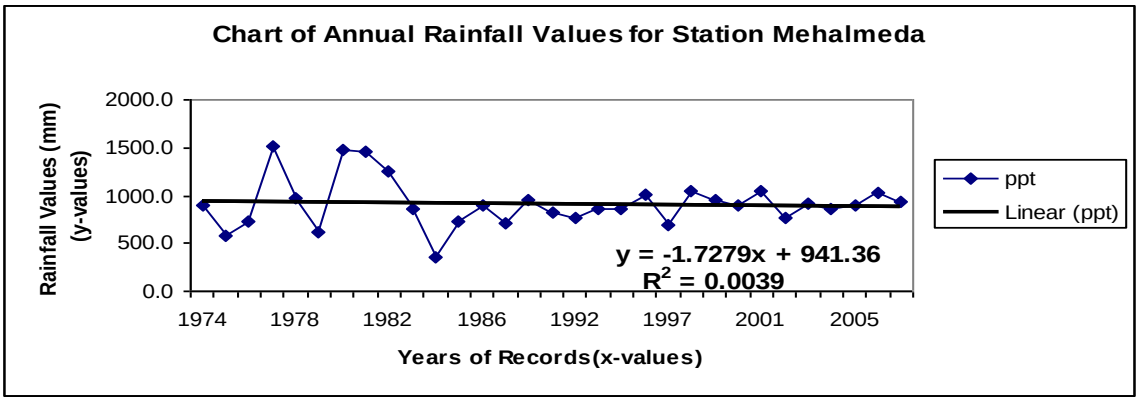


Chart of Annual Rainfall Values for Station Mehalmeda
Rainfall Values (mm) (y-values)
2000.0
1500.0
1000.0
500.0
0.0
1974
1978
1982
1986
1992
1997
2001
2005
Years of Records(x-values)
y = -1.7279x + 941.36
R2 = 0.0039
ppt
Linear (ppt)

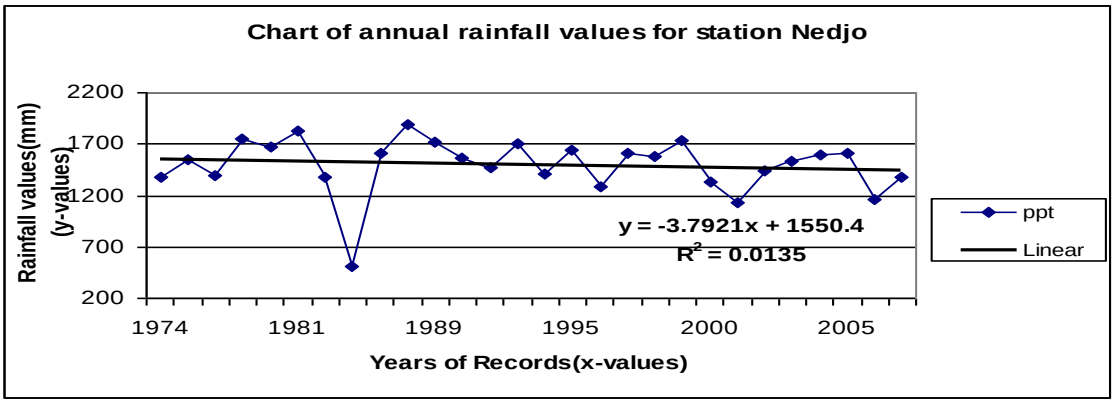


Chart of annual rainfall values for station Nedjo
Rainfall values(mm) (y-values)
2200
1700
1200
700
200
1974
1981
1989
1995
2000
2005
Years of Records(x-values)
y = -3.7921x + 1550.4
R2 = 0.0135
ppt
Linear

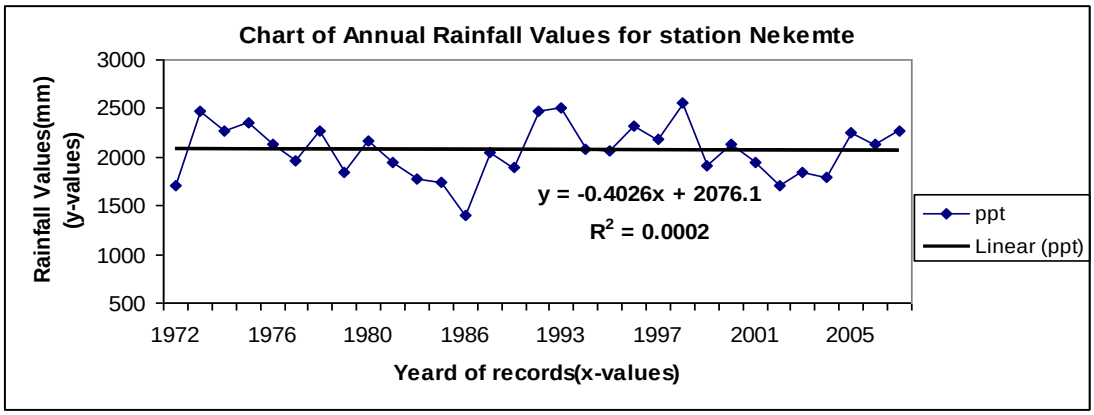


Chart of Annual Rainfall Values for station Nekemte
Rainfall Values(mm) (y-values)
3000
2500
2000
1500
1000
500
1972
1976
1980
1986
1993
1997
2001
2005
Yeard of records(x-values)
y = -0.4026x + 2076.1
R2 = 0.0002
ppt
Linear (ppt)

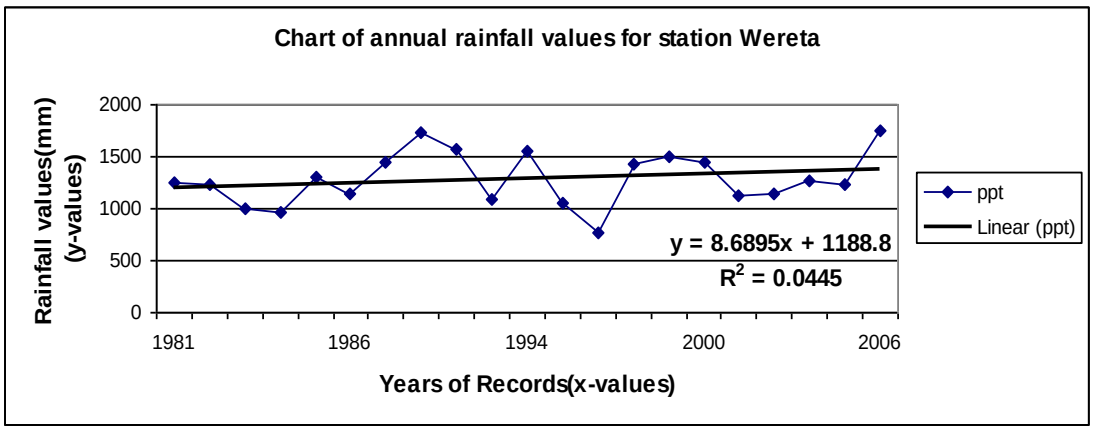


Chart of annual rainfall values for station Wereta
Rainfall values(mm) (y-values)
2000
1500
1000
500
0
1981
1986
1994
2000
2006
Years of Records(x-values)
y = 8.6895x + 1188.8
R2 = 0.0445
ppt
Linear (ppt)

APPENDIX D: GRAPHICAL RESULTS OF ANNUAL TEMPERATURES ANALYSIS

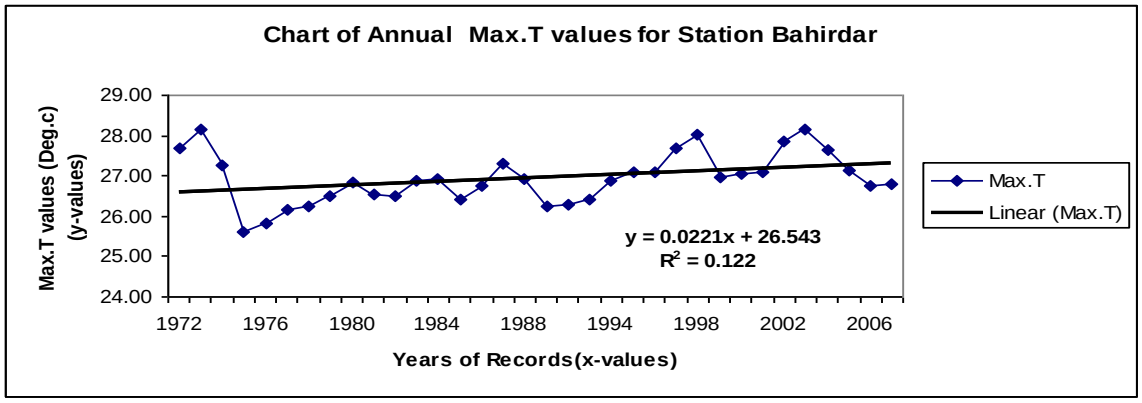


Chart of Annual Max.T values for Station Bahirdar
Max.T values (Deg.c) (y-values)
29.00
28.00
27.00
26.00
25.00
24.00
1972
1976
1980
1984
1988
1994
1998
2002
2006
Years of Records(x-values)
y = 0.0221x + 26.543
R2 = 0.122
Max.T
Linear (Max.T)

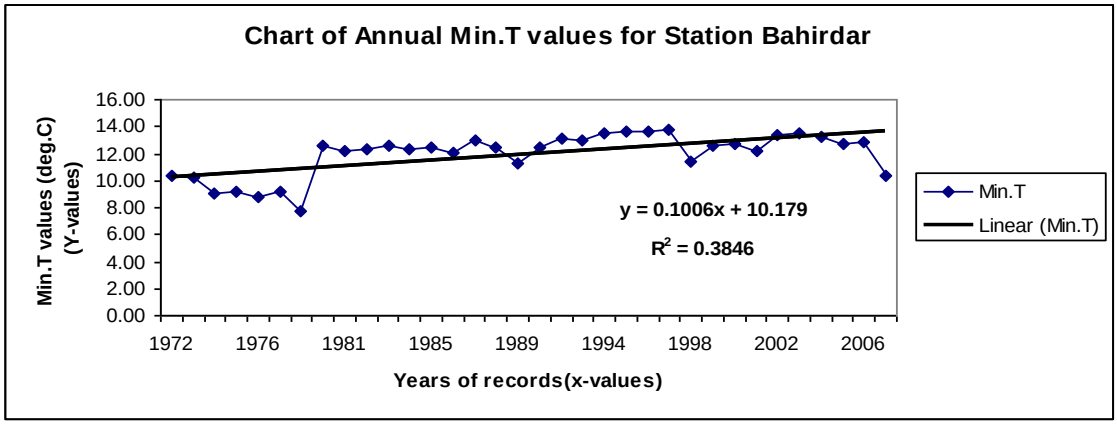


Chart of Annual Min.T values for Station Bahirdar
Min.T values (deg.C) (Y-values)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1972
1976
1981
1985
1989
1994
1998
2002
2006
Years of records(x-values)
y = 0.1006x + 10.179
R2 = 0.3846
Min.T
Linear (Min.T)

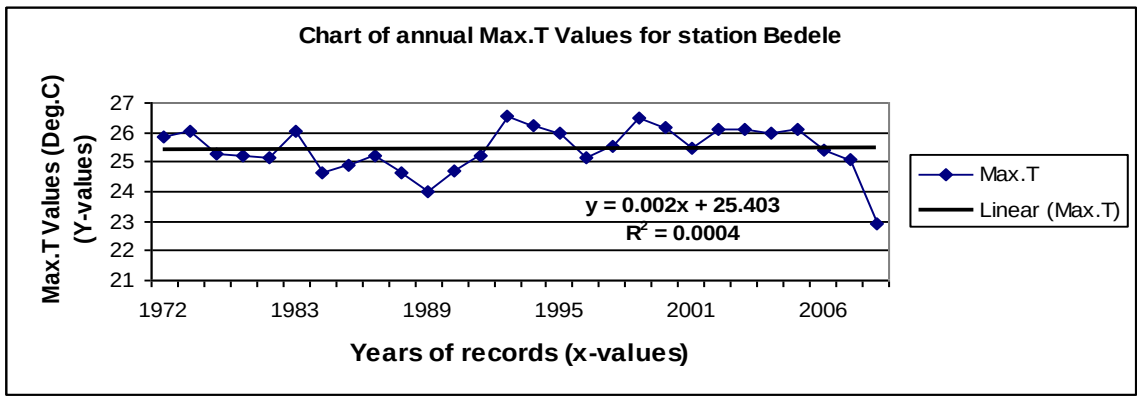


Chart of annual Max.T Values for station Bedele
Max.T Values (Deg.C) (Y-values)
27
26
25
24
23
22
21
1972
1983
1989
1995
2001
2006
Years of records (x-values)
y = 0.002x + 25.403
R2 = 0.0004
Max.T
Linear (Max.T)

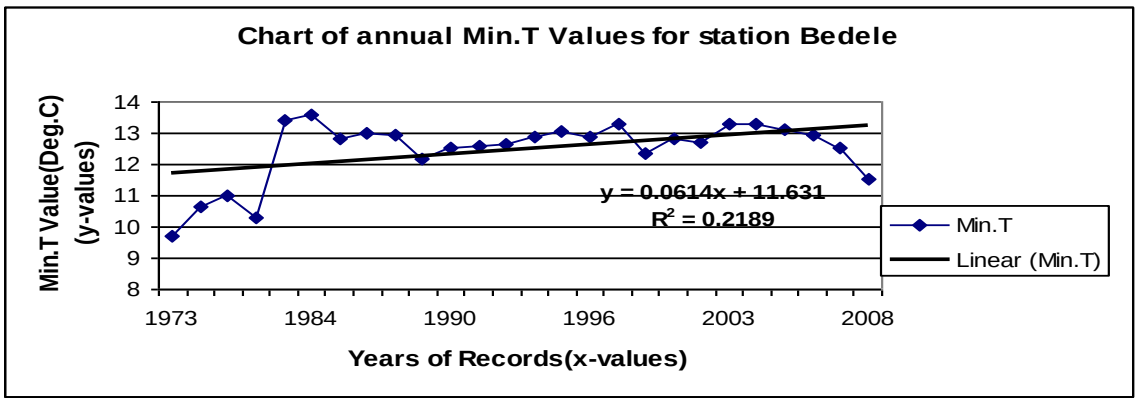


Chart of annual Min.T Values for station Bedele
Min.T Value(Deg.C) (y-values)
14
13
12
11
10
9
8
1973
1984
1990
1996
2003
2008
Years of Records(x-values)
y = 0.0614x + 11.631
R2 = 0.2189
Min.T
Linear (Min.T)

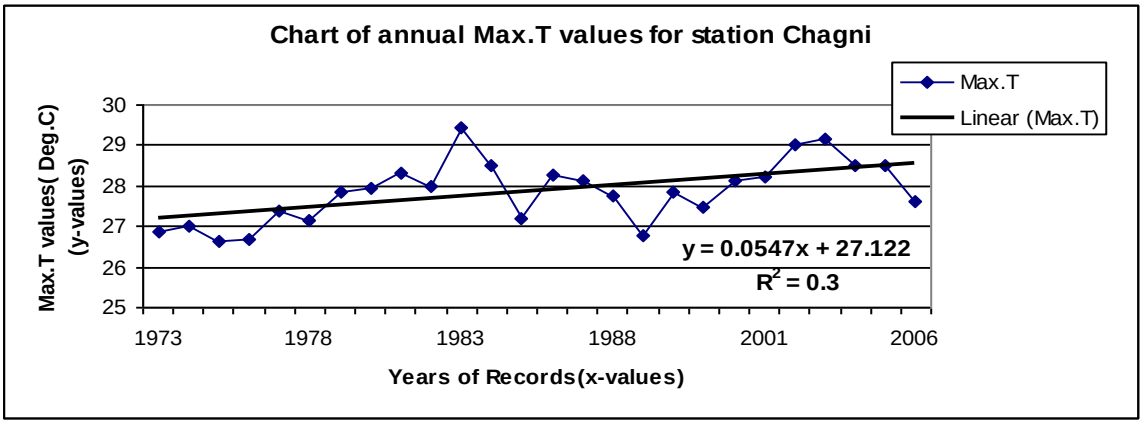


Chart of annual Max.T values for station Chagni
Max.T values(Deg.C) (y-values)
30
29
28
27
26
25
1973
1978
1983
1988
2001
2006
Years of Records(x-values)
Max.T
Linear (Max.T)
y = 0.0547x + 27.122
R2 = 0.3

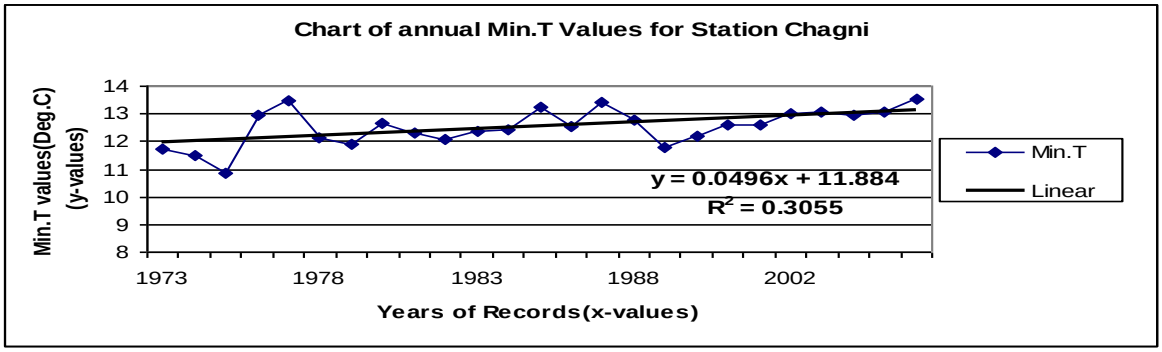


Chart of annual Min.T Values for Station Chagni
Min.T values(Deg.C) (y-values)
14
13
12
11
10
9
8
1973
1978
1983
1988
2002
Years of Records(x-values)
Min.T
Linear
y = 0.0496x + 11.884
R2 = 0.3055

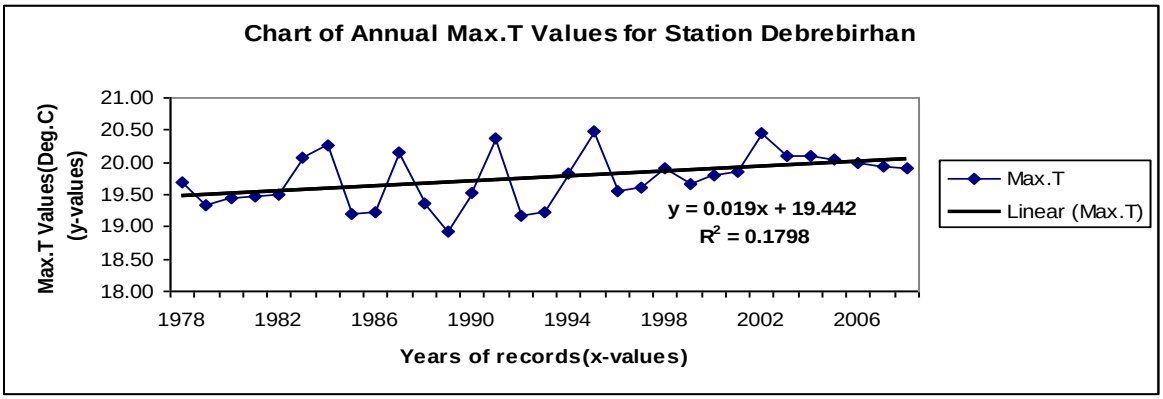


Chart of Annual Max.T Values for Station Debrebirhan
Max.T Values(Deg.C) (y-values)
21.00
20.50
20.00
19.50
19.00
18.50
18.00
1978
1982
1986
1990
1994
1998
2002
2006
Years of records(x-values)
Max.T
Linear (Max.T)
y = 0.019x + 19.442
R2 = 0.1798

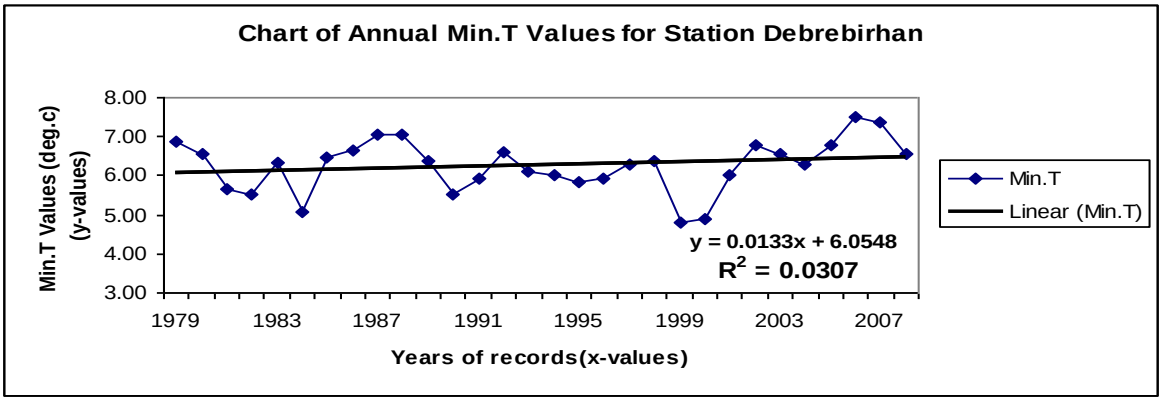


Chart of Annual Min.T Values for Station Debrebirhan
Min.T Values (deg.c) (y-values)
8.00
7.00
6.00
5.00
4.00
3.00
1979
1983
1987
1991
1995
1999
2003
2007
Years of records(x-values)
Min.T
Linear (Min.T)
y = 0.0133x + 6.0548
R2 = 0.0307

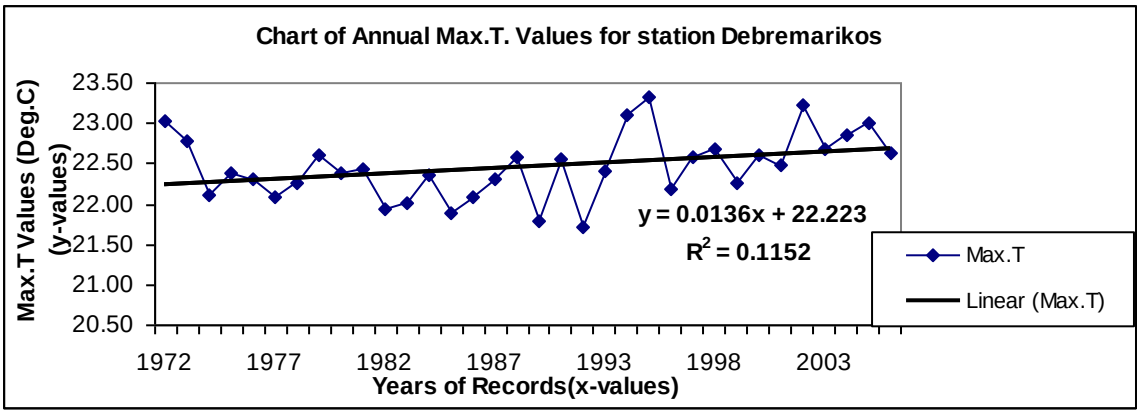


Chart of Annual Max.T. Values for station Debremarikos
Max.T Values (Deg.C) (y-values)
23.50
23.00
22.50
22.00
21.50
21.00
20.50
1972
1977
1982
1987
1993
1998
2003
Years of Records(x-values)
y = 0.0136x + 22.223
R2 = 0.1152
Max.T
Linear (Max.T)

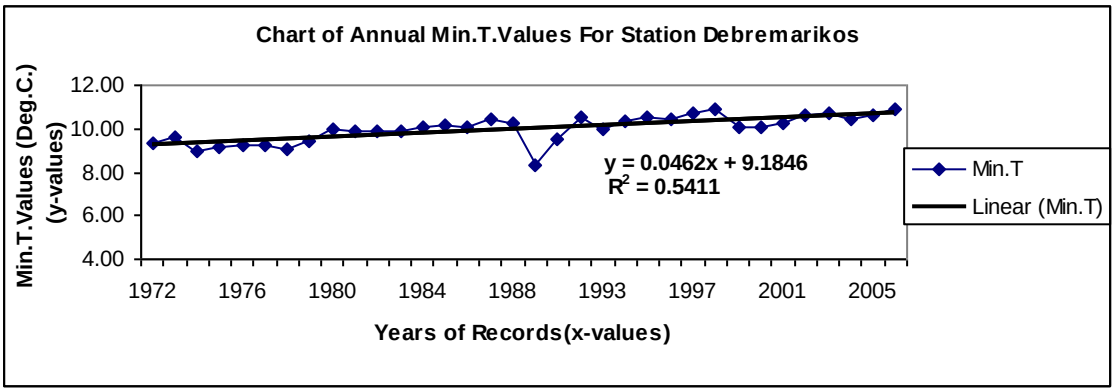


Chart of Annual Min.T.Values For Station Debremarikos
Min.T.Values (Deg.C.) (y-values)
12.00
10.00
8.00
6.00
4.00
1972
1976
1980
1984
1988
1993
1997
2001
2005
Years of Records(x-values)
y = 0.0462x + 9.1846
R2 = 0.5411
Min.T
Linear (Min.T)

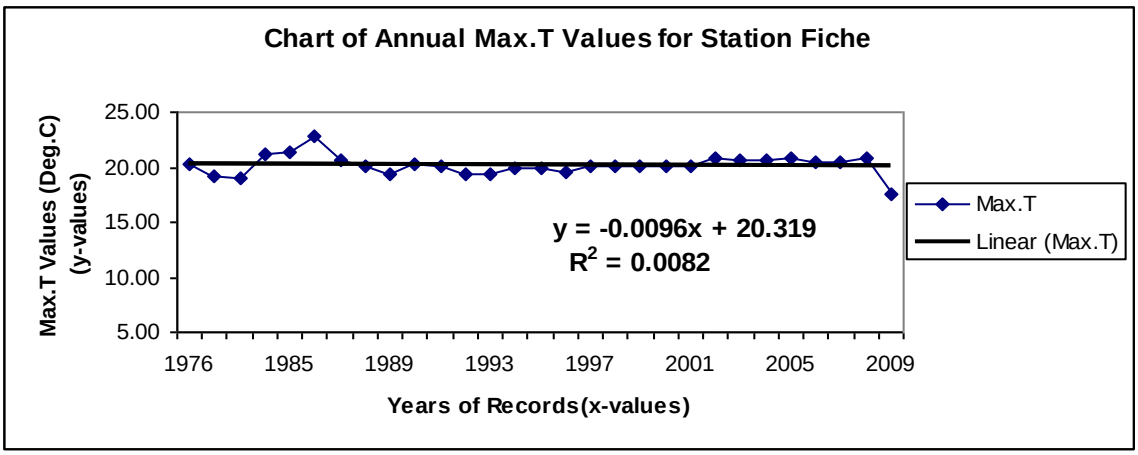


Chart of Annual Max.T Values for Station Fiche
Max.T Values (Deg.C) (y-values)
25.00
20.00
15.00
10.00
5.00
1976
1985
1989
1993
1997
2001
2005
2009
Years of Records(x-values)
y = -0.0096x + 20.319
R2 = 0.0082
Max.T
Linear (Max.T)

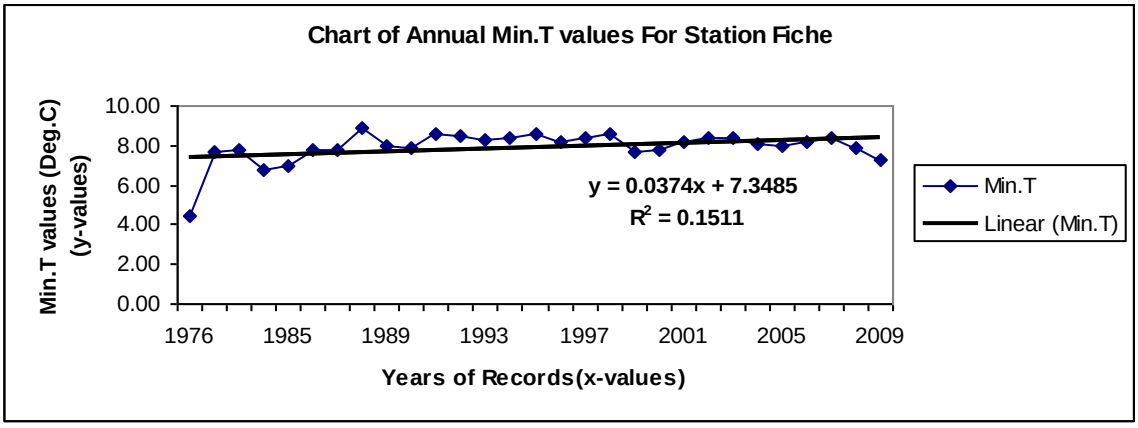


Chart of Annual Min.T values For Station Fiche
Min.T values (Deg.C) (y-values)
10.00
8.00
6.00
4.00
2.00
0.00
1976
1985
1989
1993
1997
2001
2005
2009
Years of Records(x-values)
y = 0.0374x + 7.3485
R2 = 0.1511
Min.T
Linear (Min.T)

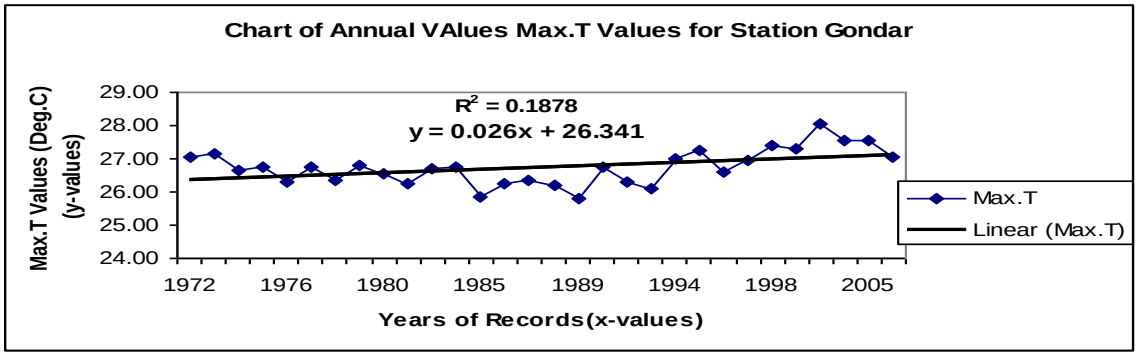


Chart of Annual VAlues Max.T Values for Station Gondar
Max.T Values (Deg.C) (y-values)
29.00
28.00
27.00
26.00
25.00
24.00
R^2 = 0.1878
y = 0.026x + 26.341
1972
1976
1980
1985
1989
1994
1998
2005
Years of Records(x-values)
Max.T
Linear (Max.T)

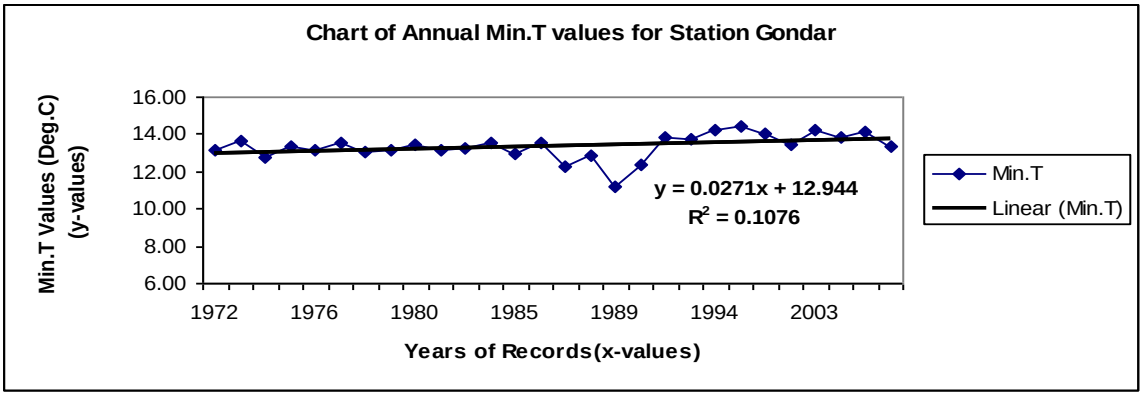


Chart of Annual Min.T values for Station Gondar
Min.T Values (Deg.C) (y-values)
16.00
14.00
12.00
10.00
8.00
6.00
y = 0.0271x + 12.944
R^2 = 0.1076
1972
1976
1980
1985
1989
1994
2003
Years of Records(x-values)
Min.T
Linear (Min.T)

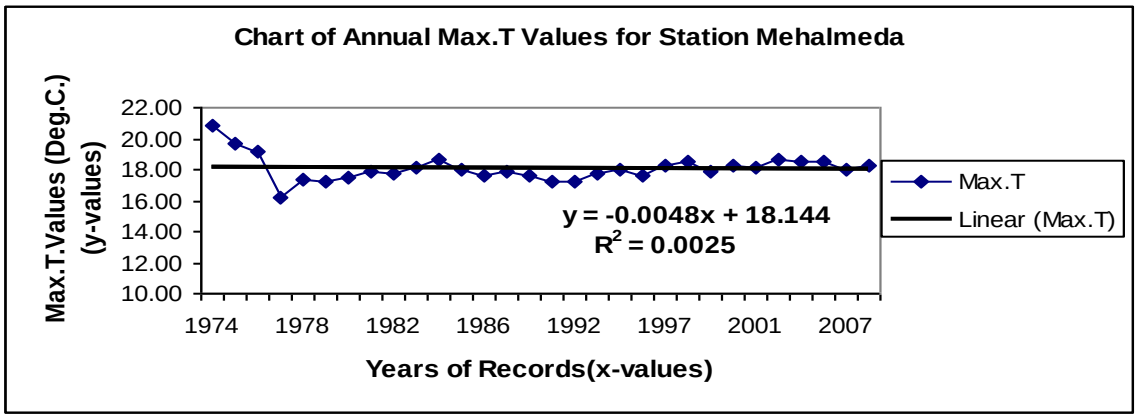


Chart of Annual Max.T Values for Station Mehalmeda
Max.T.Values (Deg.C.) (y-values)
22.00
20.00
18.00
16.00
14.00
12.00
10.00
y = -0.0048x + 18.144
R^2 = 0.0025
1974
1978
1982
1986
1992
1997
2001
2007
Years of Records(x-values)
Max.T
Linear (Max.T)

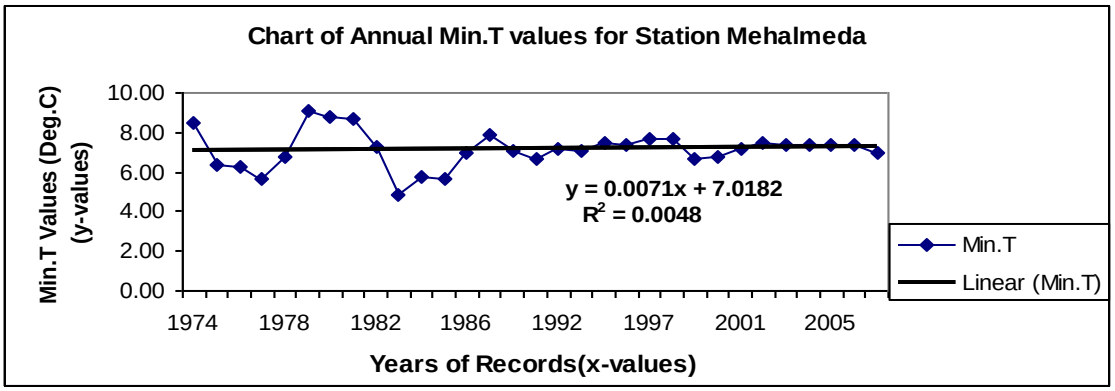


Chart of Annual Min.T values for Station Mehalmeda
Min.T Values (Deg.C) (y-values)
10.00
8.00
6.00
4.00
2.00
0.00
y = 0.0071x + 7.0182
R^2 = 0.0048
1974
1978
1982
1986
1992
1997
2001
2005
Years of Records(x-values)
Min.T
Linear (Min.T)

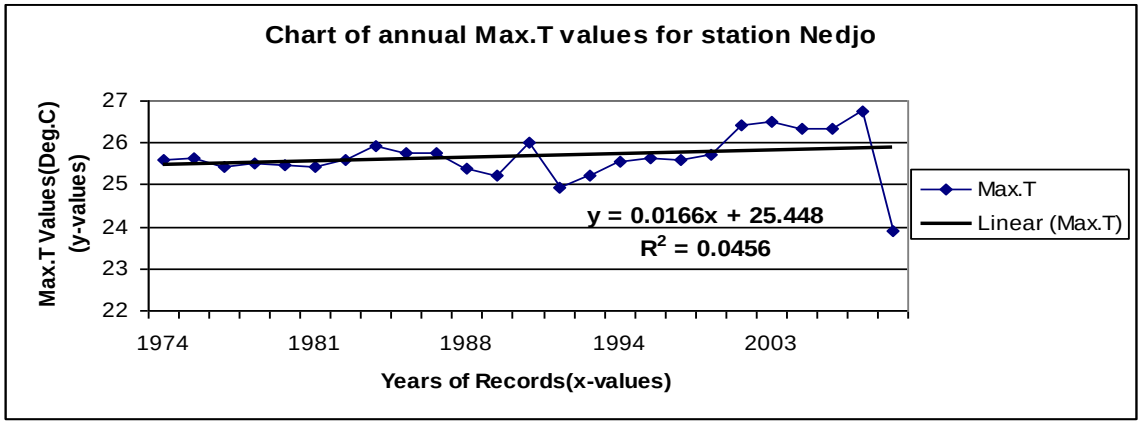


Chart of annual Max.T values for station Nedjo
Max.T Values(Deg.C) (y-values)
27
26
25
24
23
22
1974
1981
1988
1994
2003
Years of Records(x-values)
y = 0.0166x + 25.448
R2 = 0.0456
Max.T
Linear (Max.T)

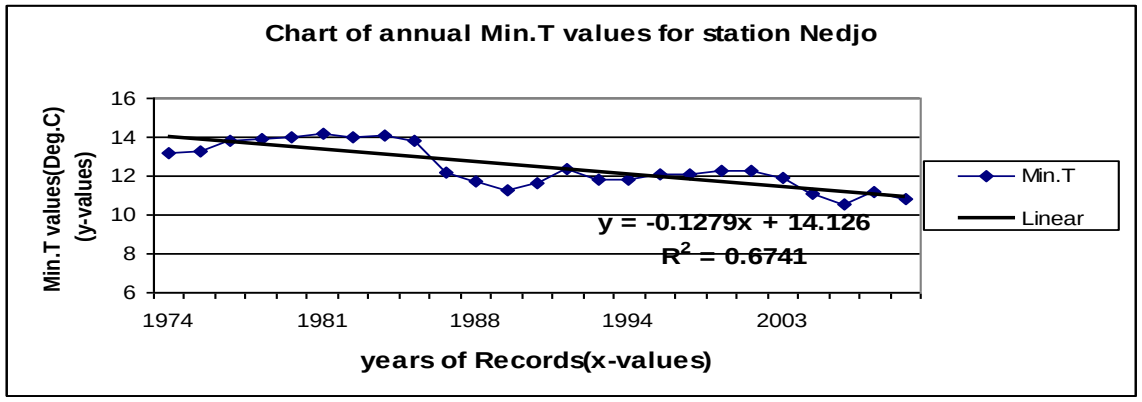


Chart of annual Min.T values for station Nedjo
Min.T values(Deg.C) (y-values)
16
14
12
10
8
6
1974
1981
1988
1994
2003
years of Records(x-values)
y = -0.1279x + 14.126
R2 = 0.6741
Min.T
Linear

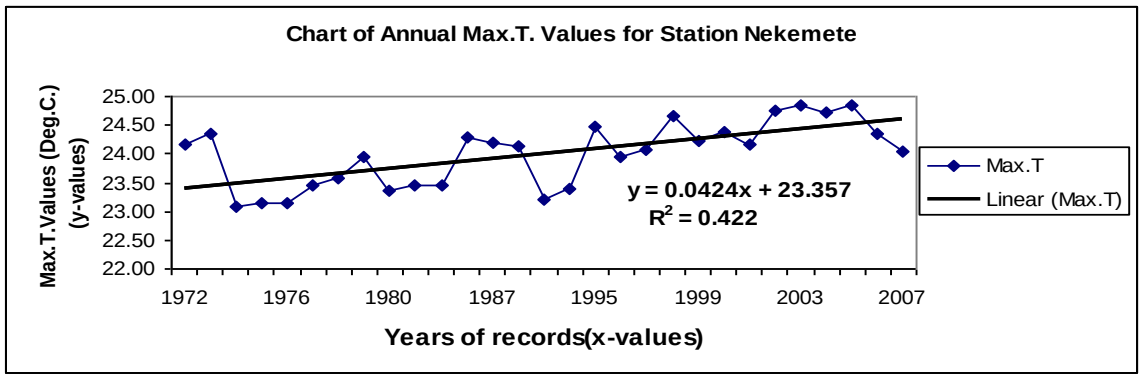


Chart of Annual Max.T. Values for Station Nekemete
Max.T.Values (Deg.C.) (y-values)
25.00
24.50
24.00
23.50
23.00
22.50
22.00
1972
1976
1980
1987
1995
1999
2003
2007
Years of records(x-values)
y = 0.0424x + 23.357
R2 = 0.422
Max.T
Linear (Max.T)

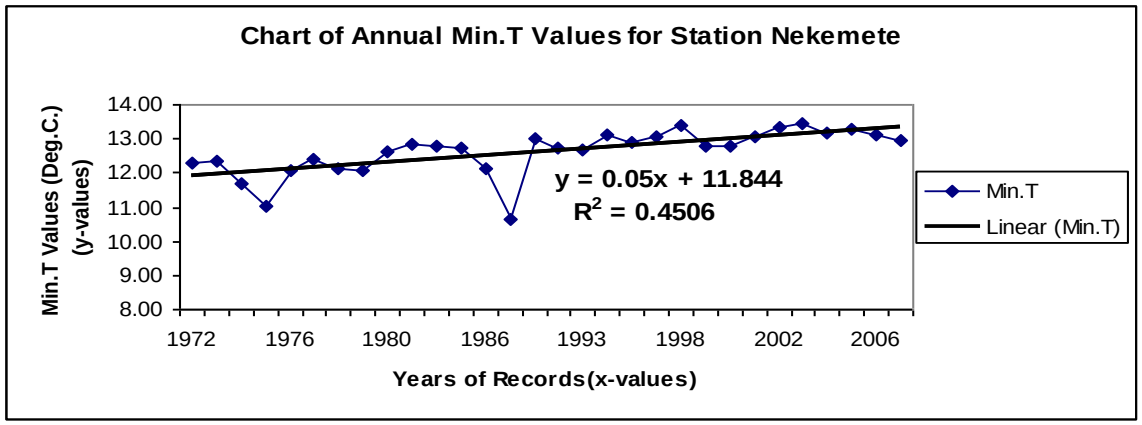


Chart of Annual Min.T Values for Station Nekemete
Min.T Values (Deg.C.) (y-values)
14.00
13.00
12.00
11.00
10.00
9.00
8.00
1972
1976
1980
1986
1993
1998
2002
2006
Years of Records(x-values)
y = 0.05x + 11.844
R2 = 0.4506
Min.T
Linear (Min.T)

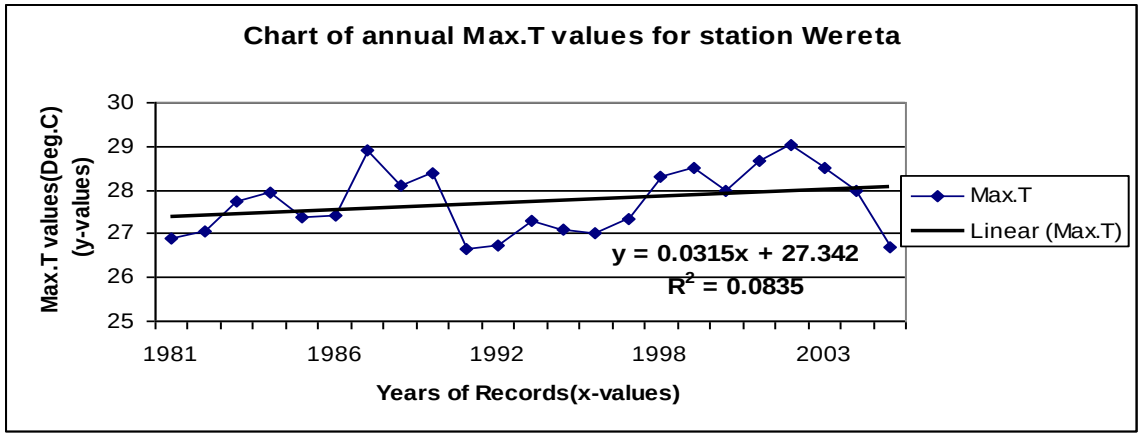


Chart of annual Max.T values for station Wereta
Max.T values(Deg.C) (y-values)
30
29
28
27
26
25
1981
1986
1992
1998
2003
Years of Records(x-values)
y = 0.0315x + 27.342
R2 = 0.0835
Max.T
Linear (Max.T)

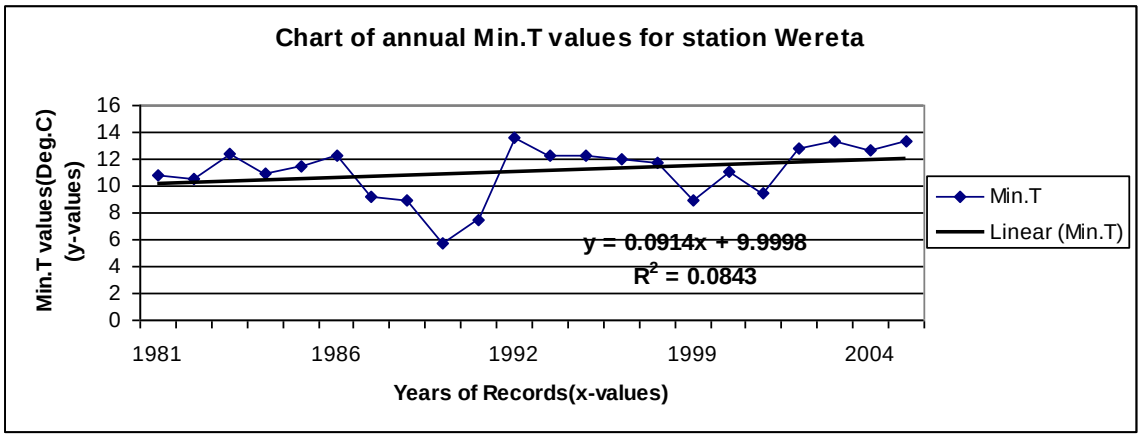
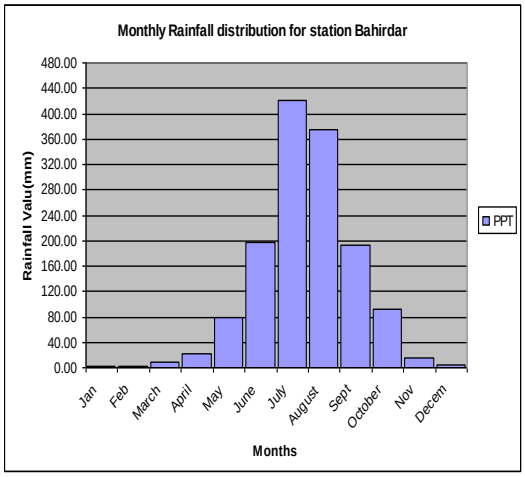
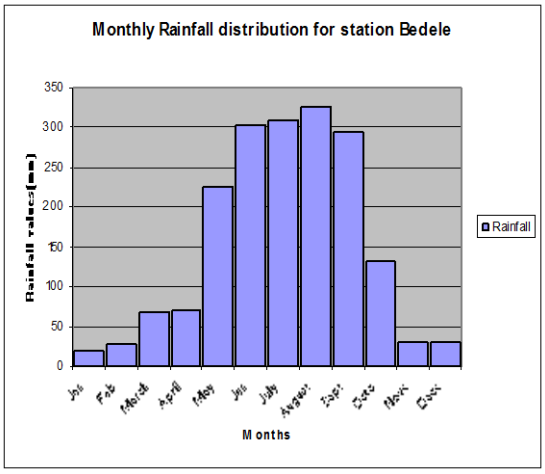
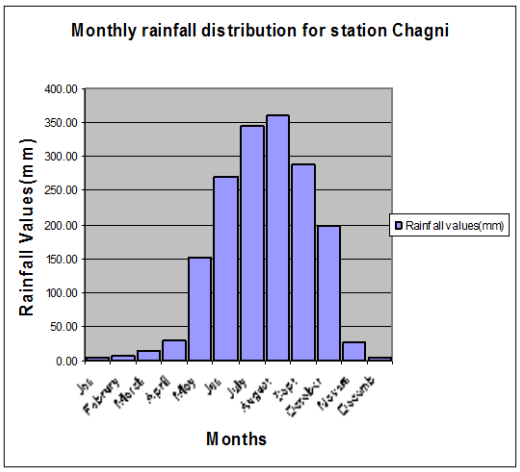


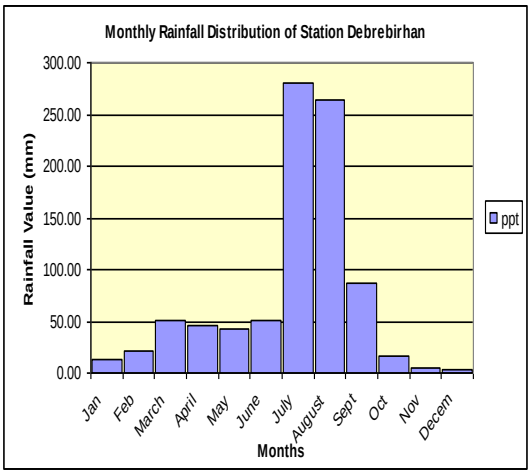
Chart of annual Min.T values for station Wereta
Min.T values(Deg.C) (y-values)
16
14
12
10
8
6
4
2
0
1981
1986
1992
1999
2004
Years of Records(x-values)
y = 0.0914x + 9.9998
R2 = 0.0843
Min.T
Linear (Min.T)

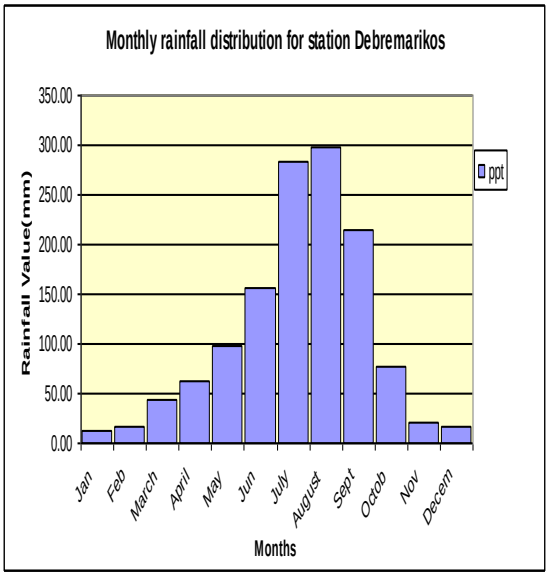
APPENDIX E: MONTHLY RAINFALL DISTRIBUTION OF SELECTED STATIONS

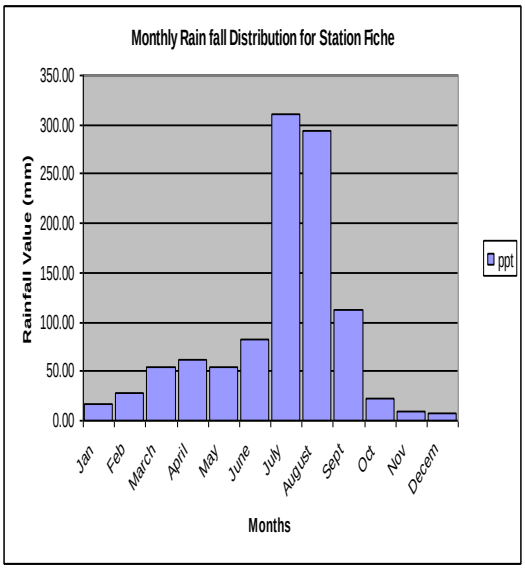

Monthly Rainfall distribution for station Bahirdar
Rainfall Valu(mm)
480.00
440.00
400.00
360.00
320.00
280.00
240.00
200.00
160.00
120.00
80.00
40.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept
October
Nov
Decem
Months
PPT

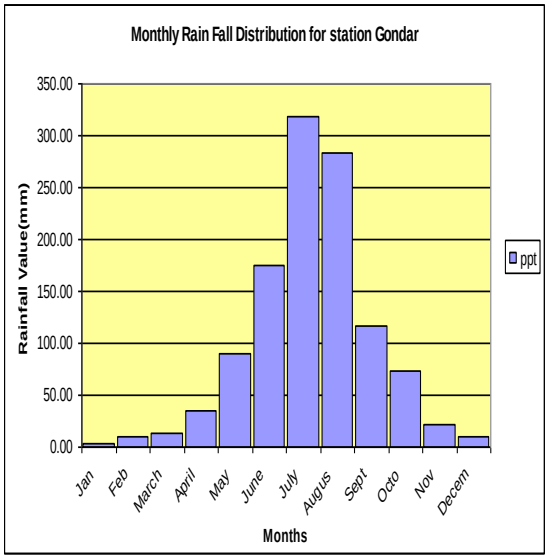

Monthly Rainfall distribution for station Bedele
Rainfall Values(mm)
350
300
250
200
150
100
50
0
Months
Rainfall

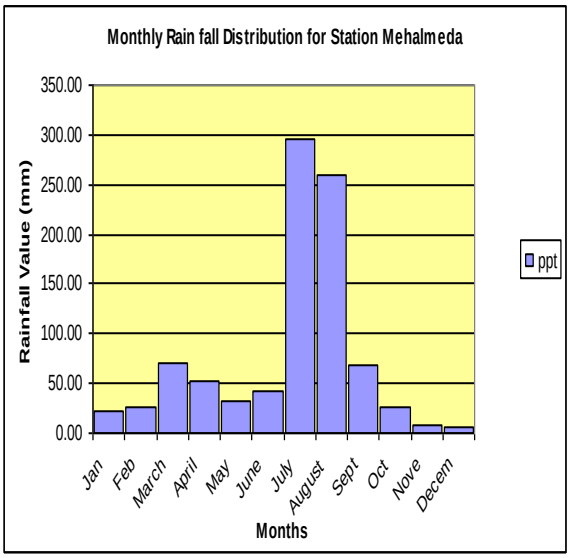

Monthly rainfall distribution for station Chagni
Rainfall Values(mm)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Months
Rainfall values(mm)

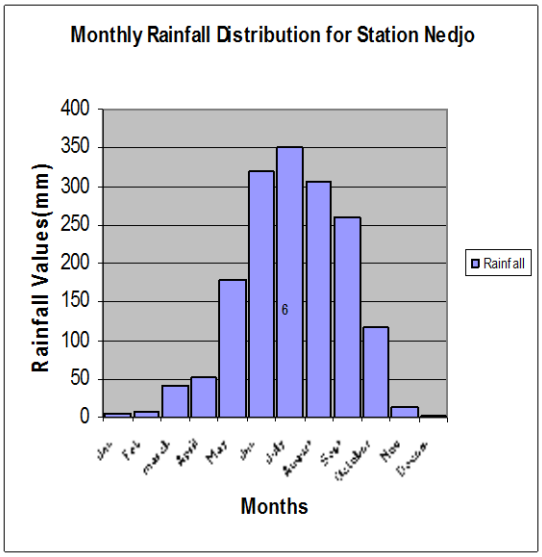

Monthly Rainfall Distribution of Station Debrebirhan
Rainfall Value (mm)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept
Oct
Nov
Decem
Months
ppt

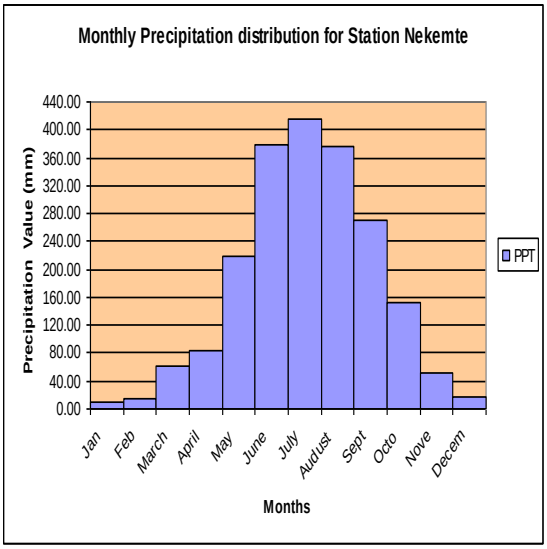

Monthly rainfall distribution for station Debremarikos
Rainfall Value(mm)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
March
April
May
Jun
July
August
Sept
Octob
Nov
Decem
Months
ppt

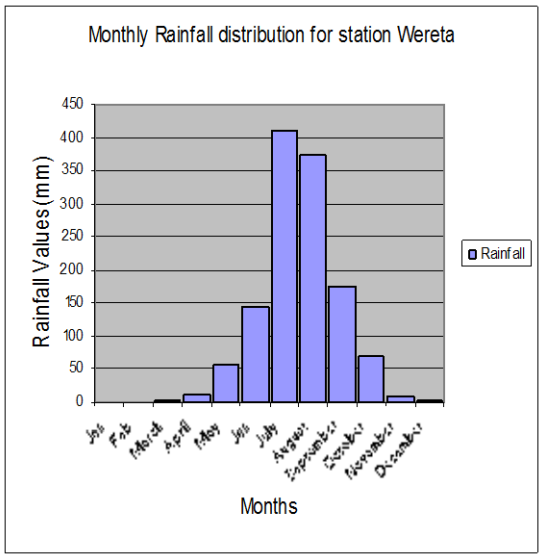

Monthly Rain fall Distribution for Station Fiche
Rainfall Value (mm)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept
Oct
Nov
Decem
Months
ppt


Monthly Rain Fall Distribution for station Gondar
Rainfall Value(mm)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
March
April
May
June
July
Augus
Sept
Octo
Nov
Decem
Months
ppt

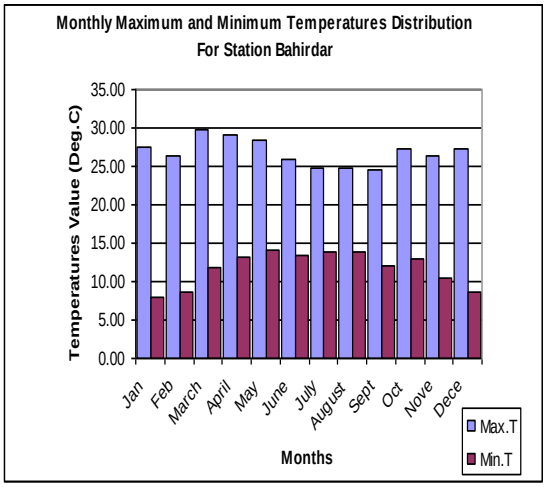

Monthly Rain fall Distribution for Station Mehalmeda
Rainfall Value (mm)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept
Oct
Nove
Decem
Months
ppt

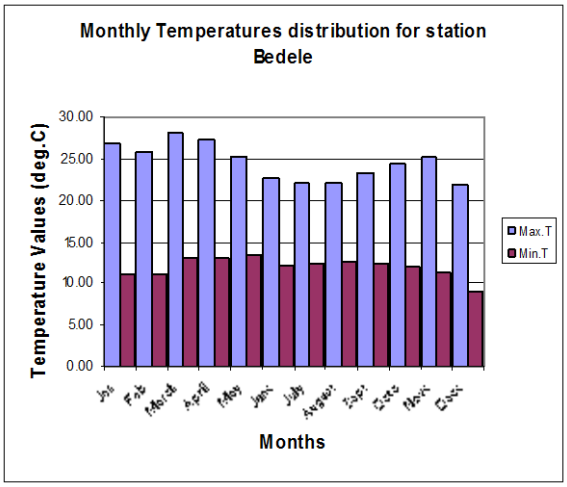

Monthly Rainfall Distribution for Station Nedjo
Rainfall Values(mm)
400
350
300
250
200
150
100
50
0
Months
Rainfall

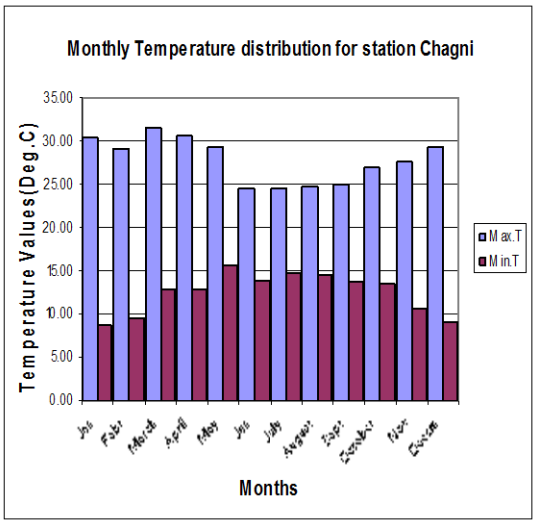

Monthly Precipitation distribution for Station Nekemte
Precipitation Value (mm)
440.00
400.00
360.00
320.00
280.00
240.00
200.00
160.00
120.00
80.00
40.00
0.00
Jan
Feb
March
April
May
June
July
Audust
Sept
Octo
Nove
Decem
Months
PPT

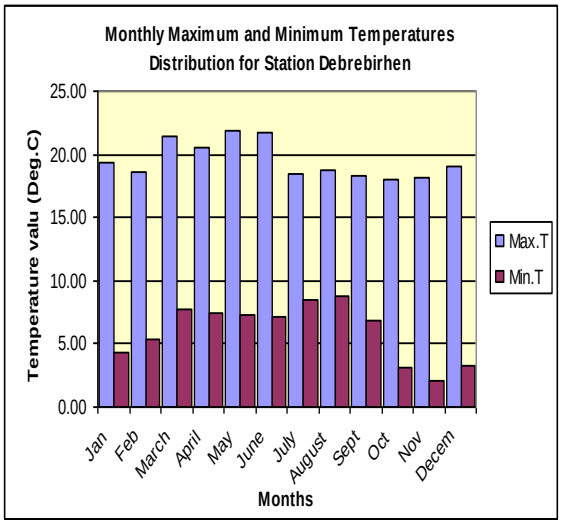

Monthly Rainfall distribution for station Wereta
Rainfall Values (mm)
450
400
350
300
250
200
150
100
50
0
Months
Rainfall

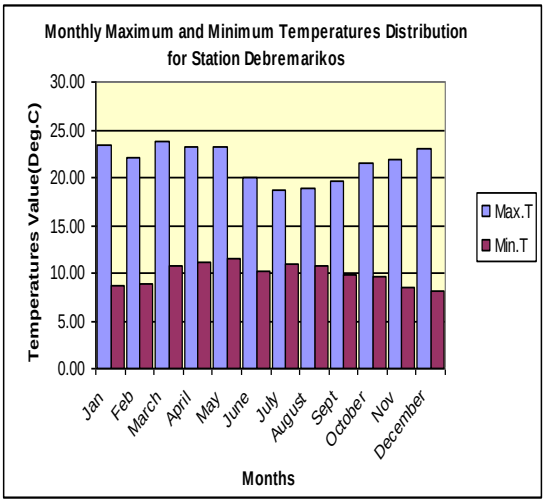
APPENDIX F: MONTHLY TEMPERATURES DISTRIBUTION OF SELECTED STATIONS

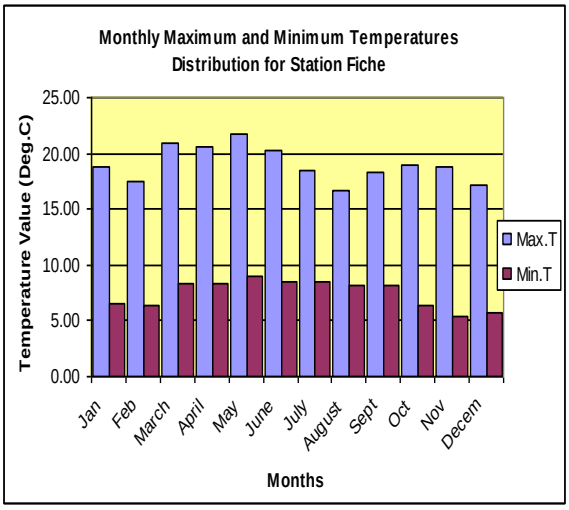

Monthly Maximum and Minimum Temperatures Distribution For Station Bahirdar
Temperatures Value (Deg.C)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept
Oct
Nove
Dece
Months
Max.T
Min.T

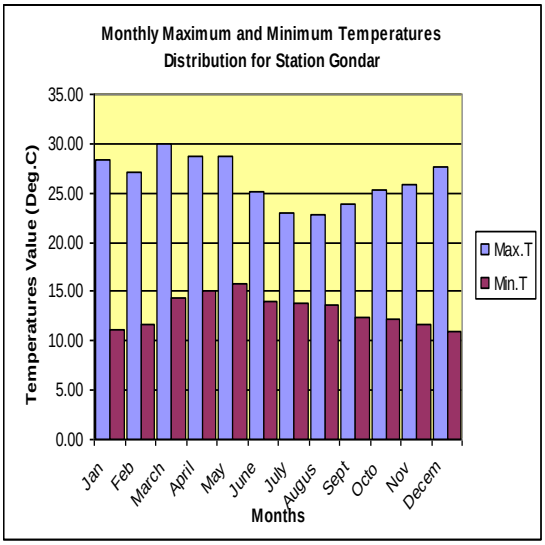

Monthly Temperatures distribution for station Bedele
Temperature Values (deg.C)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Months
Max.T
Min.T

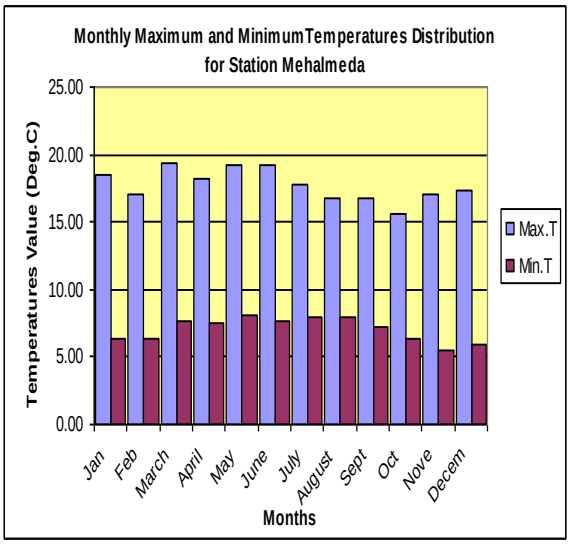

Monthly Temperature distribution for station Chagni
Temperature Values(Deg.C)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Months
Max.T
Min.T

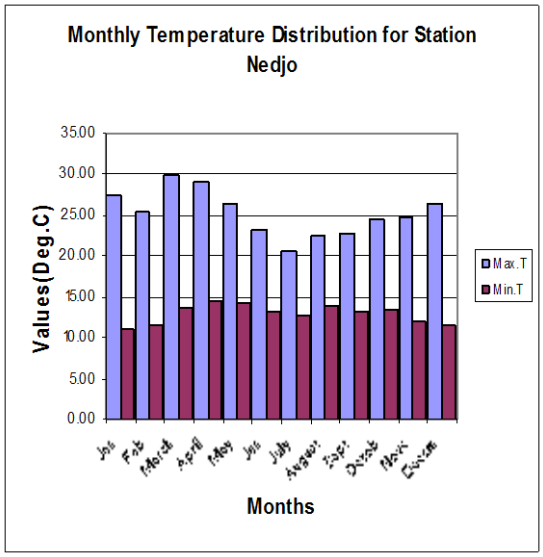

Monthly Maximum and Minimum Temperatures Distribution for Station Debrebirhen
Temperature valu (Deg.C)
25.00
20.00
15.00
10.00
5.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept
Oct
Nov
Decem
Months
Max.T
Min.T

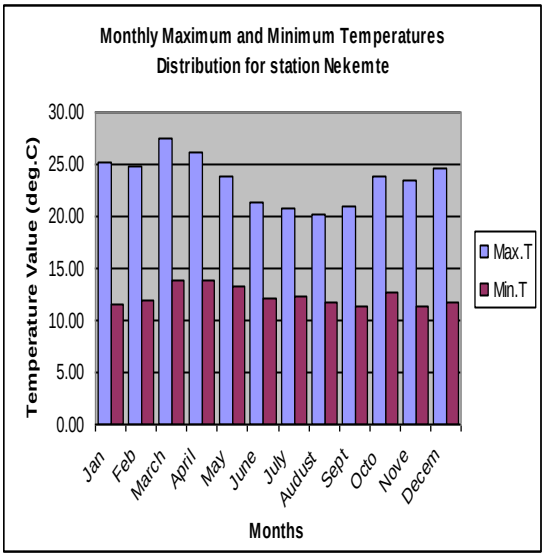

Monthly Maximum and Minimum Temperatures Distribution for Station Debremarikos
Temperatures Value(Deg.C)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept
October
Nov
December
Months
Max.T
Min.T

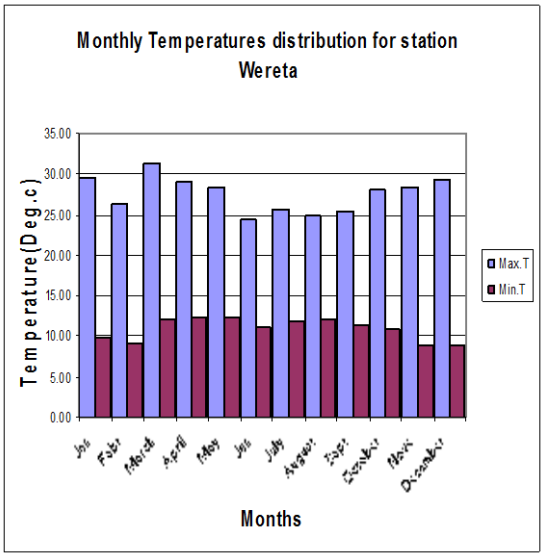

Monthly Maximum and Minimum Temperatures Distribution for Station Fiche
Temperature Value (Deg.C)
25.00
20.00
15.00
10.00
5.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept
Oct
Nov
Decem
Months
Max.T
Min.T


Monthly Maximum and Minimum Temperatures Distribution for Station Gondar
Temperatures Value (Deg.C)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jan
Feb
March
April
May
June
July
Augus
Sept
Octo
Nov
Decem
Months
Max.T
Min.T


Monthly Maximum and MinimumTemperatures Distribution for Station Mehalmeda
Temperatures Value (Deg.C)
25.00
20.00
15.00
10.00
5.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept
Oct
Nove
Decem
Months
Max.T
Min.T


Monthly Temperature Distribution for Station Nedjo
Values(Deg.C)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Months
Max.T
Min.T


Monthly Maximum and Minimum Temperatures Distribution for station Nekemte
Temperature Value (deg.C)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Jan
Feb
March
April
May
June
July
Audust
Sept
Octo
Nove
Decem
Months
Max.T
Min.T


Monthly Temperatures distribution for station Wereta
Temperature(Deg.c)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Months
Max.T
Min.T