ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

TREND ANALYSIS OF HYDRO-METEOROLOGICAL DATA AND THEIR IMPLICATION IN WATER RESOURCE DEVELOPMENT (CASE STUDY IN ARJO-DIDESSA SUB-BASIN)

A Thesis in Hydraulic Engineering

By: Feye Lema

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Trend Analysis of Hydro-meteorological data and their implication in Water Resource Development (Case Study in Arjo-didessa sub-basin)**' presented by **Feye Lema**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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DECLARATION

I confirm that research work titled “**Trend Analysis of Hydro-Meteorological Data and Their Implication in Water Resource Development (Case Study in Arjo-didessa sub-basin)**” is my work. The work has not been presented elsewhere. Where material has been used from other sources it has been properly acknowledged.

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ABSTRACT

The issue of hydro-climatic variability and trend has been taken into the attention of the scientific community over the world. As such, the variability and the length of the period during which the change would occur have considerably different implication for water resources planning and management. This study aimed to investigate and characterize the trend of hydro-meteorological variables in the Arjo-didessa sub-basin in Ethiopia.

A non-parametric test, Mann-Kendall, modified Mann-Kendall, Sen's slope estimator, and Innovative Trend tests were used to detect trends exhibited by rainfall, temperature, and stream flow on monthly, seasonal, and annual time scale. To represent the variability and trend condition in the sub-basin, monthly rainfall data from eleven stations, monthly mean temperature from three stations, and daily stream flow from three gauging stations were collected and analyzed for trends detection. Four open-source library of R packages; modifiedmk, trend, hydroTSM, and trend change were used in R language to perform trend analysis, and homogeneity tests.

The monthly rainfall trend result shows non-uniform in rainfall intensity. Different stations and variables show different results while applying the methods. Accordingly, mean monthly maximum temperature shows an increasing trend in Bedele and Nekemte. Monthly streamflow, Didessa Nr. Arjo shows an increasing trend. Only Arjo and Kone station shows a significant increasing trend in annual rainfall. A significant increasing trend in annual mean Tmax was observed for Nekemte station and significant decreasing annual mean Tmin was observed for Alibo stations.

Generally, an increasing or decreasing level of rainfall, temperature, and streamflow in each selected station for the study area indicates the change in trend. The coefficient of variation used to analyze spatial variability of annual rainfall for each station varies from 9.83% to 24.54% which indicates from less to moderate variability in rainfall data. High variability of coefficient of variation for rainfall stations was observed in the study area for seasonal time scale. The findings from this study can help experts, researchers, and policy makers to get awareness about the variability and temporal trends of precipitation, temperature, and streamflow alteration in the Arjo-didessa sub-basin which will definitely affect the water resources development.

Keywords: *hydro-climatic data; trend detection; Mann-Kendall test; Sen's slope estimator, Innovative trend analysis (ITA)*

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ABBREVIATIONS

MK	Mann-Kendall
MMK	Modified Mann-Kendall
SD	Standard Deviation
MoWIE	Ministry of Water Resources, Irrigation and Energy
OIDA	Oromia Irrigation Development Authority
OWWDSE	Oromia Water Work Design and Supervision Enterprise
OWWCE	Oromia Water Works and Construction Enterprise
ITA	Innovative Trend Analysis
WMO	Weather Monitoring Organization
GCOS	Global Climate Observation System
CV	Coefficient of Variation
MAD	Mean Absolute Deviation

1. INTRODUCTION

1.1 Background

Understanding long-term trends in the hydro-climatic variables play a significant role in sustainable water management both at the local and national level. In recent years, a trend analysis of hydro-climatic time series has received growing attention over the world (Sayama, 2019). The trend of observational and historical hydro-climatic data reflects variations in climate and is generally used to determine appropriate adaptation strategies in the planning and designing of water resources projects.

The change in hydro-climatic trends and variability are a challenge for the world in general and Africa in particular. It is explained by factors inherent to the climate system and the hydro-climatic variability greatly affects water resources with a consequence in various sectors of activity (Jun and Bantin, 2017). The majority of water resource projects are planned, designed, and operated based on the historical prototype of water availability, quality, and demands, assuming constant hydro-climatic behavior. However, such assumptions of time-invariant characteristics are not common as the control in hydro-climatic dynamics is almost impossible. Therefore, it is essential to investigate the present and probable future hydro-climatic variability patterns and their implication on water resource development so that an appropriate adaptation strategy may be implemented (Sulaiman, 2016).

Information on time-series trends is very crucial to highlight the Spatio-temporal changes of hydro-climatic variables, to gain knowledge about the status of development and sustainable management of water resources in the future as well as to plan for stabilizing environmental conditions (Fathian *et al.*, 2016). If the trend of hydro-climatic variables changes in a region is accompanied by a significant amount, and difficult to adapt these changes, then human life will be at risk.

Moreover, a significant decrease and/or increase in precipitation and its change associated with the increase in surface air temperature over a basin has a significant effect on the stream flow rate trends (Tahroudi and Ramezani, 2019). Typically, long term annual and monthly precipitation factors are employed to describe the precipitation situation in the region. Many researchers and practitioners from different parts of the world have often used the non-parametric Mann-Kendall statistical test to identify patterns in recorded hydrological time series, such as water quality, streamflow, precipitation time series, and surface temperature with increasing worries about environmental pollution and the effects of greenhouse gases on the atmosphere, Kousari et al., (2013), Gocic and Trajkovic (2013), Zhang *et al.*, (2000), (Drápela et al., (2011), Sharif *et al.*, (2013), Asfaw *et al.*, (2018) and Bekele et al., (2017), Kumar *et al.*, (2017) and Hussain *et al.*, (2015)

Hydro-climatic variability and human activity can cause long-term hydro-meteorological conditions to cause statistical shifts. For planning processes, water conservation plans, and risk mitigation measures, identification, attribution of these improvements are vital. Reasonable statistical tests and methods of trend detection can help to understand the nature of historical variability in hydrological time series in this context (Wang *et al.*, 2020).

Trend analysis has proven to be a method for efficient planning, design, and control of water supply, irrigation structures, and agricultural farming systems. Several statistical techniques have been applied to identify a significant trend in hydro-climatic variables using either parametric or non-parametric tests. Parametric tests are more powerful than non-parametric tests. However, they required time-series data to be independent and normally distributed. In contrast, the non-parametric test only requires the data to be independent and can tolerate the outlier of the data (Timbadiya *et al.*, 2013).

Some of the statistical methods for trend analysis include Pettitt (Pettitt, 1978) and CUSUM (Smadi and Zghoul, 2006) for shift point identification, Mann-Kendall (Mann, 1945; Kendall, 1975) and Spearman (Lehmann, 1975) for detecting patterns. All of these tests are based on a single null hypothesis and have to be carried out at an assigned degree of significance. As they are distribution-free and do not require knowledge of the parent distribution, non-parametric tests are commonly referred to as parametric ones. They are also proposed to be less susceptible to the existence of outliers concerning parametric tests in the frequency study of extreme events (Wang et al., 2005).

In the hydro-meteorological time series, the existence of serial correlation also makes it difficult to detect deterministic incremental or sudden shifts with tests such as the Mann-Kendall and Pettitt tests. The adverse effect of the serial association on pattern tests performed by the Mann-Kendall and Shift Point by Pettitt Test is therefore explored in this study. The test requires the serial independence of sample data. The existence of serial correlation in time series will influence the ability of the test to accurately determine the importance of the trend if sample data are serially correlated. A Modified Mann-Kendall test has been used to improve the MK statistics to remove the impact of serial correlation on the MK evaluation. This study explores the Modified Mann-Kendall test introduced by Hamed and Rao (1997), Yue and Wang (2004), Serinaldi and Kilsby (2016) to eradicate the effect of the serial association on the MK test.

Many researchers have attempted to determine trends in hydro-climatic variables on a regional scale. Most of these studies deal with an analysis of the annual and seasonal rainfall patterns for some stations or groups of stations. In the present study, the trends and variability of hydro-meteorological time series such as rainfall, temperature, and streamflow in the Arjo-Didessa sub-basin are analyzed and presented.

1.2 The Problem Statement

Changes in the dynamics of hydro-climatic variables can result from global warming. These changes will have a significant effect on the availability of food, energy, and water, especially in developing countries. Natural events like flooding, drought, irregularity of spatial and temporal distribution of water resources, and flagging water quality have caused a huge impact on industrial, agricultural production, and even on people's lives. Therefore, it's crucial to detect the hydro-climatic pattern to get comprehensive information regarding the hydrology of the sub-basin, which helps to predict the fate of the hydrological system and ecology of the study area. The issue of hydro-climatic variability and trend has been taken to the attention of the social community over the world. In the future, the effects of hydro-climatic fluctuation and instability on water availability should be a major concern for managers and policymakers, especially concerning surface water that is highly precipitation-dependent (Basin, 2019).

Climate change may increase the negative effect of rainfall uncertainty, and both current and future effects of this uncertainty could be mitigated to some extent through improved and adaptive water resource management and planning. Planning for improved and more secure water availability relies on the interpretation and projection of hydro-climatic system behavior (Koutsouris *et al.*, 2010).

Rainfall and temperature are very important factors affecting crop selection and ecological changes in a watershed. Therefore, accurately predicting precipitation trends can play an important role in a country's future economic development. Effective and efficient water resources management require not only identification of trend, it includes also whether they are abrupt or gradual. The magnitude of the change and length of the period during which the change would occur have considerably different implications for water resources planning and management. Better scientific understanding of hydrological and climatic links conditions and change is thus a key issue for effective water resource management and its climate adaptation in the Arjo-didessa sub-basin.

More importantly, the significant increase in demand due to population growth in the basin calls for a proper understanding of future trends of the available water resources. As such, little substantial research has been done before in this regard, especially in the study area as the basin has a high potential for water resource development projects including water supply, small to large irrigation projects, and high agricultural production activities.

1.3 Objectives of the study

1.3.1 General Objective

The main objective of this research is to investigate and characterize trends in hydro-meteorological data using a non-parametric test in the Arjo-didessa sub-basin.

1.3.2 Specific Objectives

- To detect temporal trends of rainfall, temperature, and streamflow data using the selected non-parametric trend analysis methods;
- To assess the annual and seasonal variability of precipitation, and temperature over the Arjo-didessa sub-basin;
- To examine the implication of hydro-climatic variability on water resource development in the Arjo-didessa sub-basin

1.4 Research Questions

- Which hydro-climatic variable shows a significant trend in the Arjo-didessa sub-basin?
- What are the patterns of trend variation?
- How does the variability of hydro-climatic data influence water resource management decisions?

1.5 Scope of the Study

The study aims to investigate and characterize the significant trends in hydro-meteorological variables using a non-parametric test. The study is limited to only three hydro-meteorological variables (rainfall, temperature, and streamflow). Monthly dataset for all three variables used in this study for analysis. The study area bounded to Arjo-didessa sub-basin using eleven rainfall stations, three temperature stations, and three streamflow gauge station.

Based on the availability of long-term data and representativeness for the study area, 36 years Tmax and Tmin, 35 years rainfall data, and 26 years streamflow data for each station were used for analysis. The results of each non-parametric test (Mann-Kendall, Sen's slope estimator, and Innovative trend Analysis) were interpreted at a 95% confidence interval (at $\alpha = 0.05$ significance level).

1.6 Significance of the Study

The results and findings from this study can help experts, researchers, and policymakers to get awareness about the variability and temporal trends of precipitation, temperature, and streamflow alteration in the Arjo-didessa sub-basin. The Outcome of the study also provides valuable information on the characteristics and variability of hydro-climatic trends essential for planning and designing sustainable water management strategy and understanding of potential trends in the future resulting from anthropogenic activities. The Results from the study creates awareness for policymakers and members of the scientific community informing them about the hydro-climatic evolution across the sub-basin and become an inordinate resource for advanced scientific research.

1.7 Outline of the Thesis

The organization of the thesis outlined as follows: Section 1 describes the introduction, statement of the problem, research objectives and significance of the study. Section 2 describes an intensive review of related literature. Section 3 discussed the description of the study area, Methods used to analyze the data, and trend detection. Results and discussion are presented under section four and finally, section 5 describes the summary of the conclusion and recommendation.

2 LITERATURE REVIEW

2.1 Review of Hydrological Test for Change Detection

Hydrology is the science of water, which deals with both the liquid, solid, and gaseous water in the hydrological cycle. Hydrological data serve many purposes, including the documentation, detection, and quantification of climate variability and change, and improving our understanding of the climate system and the links between the climate system and other systems. Hydrological data are extensively used in various endeavors of process modeling, assessment of impacts, and development of response strategies (Kundzewicz and Robson, 2000). The Global Climate Observation System is an international initiative for the implementation of a comprehensive global long-term monitoring approach that seeks to enhance our understanding of the earth's climate and its relations with other systems. A detailed but not necessarily exhaustive list of main hydrological variables was provided, the observation of which is important for climate purposes. Due to their capacity to represent changes in climatology and to enhance our understanding of the links between climate and hydrology, different hydrological indices seem to be of interest.

Data collection for the study of climate variability and alteration includes an understanding of the hydrological cycle processes and the causal relationships between variables and processes. Relevant elements of the record are the temporal and spatial cycles between measurements and must be selected to balance the processes. For instance, if the maximal streamflow is required to monitor, monthly averages will be too rough. Observations taken at regular time intervals (hourly, daily, weekly) are often simpler to analyze.

The results from several studies show that rainfall evolutions over many areas of the globe show that, hydro-climatic variability translates into Wetter conditions as well as into rainfall increate in a repetition of extreme events in the recent decades. The study by (Nouaceur and Murărescu, 2016) reveals that the results from rainfall variability and trends of annual rainfall in North Africa show extreme variability and severe drought.

2.2 Global Climate Variability and Trend

Global climate change may influence long-term rainfall patterns which affect the availability of water, along with the uncertainty of increasing drought and floods. Statistical literature reveals that the Earth's environment is evolving due to an increase in the accumulation of greenhouse gasses in the atmosphere; temperatures are rising and the volume and distribution of rainfall are altering. The temperature would rise between 1.5 and 4.5 ° C, with the best estimate of 2.0 ° C, with a doubling of the CO_2 concentration in the atmosphere in the next century(Haile Mariam, 1999). Rainfall and temperature are among the most important climatic variables that involve both spatial and temporal patterns of water availability(Wani and Sarda, 2017). Taking this into consideration, the variability and trends in temperature are among the most significant aspects of climate change studies. Many studies around the World also reveals that long-term alteration in temperature has a significant impact on the hydrological cycle and the disturbance would leads to change in rainfall pattern, extreme precipitation events and drought condition, which in turn affects the hydrological, agricultural and economic planning of the country. Although understanding trend variability of hydro-climatic factors is essential for appreciating the impact of climate change.

World Climate Application Program (WCAP, 1998) recommended several statistics to be computed from the available dataset that are very important for hydro-climatic variability studies include; mean, standard deviation, absolute mean deviation, Coefficient of kurtosis, coefficient of skewness, coefficient of variability, coefficient of auto-correlation, rank for each month, the trend in the mean, the trend in the variance, equality of sub period mean, equality of subperiod variance, number of runs, etc. (Teegavarapu, 2018). Several summary statistics are used to describe different characteristics of time series and these include central tendency, dispersion, and shape. These statistical properties are very common and conceptually simple and are evaluated to gain a better understanding of the hydrological dataset.

Recently, significant progress has been made to study trends and variability of hydro-climatic variables in different parts of the world. (Tekleab and Uhlenbrook, 2013) studied river regimes and recent hydrological change in the Duero basin in Spain over 1961-2006. The study investigates that monthly precipitation in the basin showed a great variation both in time and space. The author developed the linear regression model to interpolate precipitation and understood that topography is the main factor explaining the spatial distribution of rainfall throughout the year, with exception of July and August. However, during summer, most precipitation station is associated with storms and convective system that occur with rather high spatial irregularity. The study also shows that the monthly river discharges for all gauging station in the Duero basin reflects high variability and the shape of the hydrograph indicated the most common river regime pattern in the region.

2.3 Hydro-Climatic Trends and Variability in Ethiopia

Climate change patterns give a general idea of any changes apparent in historical data and raise questions about Weather events in the region. Analysis of global hydro-climatic dynamics indicates that precipitation, temperature, and flow patterns are experiencing major changes, likely as a result of climate change impacts (Blackmore and Sadoff, 2013). Several studies on precipitation trend analyses have also been studied all over the world. Such changes can contribute to more improvements in the watershed. For example, sediment transport through rivers is known to be highly dependent on streamflow, as higher flows bear more load than regular and low flows. Changes in flow patterns can represent changes in precipitation magnitude, distribution, and shape (Ehsanzadeh et al, 2012).

Statistical analysis techniques have been widely studied in the upper Blue Nile basin to assess trend hydro climatic trends and Spatio-temporal variability. (Asfaw *et al.*, 2018) applied Non-parametric test, Mann-Kendall, and standard Precipitation Anomalies index to assess the trend of precipitation and temperature over Woleka sub-basin. The study indicates that mean annual rainfall and Kiremt rainfall shows a decreasing trend while Belg rainfall had shown no significant change through time. Long-range anomalies of annual mean temperature showed inter-annual variability which indicates the presence of warning trend since the last decades of the 20th century.

In addition to temporal trend analysis of Hydro climatic trend, the study by (Gebremicael *et al.*, 2017) conducted that temporal and spatial changes of rainfall and streamflow in upper Tekeze, Atbara river basin using Mann-Kendall and change points for 21 rainfall stations and nine Stream flow gauges the result of the study shows the linkage between rainfall trends and Streamflow and possibly identify the major drivers of streamflow variability in the basin. The study also shows rainfall over the basin remains unchanged in the last four decades. The results of the study further show Monthly rainfall in the majority of station experiences high spatial variability in comparison with seasonal and annual timescales. Observed hydro-climatic changes indicate that Africa warmed 0.7° Cover 20th century, with a decadal temperature increase of 0.05°C. This warming has been associated with increased precipitation in some areas of Eastern Africa.

Several studies have been conducted to assess the variability and impacts of hydrological variability in different parts of the Abbay River basin (Daba and Rao, 2016); (Gebre, et al., 2015); (Melesse *et al.*, 2011). The majority of these studies indicated hydrological variability and the impacts of climate change on the hydrology of the basin. The linkage between climate change, water resources, and the hydrologic cycle are very crucial and important. The effects of climate change on water resources are due to the water quality, that caused by climate factors including rainfall and temperature changes from time to time and the result is achieved by the variation of the various water cycle linkage (Nan et al., 2011). Climate change will significantly change the world of the present situation of the hydrologic cycle and resulted in the redistribution of water resources both temporal and spatial. The change in redistribution and change of water resources in space would cause human society and ecology to change a lot. Similarly, the water resources system change would again affect the local climate and will exacerbate change to a certain extent.

2.4 Non-parametric Trend Analysis

There are many studies over the world that investigated anthropogenic changes in the form of gradual trends or abrupt changes in the hydro-meteorological time series dataset (Kisi and Murat, 2014); (Totaro et al., 2020) and (Yue and Wang, 2004). Statistical hypothesis tests including deterministic hydrological models, climate models, and expert opinion are undoubtedly indispensable tools for trend detection as chaos theory states that even deterministic systems may perform unpredictably. A rank-based non-parametric Mann-Kendall statistical test (Mann, 1945); (Kendall, 1975) has been widely used for detecting trends in hydro-meteorological time series such as precipitation, temperature, streamflow, groundwater, water quality, and lake levels. As compared to parametric methods (Linear regression and Multiple regression), a non-parametric test (Mann-Kendall, Modified Mann-Kendall, Spearman rho Correlation test, Sen's slope estimator, and Innovative trend analysis) have no requirement for homoscedasticity or assumptions on the distribution of data sample to be normal distribution and are less sensitive to outliers (Hamed and Rao, 1997); (Teegavarapu, 2018).

Moreover, the Mann-Kendall test is relatively effective and robust and has a basic requirement that the data should be independent. The test is not robust against serial correlation, which may be statistically significant in the hydrological and climate time series dataset. A positive serial correlation that exists in the dataset will result in overestimation and rejection of the null hypothesis of no monotonic trend (Hirsch and Slack, 1984). Two approaches are proposed to eliminate the influence of serial correlation in the time series dataset. The first one is the application of pretreatment to the data and the second one is using the Modified Mann-Kendall test to account for serial correlation.

The use of statistical techniques in development of research has created concerns for many years. Statisticians have long expressed concern about the slow adoption of statistical ideas by researchers and the frequent misuse of statistics when statistical methods were used (Iacobellis et al., 2019). Hydrological time series are often composed by non-normally independent realizations of phenomena, and this characteristics makes the use of non-parametric trend tests very attractive. Mann-Kendall test is a widely used rank based tools for detecting monotonic, and not necessarily linear, trends. In practice Mann-Kendall test is performed using Z statistics.

2.5 The implication of hydro-climatic variability in water resources development

Population growth, economic development, and associated water resources development have altered the natural flow of rivers around the world. Providing reliable and affordable water supplies for growing populations while preserving the vitality of the riverine ecosystem is a crucial challenge over World Wide. In the development and management of water resources, humans have altered the natural flow of rivers around the world and the impact of such flow alteration on the river has been well documented (Richter *et al.*, 1996).

Water resources and river hydrology systems are widely determined by climate and intensely modified by human action. These anthropogenic activities can disturb streamflow, predominantly with side to side precipitation, temperature, evapotranspiration, and relative humidity. Human activities such as land use/ land cover change, reservoir building, and direct water withdrawal from surface water and groundwater will imply streamflow volume (Ndehedehe *et al.*, 2020).

Understanding and determination of trends of precipitation, temperature, and streamflow have infinite use for water managers and scientists in identifying both spatial and temporal variability and management of inadequate water resources for further future economic development. It also plays a vital role in looking into the effects of climate change in water resources forecasting and management system. Several studies by Chinchorkar *et al.*, (2015); Saini *et al.*, (2020); Lins and Slack, (1999) suggested that the alteration of hydro-climatic variables demonstrate a variability pattern in both spatial and temporal trend at the regional and local scale as a result of nature dynamism. Moreover, these climatic variability will imply concerning frequency and intensity of temperature and precipitation variability (Girma *et al.*, 2020). The author attempted to investigate the trend of temperature, precipitation, and stream changes to determine their relationship in the Upper Huai river basin using Mann-Kendall, Sen's slope estimator and innovative trend detection methods to detect the trends and concluded that the main possible reason for declining streamflow in the study area is the declining amount of precipitation and on some specific months due to the occurrences of climate change.

Similarly, (Swansburg *et al.*, 2004) studied hydro-meteorological trends and their implications for Salmon growth. The author suggests that hydro-meteorological conditions are an important determinant of the distribution and production of Salmon in freshwater habitats. Environmental conditions, such as temperature, precipitation, and streamflow affect an aquatic organism in ecosystem growth rate, developmental rate, behavior, and ultimate survival. The author monitors climate and hydrological conditions over 30 years, providing a unique opportunity to examine long-term changes in temperature, precipitation, and streamflow and their effects on juvenile Atlantic salmon.

3. DATA AND METHOD

3.1 General

In Ethiopia, rain fed-agriculture is the main dominant source of food production. The temporal and spatial fluctuation of rainfall, temperature, and streamflow results in low food production from drought or unfavorable wet conditions (Melesse *et al.*, 2011). For spatial characterization and temporal trend analysis, sufficient data length and quality would be needed. Point rainfall frequency analysis characterizes the temporal and spatial variation of rainfall of gauges and analysis from many gauges can help to detect a temporal trend. In the present study, trend analysis for three variables including rainfall, temperature, and streamflow was conducted in the Arjo-Didessa sub-basin.

In the present study, trend analysis for three variables including rainfall, temperature and streamflow were conducted in Arjo-didesa sub-basin. The overall study was conducted in the four steps. First, a brief description of the study area showing the general characteristics of water resources, physiographic characteristics and the climate is given. Second, the data needed for the study were identified and collected from the available sources which is followed by proper data quality controls. Third, the overall characteristics of the collected hydro-meteorological data were evaluated on monthly, seasonal and annual time steps. Finally, the fourth step is to conduct trend analysis using appropriate methodologies. Among others, the widely used Man-Kendal, Sen's slope and innovative trend analysis methods were thoroughly explored and utilized in the study. Details of all the four steps are given in the subsequent section (i.e. section 3.2 to 3.7) and the activity flow is shown in Figure 3.1. The analysis were conducted using appropriate tools including ArcGIS, and R-Studio.

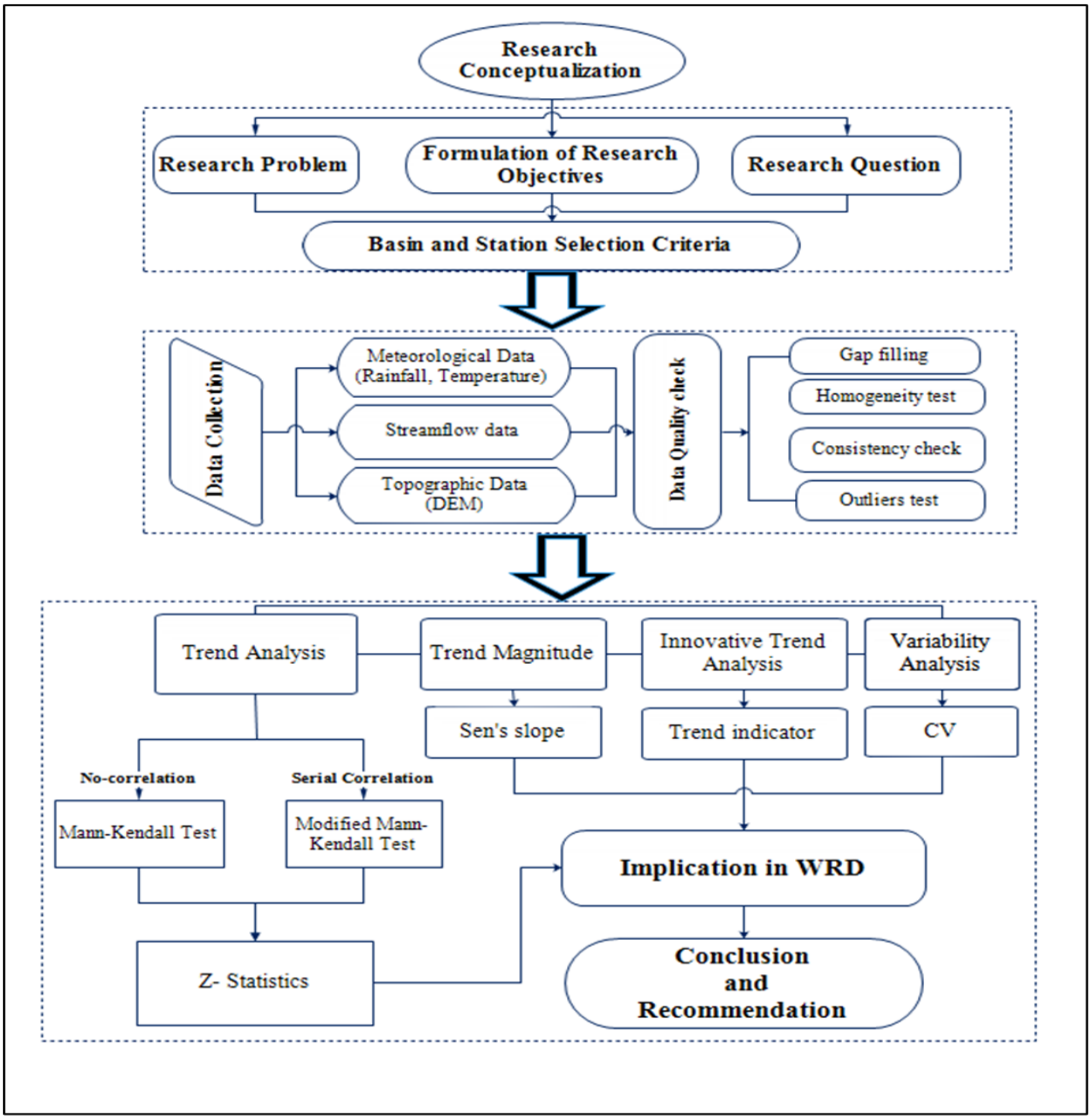


Figure 3-1: General framework of the study

3.2 Description of Study Area

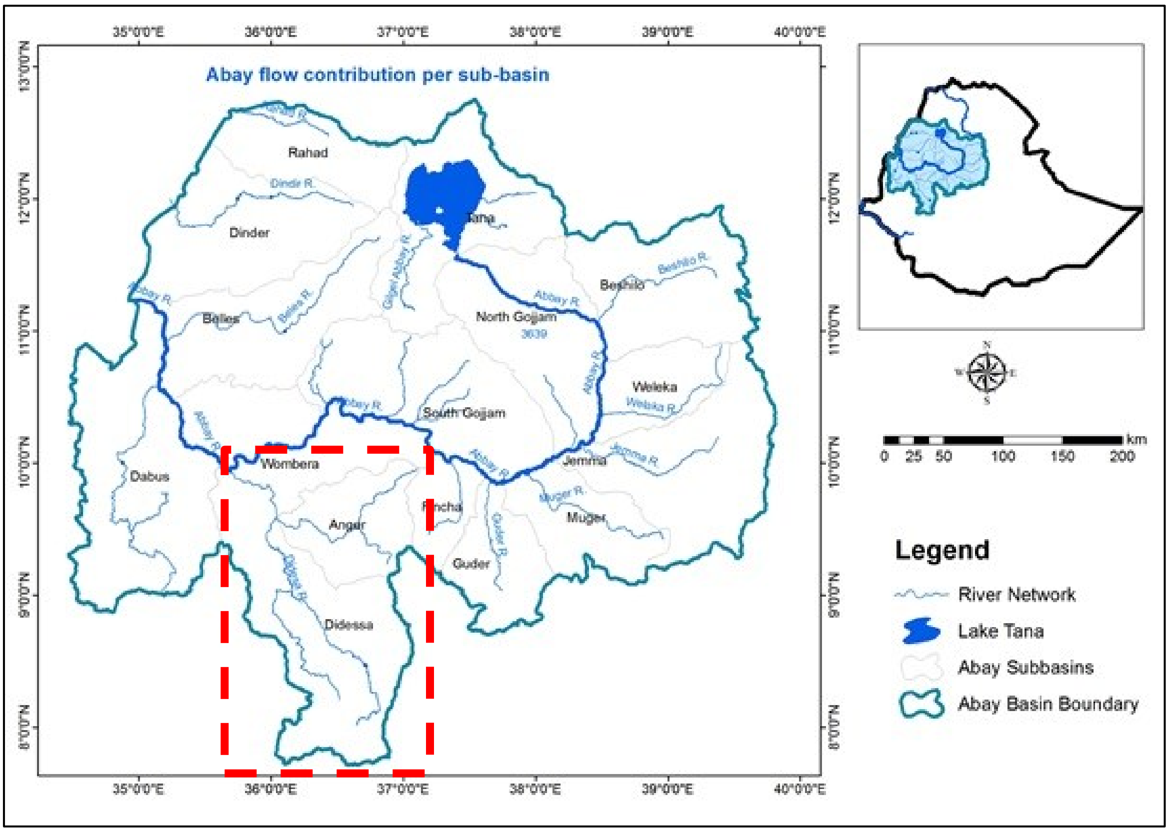
3.2.1 Location

The upper Blue Nile basin is the largest river basin in terms of volume of discharge and second largest basin in terms of area in Ethiopia, and the largest tributary of the Main Nile. It comprises seventeen percent of the area of Ethiopian territory about 176,000km^2 out of 1,100,000km^2 total area. The range in elevation within the basin (from 500 to 4050m) has a major influence both on the climate and human activities (Yilma and Zanke, 2004). The Blue Nile is known as Abbay within Ethiopia and its tributaries rise at an elevation of 2000m to 3300m, and starts at Lake

Tana in North West Ethiopian highlands and pass through deep Ethiopian gorges and valleys for about 1609km before entering Sudan. The basin encompasses 16 main sub-basins and among the sub-basins.

Arjo-didessa is one of the largest tributaries of the Blue Nile Basin in terms of volume of water contributing roughly a quarter of the total flow as measured at the Sudan border (Gebre, 2015). It is located in the southernmost part of the Blue Nile basin. Having many small tributaries, the Arjo-didessa sub-basin covers nearly 25800km^2 of drainage area. The drainage area of the sub-basin subtends four administrative zones of Oromia regional state: Jimma zone in most middle and upper part, Illubabor in the middle part, East and West Wellega in lower parts. Concerning drainage, Yebu, Urgessa, Temssa, Indris, Wama, Dabana, Anger Tato, and Uke are among the tributaries of the Didessa river system.

Arjo-didessa sub-basin is geographically located between 36°02' and 36°46'E longitude, and between 7°43' and 8°13'N latitude. The mean annual precipitation in the study area varies from 1500 mm in the south to 2300 mm in the northern catchments. The majority of the area in the basin is characterized by a humid tropical climate receiving heavy rainfall during one season called summer (June, July, and August). The maximum and minimum temperature with the basin ranges from 21.1°C to 36.5°C and 7.9°C to 16.8°C respectively



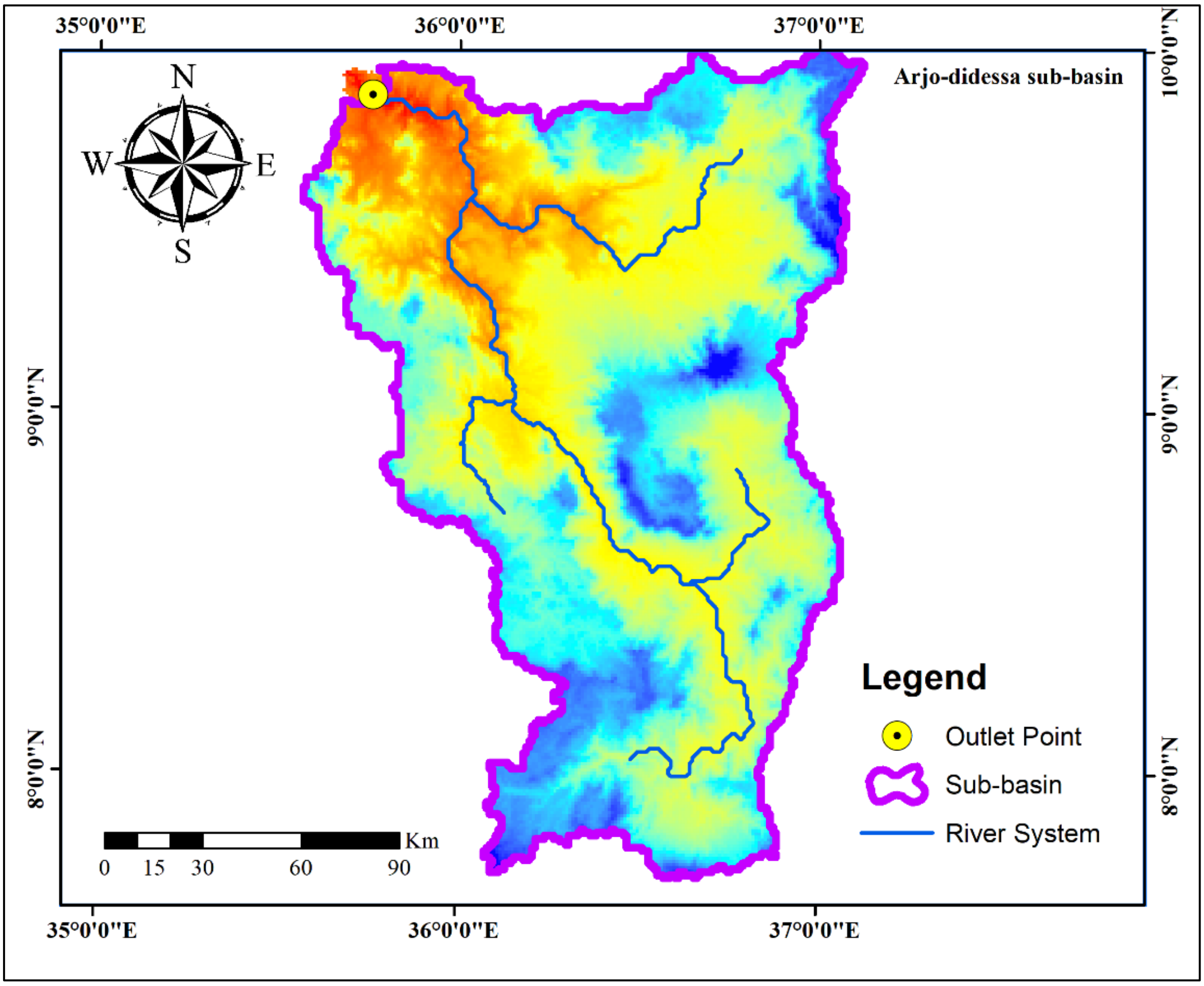


Figure 3-2: Map of the study area (upper panel is Abay basin and the lower is Arjo-Didesa)

3.2.2 Topography

Arjo-didessa is one of the sub-basins of the Abbay River basin (Figure 3-2), where agriculture is the major economic activity among which, coffee production, crop cultivation, and livestock production are dominant sector undertaken by stakeholders' farmers. Topographically the sub-basin has an estimated area of 27,800km^2 and the altitude ranges between 620 to 3203m above sea level (Figure 3-3) excluding mountains of height greater than 35,000m. (Chala et al, 2020).

Dhidhessa River emanates from Wacha and Vennio mountain ridges and travels for a distance of nearly 210 km until it reaches Arjo station. The longitudinal profile of the main river course shows steepest slope along its upper 0 km distance upstream of Dembi (Toba) gauging station. However, for the sections between Dembi and Arjo, the slope is in the order of 0 to 1%, (Shown in the right panel of Figure 3.3).

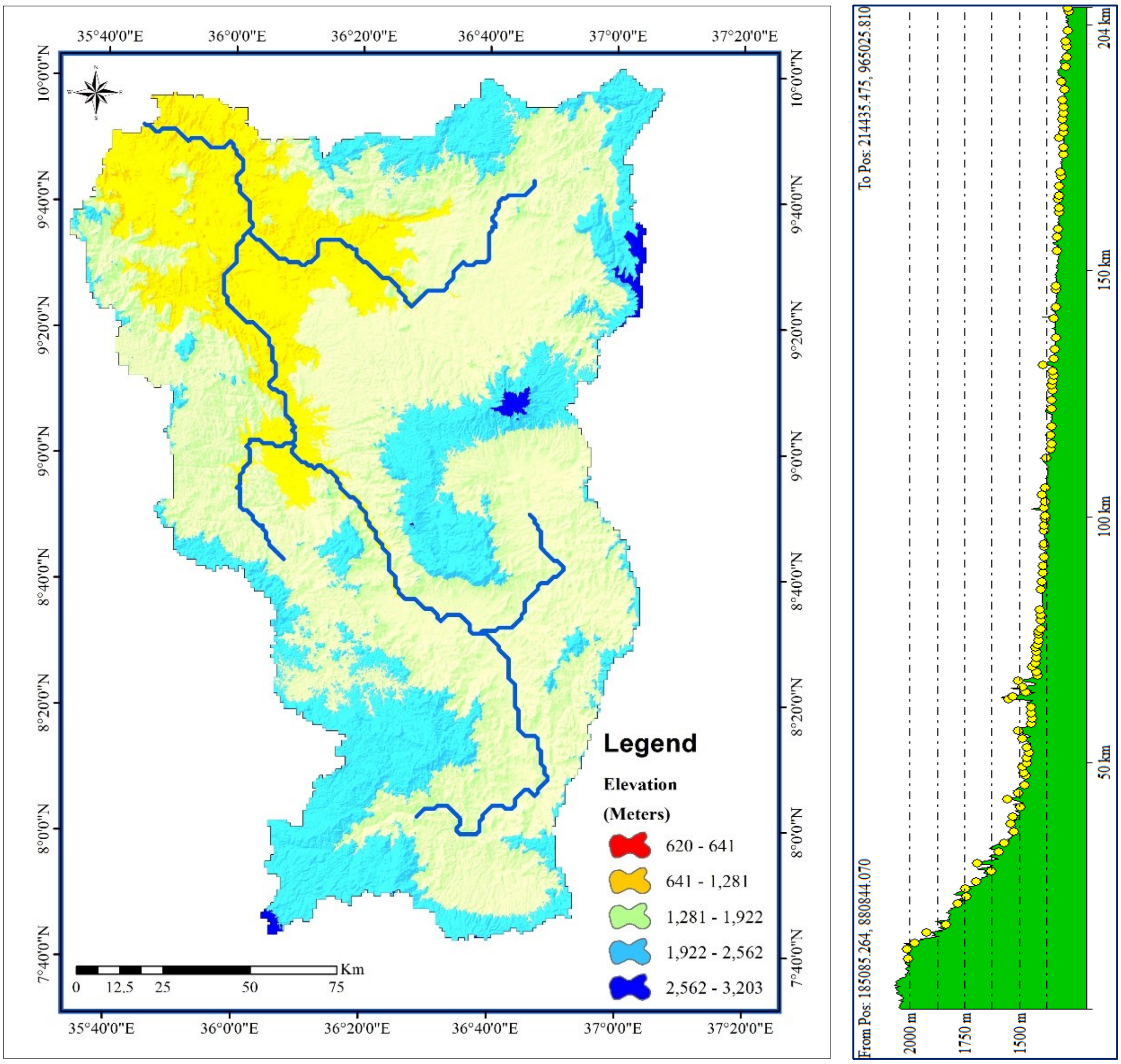


Figure 3-3: Topography of the Study area

3.2.3 Climate

The Climate of Arjo-didessa Sub-basin results from its location and elevations. The mountainous, highly rugged, and dissected topography with deep slopes characterizes the topography of the sub-basin. The lowest part of the catchment is characterized by a valley floor with a flat and gentle slope. Moreover, the climate of the sub-basin is affected by the movement of the Inter-Tropical Convergence Zone like many other river basins in Ethiopia. According to the traditional classification of Ethiopian climate (shown in Table 3.1) based on the altitude and temperature, the sub-basin is divided into three zones: Dega (elevation above 2400 m with mean annual temperature 6 to 16°C, Woina Dega (elevation between 1800 – 2400 m with mean annual temperature from 16°C to 20°C), and Kola (elevation below 1800 m with mean annual temperature 20 to 28°C). Most of the rainfall in the sub-basin is concentrated in the time window from June to September with virtual drought from November through February. This is also confirmed from the rainfall regime definition given by the National Meteorological Service Agency (NMSA) and (Berhanu *et al.*, 2016) where the catchment lies in a mono-modal region where the peak rainfall is expected to occur in June/July to August.

Table 3-1: Climate classification of Ethiopia

Local Class	Global Definition	Description
Wurch	Alpine	Cold climate at > 3000m altitude
Dega	Temperate	Highland climate within range of 2500-3000m
Woina Dega	Sub-Tropical	Warm between 1500-2500m
Kola	Tropical	Hot and arid type, less than 1500m in altitude
Bereha	Desert	Hot and hyper-arid type climates, elevations < 500m

More specifically, the Arjo Didessa project area lies between sub-regions B1 and B2 (Figure 3.4.). Accordingly, seasonal variation of rainfall in the Didessa sub-basin is also common characteristics. Being situated in region B, the sub-basin is dominated by two season types: wet (Kiremt) and dry (Bega). However, there exists unconditional third season called Belg that covers the period from mid-February to mid-May i[th] high inter-annual and inter- seasonal rainfall variation. The mean annual rainfall ranges between 1500 mm to more than 2000 mm.

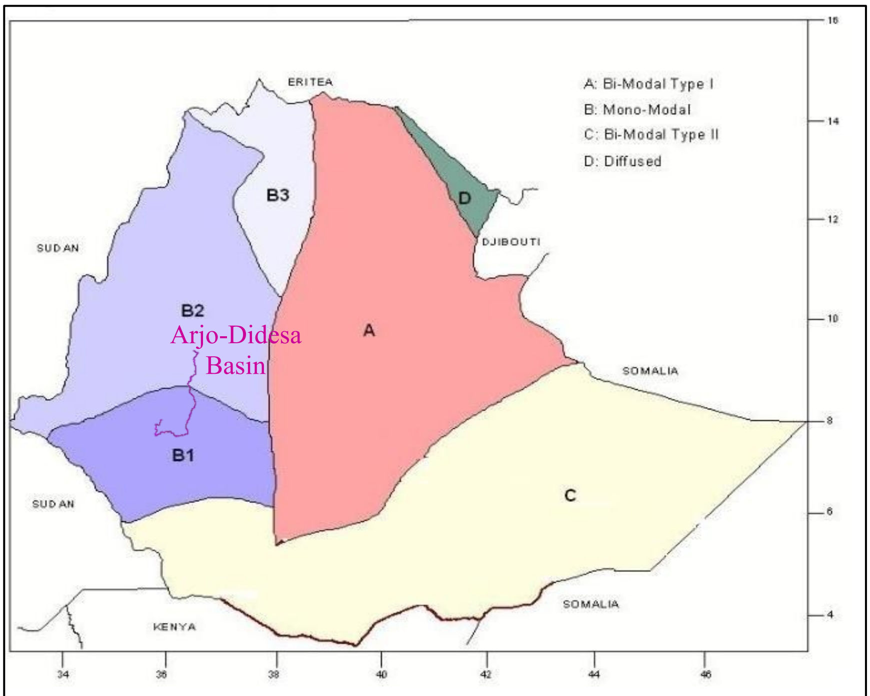


Figure 3-4: Rainfall regimes of Ethiopia (Source: NMSA, 1996)

3.2.4 River Flow Characteristics

As reported in many of the previous studies, Didessa River emanates from Wacha and Vennio mountain ridges and travels for a distance of nearly 210 km until it reaches Arjo station. The longitudinal profile of the main river course shows steepest slope along its upper 50 km distance upstream of Dembi (Toba) gauging station. However, for the sections between Dembi and Arjo, the slope is in the order of 0 to 1%, Figure 3-3 (right panel). The mean annual flow of Didessa River at Arjo station is about 3,800 MCM having its maximum flow in August and September (52 percent of the annual) and minimum flow in February and March (less than 1.5 percent of the annual).

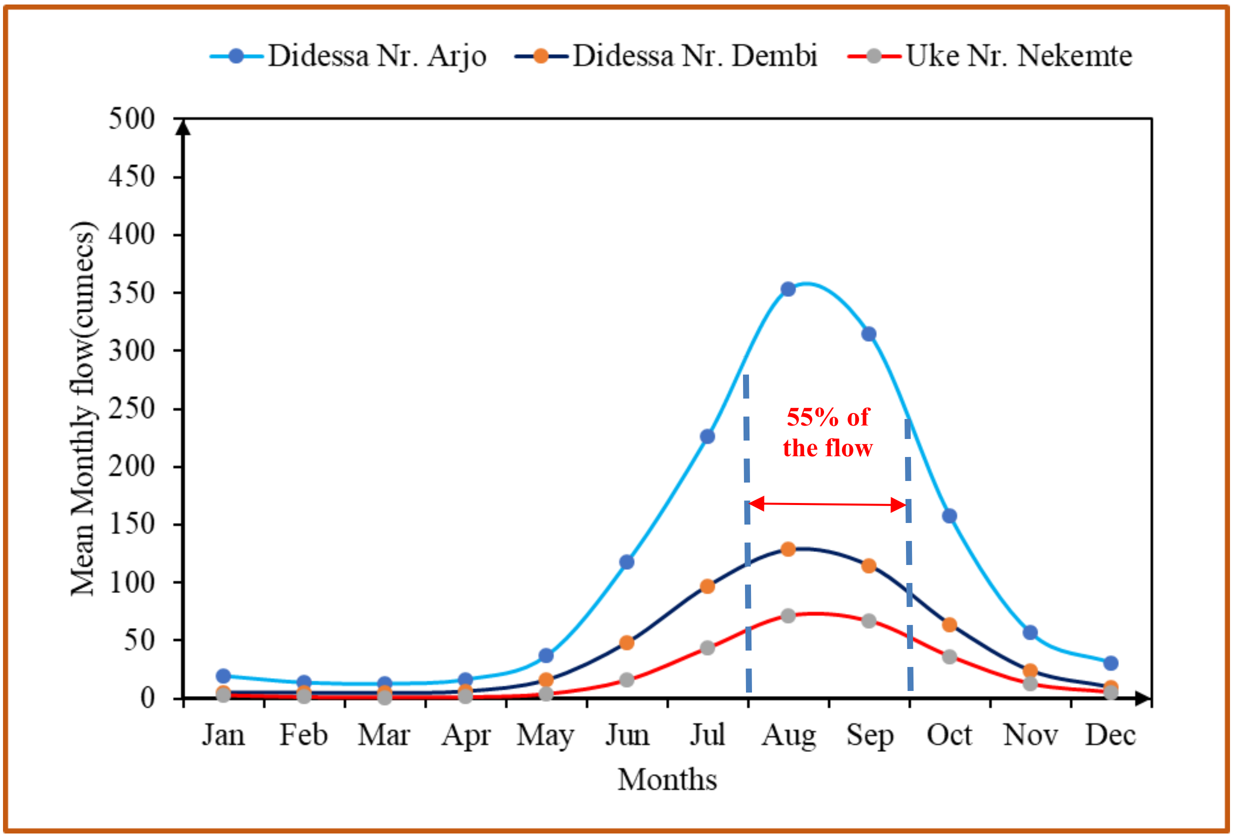


Figure 3-5: Stream flow characteristics at three selected gauging station

3.3 Data Collection and Processing

In this study, data were obtained from the Ministry of Water, Irrigation, and Energy (MoWIE) and the National Meteorological Service Agency (NMSA). Besides, the Digital Elevation Model with(30x30) resolution of the Abbay River basin, Hydrological shape files were obtained from the GIS department of MoWIE. Long term available meteorological data (rainfall and temperature) and hydrological data (streamflow) were collected from NMSA and MoWIE, hydrology department.

3.3.1. Meteorological data

Rainfall data from eleven stations, Tmax and Tmin data from three stations were collected from NMSA. Meteorological station and gauging stations were selected based on the following three conditions: (i) availability of long-term data, (ii) percentage of missing data, and (iii) their representativeness to the basin.

Table 3-2: Description of Selected meteorological Rainfall station for the study area

S/N	Station	Lat. (N)	Long. (E)	Elevation (m)	Length of Records	MAR (mm)
1	Abdela	8.366	36.233	1942	1983-2014	1908
2	Agaro	7.850	36.500	2030	1983-2017	1694
3	Arjo	8.750	36.500	2565	1983-2017	1400
4	Alibo	9.886	37.074	2513	1983-2017	2019
5	Bedele	8.450	36.333	2011	1983-2017	1857
6	Dedessa	9.383	36.100	1310	1983-2017	1548
7	Kone	8.683	36.783	2000	1983-2014	1853
8	Gidayana	9.866	36.616	1850	1983-2014	1768
9	Gimbi	9.166	35.783	1970	1983-2017	1870
10	Nekemte	9.100	36.500	2080	1983-2017	2101
11	Shambu	9.571	37.121	2460	1983-2017	1597

(Note: MAR = mean annual rainfall in mm)

Table 3-3: Description of selected Tmax and Tmin meteorological station

S/N	Station	Lat. (N)	Long. (E)	Elevation (m)	Length of Records	MATmax/MATmin
	Tmax					
1	Alibo	9.886	37.074	2513	1981-2016	22.99
2	Bedele	8.450	36.333	2011	1983-2016	25.59
3	Nekemte	9.100	36.500	2080	1981-2014	24.28
	Tmin					
1	Alibo	9.886	37.074	2513	1981-2016	11.7
2	Bedele	8.450	36.333	2011	1983-2016	12.86
3	Nekemte	9.100	36.500	2080	1981-2014	12.86

(Note: MATmax = mean annual Tmax in °C, and MATmin = mean annual Tmin in °C)

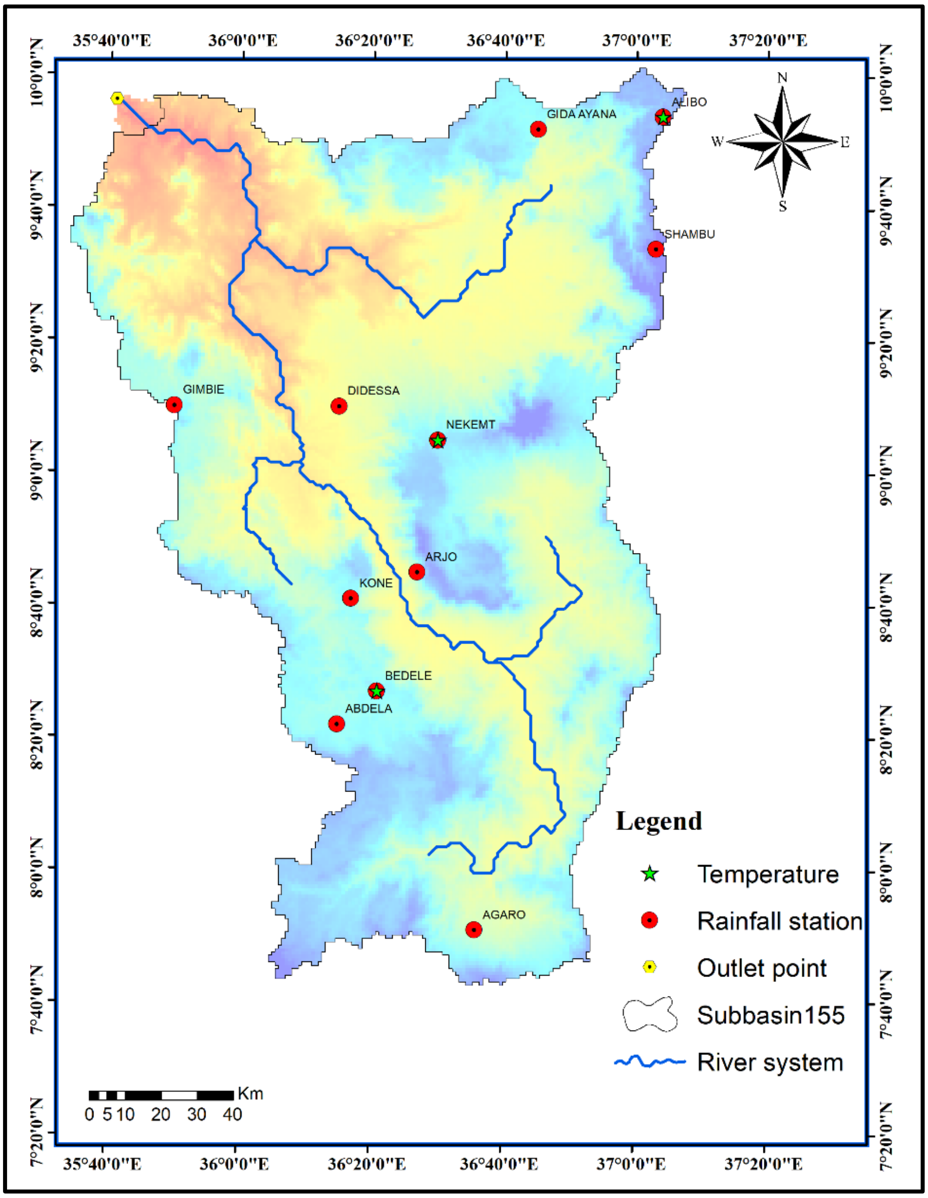


Figure 3-6: Location of Meteorological Station for the study area

3.3.2. River flow data

Daily streamflow data of the Arjo-didessa sub-basin from three gauging stations were collected from the hydrology department of MoWIE. Then daily data were aggregated into monthly, seasonal, and annual after filling the gap and quality test for further Analysis.

Table 3-4. List of selected hydrological gauging station in Arjo-didessa sub-basin

S/N	Code	Gauge Station	Area (km$^{2)}$	Lat. (°N)	Long(°E)	Record length
1	140014	Didessa Nr. Dembi	1806	8:3:0	36:27:0	1990-2015
2	114001	Didessa Nr. Arjo	9981	8:41:0	36:25:0	1990-2015
3	114002	Uke Nr. Nekemte	4674	9:26:0	36:31:0	1990-2014

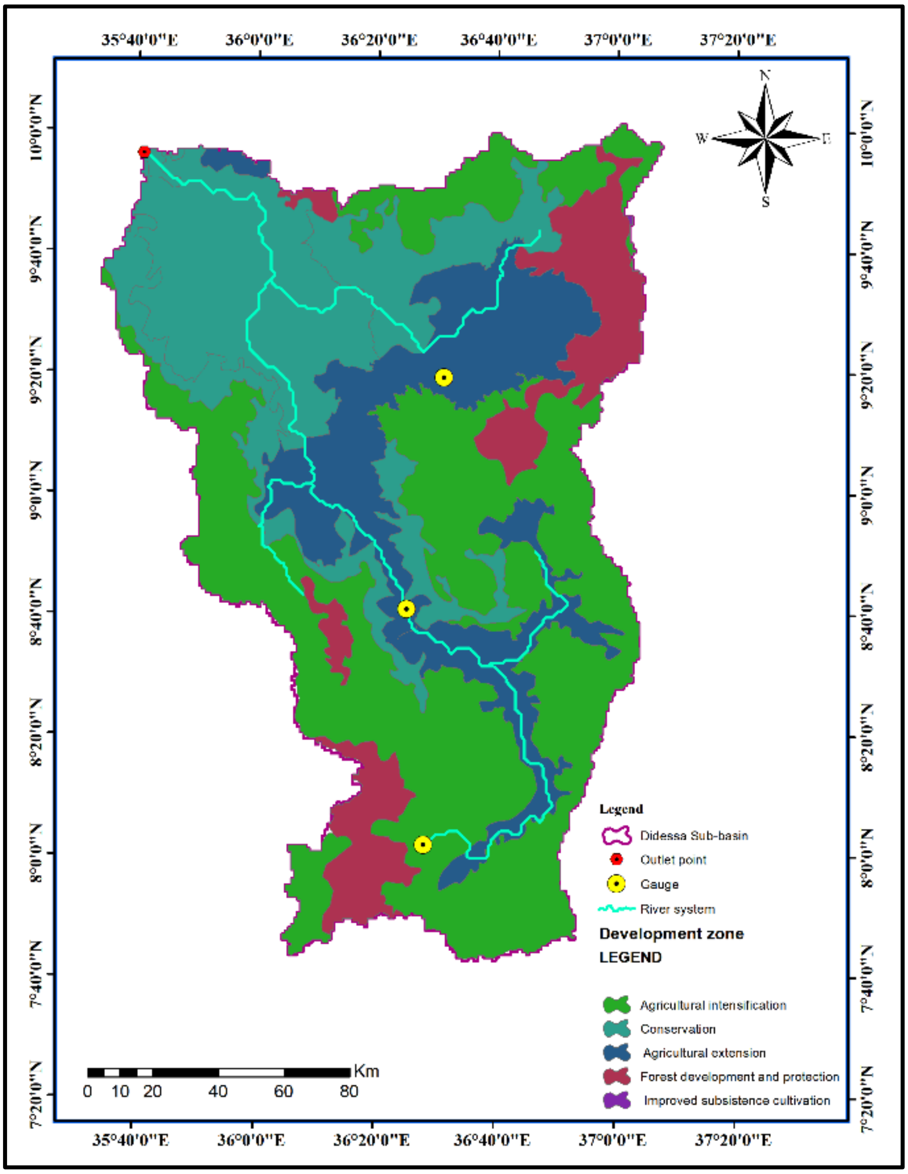


Figure 3-7: Location of streamflow gauge in the study area

Table 3-5: Description of Selected Streamflow Gauge stations

Gauging Station	Lat. (N)	Long. (E)	Record Length	MAR
Didessa Nr. Arjo	8:3:0	36:27:0	1990-2015	1357.0
Didessa Nr. Dembi	8:41:0	36:25:0	1983-2015	525.1
Uke Nr. Nekemte	9:26:0	36:31:0	1983-2014	263.7

(Note: MAF is Mean Annual Flow in m^3/s)

3.4. Data Quality Control

As most of the time series data sets used in the present study are from secondary sources, four quality control methods were adopted in the present study including: missing data filling, consistency checking, homogeneity test and outlier tests. These are adopted based on the objective of the present study and their details are described in the subsequent sub-sections (3.4.1 to 3.4.4).

3.4.1. Filling Missing data

Incomplete climate data records pose a major challenge to decision-makers that utilize climate data as their inputs. The major challenges of hydrological studies in the province in missing rainfall, temperature, and streamflow data, whose percentage in the study area was found to vary by up to 20%. The consistency and continuity of meteorological data are very crucial in statistical analysis. Both consistency and continuity may be distributed due to the change in observational procedure and incomplete records or missing observations that may vary in length of the data. However, filling the gaps generated by inconsistent data is essential and different procedures and approaches are available to accomplish this task (De Silva et al, 2007).

Table 3-6. Percentage of missing data for selected Rainfall stations

S/N	Stations	Elevation (m)	Duration	Missing data (%)
1	Abdela	1942	1983-2014	11.45
2	Agaro	2030	1983-2017	16.19
3	Arjo	2565	1983-2017	12.23
4	Alibo	2513	1983-2017	11.42
5	Bedele	2011	1983-2017	12.14
6	Didessa	1310	1983-2017	15.47
7	Kone	2000	1983-2014	10.98
8	Gidayana	1850	1983-2014	7.29
9	Gimbi	1970	1983-2017	16.67
10	Nekemte	2080	1983-2017	16.9
11	Shambu	2460	1983-2017	14.04

Table 3-7: Percentage of missing data for selected Tmax and Tmin stations

S/N	Stations	Elevation (m)	Duration	Missing data (%)
	Tmax			
1	Alibo	2513	1981-2016	11.80
2	Bedele	2011	1983-2016	15.20
3	Nekemte	2080	1981-2014	11.03
	Tmin			
1	Alibo	2513	1981-2016	16.20
2	Bedele	2011	1983-2016	16.90
3	Nekemte	2080	1981-2014	10.54

The most common method used to estimate missing rainfall data is the Normal Ratio Method. The normal ratio method used past observation of target rain gauge and surrounding rain gauges (Mohanty et al, 2014). This method is used in the surrounding gauges have the normal annual precipitation exceeding 10% of the target gauges. Therefore, missing rainfall data at the target gauge is estimated by;

$$P_x = \frac{1}{M}\sum_{i=1}^{M}\left[\frac{N_x}{N_i}\right] * P_i \qquad (1)$$

Where; M is the number of observations surrounding the station, P_x is estimated for the ungauged station, P_i is the rainfall value of the rain gauge used for estimation, N_i is a normal annual rainfall of the surrounding station and N_x is the normal annual rainfall of ungauged.

In addition to the normal ratio method, Averaging Arithmetic (AA) was used to fill missing monthly minimum and maximum temperature based on the best correlated neighboring station to target station. For Averaging Arithmetic based on best-correlated station, estimation of missing value is based on averaging the values of the best-correlated stations. Neighboring stations are ranked based on their data correlation with the target stations (Shabalala *et al.*, 2019). The averaging Arithmetic technique uses the following equation for missing value estimation.

$$P_X = \frac{1}{N}\sum_{i=1}^{n} P_i \qquad (2)$$

Where; P_x is the estimated value of missing data, P_i is the value of the same parameters at i^{th} nearest station, and N is the number of the nearest stations.

Table 3-8: Correlation Coefficient between each station (Annual Mean Temperature)

	Bedele	***Alibo***	***Nekemte***
Bedele	1		
Alibo	0.87	1	
Nekemte	0.94	0.90	1

3.4.2. Checking Consistency of the data

The consistency of the long-term hydrologic data series is questionable because strict experimental control is impossible to achieve and the inherent variability of the water cycle phenomenon is poorly understood. This Dualistic nature of causes has reduced much of hydrologic research to the level of profound uncertainty. Therefore, contemporary hydrologists have been content with achieving relative consistency in data series. An observed time series data is relatively consistent if the periodic data are relatively proportional to an appropriate simultaneous series.

This proportionality can be tested by using the standard procedure of double mass analysis. Moreover, inconsistent partial series can be adjusted to relative consistency with the simultaneous series based on the proportionality constant among the partial studies. Double mass curves are always used by hydrologists to adjust or correct precipitation records for change in gauge location, gauge environment, or observational procedures when these factors introduce new factors of proportionality. For precipitation records, a double mass curve can be used to detect a change in the consistency of precipitation records and determine the amount of adjustment to be applied to make them consistent. The precipitation records being used should first be tested for consistency by the double mass curve method. The records should be made as consistent as possible and plotted against each other to define a relation.

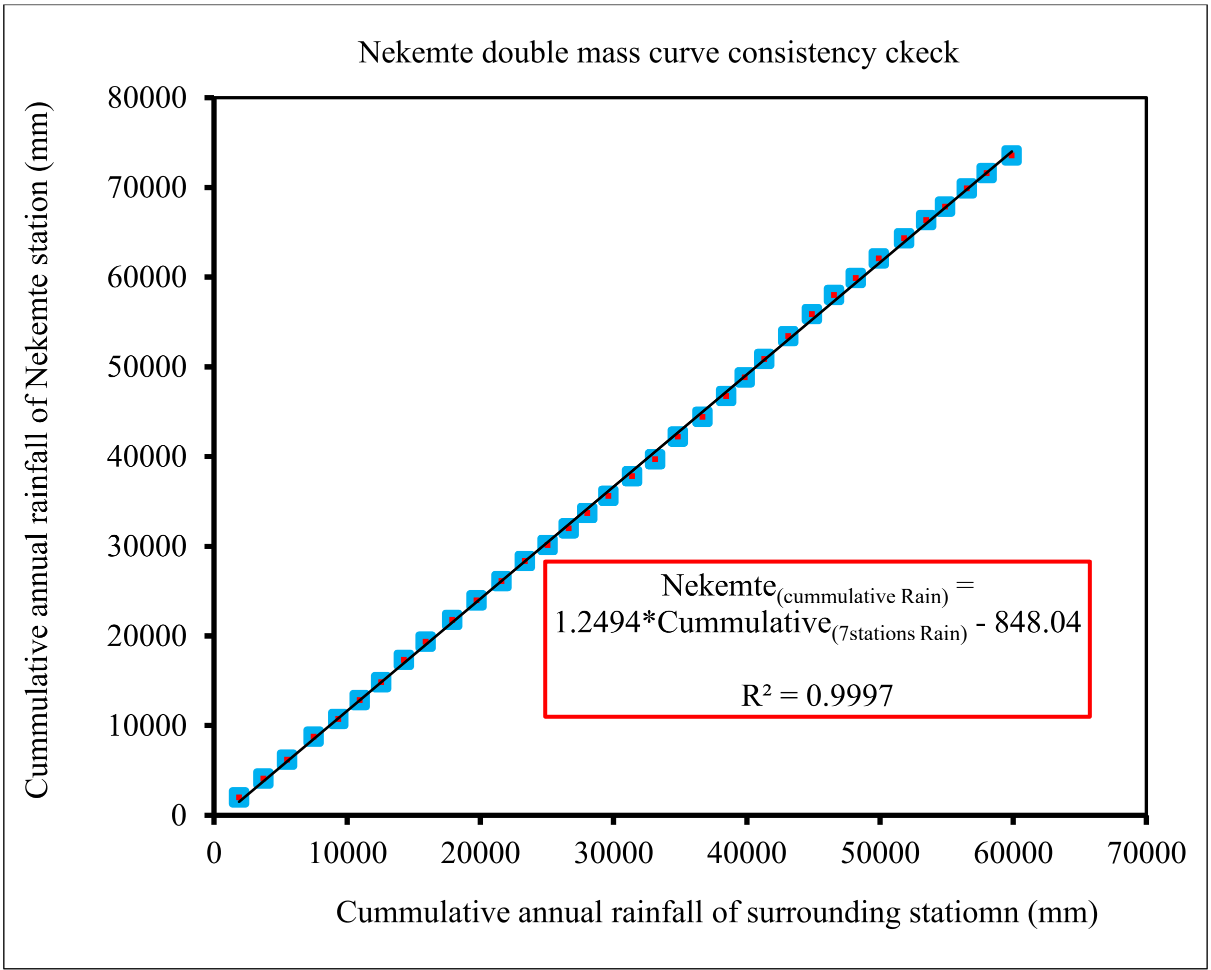


Figure 3-8: Double mass analysis for rainfall consistency check

3.4.3. Homogeneity test

The accuracy and reliability of climatic variability, flood and drought modeling, water resources planning, determination of rainfall-runoff relationship, and river flow estimation models vary according to the quality of the data used. Several factors such as methods of gauging and data collection, the conditions around the station, station relocation, and the reliability of the measurement tools affect the homogeneous precipitation records (Awiti *et al.*, 2016). For this reason, the data recorded at each gauging station should be tested and checked for reliability and homogeneity before their use for analysis.

Homogeneous time series is defined as one in which variation is caused by only the weather and the climate. Homogeneity of time series may be of two types. Absolute homogeneity and relative homogeneity. Absolute homogeneity is used for each station separately while relative homogeneity considers neighboring stations in testing the homogeneity (Ahmed *et al.*, 2018). Four absolute homogeneity tests were applied to the observed rainfall, Tmax, and Tmin dataset to the representative station for this study.

The test results were grouped into three individual classes based on the homogeneity test that rejects the null hypothesis of a homogeneous dataset for a significance level of 5%. The alternative hypothesis proclaims that there is a date with a change in the data in accordance with (Wijngaard, et al., 2003). The results of the test were classified as: Useful if the rejected one or none of the null hypothesis under four tests at 5% significant level and then considered as homogeneous and can be used for further analysis. If the series rejects the two null hypotheses of four tests, it was considered as doubtful and inspected before further analysis. A data series was considered as suspect if it rejects three of the four null hypotheses and therefore was not considered for further analysis. The test was done using the R Studio software and presented in the following table 3-9 and table 3-10 as shown below.

Table 3-9: Absolute homogeneity test result for selected rainfall stations

	Absolute Homogeneity Tests							
	VNR Test		**BR Test**		**Pettit's test**		**SNHT test**	
Station	RVN	p-value	$R/\sqrt{n}$	p-value	U	p-value	T	p-value
Abdela	1.4293	**0.0495**	1.559	**0.0359**	105	0.2824	4.610	0.3061
Kone	1.4824	0.0681	1.378	0.1129	140	0.0616	9.610	**0.017**
Gimbi	1.7329	0.2238	0.884	0.7645	68	0.880	14.280	**<0.001**
Nekemte	1.6103	0.1328	1.025	0.5445	85	0.5545	6.230	0.1406
Bedele	1.7423	0.232	0.859	0.7994	74	0.7564	3.410	0.5363
Arjo	0.9028	**0.0003**	1.996	**0.0004**	213	**0.0006**	17.650	**<0.001**
Agaro	1.9339	0.4258	1.111	0.4111	79	0.6604	4.780	0.2979
Alibo	1.8149	0.2998	1.258	0.2148	73	0.7764	2.910	0.6476
Gidayana	1.0707	**0.0026**	0.910	0.7256	61	**1.033**	4.4425	0.350
Shambu	1.4993	0.0749	1.579	**0.0273**	151	**0.0349**	8.720	**0.0341**
Didessa	1.9139	0.4037	1.049	0.503	75	0.7367	3.560	0.5012

(Note: bolded value shows non-homogeneity at α = 0.05 significance level)

Table 3-10: Absolute homogeneity test for selected Tmax and Tmin stations

Station	Absolute Homogeneity Tests							
	VNR Test		BR Test		Pettit's test		SNHT test	
	RVN	p-value	$R/\sqrt{n}$	p-value	U	p-value	T	p-value
			Tmax					
Alibo	0.5715	**<0.0001**	1.782	**0.0059**	268	**0.00025**	8.6328	**0.040**
Bedele	1.6611	0.1598	1.052	0.5066	78	0.8113	4.9518	0.2735
Nekemte	0.7493	**0.0172**	1.650	**0.0172**	228	**0.0008**	13.05	**0.0024**
			Tmin					
Alibo	2.043	0.5513	1.124	0.3966	67	1.00	4.3783	0.3708
Bedele	0.980	**0.0007**	1.765	**0.0060**	189	**0.010**	16.019	**0.0002**
Nekemte	0.947	**0.0004**	1.891	**0.0015**	229	**0.0008**	14.308	**0.0006**

(Note: bolded value shows non-homogeneity at α = 0.05 significance level)

3.4.4. Outlier test

Typically, for a variety of reasons, hydro-meteorological time series have outlier observations. The detection of outlier observations is an essential task that must be undertaken for any analysis to obtain error-free time-series data. An outlier is an unusual finding, different numerically from a series of observations (Atkinson, et al., 1997). In the case of precipitation data, precipitation depth magnitudes can be used for the detection of outliers or irregularities over different time scales. It is important to easily distinguish physically impossible values. For quality control of the data, it is possible to develop a simple rule-based method (precipitation data-specific rules). Methods based on rules can help identify: Possible erroneous values associated with specific types of rain gauges, Values greater than regional record rainfall for different duration, and Repetition of non-zero constant values over the time interval.

3.5. Monthly and Annual characteristics of Hydro-meteorological data

3.5.1. Monthly Rainfall Variability

Long-term variation of rainfall is of prime importance for the efficient management of water resources. The variation of monthly mean rainfall, rainfall over 35 years of 11 rainfall stations in the Arjo-didessa sub-basin is shown in figure 7 below with the help of a graphical presentation. Mean monthly rainfall in the Arjo-didessa sub-basin ranges from 2.6mm to 400mm between the recording periods of 1983 to 2017. Comparatively, monthly rainfall was low during December, January, and February and dramatically increase during June, July, and August. The highest rainfall record was observed during June and July with maximum mean rainfall at Nekemte meteorological station and Minimum mean monthly rainfall record observed during January and December at Gimbi meteorological Station. The mean monthly rainfall for each station in Arjo-didessa is recorded in varying quantities almost all year round, but the main increasing rainfall season occurs between May and October when very high rainfall amounts are measured.

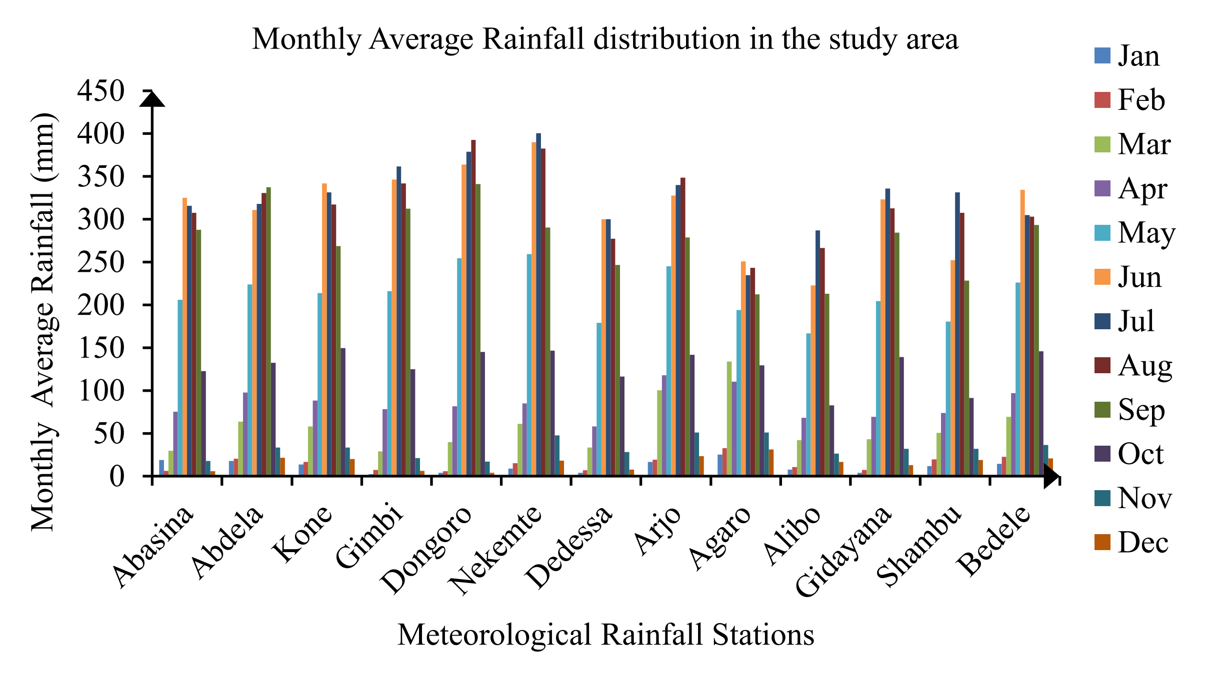


Figure 3-9: Mean monthly rainfall of selected rainfall stations

3.5.2. Annual Rainfall variation

As concluded from Table 10 below, the temporal variation of annual mean rainfall is highest for Nekemte station and the lowest annual mean rainfall record is observed for Alibo station across the Arjo-didessa sub-basin using 11 rain-gauge stations. Similarly, annual rainfall over the study area varies from 950.2mm to 3147mm from Didessa and Kone Station respectively.

Table 3-11: The statistical description of Annual rainfall for the selected station

Station	Min.	Max.	Mean	1st Qu.	3rd Qu.	SD	Kurt.	Skew
Abdela	1225	2740	1908	1737	2037	316.73	1.0464	0.6268
Kone	1154	3147	1853	1614	2020	454.66	1.2566	0.9429
Gimbi	1376	2910	1870	1696	1980	297.37	2.6344	1.3220
Nekemte	1507	2563	2101	1959	2211	250.19	-0.3399	0.0277
Bedele	1393	2358	1857	1741	1987	239.95	-0.3163	0.0630
Didessa	905.2	2098	1548	1363	1747	278.48	-0.4228	0.0463
Arjo	1328	2766	2019	1808	2224	348.68	-0.3964	0.2846
Agaro	1039	2695	1694	1471	1914	341.06	0.3768	0.5604
Alibo	1102	1785	1400	1270	1481	183.76	-0.716	0.5402
Gidayana	1161	2240	1768	1706	1895	227.47	0.5771	-0.6410
Shambu	1276	1835	1597	1488	1722	156.94	-1.1885	-0.2694

3.5.3. Temperature Variation

Air surface temperature of Arjo-didessa sub-basin was analyzed using monthly minimum and maximum data from three stations based on long term availability of data. The period of record varies from 34 to 36 years, for Alibo (1981-2016), for Bedele (1983-2016), and Nekemte (1981-2014). The summary of Annual Mean Tmax and Tmin for selected stations across the Study area is as shown in Table 9 below.

Table 3-12: Statistical description of Mean Annual Tmax and Tmin for three station

Station	Min.	Max.	Mean	1st Qu.	3rd Qu.	SD	Kurt.	Skew.
Tmax								
Alibo	22.32	23.95	22.99	22.69	23.16	0.3813	0.1485	0.6139
Bedele	24.05	26.49	25.59	25.25	25.99	0.5455	0.1216	-0.6266
Nekemte	23.21	25.13	24.28	24.07	24.57	0.4526	-0.2596	-0.3825
Tmin								
Alibo	10.48	16.20	11.70	11.02	11.84	1.1945	4.9317	2.2113
Bedele	12.20	13.45	12.86	12.67	13.05	0.2758	-0.2805	-0.1170
Nekemte	10.79	13.48	12.86	12.74	13.12	0.4733	8.3172	-2.3907

3.5.4. Streamflow Variation

Streamflow statistics are extensively employed for the management and development of water resources. For example, a wide range of streamflow statistics is used for consumptive water use mitigation, reservoir operation, and minimum release management. Water resources managers often assume that streamflow series is stationary over time when using streamflow data and statistics. These Assumptions may not work if the watershed under consideration is sensitive to anthropogenic activities. Generally, climate variability, change in population, land use, and water use is implicated in non-stationary streamflow series.

Table 3-13: Statistical summary of Annual Streamflow for selected gauge station

Station	Max	Min	Mean	1stQ	3rdQ	SD	Kurt	Skew
Didessa Nr. Dembi	667.4	363.3	525.1	456.7	593.8	85.3	-1.127	-0.098
Didessa Nr. Arjo	2219.0	662.4	1357.0	1227	1516.0	296.3	0.538	0.286
Uke Nr. Nekemte	400.5	125.6	263.7	229.1	300.4	60.9	0.011	-0.305

3.6. Software Used (R Studio)

To undertake this study, the majority of the works have been done using different software. Among the software used in this study, R Studio, ArcGIS 10.4, Microsoft Excel are the most widely used starting from study area delineation to data analysis and visualization. The statistical software R has come into prominence due to its flexibility as an efficient language that builds a bridge between software development and data analysis.

R studio is a customizable Integrated Development environment (IDE) for R environment where users can have easy access to plots, data, help, files, objects, and many other features that are useful to work efficiently with R. An open-source programming language R has gained a central place in hydrological science over the last decade, driven by the availability of diverse hydro-meteorological data archives and the development of open-source computational tools. The growth of R 's usage in hydrology is reflected in several newly published hydrological packages, strengthening online communication, and the popularity of training courses and events (Harrigan *et al.*, 2019).

Table 3-14: List of Software used for the study

Software Used	Purpose	Source
ArcGIS	Study Area delineation	***Student trial licenses/open-source from AAU Portal***
R	Explore and/or manipulate data	***http://cran.r-project.org/***
R Studio	For data analysis, statistical visualization, and time-series plot	***https://www.r-project.org/***
Mendeley Desktop	To organize journals and other material for citation	***https://www.mendeley.com/***

3.7. R Studio packages for hydrological statistics

R was initially developed as a statistical computing language and the primary language in which novel statistical methods are coded and distributed. Statistical approaches are employed for an extremely wide range of tasks in hydrology and it is virtually impossible to give complete coverage of all possible packages that might be useful to hydrologists. Several statistical estimation procedures can be carried out using the R stats package, which includes correlation analysis, Mann-Kendall testing, linear regression, and change point detection. Four open-source library packages namely; modifiedmk, trend, hydroTSM, trend change were developed in R language and used to perform non-parametric Mann-Kendall, Sen's slope estimator, and modified Mann-Kendall test. Another package trend was used for the absolute homogeneity test.

Table 3-15: List of Hydrological R packages used in this study.

Packages	Description	Author
modifiedmk	*Modified Version of Mann-Kendall and Spearman Rho Trend Test*	*Hamed and Rao, 1997*
hydroTSM	*Time Series Management and Analysis for Hydrological Modelling*	*Mauricio Zambrano-Bigiarini, 2020*
trend	*Non-parametric Test and Change Point Detection*	*Thorsten Pohlert, 2020*

trend change	*Innovative Trend Analysis and Time Series Change Point Analysis*	*Sandeep Kumar Patakamuri, 2019*

3.8. Methods

In this study, both graphical and statistical methods of time series analysis were applied to determine temporal patterns in hydro-meteorological data on a monthly, seasonal, and annual time scale. Trends and homogeneity tests are the two most important statistical characteristics of the hydrological time series, which reveals the temporal variability of hydrologic variables. R Studio Packages are used to present temporal patterns of monotonic trend and homogeneity test for hydro-meteorological time series in the study area. It is quite common to use only one or two tests for time series analysis which facilitates an easy decision-making process.

According to (Machiwal and Jha, 2008) an adequate number of statistical tests must be applied for detecting a particular time series characteristics and results should be analyzed critically to arrive at a reliable decision. Therefore, adequate multiple statistical tests were applied in this study to ensure realistic decisions about the time series analysis. The trend in the datasets can be done with non-parametric methods, which is widely used for analyzing the trends in several hydrologic time series especially rainfall, temperature, and streamflow. Accordingly, the Mann-Kendall test (Mann, 1944, Kendall, 1975), Sen's estimator (Sen, 1968), and coefficient of variation in the time series were investigated to detect the trend and assess the temporal variability of hydro-meteorological time series.

Many parametric and non-parametric methods have been applied for the detection of trends. Parametric tests are more efficient than non-parametric tests, but the assumption that the data are normally distributed must be met. Hydro-meteorological time series is also characterized by data that show deviations from normality, and thus non-parametric tests are known to be more reliable compared to the parametric counterparts. One of the most commonly used non-parametric tests to detect trends in the hydro-meteorological time series are the Mann Kendall test (Mann, 1945; Kendall, 1975).

3.8.1. Measures of Temporal Variability

When analyzing the variability of precipitation, temperature, and streamflow, we do not overlook the fluctuations in seasonal timescales over the decades. Another significant feature of a region's climate is the degree to which rainfall amounts differ across an area or over time. Common variability measurements, such as the standard deviation, absolute mean deviation, coefficient of variability, percentage of inter-annual variability were analyzed for this study, in addition to trend detection, for climate and environmental analysis purposes based on an assumption of an underlying standard normal distribution.

Recently, the coefficient of variation (CV) is used as a statistical measure of how each data value varies about the mean values. It is calculated to evaluate the variability of hydro-meteorological time series (Rainfall, Temperature, and Streamflow) in this study. The greater value of CV, the higher degree of variability in individual data values from their mean values and vice versa. The standard deviation of the data series must always be understood in the context of the data series. Thus CV being a dimensionless number is an advantage over standard deviation. (Asfaw *et al.*, 2018). Coefficient of variation gives a normalized measure of spreading about the mean and estimated as:

$$CV = \frac{SD}{\mu} \qquad (3)$$

Where CV is the coefficient of Variation, μ is the mean of the data and SD is the standard deviation of the time series. Hydrologic variables with larger CV values are more variable than those with smaller values. (William, 2016) suggested a classification scheme for identifying the extent of variability of hydrologic time series (Rainfall) based on CV values where, (CV < 20%), (20% < CV < 30%), and (CV >30%) are the classification that indicates less variability, moderate variability, and high variability respectively.

3.8.2. Non-parametric test for independence

Serial auto-correlation was applied to check if the time series undergoes non-random characteristics if a serial correlation exists in a time series, it increases the likelihood to reject the null hypothesis of no trend, when in fact the null hypothesis should be accepted (Society *et al.*, 2016). In this study, the auto-correlation coefficient is referred to as the serial correlation coefficient (ACFs) at lag-1 and used to determine the presence of significant auto-correlation. The lag-1 correlation coefficient in time series is commonly used to determine whether time a series exhibit non-random characteristics.Lag-1 auto-correlation coefficient was computed for N-1 observations using the following equations 3 and 4 below according to Yue *et al.*, 2002; Nalley *et al.*, 2013). To detect the trend in time series, the statistical test assumes the subsequent data in the series to be independent. The power of trend tests is highly influenced by the presence of serial autocorrelation in data.

$$R = \frac{(1/n-1)\sum_{t=1}^{n-1}[x_t-\overline{x}_t][x_{t+1}-\overline{x}_t]}{(1/n)\sum_{t=1}^{n}[x_t-\overline{x}_t]^2} \tag{4}$$

$$\frac{\{-1-1.645(\sqrt{n-2})\}}{n-1} \le R \le \frac{\{-1+1.645(\sqrt{n-2}\}}{n-1} \tag{5}$$

Where R represents the auto-correlation coefficient at lag-1 of the time series x_t, x represents the mean of the data. If the computed lag-1 autocorrelation coefficient (R) is found between the intervals defined by equation 6, it can be concluded that the time series does not exhibit significant autocorrelation (Ahmad *et al.*, 2015). On the other hand, if the lag-1 auto-correlation value (R) calculated is outside of the interval, it can be said that the time series exhibit a significant auto-correlation at the 5% significant level.

3.8.3. Trend Detection Methods

For detection of the trend in hydro-meteorological time series, prewhitened time series for eliminating the effect of serial correlation observation using lag-1 auto-correlation, Application of Mann-Kendall and Modified Mann-Kendall trend analysis to identify the significance of trends and Sen's slope estimator to assess the trend of slope line. Due to linear and nonlinear (monotonic) trends, variability in hydro-climatic time series data may be observed, as well as variations in values across time or through temporal. For analysis, three main components in most every time series data are of concern and they are (1) trend; (2) seasonality; (3) distortion. Quality evaluation of time series to ensure serially continuous, error-free, and gap-free data should be conducted before any time series analysis can be taken up (Teegavarapu, 2018).

Analysis of any hydrological time series would require evaluation of general characteristics of the variables, Trend and variation in variables at different temporal scale, inter-annual and interannual variation, changing extremes overtimes, changes and trends in temporally aggregated variable values, spatial variation of the trend, variation in summary statistics of observation, and indices that specific to particular hydro climatic variables.

This study mainly focuses on-trend and variation in hydro-climatic variables at different temporal time scales. Statistical tests to analyze shifts in hydro-climate or other time series depend on the type of change and include: (1) abrupt mean change; (2) gradual mean change;

(3) shifting levels (more than one mean change); (4) constant mean trend; (5) cyclical patterns; and (6) changes in variability.

3.8.4. Original Mann-Kendall Test

To Evaluate the trends in the hydro-meteorological time-series data, a non-parametric rank-based Mann-Kendall (MK) and Modified Mann-Kendall (MMK) trend analysis test was commonly used (Blain, 2013). The key drawback of the MK test is that no assumptions are taken as to the statistical distribution of the data from the sample. Although the approach is rank-based, the findings would not largely be affected by extreme data points (an outlier) in the hydro-meteorological time-series. Due to the presence of auto-correlation in the monthly, seasonal, and annual based data, the modified version of the Mann-Kendall tests by (Hirsch and Slack, 1984), (Hamed and Rao, 1997) was used for the data that exhibited significant lag-1 auto-correlation. The statistic of the MK test (S) is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \qquad (6)$$

$$\operatorname{sgn}(x_j - x_i) = \begin{Bmatrix} 1 & if \ (x_j - x_i) > 0 \\ 0 & if \ (x_j - x_i) = 0 \\ -1 & if \ (x_j - x) < 0 \end{Bmatrix} \qquad (7)$$

Where n denotes the length of datasets and x_j and x_i are sequential data values at time j and i. n is the length of the dataset. A positive value of S indicates an increasing (upward) trend and a negative value indicates a decreasing (downward) trend in time series data. The variance of S can be computed as follow:

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i - 1)(2t_i + 5)}{18} \qquad (8)$$

Where; i is the number of tied groups in the dataset and t_i is the number of data points at i^{th} tied group and p is the number of tied groups in the dataset. However, if there are no tied group in the dataset, then this may be ignored. After computing the variance *Var(S)* from equation (9), the standardized test statistics (Z_{mk}) value is computed by using the following equation:

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{V(S)}} & s < 0 \end{cases} \tag{9}$$

Where; Z_{mk} is the Mann-Kendall test. A positive value of Z_{mk} indicates an upward trend (increasing), whereas a negative Z_{mk} indicates a downward trend (decreasing). The statistical test (S) follows the standard normal distribution, where the probability of observing a value higher than the test statistics Z_{mk} is tested under the null hypothesis, $\boldsymbol{H_0}$, that there is no trend for the chosen α-level of significance. The null hypothesis $\boldsymbol{H_0}$ is rejected and an alternative hypothesis $\boldsymbol{H_a}$ is accepted if the absolute value of $\boldsymbol{Z_{mk} > Z_{1-\alpha/2}}$ at the α- a level of significance. For independent sample data without trend, the p-value should equal 0.05. For sample data with a largely positive trend, the p-value should be close to 1. Whereas a large negative trend should yield a p-value closer to 0. The critical value of $Z_{1-\alpha/2}$ for a p-value of 0.05 (α = 5% significance level) from the standard normal table is 1.96. Therefore, the p-value of the Mann-Kendall statistics S of the sample data can be estimated using the normal cumulative distribution function as:

$$p-value = \frac{1}{\sqrt{2\pi}} \int_{\infty}^{z} e^{-t^2/2} dt \tag{10}$$

$$\tau = \frac{S}{D} \tag{11}$$

$$D = \left[\frac{1}{2} n(n-1) - \frac{1}{2} \sum_{j=1}^{p} t_j \left(t_j - 1 \right) \right]^{0.5} \left[\frac{1}{2} n(n-1 \right]^{0.5} \tag{12}$$

3.8.5. Modified Mann-Kendall Test

The modified MK test by (Hamed and Rao, 1997) is intended to indicate the serial auto-correlation structure in a dataset by looking at their effects on the mean and variance of the original Mann-Kendall test. Modified Mann-Kendall test was used on time series that exhibits only significant auto-correlation at lag-1, whereas the original Mann-Kendall test applied to time series that exhibits neither significant auto-correlation at lag-1 nor seasonality pattern.

3.8.6. Sen's Slope Estimator

The magnitude of the trend in hydrological time series can be determined using a non-parametric method called Sen's slope estimator (Sen, 1968). To estimate the true slope of an existing trend such as the amount of change per year, Sen's non-parametric method is used. Sen's method can be used in the case where the trend can be assumed to be linear such as:

$$f(t) = Q + B \tag{13}$$

Where; Q is the slope and B is constant. To get the slope estimate Q in the above equation, the slope of the n data pairs would first be estimated using the following equation:

$$Q = median\left(\frac{x_j - x_i}{j - i}\right) for, j > i \tag{14}$$

Where; X_j and X_i are the data values in j and i year, for j>i, and Q is Sen's slope estimate. Sen's slope estimator is the median Q_{med} of the N pairs of Q_i. In the procedure, the N value of Q_i is ranked from smallest to largest and Sen's estimator is determined by using the following equations.

$$\begin{Bmatrix} Q_{[(N+1)/2]} & if \;\; N \; is \; odd \\ \frac{1}{2}[Q_{(N/2)} + Q_{[(N+2)/2]} & if \; N \; is \; even \end{Bmatrix}$$

A positive Q value represents an increasing trend a negative Q value represents a decreasing trend.

3.8.7. Innovative Trend Analysis method

Innovative trend analysis test is another non-parametric method used to detect hydro-meteorological and climatological time series data and its reliability is confirmed by comparing with the Mann-Kendall test. It was first developed by Sen (2012), which can be applied to any time series data without limiting to the assumptions of hydro-meteorological data. One of the added value of the innovative trend analysis method is that it is not affected by the restriction requirements for the Mann-Kendall application (Şen, 2017) such as serial autocorrelation and outliers. The method is applied in the following steps:

Step-1: The observed time-series data will be divided into two equal sections as X_i and X_j where X represents the variable (say annual rainfall) and i= 1, 2, 3 … n/2; j= n/2-1, n/2-2… n; for total n number of observations;

Step-2: Both datasets are then arranged in ascending order and plotted on a graph with X_i in horizontal axis and X_j in vertical axis in Cartesian coordinate system (as shown in figure 3-12 for demonstration purpose).

Step-3: The variable (rainfall) data points are plotted on 1:1 (45°) line on the coordinate (if the point falls exactly on this line, it indicates that there is no trend in the time-series data), otherwise there is an increasing (above the line) or decreasing (below the line) trend in the data.

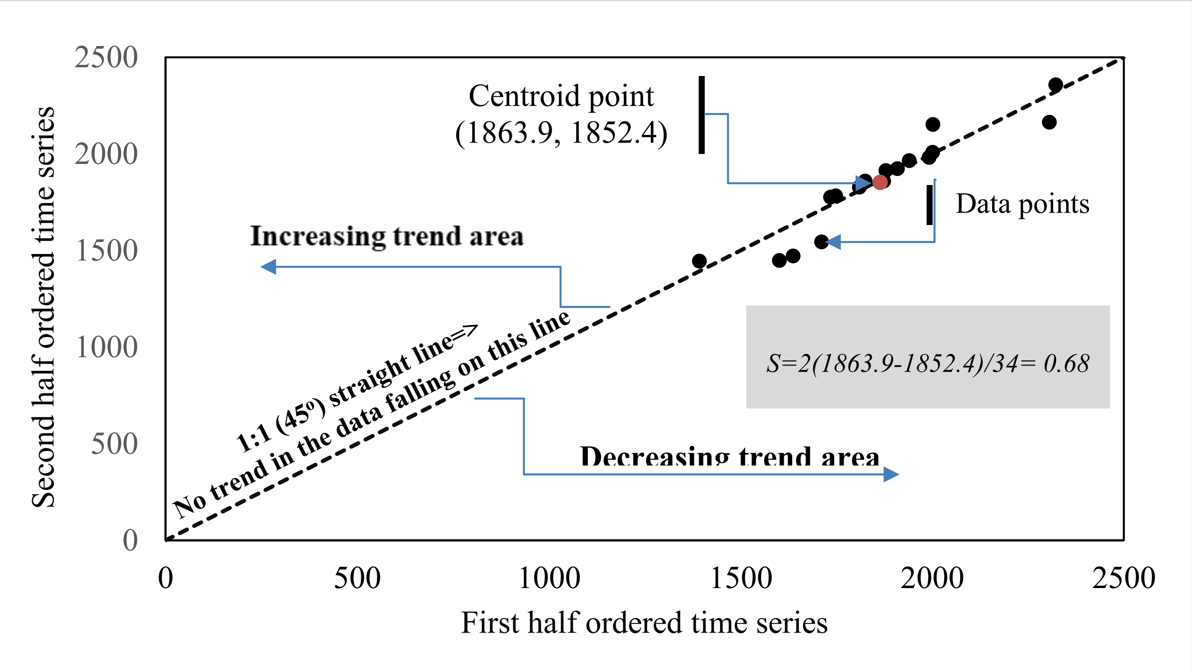


Figure 3-10: Demonstration of Innovative Trend Analysis Method (Bedele Station)

According to Wu and Qian (2017), if the sub-series are equal, which indicates no trend, the points in the scatter plot are collected on the 1:1 (45°) line. If the points fall above the 1:1 (45°) line, it can be said that the time series exhibits an increasing trend. If the points are accumulated below the 1:1 (45°) line, it is concluded that a decreasing trend is present in a time series. The absolute values of the difference between the y and x values of a point are the horizontal or vertical distance from the 1:1 (45°). The difference indicates the magnitude of increasing or decreasing trend. Therefore, it can be employed to measure a trend, and the average differences indicate the overall trend of the time series. As the detection of change is based on the first sub-series, the trend indicator is derived from the average difference divided by the average of the first sub-series. To allow direct comparison, the indicator is multiplied by 10 to reach the same scale as that of the Mann-Kendall trend analysis (Alifujiang *et al.*, 2020). ITA indicator is estimated using the formulae below:

$$\phi = \frac{1}{n}\sum_{i=1}^{n} 10\left(y_i - x_i\right) \tag{15}$$

$$Si = 2\left(\frac{\overline{y} - \overline{x}}{\overline{x}}\right) \tag{16}$$

Where; ϕ is the trend indicator, and a positive value for ϕ indicates an increasing trend, whereas a negative value indicates a decreasing trend; n is the number of observations of each sub-series. Similarly, Si represents ITA slope, while xbar and ybar represents the mean of first half ordered and second half ordered of the time series.

3.9. Hypothesis Tests in Trend Analysis

The importance of a hypothesis test is to evaluate and compare a group of data based on a decision. The significance test starts with a careful statement of the claims being compared. The claims are tested by a statistical test called the ***Null hypothesis (Ho)*** or ***Alternative hypothesis (Ha)***. The outcome of the test is the decision. The test is designed to assess whether there is a monotonic trend or not in time series data. The null hypothesis: Ho is that there is no monotonic trend and Alternative hypothesis: Ha is there is a monotonic trend (reject the null hypothesis)

Table 3-16: Probabilities associated with the possible outcome of the trend test

	Decision	
True Situation	Accept *Ho*	Reject *Ha*
Ho is True	No error (Pr. = 1-α)	Type I error (Pr. = α)
Ha is True	Type II error (Pr. = ß)	No error (Pr. = 1-ß)

The Mann-Kendall test are used to perceive statistically significant decreasing or increasing trend in long term temporal data. The trend test based on the two hypothesis; Null hypothesis and Alternative hypothesis.

Null hypothesis express the existence of no trend while alternative hypothesis elucidate significant rising or declining trend in time series data. On the basis of 5% significance level, if p value is less than alpha (α = 0.05), then alternative hypothesis accepted which signifies the presence of trend in the data and if p value is greater than alpha (α = 0.05), then null hypothesis will be accepted that denotes the absence of the trend in the data.

4. RESULT AND DISCUSSION

4.1 Preliminary Results

The preliminary analysis of this study includes computation of the mean, standard deviation, kurtosis, skewness, and coefficient of variation in the annual rainfall, annual streamflow, and mean annual Tmax and Tmin time series for each selected station. As the non-parametric trend analysis are not affected by the issues of outliers and extreme values the quality control results were not presented here. However the analysis is done for the sake of completeness.

In the present study, trend analysis of hydro meteorological data in Arjo-didessa sub-basin is presented individually for each selected station using Mann-Kendall/ Modified Mann-Kendall and Innovative Trend analysis for 35, 36 and 25 years for rainfall, temperature and stream flow data respectively on monthly, seasonally and annual basis.

4.2 Monthly Trend Analysis Result

The trend of rainfall data on monthly basis was computed individually for each station for each month using MK/MMK and Sen’s slope estimator method. It was analyzed that there is a significant trend in some months except for four stations: Bedele, Gidayana, Nekemte, and Shambu. Generally, seven stations show a significant trend for some months. Abdela station shows a significant increasing trend during five months (April, August, September, November and, December), Agaro station shows a significant increasing trend during two months (September and October), Alibo station shows a significant increasing trend during March and significant decreasing trend during February, Arjo station shows a significant increasing trend during three months (May, June, and November), Didessa station shows a significant decreasing trend in August and increasing during October, Gimbi station shows a significant increasing trend during three months (February, May, and December), whereas Kone station show an only significant increasing trend during June. In addition to a significant increasing trend, each station shows decreasing and increasing non-significant during the rest of the months.

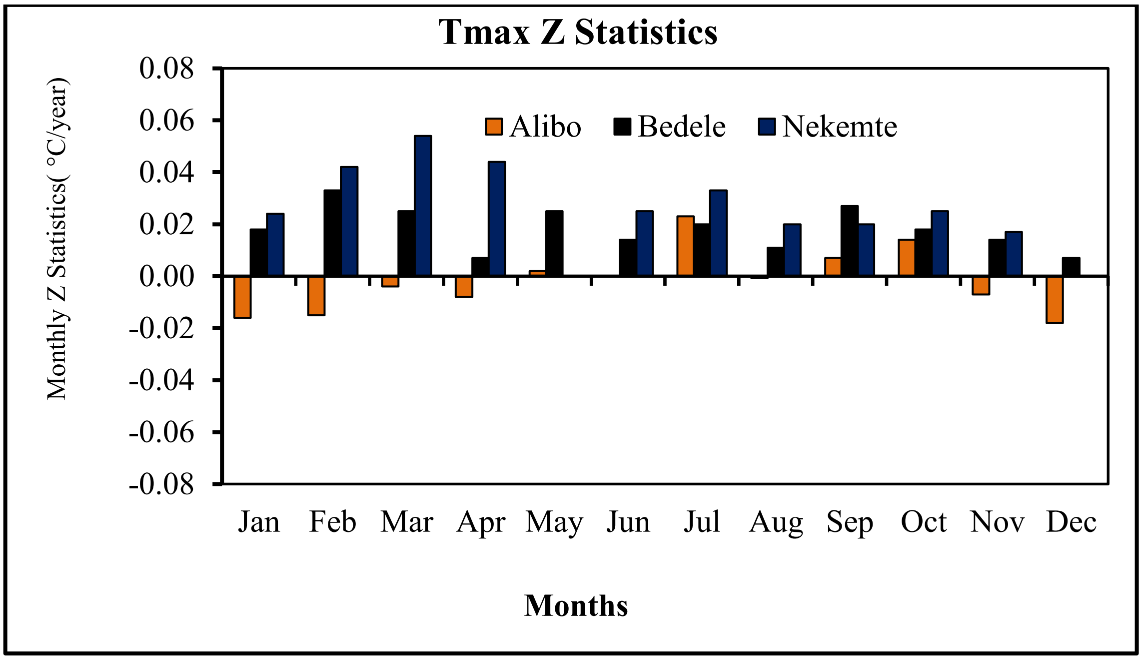


Figure 4-1: Monthly trend analysis results of climate data in Arjo-Didesa basin (Tmax)

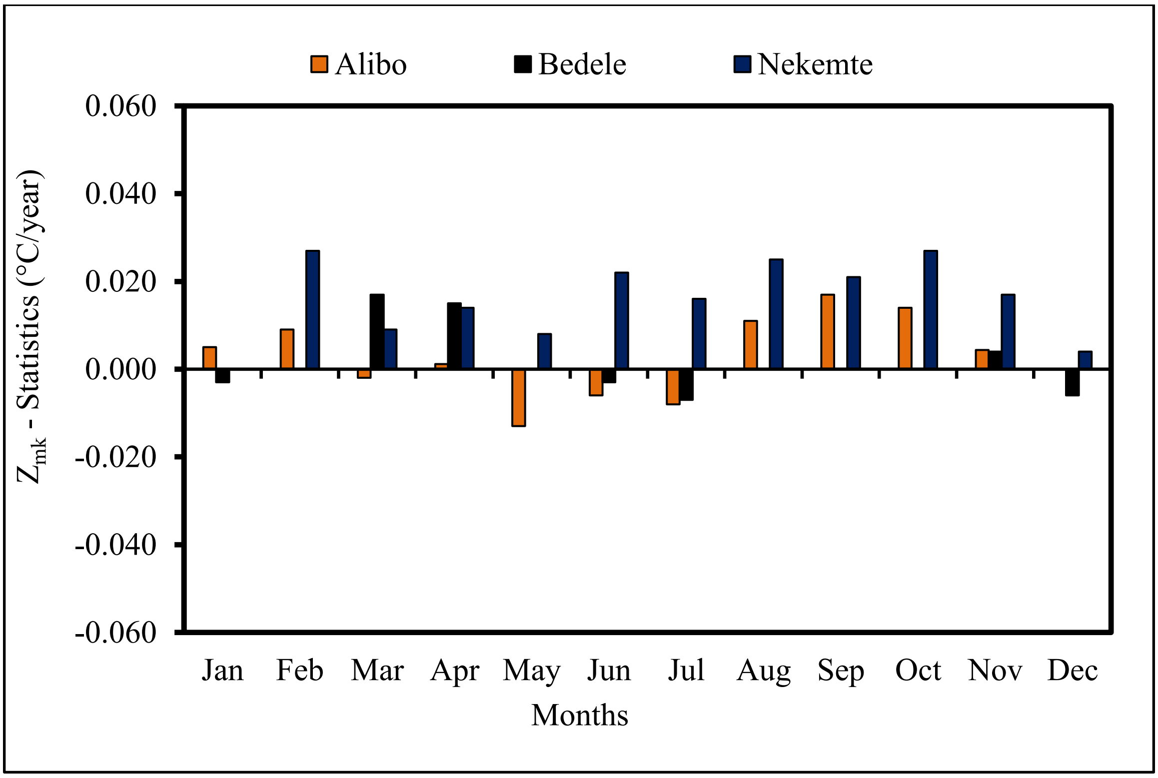


Figure 4-2: Monthly trend analysis results of climate data in Arjo-Didesa basin (Tmin)

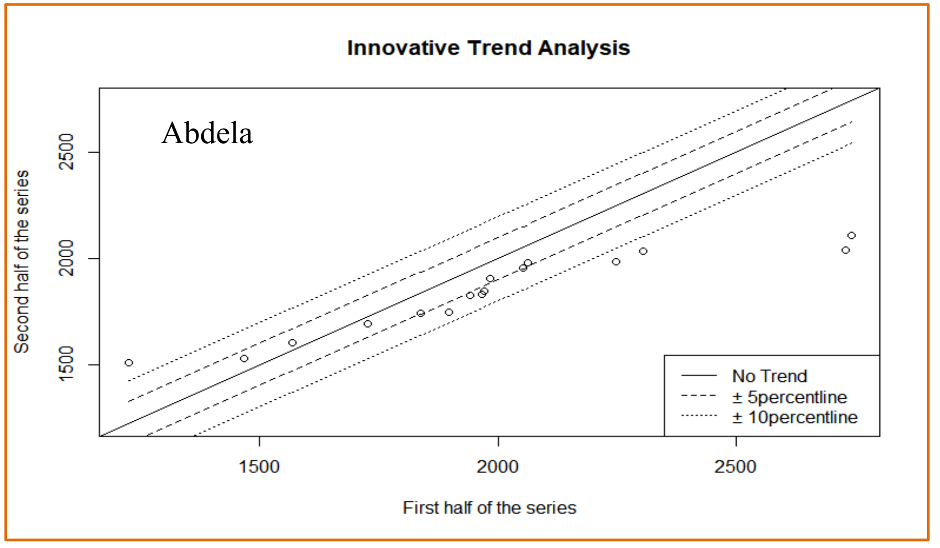
None of the three Tmax and Tmin stations used for this study shows a significant trend. Bedele and Nekemte show increasing non-significant trends for Tmax and only Nekemte station shows an increasing non-significant trend for Tmin.

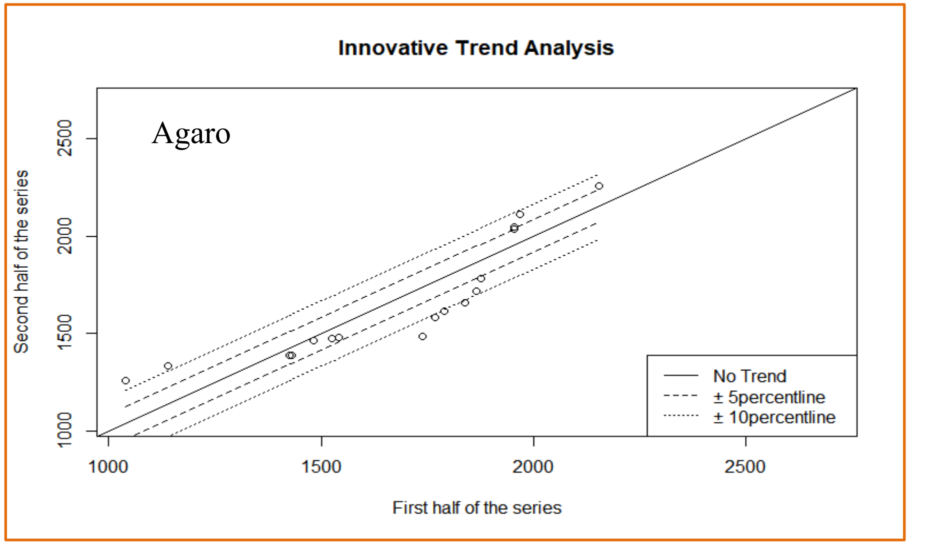
4.3 Annual and Seasonal Trend Analysis

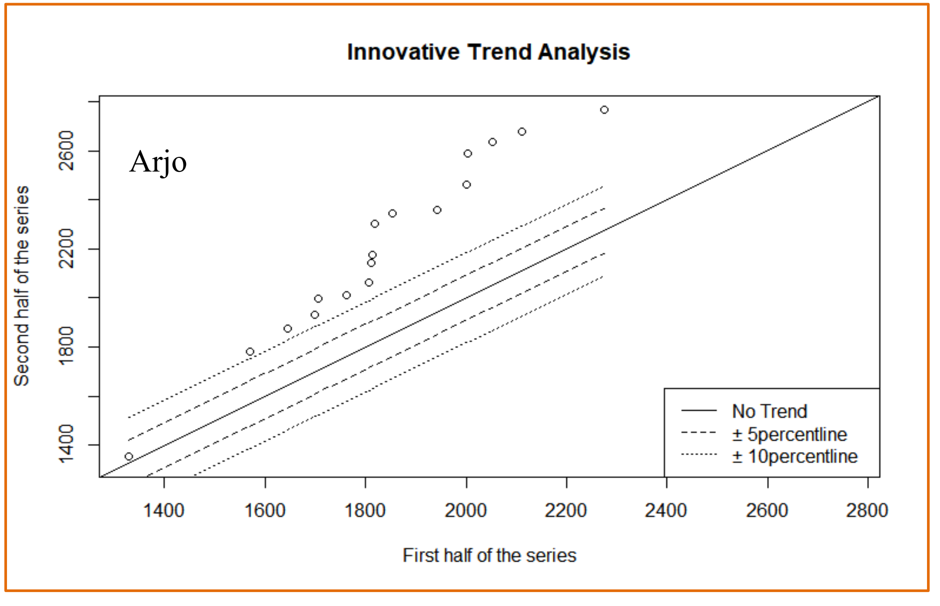
For the analysis of the hydro-meteorological trend in the time series dataset, Mann-Kendall, modified Mann-Kendall (for serially correlated time series), Sen's slope estimator, and Innovative Trend analysis (ITA) tests were used in this study. Trend analysis was performed for eleven rainfall, three temperature stations (Tmax and Tmin), and three streamflow gauging station for the Arjo-didessa sub-basin to identify the seasonal and annual impact on water resources in the area.

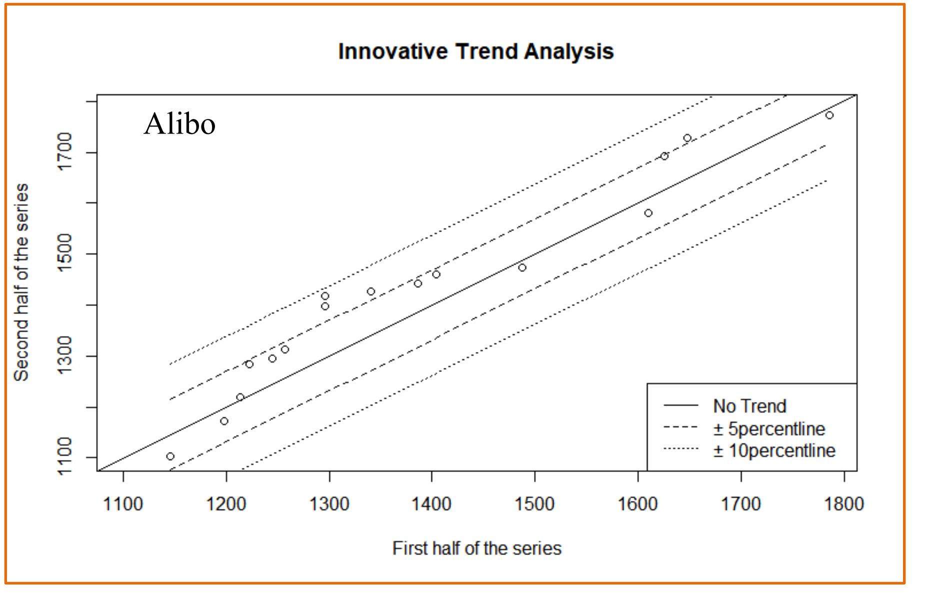
It has to be noted that the key difference in the original Mann-Kendal and modified Mann-Kendal test is that the modified Mann-Kendal test removes the significant autocorrelations from the datasets to remove the bias and apply the Mann-Kendal test. Using Mann-Kendall and modified Mann-Kendall test significant increasing rainfall trend was noticed for the annual time scale and during two seasons (i.e. spring and summer) in Arjo station. Results of the Mann-Kendall analysis were already presented in table 4-3. For the analysis that show non-significant result autocorrelation original Mann-Kendal test is used and for the significant ones the modified Mann-Kendal test was used. Accordingly, Kone station shows a significant increasing trend for annual time scale. While, five rainfall stations (Agaro, Alibo, Gidayana, Gimbi, and Nekemte) show increasing insignificant trends, four rainfall stations (Abdela, Bedele, Didessa, and Shambu) undergoes decreasing insignificant trends. A significant increasing T_{max} trend was observed in Nekemte and a decreasing significant trend for T_{min} was observed in Alibo station. Only a significant increase in annual streamflow was observed for the Didessa Nr Arjo gauge station.

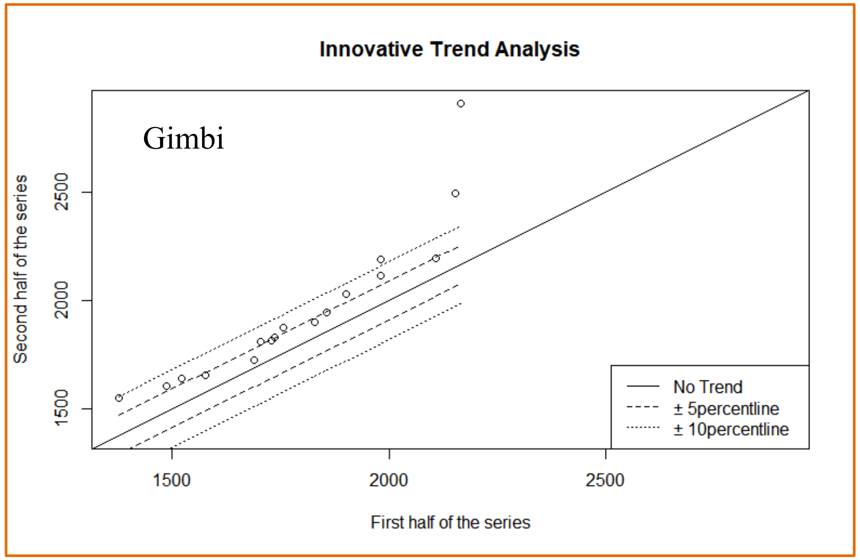
Similarly, the results from Innovative Trend Analysis for annual rainfall, mean annual temperature and annual streamflow were as shown in the figure below.

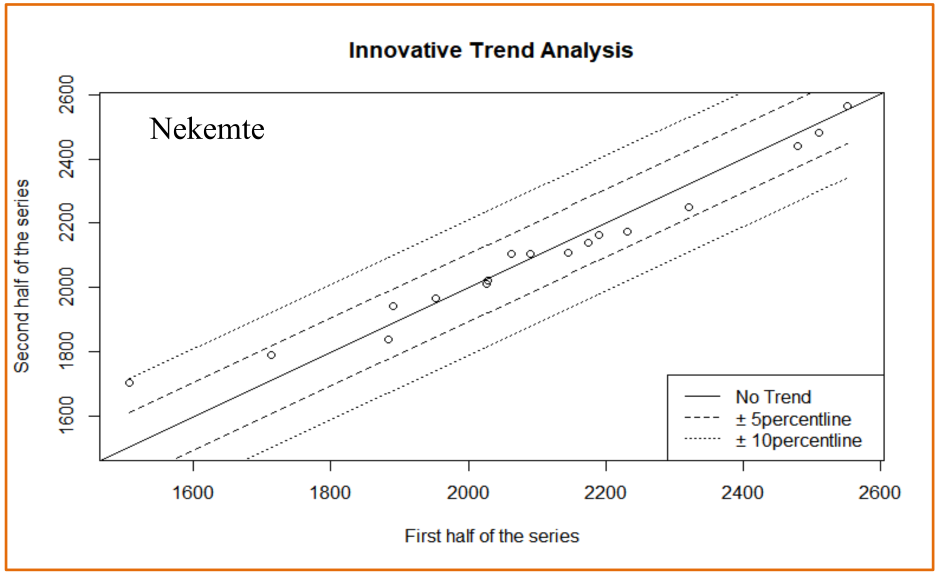

Innovative Trend Analysis
Abdela
Second half of the series
First half of the series
1500
2000
2500
No Trend
± 5percentline
± 10percentline

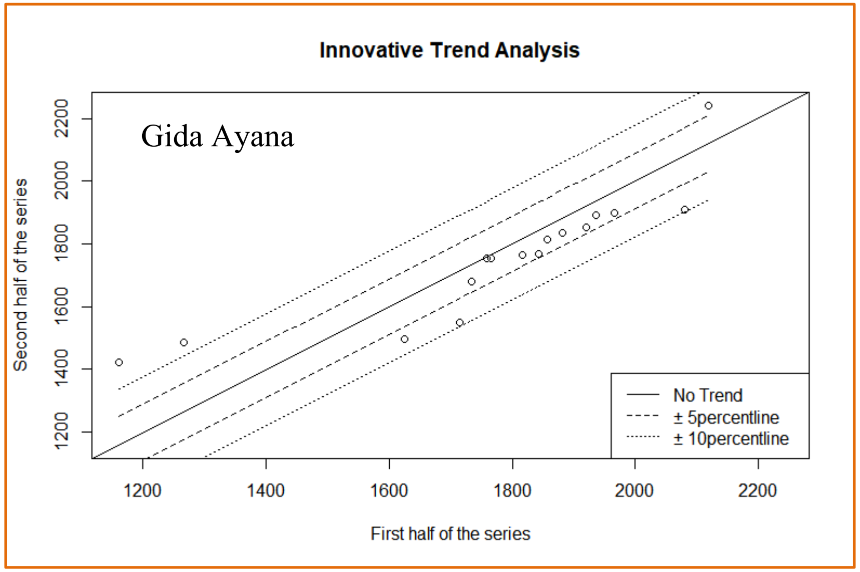

Innovative Trend Analysis
Agaro
Second half of the series
First half of the series
1000
1500
2000
2500
No Trend
± 5percentline
± 10percentline

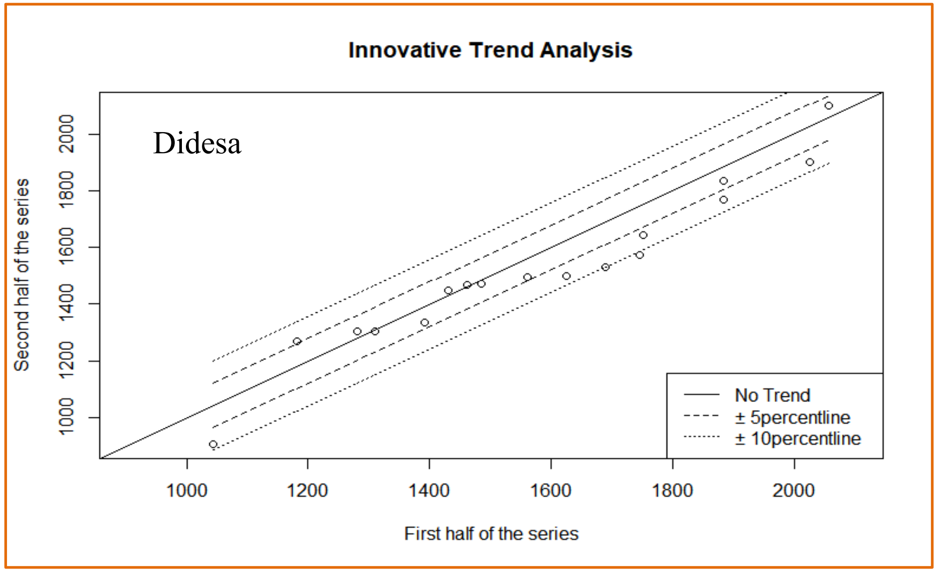

Innovative Trend Analysis
Arjo
Second half of the series
First half of the series
1400
1800
2200
2600
1600
2000
2400
2800
No Trend
± 5percentline
± 10percentline

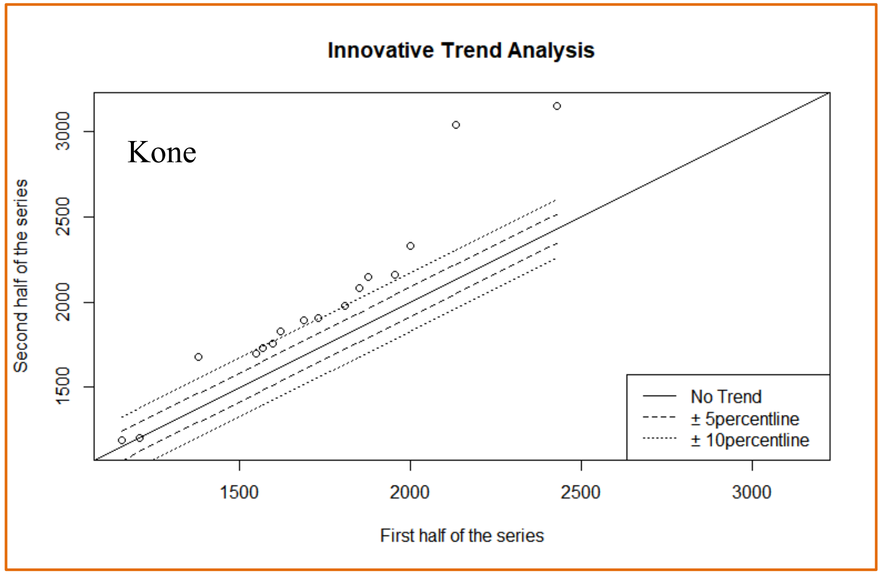

Innovative Trend Analysis
Alibo
Second half of the series
First half of the series
1100
1300
1500
1700
1200
1400
1600
1800
No Trend
± 5percentline
± 10percentline

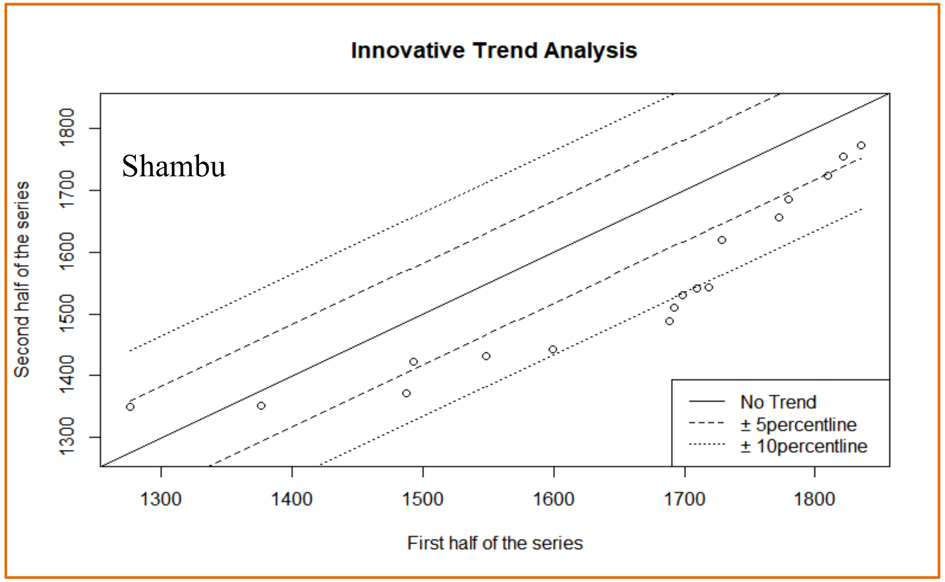

Innovative Trend Analysis
Gimbi
Second half of the series
1500
2000
2500
First half of the series
1500
2000
2500
No Trend
± 5percentline
± 10percentline


Innovative Trend Analysis
Nekemte
Second half of the series
1600
1800
2000
2200
2400
2600
First half of the series
1600
1800
2000
2200
2400
2600
No Trend
± 5percentline
± 10percentline


Innovative Trend Analysis
Gida Ayana
Second half of the series
1200
1400
1600
1800
2000
2200
First half of the series
1200
1400
1600
1800
2000
2200
No Trend
± 5percentline
± 10percentline


Innovative Trend Analysis
Didesa
Second half of the series
1000
1200
1400
1600
1800
2000
First half of the series
1000
1200
1400
1600
1800
2000
No Trend
± 5percentline
± 10percentline





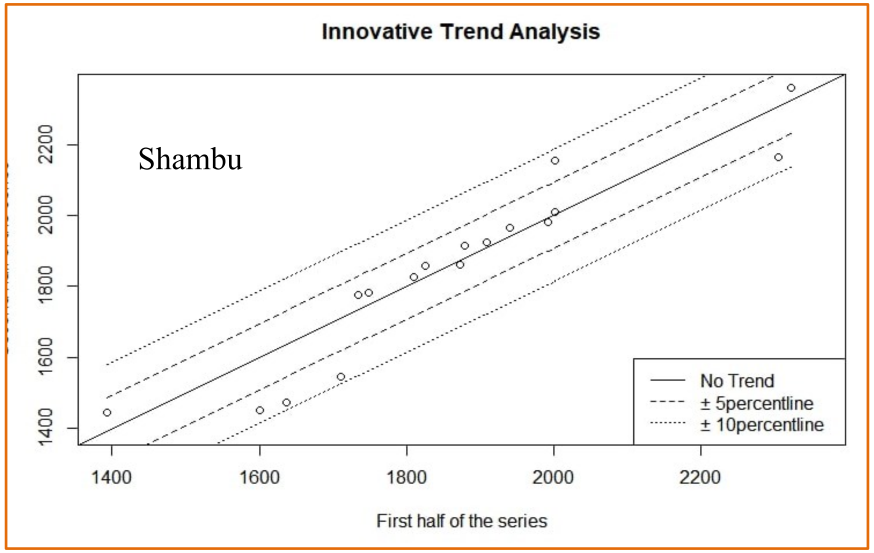
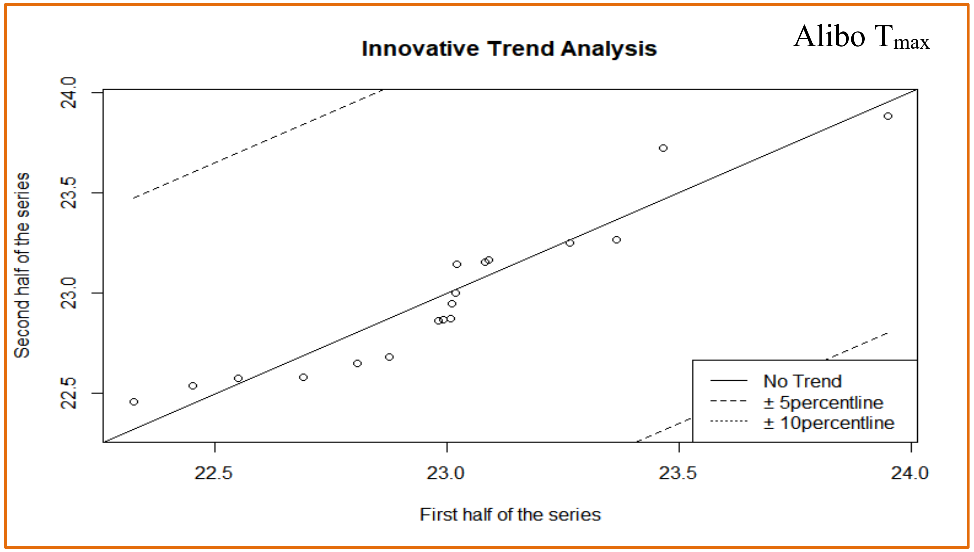
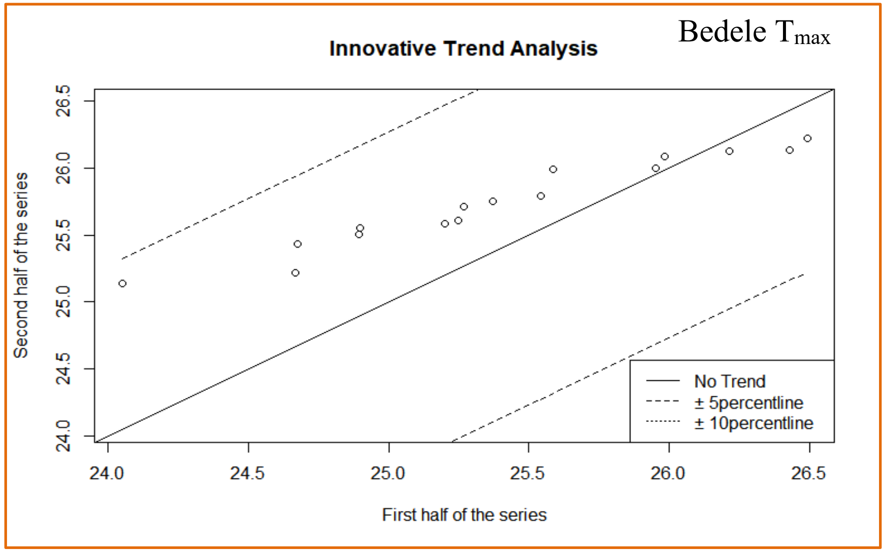
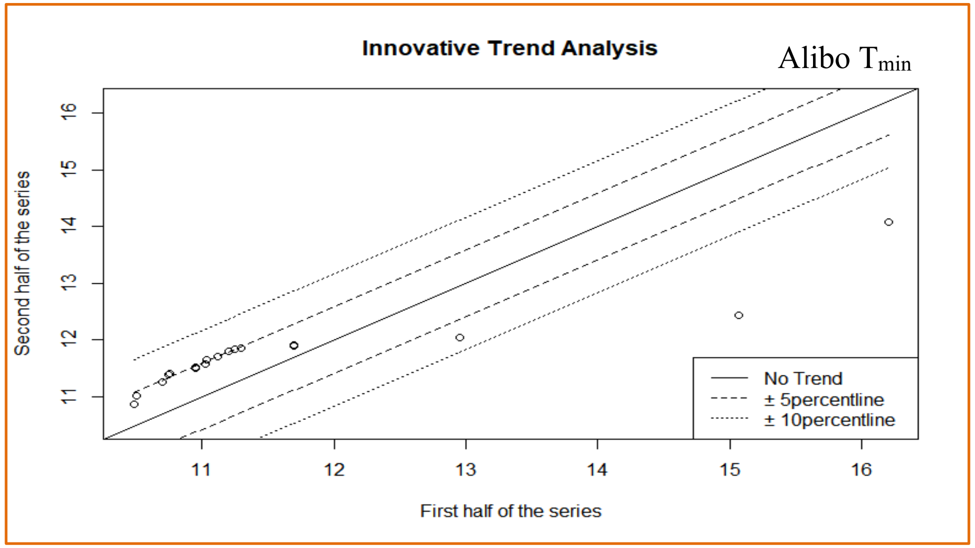


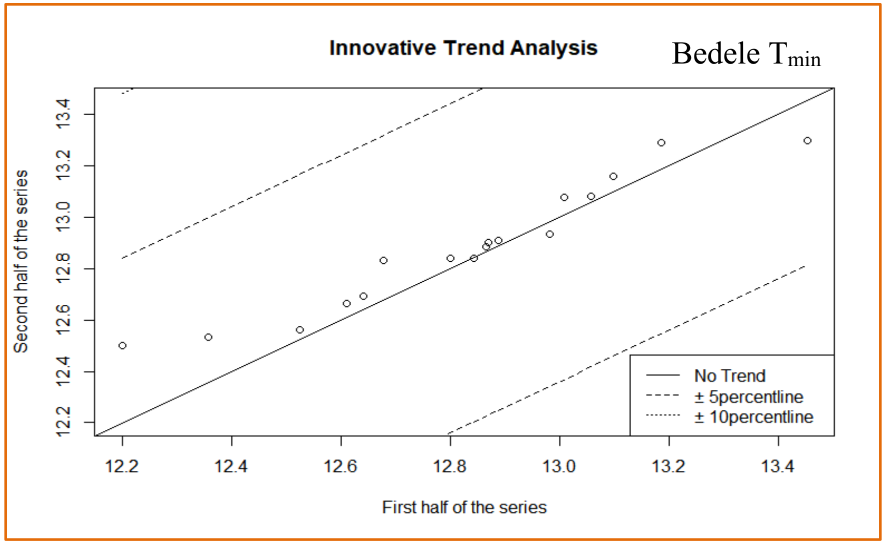
Figure 4-3: The result of ITA for annual rainfall at 11stations in the study area

Similarly, the result of ITA for Temperature and streamflow for selected stations are shown in the figure below.









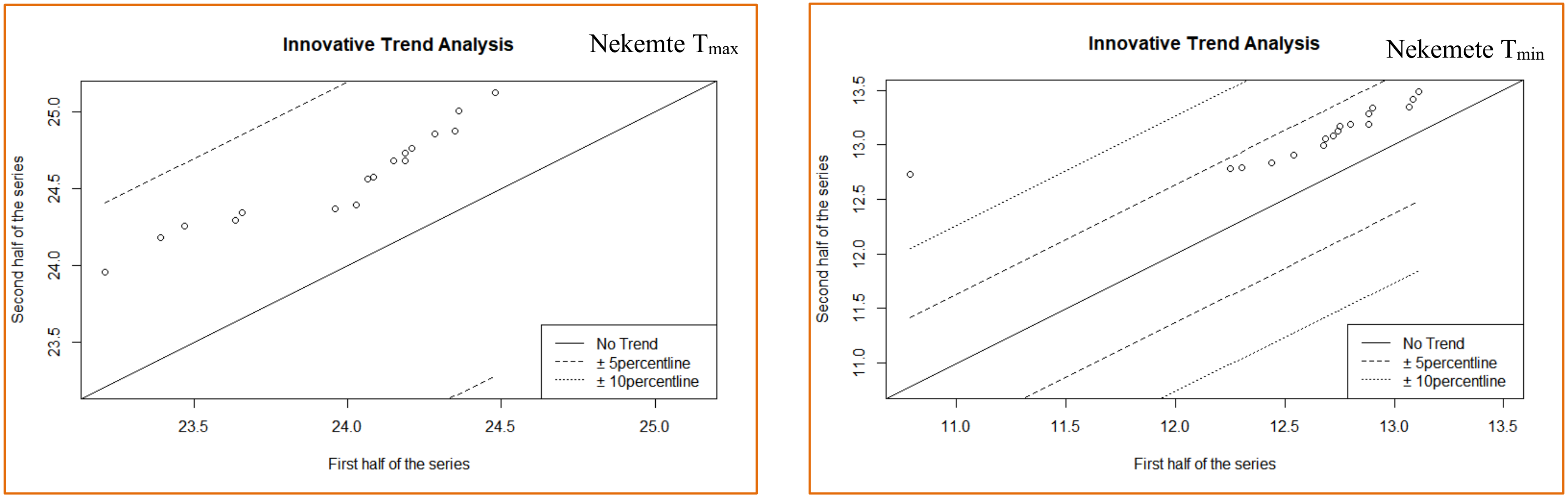
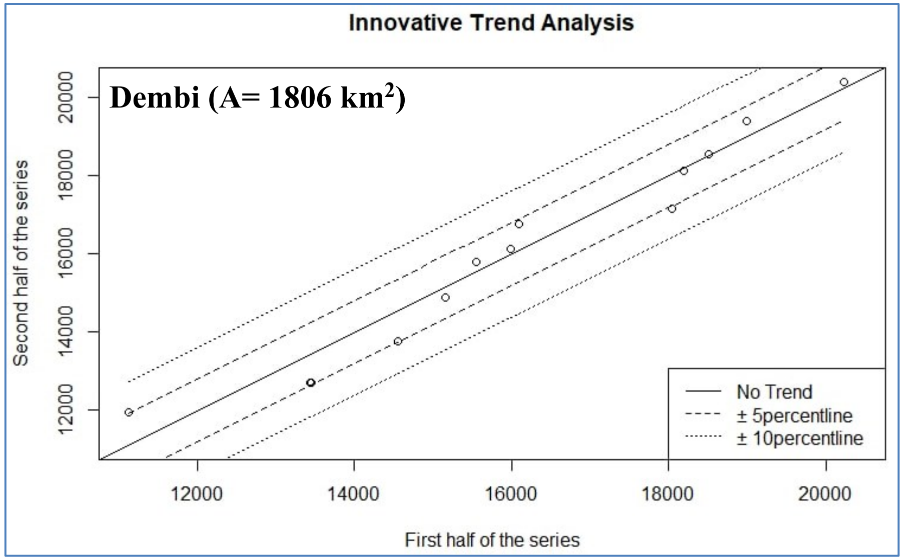
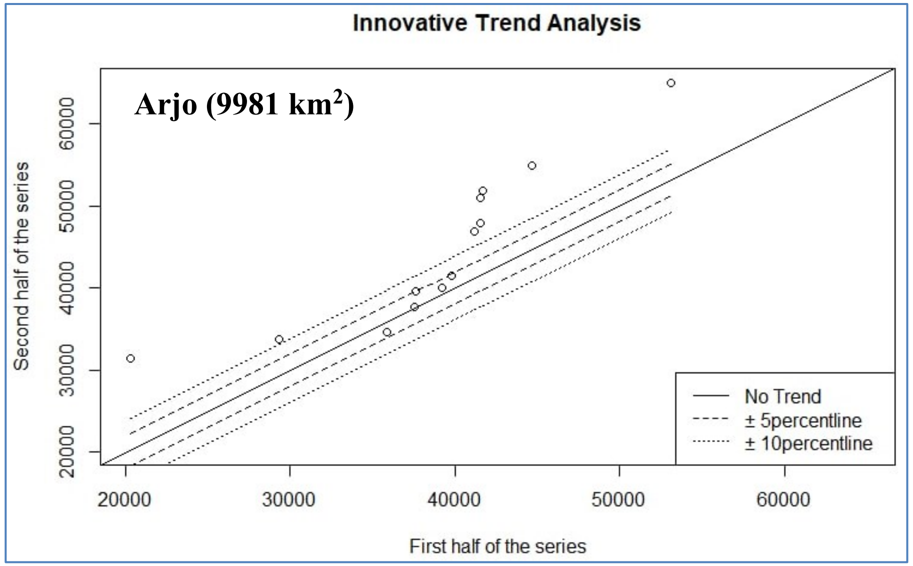


Figure 4-4: Results of ITA for three Tmax and Tmin Stations





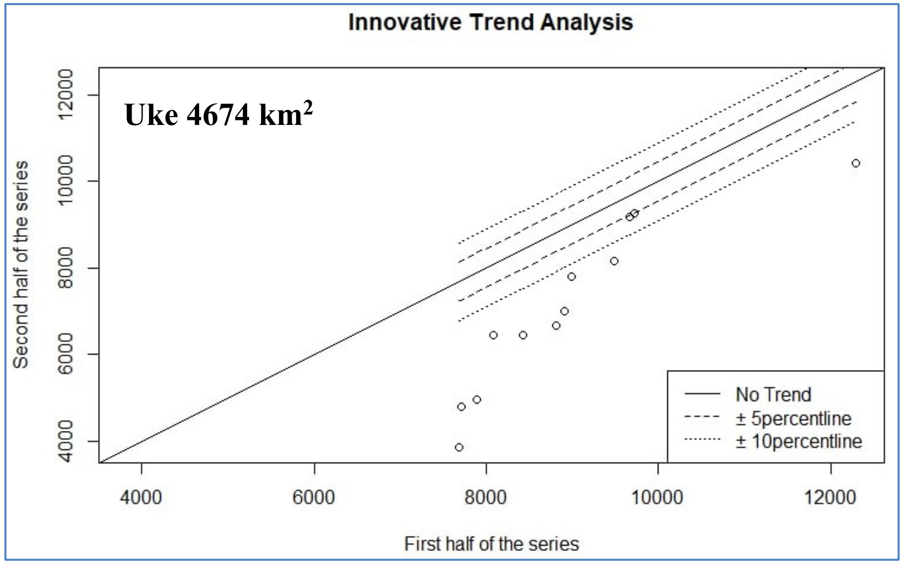
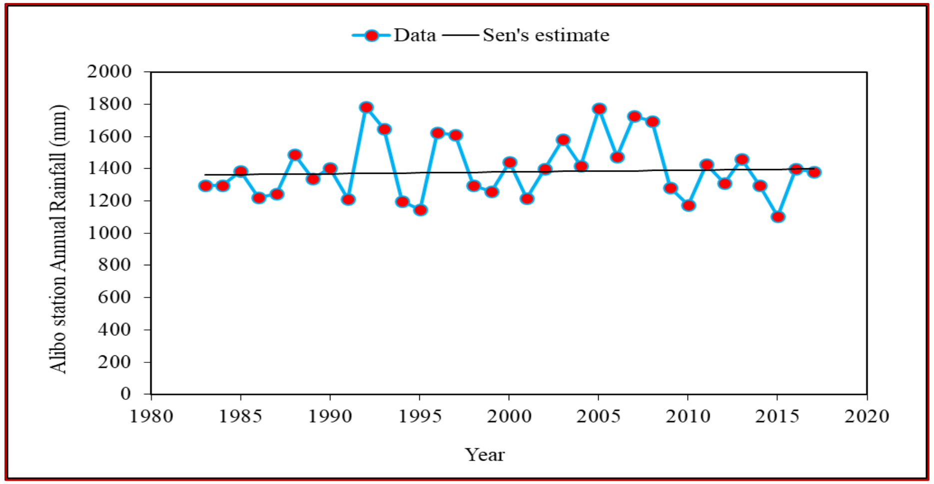
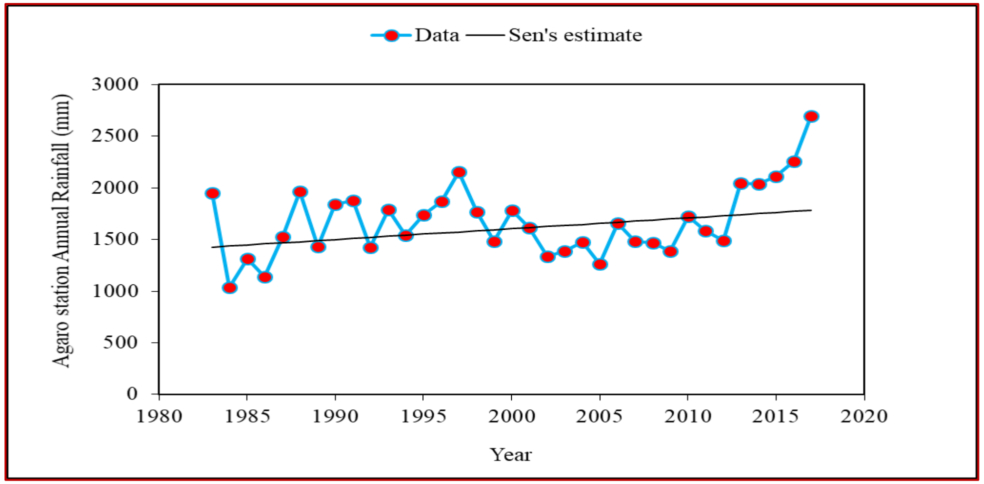
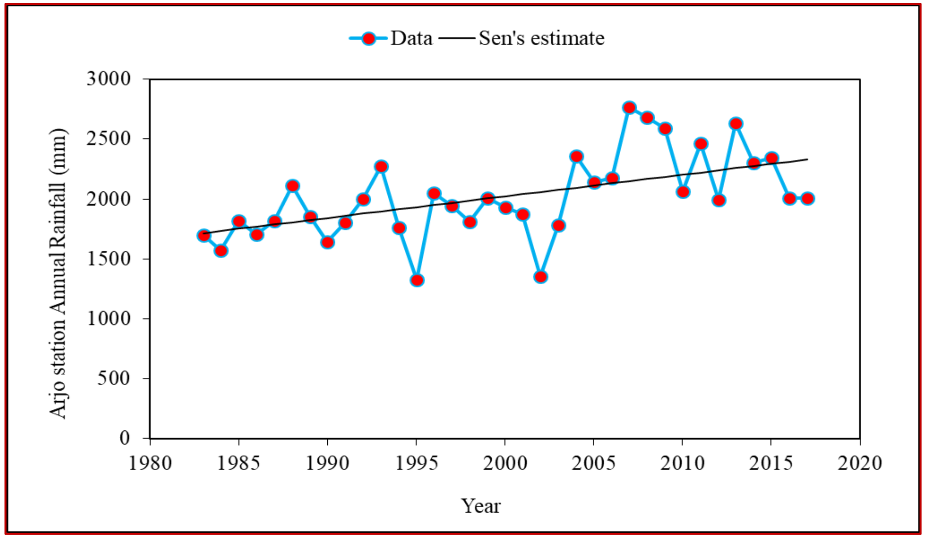


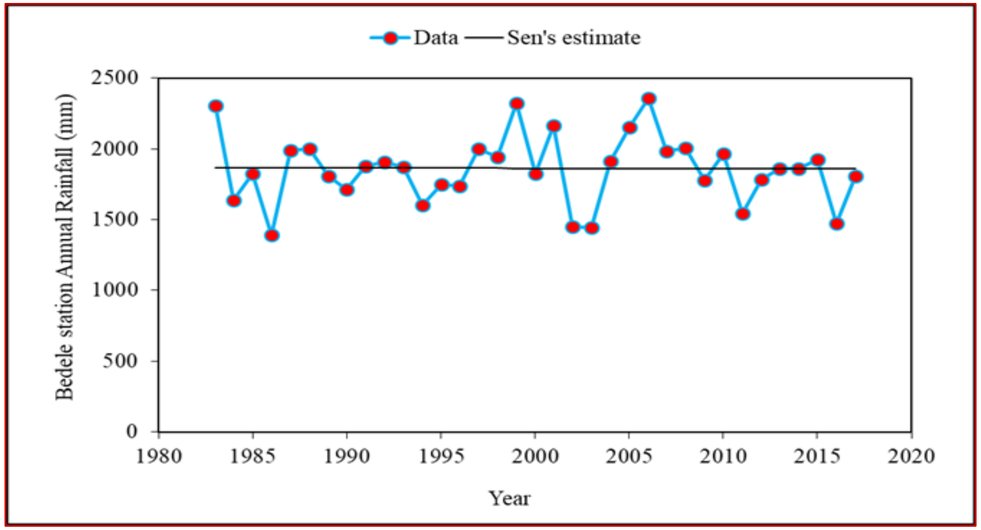
Figure 4-5: Results of ITA for three streamflow stations

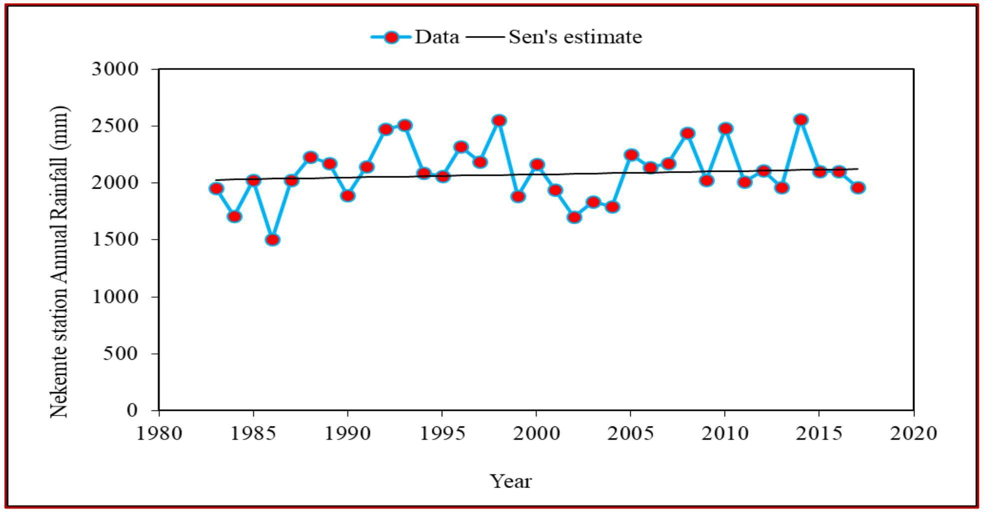
The results of Sen's slope estimate for annual rainfall data for each selected stations is shown as figure below.

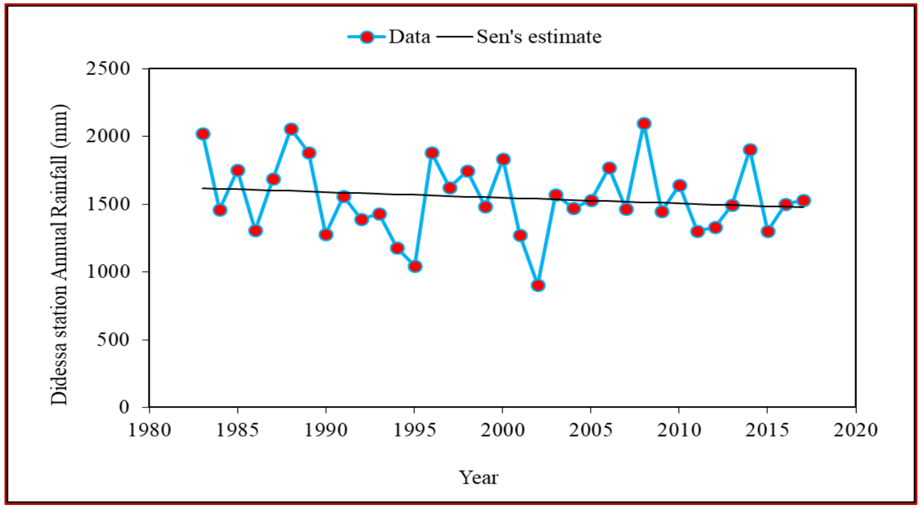









Data
Sen's estimate
Nekente station Annual Rainfall (mm)
0
500
1000
1500
2000
2500
3000
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year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1500
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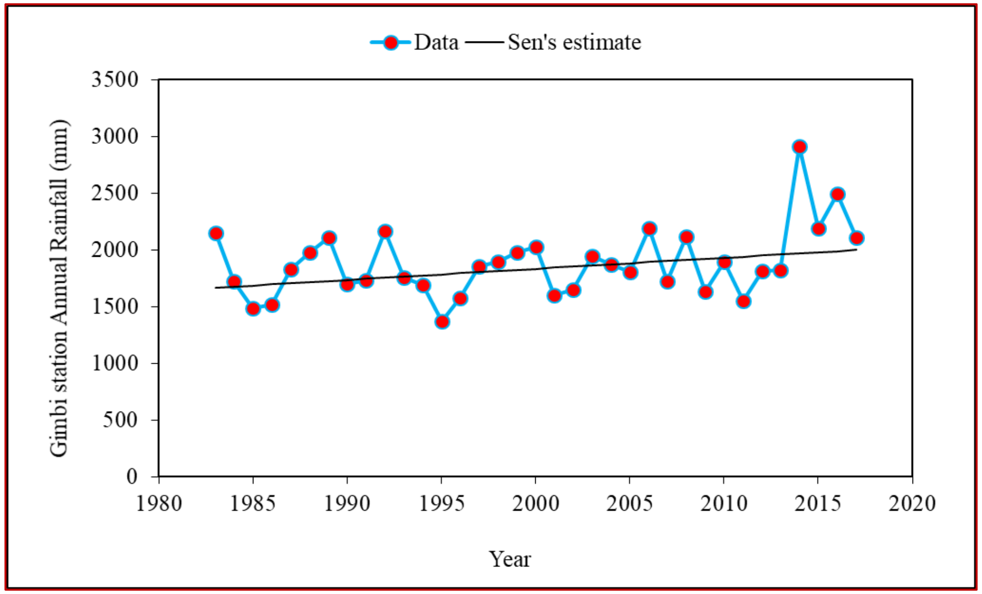
2500
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year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Sen's estimate
Gimbi station Annual Rainfall (mm)
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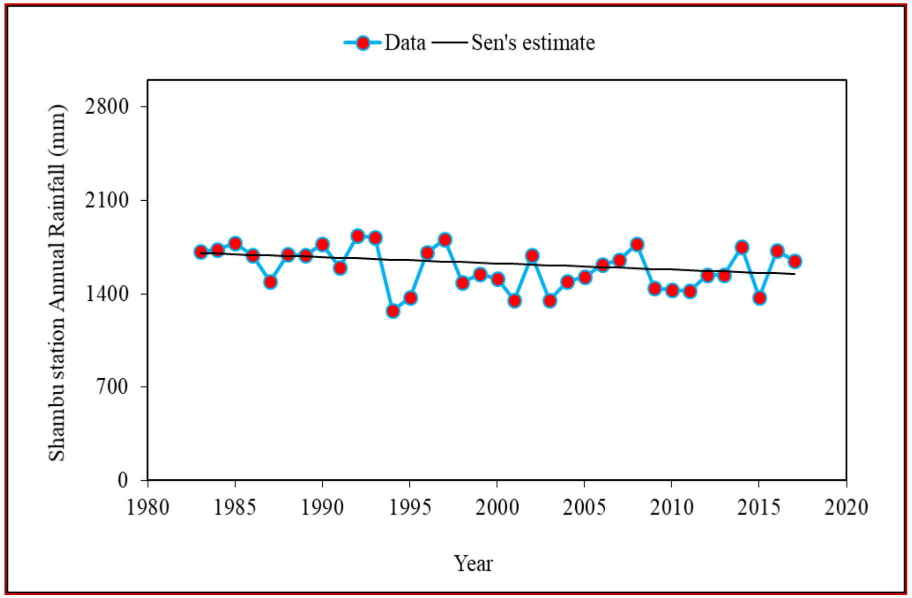
1000
1500
2000
2500
3000
3500
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year


Data
Sen's estimate
Shambu station Annual Rainfall (mm)
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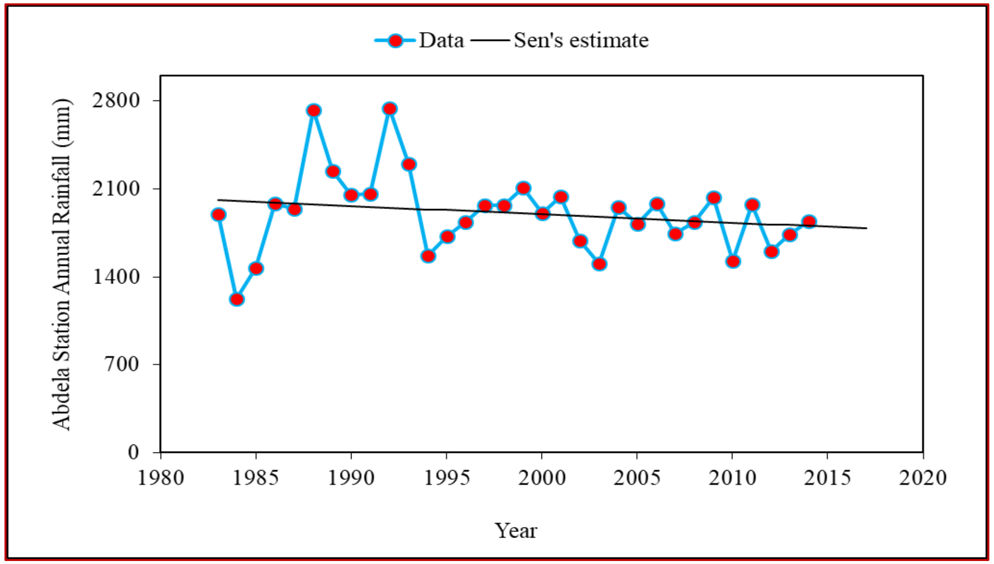
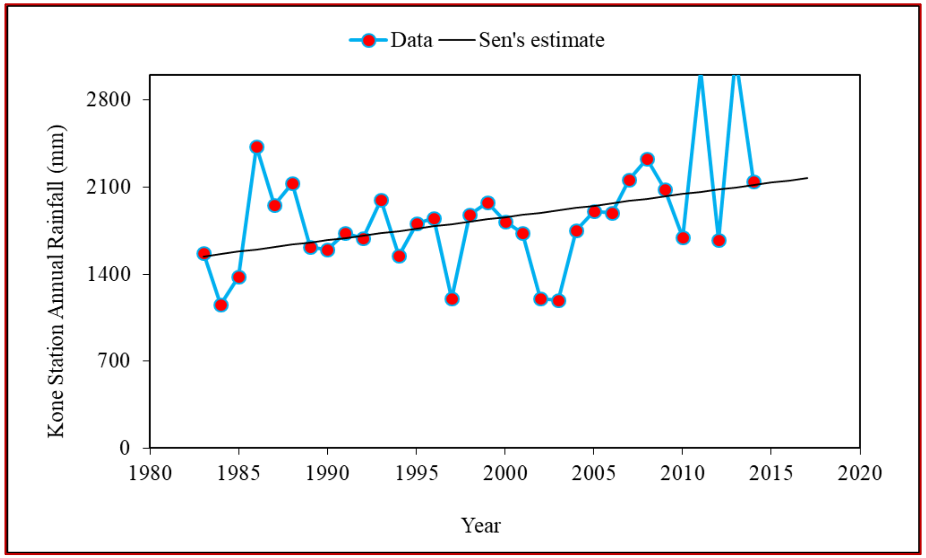
1400
2100
2800
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year





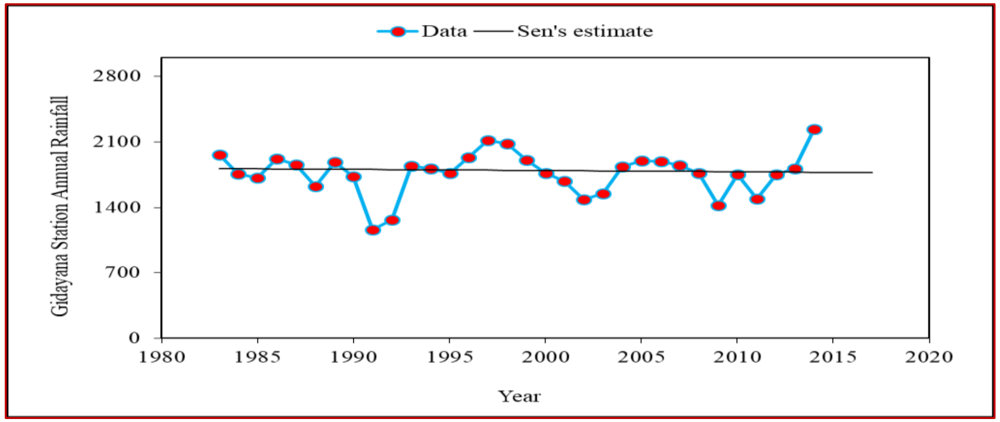
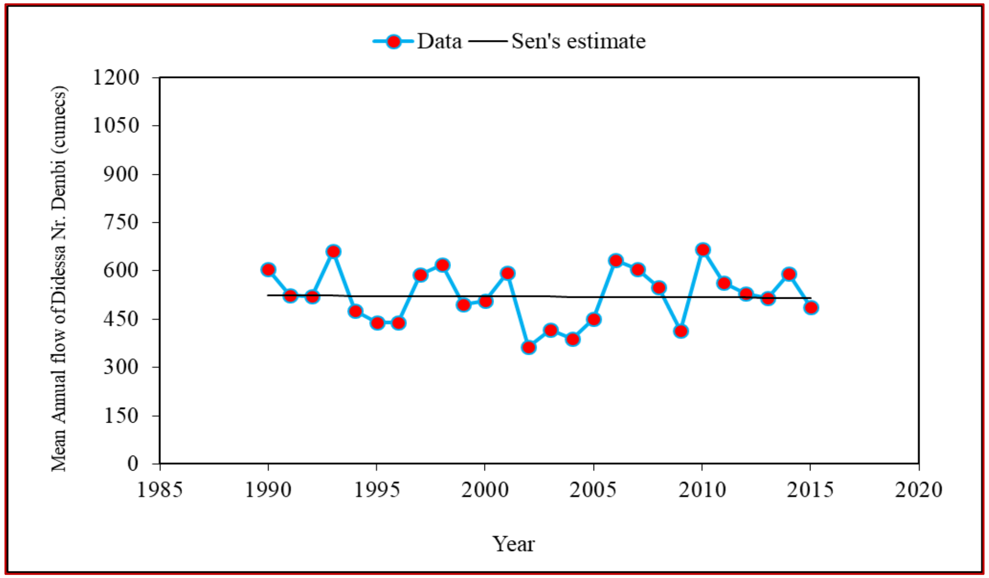
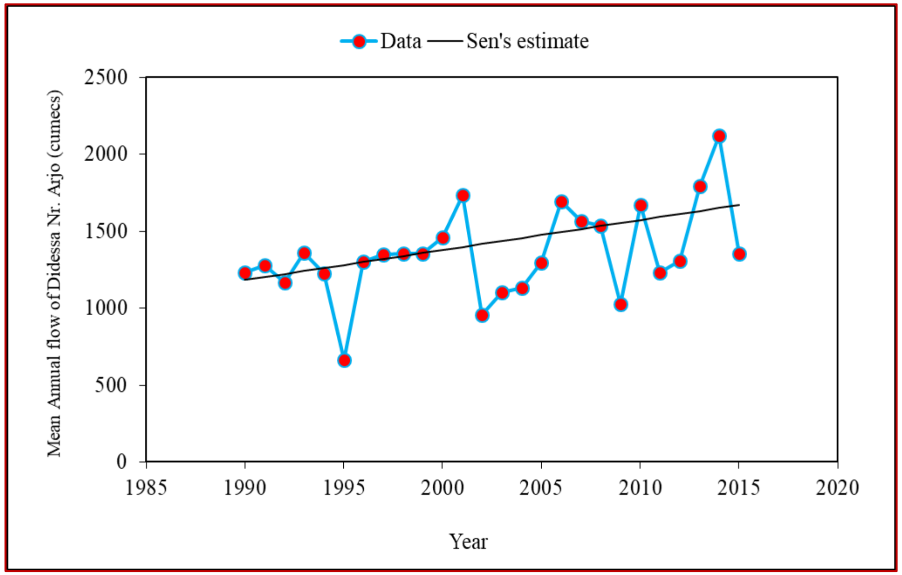


Figure 4-6: Trend and Sen's Slope for selected Rainfall station in the study area





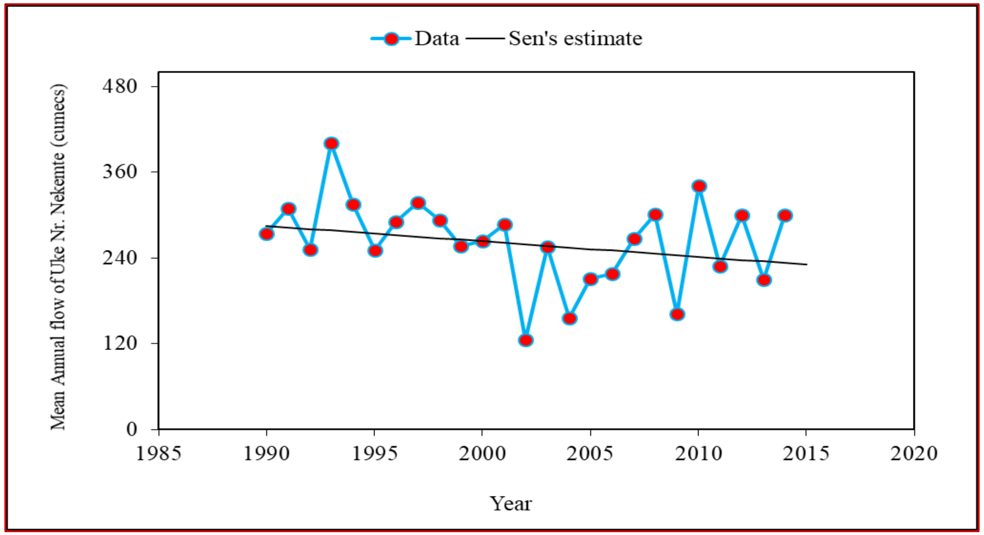


Figure 4-7: Trend and Sen's slope for Selected gauging station in the study area

The result from comparison reveals that the ITA method is superior to the Mann-Kendall method. The result the three method show that there is some difference: for example in annual rainfall ITA showed a negative trend at Agaro and Gidayana stations while Mann-Kendall and Sen's slope indicates positive trend. Similarly, ITA shows a negative trend in annual mean T_{max} at Alibo station while Mann-Kendall and Sen's slope shows a positive trend. The summary of the three methods is given in Table 4-4 below.

Table 4-1: Comparison of (Z), (Q), and (ϕ) for selected rainfall stations

S/N	**Stations**	**Z**	**Q**	**ϕ**
		Rainfall (Annual)		
1	Abdela	-0.408	-1.839	-0.753
2	Agaro	0.952	6.905	-0.136
3	Alibo	0.284	1.102	0.3051
4	Arjo	**2.223***	11.084	2.0087
5	Bedele	-0.028	-0.241	-0.0615
6	Didessa	-0.625	-4.192	-0.3538
7	Gidayana	0.748	3.318	-0.1149
8	Gimbi	1.335	5.430	0.8900
9	Kone	**2.254***	18.508	1.528
10	Nekemte	0.667	2.761	0.0136
11	Shambu	-1.733	-4.602	-0.654

(Note: Z = Mann-Kendall Value, Q = Sen's slope Value and ϕ = ITA value)

Table 4-2: Comparison of (Z), (Q), and (ϕ) for selected Temperature stations

		Tmax (Mean Annual)		
S/N	**Station**	**Z**	**Q**	**ϕ**
1	Alibo	0.1225	0.0014	-0.0078
2	Bedele	1.7818	0.0134	0.13418
3	Nekemte	**2.4016***	0.0174	0.2448
		Tmin (Mean Annual)		
1	Alibo	**-5.680***	-0.0004	0.0977
2	Bedele	-0.2075	-0.0006	0.0427
3	Nekemte	1.874	0.0103	0.3769

(Note: Z = Mann-Kendall Value, Q = Sen's slope Value and ϕ = ITA value)

Table 4-3: Comparison of (Z), (Q), and (ϕ) for selected stream flow gauge stations

		Streamflow (Mean Annual)		
S/N	**Gauge station**	**Z**	**Q**	**ϕ**
1	Didessa Nr. Dembi	-0.1322	-0.024	-0.0136
2	Didessa. Nr. Arjo	**2.184***	0.487	1.178
3	Uke Nr. Nekemte	-1.144	-0.181	-0.408

(Note: Z = Mann-Kendall Statistics; (Note: Z = Mann-Kendall Value, Q = Sen's slope Value, ϕ = ITA value, and * significant trend at 0.05 significant level)

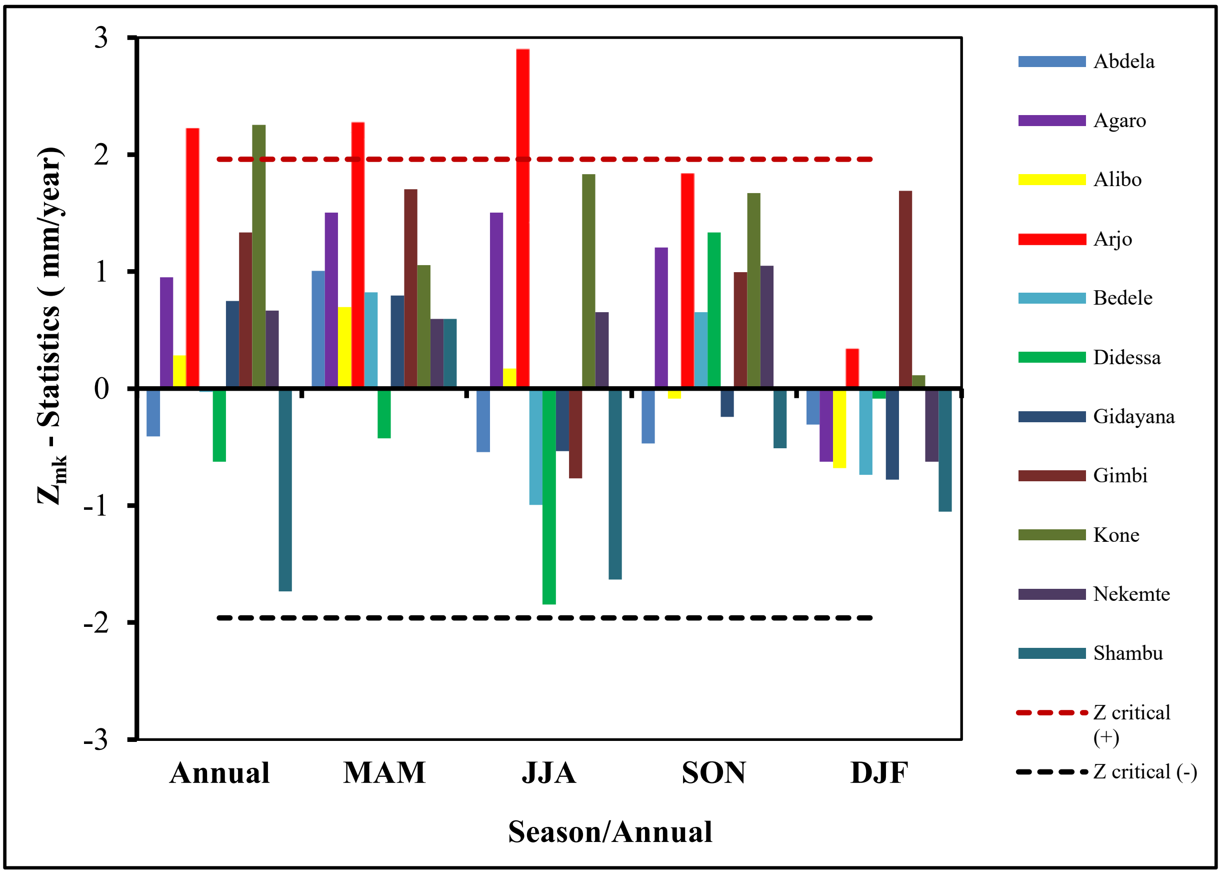


Figure 4-8: Annual and Seasonal Rainfall Z- Statistics

As observed from the above figure 4-8, only two rainfall station show an increasing significant trend; Arjo station during Annual, spring, and Summer time scale and Kone station during Annual time scale.

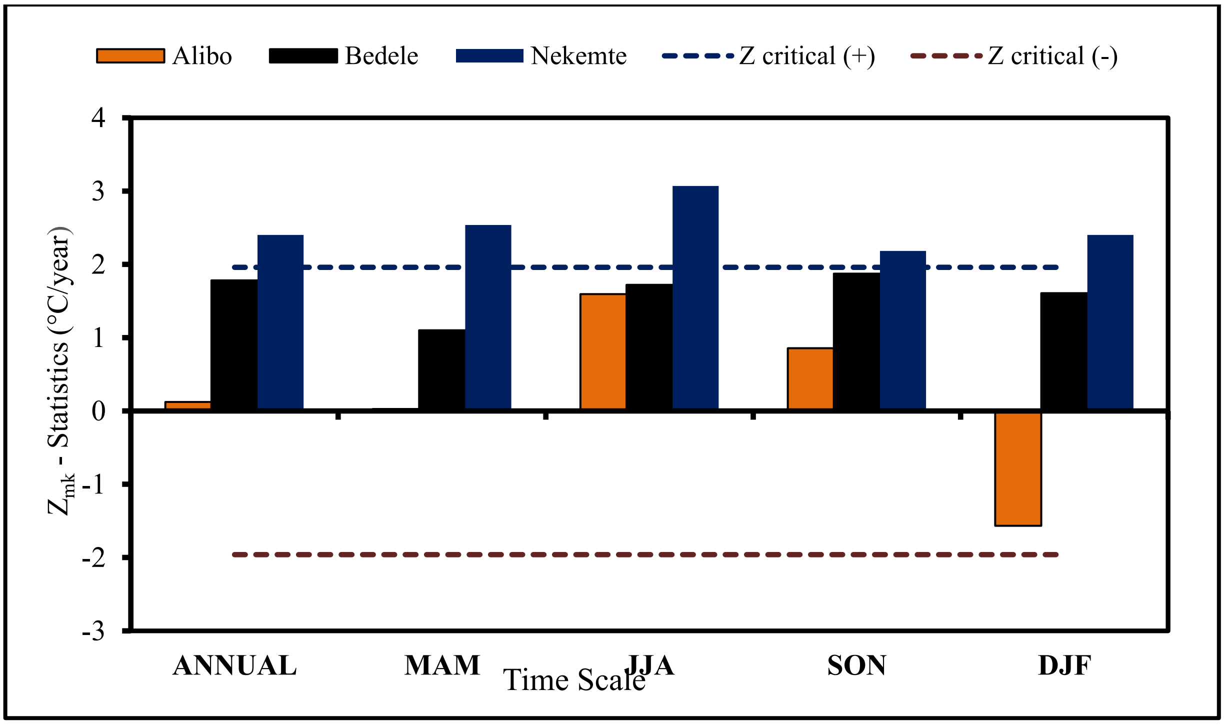


Figure 4-9: Annual mean and Seasonal Tmax Z-Statistics

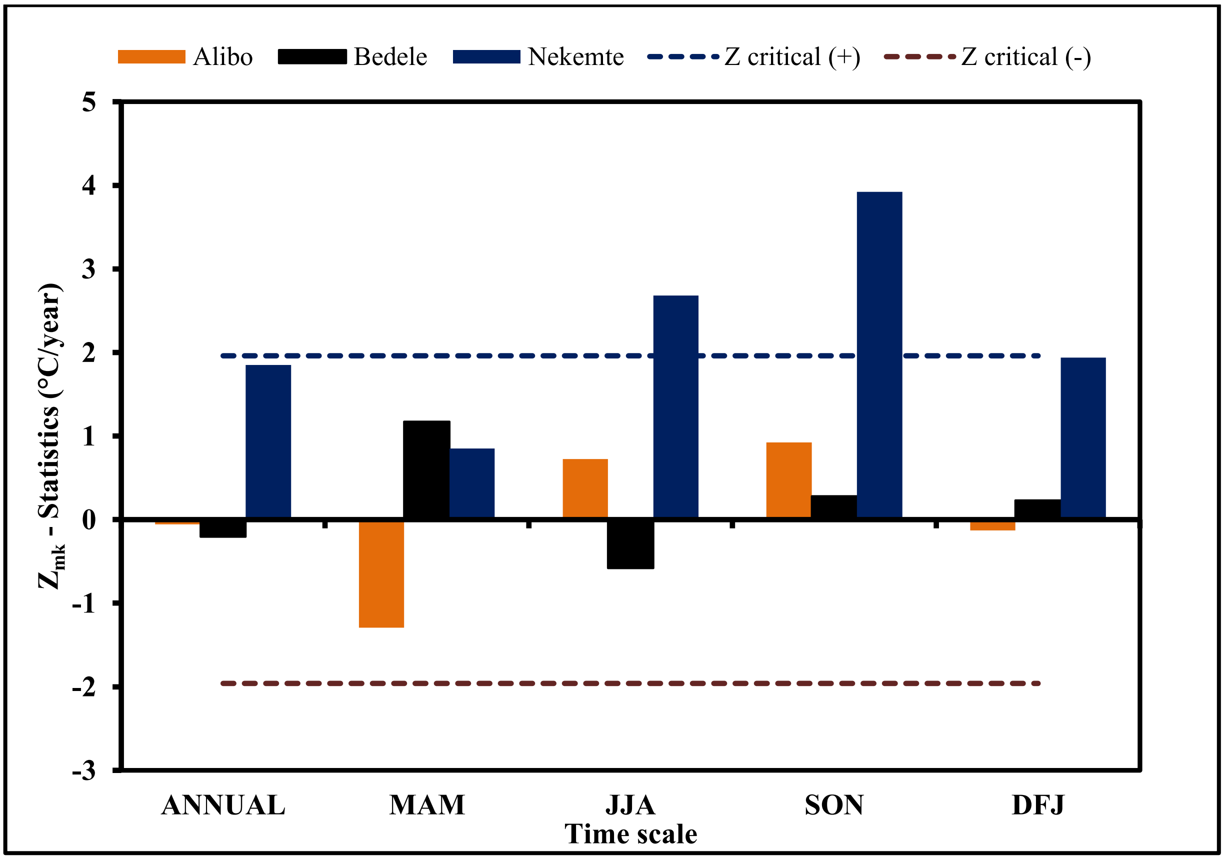


Figure 4-10: Annual mean and Seasonal Tmin Z-Statistics

Table 4-4: Results of Seasonal MK/MMK and Sen's slope estimator

Station/ variable	Mann-Kendall/modified Mann-Kendall Z Statistics and Sen's slope Value							
	Spring		**Summer**		**Autumn**		**Winter**	
Rainfall	Z	Q	Z	Q	Z	Q	Z	Q
Abdela	1.005	1.672	-0.544	1.728	-0.470	-1.044	-0.308	-0.425
Agaro	1.505	2.186	1.505	4.639	1.207	4.318	-0.625	-0.597
Alibo	0.696	1.791	0.1704	0.300	-0.085	-0.132	-0.681	-0.285
Arjo	**2.272***	6.030	**2.897***	5.677	1.838	4.359	0.341	0.294
Bedele	0.823	1.414	-0.994	-2.116	0.653	1.440	-0.738	-0.422
Didessa	-0.426	-0.626	-1.846	-5.681	1.335	2.639	-0.085	-0.021
Gidayana	0.795	2.888	-0.535	-1.596	-0.243	-0.611	-0.778	-0.220
Gimbi	1.704	3.351	-0.767	-1.900	0.994	2.385	1.690	0.515
Kone	1.054	1.730	1.832	9.832	1.670	6.216	0.114	0.183
Nekemte	0.596	1.533	0.653	1.647	1.051	1.931	-0.625	-0.413
Shambu	0.596	1.210	-1.633	-3.122	-0.511	-0.685	-1.051	-0.452
Tmax								
Alibo	0.0272	0.000	1.594	0.0171	0.8588	0.0048	-0.639	-0.0072
Bedele	1.100	0.0157	1.721	0.0163	1.874	0.0151	1.069	0.0117
Nekemte	**2.061***	0.0257	**3.072***	0.0293	**2.185***	0.0144	**2.402***	0.022
Tmin								
Alibo	-1.292	-0.012	0.7243	0.0058	0.0923	0.0094	-0.128	-0.0003
Bedele	1.172	0.0141	-0.593	-0.025	0.282	0.0011	0.232	0.0026
Nekemte	0.852	0.0068	**2.681***	0.0168	**4.109***	0.0218	1.9368	0.0156
Streamflow								
Nr. Arjo	0.79	0.48	2.24	8.17	1.54	4.87	0.63	0.22
Nr. Dembi	-1.01	-0.37	-0.13	-0.26	0.66	0.78	-0.44	-0.14
Nr. Nekemte	0.72	-1.56	-1.56	-2.03	-0.54	-0.24	0.02	0.00

(Note: Z = Mann-Kendall Statistics; Q = Sen's slope value; * is significant trend at 95% confidence level)

4.4 Hydro-meteorological Variability results

The basic statistical characteristics of annual and seasonal coefficient of variation based on (standard deviation and mean), absolute mean deviation was used in this study to detect temporal variability of rainfall, temperature, and streamflow for each station individually on the annual time scale.

Table 4-5: Annual and Seasonal Rainfall (mm) and their CV, and Standard deviation

Station	**Spring**		**Summer**		**Autumn**		**Winter**		**Annual**	
					Rainfall					
	SD	CV	SD	CV	SD	CV	SD	CV	SD	CV
Abdela	104.65	27.16	156.62	16.32	184.87	36.75	46.38	78.00	316.72	16.60
Agaro	120.11	28.96	146.39	19.45	179.19	41.51	62.41	70.13	341.05	20.14
Alibo	105.15	37.68	123.07	16.09	92.24	28.64	26.93	78.63	183.76	13.12
Arjo	141.07	30.13	161.95	15.94	141.78	29.80	36.66	62.19	348.68	17.27
Bedele	95.19	24.19	122.50	13.03	131.10	28.12	36.48	63.80	239.95	12.92
Didessa	91.62	34.17	188.72	21.69	126.99	32.50	14.64	76.48	278.48	17.99
Gidayana	137.85	43.52	163.68	16.85	133.96	29.44	21.14	87.10	227.47	12.87
Gimbi	150.82	46.85	137.48	13.16	149.26	31.53	76.36	258.04	297.37	15.91
Kone	98.42	27.32	296.60	29.94	166.48	36.87	41.46	82.63	454.66	24.54
Nekemte	135.06	33.49	141.54	12.06	122.72	25.48	29.43	70.65	250.19	11.91
Shambu	90.67	29.32	118.85	13.37	92.38	26.52	41.77	83.93	156.94	9.83
					Tmax					
Alibo	1.62	2.99	2.25	3.42	2.11	2.55	1.67	2.22	4.57	1.66
Bedele	2.35	2.85	1.66	2.43	1.98	2.68	2.18	2.68	6.54	2.13
Nekemte	2.37	3.01	1.59	2.50	1.39	1.98	1.65	2.11	5.43	1.86
					Tmin					
Alibo	3.65	9.64	4.11	12.15	4.80	14.04	3.13	9.08	14.33	10.21
Bedele	1.75	4.19	0.79	2.07	1.20	3.25	1.51	4.13	3.31	2.15
Nekemte	1.71	4.09	1.99	5.30	1.72	4.58	1.32	3.55	5.67	3.68

(Note: CV = Coefficient of Variation; SD = Standard Deviation)

					Stream Flow					
Nr. Dembi	13.23	48.29	51.59	18.82	38.28	18.85	7.94	38.93	7.11	16.25
Nr. Arjo	36.12	54.62	205.54	29.48	105.7	19.98	21.73	33.82	24.03	21.76
Nr. Nekemte	3.43	55.43	47.07	35.88	26.48	22.73	3.22	33.22	5.08	23.13

(Note: CV = Coefficient of Variation; SD = Standard Deviation)

4.5 The implication of Trends in water resource management

Hydro-climatic variability has a large implication on water resources as it is a fundamental driver of hydrological cycles. An increase in temperatures will contribute to evapotranspiration, which in turn leads to the reduction in the water level of the reservoir or streamflow discharge reduction. Rainfall, temperature, and streamflow are the three important variables which have a direct implication on agricultural production, water resources availability, water resources development project which in turn affects urban and rural water supply, industrial, and agricultural water uses. In this study as decreasing trends in annual rainfall were observed in four stations (Abdela, Bedele, Didessa, and Shambu), and rain fed-agriculture is widely practiced, decreasing trend in rainfall is an alarming indicator and significant increasing trend in five stations also indicates the susceptibility of the area for flooding.

However, one interesting clear feature of the regional scale and local scale discharge data implications has also been found in the present results during the time of significant trends in inter-annual hydrological discharge. This feature reveals that neither regional nor local patterns are climate-driven in the inter-annual discharge changes. Instead, local and regional water usage and land use improvements are most likely due to the latest observed discharge trends. This is in line with the major changes in land use such as deforestation and agricultural development, as well as population growth.

This study provides insights into identifying vulnerable areas within the study area by analyzing the variability of rainfall, so that better decisions on water management, conservation, and irrigation infrastructure, cropping options are possibly implemented operational plans for the effective use of land and water resource.

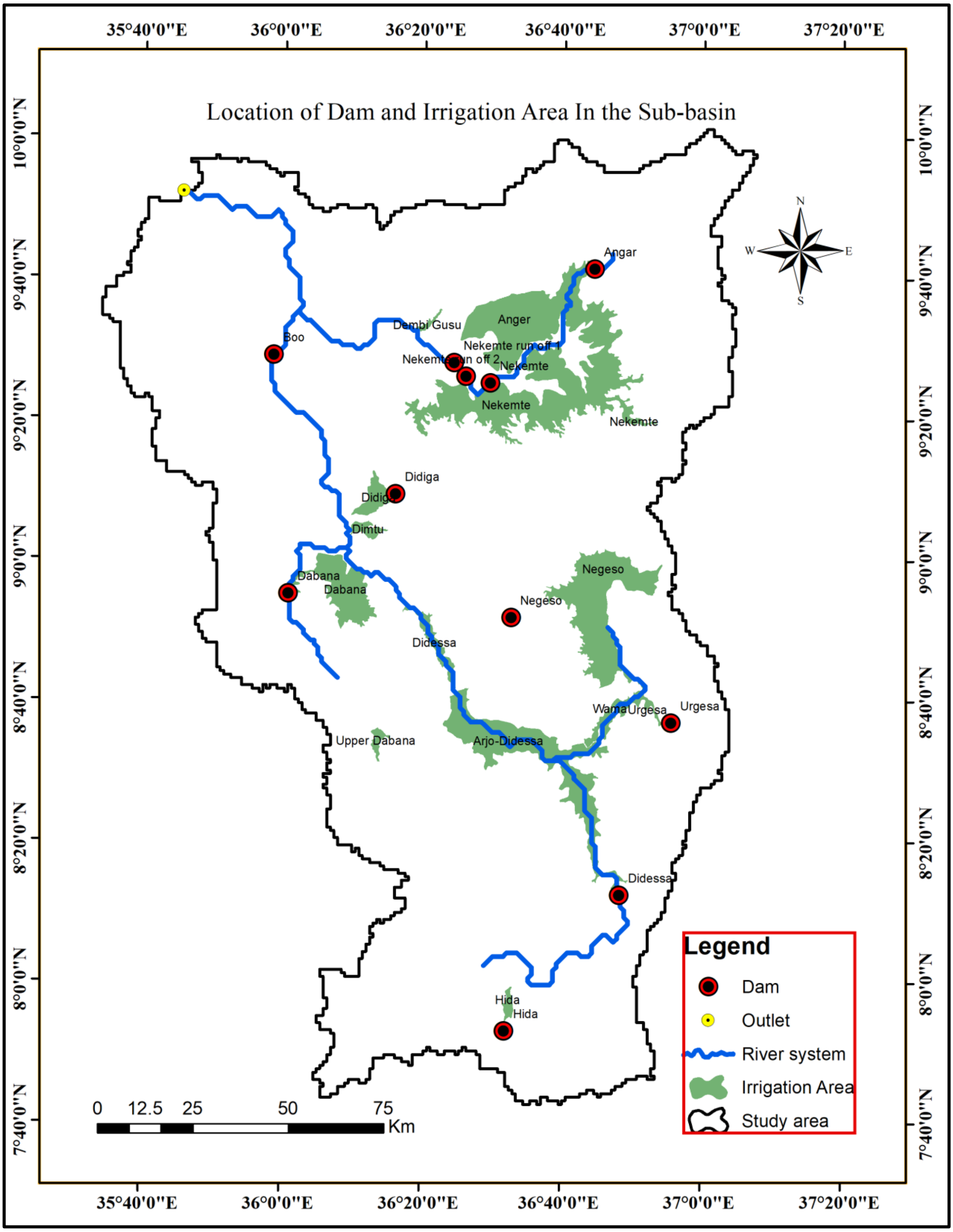


Figure 4-11: List of some water resources projects in the study area

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In this study, long-term rainfall, temperature, and streamflow data were utilized and an upward (increasing) and downward (decreasing) trend were observed using three non-parametric tests (Mann-Kendall, Sen's slope estimator, and ITA). Eleven rainfall stations, three temperature, and three streamflow gauge stations were involved in this study. A monthly rainfall and temperature trend result shows a non-uniform trend in each station.

An increasing trend in seasonal (56%) and annual (63%) rainfall is observed over the sub-basin using selected stations. A significant increasing trend in rainfall was observed in Arjo station (annual, spring, and summer) and Kone station (annual). Similarly, a significant increasing Tmax trend was observed in Nekemte station (Annual, spring, Summer, autumn, and winter) while a significant increasing Tmin trend was observed in Nekemte (summer and autumn). ITA provides visual-graphical illustrations and identification of trends for annual rainfall, streamflow, and mean annual Tmax and Tmin time series. The result from ITA shows that the annual rainfall for five stations undergoes increasing trends while six stations show a decreasing trend. Annual mean Tmax and Tmin show an increasing trend except for Alibo (Tmax) station which undergoes a decreasing trend. Similarly, two streamflow gauging stations (i.e. Didessa Nr. Dembi and Uke Nr. Nekemte) show a decreasing trend while an increasing trend was observed for Didessa Nr. Arjo. Therefore, it can be inferred from the above results that trends in hydro-meteorological variables are site specific and the method applied to detect has significant impact on the results. Moreover, there is discrepancies in time variations for the trends of the data.

The highest coefficient of variation during annual (24.54%) is recorded at Gimbi station and the lower coefficient of variation during annual (9.83%) is recorded at Shambu station. The coefficient of variation highly denotes that the rainfall in the sub-basin is not uniformly distributed.

Generally, it is hoped that this study provides valuable support for water resources planning and coping with droughts and floods and for the future development of a water resource management system.

5.2 Recommendations

For a better understanding of the results from this study in detail, future studies could address the following points in general.

- This study considers only three variables for trend analysis; rainfall, temperature, and streamflow data. Therefore, consideration of other variables such as evapotranspiration and relative humidity would have been an immense implication on trend identification that supports getting a more comprehensive impact on water resources.
- This study mainly focuses only on temporal hydro-climatic variability and trends, so that spatial analysis is also considered to get a better understanding of possible anthropogenic activities like urbanization.
- In this study only non-parametric tests were applied for analysis, therefore the comparison of parametric with non-parametric resulted may come with better interpretation and make them more reliable.

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APPENDIX A

Appendices I: Monthly, Seasonal and Annual Z statistics and Sen's slope estimator values for each three variables (Rainfall, Temperature and Streamflow) dataset.

A. Monthly Rainfall Z - Statistics for 11 stations

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abdela	0.132	-0.422	-1.248	**4.865**	1.541	-0.162	-1.378	**3.399**	**3.405**	-0.341	**7.297**	**7.525**
Agaro	-0.313	-0.213	-0.312	0.653	1.897	1.541	-0.170	1.250	**2.812**	**7.845**	-0.526	-0.342
Alibo	1.029	**-4.003**	**4.403**	-0.341	0.682	0.824	-0.199	-1.079	-0.369	-0.369	0.8095	-0.232
Arjo	-0.014	0.000	0.980	0.312	**2.471**	**2.698**	1.960	1.107	1.512	0.881	**2.528**	0.699
Bedele	0.255	-1.181	0.000	0.227	0.965	-0.568	0.227	-0.795	0.923	-0.142	0.014	0.171
Didessa	-0.464	-0.450	-0.440	-0.156	-0.426	-0.227	-0.306	**-2.272**	1.193	**2.272**	0.909	-0.071
Gidayana	0.755	0.319	-0.486	-0.422	1.524	0.146	-1.605	0.243	0.081	0.136	1.086	-1.395
Gimbi	1.690	**5.337**	-0.284	-0.398	**2.045**	1.136	-0.880	-0.284	1.136	1.008	1.052	**2.751**
Kone	1.446	-1.026	-0.276	-1.233	1.752	**2.222**	1.022	1.151	1.249	0.470	0.924	0.423
Nekemte	0.415	-0.199	-1.179	1.108	0.809	1.306	-1.108	0.341	0.880	1.108	1.562	-0.457
Shambu	-0.739	-0.782	-0.511	-0.682	1.363	-0.483	-0.710	-1.250	-0.710	0.000	0.653	-0.313

B. Monthly Z- Statistics for Tmax

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alibo	-0.016	-0.015	-0.004	-0.008	0.002	0.000	0.023	-0.0007	0.007	0.014	-0.007	-0.018
Bedele	0.018	0.033	0.025	0.007	0.025	0.014	0.020	0.011	0.027	0.018	0.014	0.007
Nekemte	0.024	0.042	0.054	0.044	0.000	0.025	0.033	0.020	0.020	0.025	0.017	0.000

C. Monthly Z- Statistics for Tmin

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alibo	0.005	0.009	-0.002	0.0012	-0.013	-0.006	-0.008	0.011	0.017	0.014	0.0044	0.000
Bedele	-0.003	0.000	0.017	0.015	0.000	-0.003	-0.007	0.000	0.000	0.000	0.004	-0.006
Nekemte	0.000	0.027	0.009	0.014	0.008	0.022	0.016	0.025	0.021	0.027	0.017	0.004

D. Monthly Z – Statistics for Stream flow

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nr. Dembi	0.198	**-2.48***	**-2.403***	-1.433	0.967	1.851	0.088	0.117	0.837	-0.256	1.191	1.544
Nr. Arjo	0.327	0.256	0.63	0.797	1.372	**2.076***	1.899	0.044	1.903	0.735	0.234	1.894
Nr. Nekemte	-0.39	-1.004	-1.424	-1.424	1.378	-0.07	-1.144	-2.26	-0.30	-0.233	-1.518	-0.887

E. Monthly Rainfall Sen's slope Value for 11 stations

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abdela	0.000	-0.092	-0.977	0.035	2.253	-0.301	-0.960	0.059	0.784	-0.654	0.369	0.040
Agaro	-0.059	-0.076	-0.238	0.571	2.588	2.008	-0.228	1.894	3.687	1.587	-0.346	-0.060
Alibo	0.000	-0.002	0.264	-0.228	1.268	1.550	-0.207	-0.911	-0.407	-0.282	0.345	0.000
Arjo	0.000	0.000	0.992	0.292	4.787	3.378	1.875	1.230	2.395	1.308	1.636	0.186
Bedele	0.020	-0.325	0.000	0.233	1.352	-0.556	0.208	-0.980	1.106	-0.211	0.011	0.000
Didessa	0.000	0.000	-0.135	-0.067	-0.557	-0.421	-2.533	-2.780	1.971	0.233	0.250	0.000
Gidayana	0.000	0.000	-0.202	-0.507	3.313	0.262	-2.491	0.592	0.140	0.204	0.565	-0.162
Gimbi	0.000	0.000	-0.093	-0.162	3.500	0.959	-1.469	-0.304	0.368	0.994	0.200	0.148
Kone	0.227	-0.175	-0.257	-0.885	2.846	4.871	1.928	1.872	2.327	1.266	0.500	0.036
Nekemte	0.000	0.000	-0.729	0.993	1.183	1.552	-1.407	6.907	0.630	1.457	0.800	-0.034
Shambu	-0.056	-0.105	-0.262	-0.569	1.850	-0.587	-0.647	-1.700	-0.525	-0.116	0.263	-0.044

F. Monthly Tmin Sen's slope Value

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alibo	0.005	0.009	-0.002	0.001	-0.013	-0.006	-0.008	0.011	0.017	0.014	0.004	0.000
Bedele	-0.003	0.000	0.017	0.015	0.000	-0.003	-0.007	0.000	0.000	0.000	0.004	-0.006
Nekemte	0.000	0.027	0.009	0.014	0.008	0.022	0.016	0.025	0.021	0.027	0.017	0.004

G. Monthly Tmax Sen's slope value

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alibo	-0.016	-0.015	-0.004	-0.008	0.002	0.000	0.023	-0.001	0.007	0.014	-0.007	-0.018
Bedele	0.018	0.033	0.025	0.007	0.025	0.014	0.020	0.011	0.027	0.018	0.014	0.007
Nekemte	0.024	0.042	0.054	0.044	0.000	0.025	0.033	0.020	0.020	0.025	0.017	0.000

H. Monthly Streamflow Sen's slope value

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nr. Dembi	0.344	-4.103	-4.874	-4.38	7.65	28.65	3.621	4.902	19.84	-3.98	10.89	3.85
Nr. Arjo	2.327	1.008	3.234	3.556	18.47	90.45	112.81	0.000	135.5	20.87	0.725	11.56
Nr. Nekemte	-0.50	-0.293	-0.456	-0.957	4.078	-0.663	-22.99	-57.21	-4.64	-0.171	-5.86	-1.277

Appendices II: Rainfall data for selected station after filling of missing data and quality check

Abdela Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	18.50	77.00	64.40	66.70	216.00	207.90	371.70	300.60	329.20	153.60	92.00	0.00
1984	0.00	2.79	17.80	34.80	220.50	211.99	344.90	207.15	140.80	16.00	25.57	2.65
1985	1.90	3.60	19.50	87.50	149.50	269.00	262.10	242.90	289.30	67.60	32.60	43.00
1986	0.00	26.80	52.80	90.90	173.10	362.80	363.50	205.70	594.30	91.50	21.40	0.00
1987	16.80	21.00	100.00	75.50	168.10	266.50	443.20	331.30	228.80	166.70	115.20	7.90
1988	40.10	74.60	76.90	30.00	244.80	554.20	313.40	309.10	712.40	365.80	5.00	2.40
1989	34.30	3.80	140.50	54.60	171.10	355.60	335.40	381.10	442.00	93.90	38.60	196.50
1990	2.80	25.80	98.90	66.20	127.90	385.90	243.80	644.80	431.90	10.00	10.70	2.40
1991	24.80	9.70	61.80	179.30	238.10	246.90	453.70	529.70	256.80	26.10	11.70	22.40
1992	0.00	0.00	91.00	70.70	166.08	332.00	503.90	548.60	477.60	446.10	96.30	7.60
1993	41.30	76.40	59.80	316.80	373.70	342.94	268.70	371.20	240.66	197.00	14.90	0.00
1994	22.20	5.20	43.30	117.80	199.40	239.71	377.50	265.40	298.58	0.00	0.00	0.00
1995	0.58	6.30	131.60	116.97	211.89	222.53	253.70	342.50	291.80	81.00	4.50	62.50
1996	59.30	22.90	150.90	117.40	214.10	269.50	342.90	290.90	236.80	87.50	38.90	5.70
1997	69.50	1.30	53.10	174.60	251.90	308.80	224.60	319.40	240.60	282.90	43.10	1.50
1998	8.70	25.50	102.90	67.30	161.40	320.50	272.90	400.20	265.40	303.70	38.10	0.00
1999	30.73	0.00	6.40	121.00	360.50	284.20	306.50	283.80	417.60	267.60	0.40	29.20
2000	0.90	0.00	4.60	125.30	262.20	406.70	231.80	348.50	336.00	142.00	45.83	2.80
2001	0.00	48.80	77.30	81.50	333.40	396.40	291.80	303.60	286.70	177.00	19.80	23.80
2002	14.10	6.30	73.40	88.00	116.60	308.90	365.90	286.00	259.60	108.20	3.00	60.10
2003	20.50	53.10	116.10	104.30	38.40	349.60	276.93	207.40	287.60	33.00	14.80	5.10
2004	5.00	3.30	27.50	54.80	237.30	449.30	319.00	327.00	349.40	132.20	41.80	7.70
2005	12.00	3.40	76.80	106.60	124.70	318.50	275.10	405.80	365.00	106.90	25.50	4.90
2006	0.00	1.40	57.30	21.90	265.70	370.70	341.90	231.30	447.90	86.70	51.80	107.40
2007	13.70	28.90	43.50	116.80	292.90	308.10	312.70	237.80	322.30	45.10	27.00	0.00
2008	26.90	8.50	0.40	143.00	397.80	279.70	423.23	259.00	162.40	105.00	27.20	0.00
2009	30.60	41.30	90.00	251.60	50.50	333.30	328.00	417.90	215.20	237.90	21.00	18.00
2010	4.80	41.90	25.40	25.50	240.10	254.40	240.80	145.90	400.10	53.20	46.90	49.20
2011	41.80	10.67	32.20	45.10	398.57	187.20	296.30	438.23	443.42	26.00	58.20	0.00
2012	0.00	0.60	69.60	39.60	290.90	258.60	181.80	309.70	348.90	55.30	39.80	8.40
2013	15.40	4.97	0.00	46.00	230.90	266.50	298.30	374.40	333.10	133.64	30.00	8.00
2014	10.60	11.20	74.16	92.81	232.13	276.30	313.58	319.92	338.20	132.23	33.46	8.80

Agaro station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	19.60	9.80	110.70	73.23	196.56	274.53	151.10	445.30	270.80	278.40	123.30	0.00
1984	3.80	4.79	38.65	50.10	167.10	156.80	218.90	131.90	119.60	13.60	107.20	26.60
1985	0.00	0.00	1250.66	118.00	198.70	220.50	305.50	189.90	135.40	21.63	34.10	30.80
1986	18.40	53.00	128.80	66.70	143.40	202.40	237.10	84.60	139.30	31.30	23.20	11.50
1987	8.10	40.20	101.70	81.50	200.90	171.80	238.30	192.60	230.80	160.40	82.38	16.00
1988	60.90	143.22	39.30	58.80	220.80	390.00	246.30	285.80	218.90	289.50	3.90	10.20
1989	14.40	19.80	101.10	117.20	106.10	167.10	248.50	285.90	85.00	88.50	47.50	149.30
1990	0.00	82.50	282.60	121.90	106.10	282.40	285.20	373.40	200.80	25.50	71.70	6.80
1991	116.90	25.10	62.60	169.60	331.40	274.83	278.80	241.90	195.40	57.40	19.90	100.80
1992	43.10	21.34	109.00	134.80	184.00	183.80	265.90	137.80	188.40	101.30	46.90	9.70
1993	44.00	122.60	71.80	191.90	248.70	306.10	141.00	241.10	176.30	239.00	8.30	0.00
1994	9.00	1.50	49.20	75.50	217.10	221.80	319.78	309.17	286.79	16.32	34.45	0.00
1995	1.18	14.00	216.63	138.23	178.61	191.70	201.00	295.90	242.30	63.90	24.80	169.10
1996	36.80	58.30	189.30	118.70	262.90	228.30	369.20	108.30	288.10	63.70	118.00	24.80
1997	87.30	21.60	56.70	126.40	264.50	351.30	201.30	238.80	206.70	310.70	207.10	80.00
1998	70.60	21.50	117.50	66.60	116.50	277.40	270.90	331.40	208.50	212.00	75.80	0.00
1999	3.80	6.80	34.10	98.40	212.00	351.10	197.60	144.20	191.30	209.60	16.30	17.90
2000	0.00	1.00	118.50	99.70	266.90	297.30	184.40	187.20	273.90	293.10	30.70	32.30
2001	14.30	30.70	103.00	126.00	304.27	207.20	231.10	221.90	211.60	147.10	17.40	0.00
2002	6.60	0.00	85.70	49.40	93.20	280.60	278.20	267.00	156.30	56.00	4.60	56.49
2003	19.10	72.00	127.50	216.40	31.65	223.96	265.40	215.70	111.50	78.40	8.70	17.90
2004	23.50	2.40	55.80	148.20	153.10	205.10	202.54	220.30	257.50	134.10	33.90	39.80
2005	16.40	0.00	20.50	88.90	86.60	273.20	195.80	181.60	277.90	83.20	34.30	1.63
2006	21.20	37.30	138.80	94.70	140.20	262.40	286.60	227.50	174.00	181.70	55.50	39.50
2007	33.00	45.20	96.80	64.40	197.60	166.80	263.70	270.10	243.70	67.80	30.30	0.60
2008	19.60	9.90	19.40	154.30	224.10	262.70	233.50	252.30	77.50	142.40	39.90	30.00
2009	32.40	13.80	73.70	131.70	103.00	163.80	144.10	177.40	268.90	235.72	20.50	23.50
2010	2.00	99.30	42.70	63.16	250.20	277.89	216.76	219.87	384.00	55.73	61.58	46.83
2011	27.40	20.53	84.25	107.74	165.60	354.90	161.60	277.00	259.40	20.00	81.35	22.54
2012	5.57	1.14	128.32	67.48	273.93	188.40	223.60	248.40	216.30	53.10	54.20	26.76
2013	22.40	25.80	36.02	70.84	268.16	463.90	239.60	352.00	231.50	273.60	62.60	1.00
2014	29.20	37.07	188.40	242.00	295.80	146.80	211.20	427.60	268.00	133.22	53.50	5.00
2015	0.00	5.50	48.30	106.30	290.70	378.20	202.50	384.90	333.90	32.80	143.70	184.10
2016	17.80	31.75	94.06	110.27	436.70	260.30	608.60	247.54	298.00	155.10	0.00	0.00
2017	0.00	25.80	102.80	108.00	422.40	200.70	498.20	241.54	383.50	712.00	0.00	0.00

Alibo Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	0.00	4.00	22.50	5.60	182.50	127.70	249.30	308.90	260.90	114.70	20.30	0.00
1984	0.00	0.10	25.60	23.30	164.60	252.20	286.40	259.30	231.70	35.20	11.20	6.90
1985	20.40	0.00	26.00	81.90	161.60	238.80	280.10	345.90	125.50	59.30	8.90	37.50
1986	0.00	10.20	27.20	96.20	45.20	271.30	294.90	218.50	188.70	63.50	6.90	0.00
1987	4.40	4.60	46.50	45.90	339.10	134.50	221.40	217.70	119.50	72.50	1.50	37.70
1988	4.00	75.00	13.80	2.70	123.50	250.10	323.20	267.60	285.00	138.80	4.20	0.00
1989	0.00	6.80	93.30	69.89	106.60	107.30	269.20	216.80	230.10	81.13	87.90	71.30
1990	10.60	2.90	49.50	22.50	68.00	212.20	411.90	298.00	249.80	62.90	15.10	0.00
1991	2.87	14.40	13.30	104.80	225.60	249.00	224.40	176.70	162.30	0.00	39.00	1.00
1992	14.00	3.51	50.60	122.10	202.80	88.30	377.00	393.10	225.00	191.60	53.80	63.40
1993	11.40	10.70	52.20	150.40	201.10	186.00	288.90	318.10	269.20	139.00	20.90	0.00
1994	0.00	3.80	11.50	62.50	293.03	156.50	199.90	258.90	179.60	1.00	22.20	9.60
1995	1.47	1.60	35.40	80.90	179.40	159.20	236.40	249.30	145.80	12.30	1.60	42.40
1996	12.90	3.94	104.00	68.70	243.30	214.00	329.50	280.80	223.90	56.20	49.47	38.70
1997	0.00	0.00	59.80	154.63	214.20	230.80	221.50	307.00	179.90	139.90	96.87	4.93
1998	14.36	3.97	58.19	29.93	122.10	171.30	206.30	312.80	218.60	141.00	17.90	0.00
1999	27.80	0.00	0.30	78.70	80.70	233.43	254.40	221.50	142.60	185.80	15.20	16.20
2000	0.00	0.00	1.90	151.00	130.00	169.60	266.70	255.80	246.80	168.70	37.70	15.10
2001	0.00	2.10	24.70	50.20	194.50	245.80	255.20	206.00	107.80	92.30	13.20	26.10
2002	0.00	24.50	82.70	26.20	63.90	268.40	406.30	186.60	242.40	42.70	11.60	41.90
2003	0.40	68.70	58.32	0.00	10.40	374.17	275.00	253.00	425.70	29.60	37.70	47.50
2004	37.90	3.40	10.80	80.40	115.60	301.40	324.90	216.70	186.90	112.30	26.80	0.00
2005	3.20	0.00	150.10	9.40	88.10	338.80	325.47	376.03	313.07	128.90	40.47	0.00
2006	0.00	1.20	34.90	38.53	173.40	229.50	392.80	251.20	242.00	21.50	39.60	48.70
2007	1.20	50.13	26.00	87.60	234.60	382.37	341.13	269.50	273.37	53.50	9.30	0.00
2008	36.20	0.67	0.03	186.63	311.40	122.00	321.90	351.00	284.00	60.80	17.10	0.40
2009	1.10	19.90	55.00	125.50	39.40	208.70	288.80	265.00	148.30	116.60	3.20	11.30
2010	17.90	5.80	23.80	46.80	263.50	149.20	199.10	270.40	178.60	15.20	0.00	2.10
2011	19.10	0.00	66.60	46.30	211.50	302.90	257.70	225.70	249.50	46.70	0.90	0.00
2012	0.00	2.60	31.10	0.60	24.10	370.27	302.80	242.50	199.90	70.00	55.00	13.00
2013	8.90	0.00	34.40	3.20	315.90	217.20	293.80	262.90	164.90	106.40	52.70	0.00
2014	0.00	11.70	52.60	133.50	203.50	168.40	258.20	244.80	112.50	84.20	26.30	0.00
2015	0.00	20.60	43.00	26.90	216.70	105.80	205.10	168.70	186.80	27.70	82.40	18.40
2016	0.00	0.00	21.20	12.40	305.90	235.60	284.53	263.54	212.14	57.70	0.70	3.50
2017	7.36	10.49	41.38	65.47	172.23	219.79	215.20	227.30	200.00	97.00	107.20	16.40

Arjo Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	3.10	34.30	64.00	37.30	162.50	184.10	282.20	440.90	330.90	90.10	70.40	0.00
1984	0.00	3.10	43.76	53.11	280.68	252.25	293.00	235.63	346.40	19.30	41.00	1.20
1985	32.40	0.00	47.10	173.00	253.50	296.40	411.20	283.30	235.40	66.70	8.20	7.60
1986	0.00	45.30	76.80	103.50	92.90	352.60	289.80	356.10	293.40	58.10	21.60	16.30
1987	16.10	25.60	150.10	174.60	170.00	332.30	332.70	271.80	164.30	132.40	37.81	10.67
1988	44.20	60.40	20.00	11.10	345.20	337.70	330.40	370.40	334.30	242.40	8.00	6.30
1989	0.40	22.30	214.80	106.30	133.70	238.30	227.90	383.20	246.80	130.40	36.00	114.40
1990	11.90	14.00	115.88	84.70	159.10	316.10	289.30	306.40	245.50	61.70	40.00	0.00
1991	9.20	14.80	72.20	137.92	223.16	288.42	457.56	350.10	142.10	53.00	12.60	45.00
1992	44.50	17.00	113.60	188.90	181.70	328.40	216.60	338.30	194.60	215.00	127.70	35.10
1993	11.30	54.10	69.40	256.40	241.06	403.66	346.31	399.90	265.60	217.11	9.35	0.00
1994	27.40	0.00	17.50	100.58	279.14	280.91	276.00	384.44	290.80	38.40	66.31	0.79
1995	0.00	0.00	105.40	138.90	116.50	128.20	263.50	282.00	161.90	81.53	2.00	48.10
1996	52.70	0.00	304.62	130.40	257.00	399.70	389.70	213.50	158.40	97.80	23.00	24.73
1997	8.00	0.40	46.30	215.00	295.20	258.70	344.30	305.24	142.60	276.70	47.50	3.60
1998	7.20	32.40	76.90	34.70	186.00	367.60	284.40	283.90	224.50	272.93	29.90	10.28
1999	30.40	3.87	5.33	79.60	286.40	259.10	306.00	343.20	276.20	375.67	5.40	33.00
2000	0.00	0.00	1.40	71.90	268.80	274.20	379.00	352.50	336.00	150.80	78.60	16.70
2001	0.00	18.30	243.40	141.50	215.90	333.70	255.50	321.00	152.70	149.00	28.90	13.40
2002	25.70	3.60	77.50	69.20	115.90	291.60	292.30	177.50	219.30	24.60	10.00	46.40
2003	0.00	84.50	105.40	52.80	52.80	285.80	314.60	404.60	359.70	77.70	34.00	9.00
2004	10.20	0.00	55.20	95.70	229.00	418.80	494.20	456.90	385.90	157.90	11.60	45.30
2005	0.60	0.00	138.10	108.60	206.20	395.50	377.40	392.90	304.50	120.20	99.00	0.00
2006	0.00	19.95	154.73	53.70	263.29	289.10	402.80	266.90	347.50	213.40	61.50	101.00
2007	8.30	89.00	52.40	198.20	407.20	455.40	403.60	601.30	461.10	82.40	7.60	0.00
2008	28.77	1.60	2.40	226.70	454.80	392.30	325.00	405.20	424.10	210.40	167.20	41.10
2009	23.40	15.70	100.40	296.40	138.30	475.50	423.80	402.00	280.30	315.40	47.20	69.60
2010	28.30	6.80	3.60	80.80	388.10	354.50	514.40	299.30	239.10	74.90	44.00	31.40
2011	82.60	30.10	170.70	142.30	368.40	386.40	411.10	398.70	376.40	15.20	67.10	12.70
2012	0.00	1.60	90.70	36.20	341.80	297.50	300.50	425.50	342.20	59.80	100.80	0.00
2013	15.20	5.70	374.00	62.30	384.20	438.20	319.40	359.00	244.30	240.50	192.90	0.00
2014	5.10	7.66	91.94	113.61	343.17	369.77	328.22	344.78	387.50	209.60	100.00	3.40
2015	0.00	22.40	139.50	81.00	421.70	392.30	331.76	295.80	360.80	94.40	180.00	24.40
2016	15.82	21.49	98.24	123.32	243.62	333.49	336.25	345.83	280.17	126.40	57.63	28.05
2017	15.82	20.93	97.73	120.13	240.44	335.27	330.56	347.75	279.99	134.08	58.49	28.70

Bedele Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	12.80	54.84	47.50	61.70	191.09	368.80	498.90	467.90	305.90	197.40	99.10	0.00
1984	0.03	0.00	44.60	65.60	291.20	275.20	469.50	210.90	241.80	8.90	24.60	5.00
1985	4.90	0.00	17.50	138.10	299.70	399.30	248.40	290.30	313.80	50.90	28.60	33.40
1986	0.00	63.70	43.00	54.10	69.10	308.70	263.90	272.00	193.70	92.60	31.50	0.40
1987	5.00	27.60	103.10	71.90	167.90	307.60	491.70	335.80	194.10	228.20	31.20	27.70
1988	18.10	59.50	66.30	14.10	337.00	327.90	217.20	350.00	366.20	225.20	13.30	6.70
1989	10.50	11.60	135.20	45.50	116.10	273.50	306.80	321.30	275.60	134.70	39.20	140.30
1990	13.30	34.30	77.00	90.00	97.00	419.70	231.10	363.90	279.90	62.90	29.00	13.40
1991	25.40	17.90	62.32	105.48	240.71	330.58	371.10	349.00	248.40	85.50	31.70	11.50
1992	35.60	38.90	103.40	136.80	203.10	259.20	288.80	280.40	255.70	213.90	64.50	28.90
1993	1.80	34.10	80.30	141.40	242.50	340.98	289.63	356.80	199.90	182.30	3.40	0.00
1994	16.80	2.00	32.60	107.16	225.10	337.38	308.83	257.40	275.90	20.70	17.20	0.00
1995	0.00	16.60	101.80	129.60	166.55	291.70	256.80	318.20	352.70	77.40	10.30	26.30
1996	48.30	33.50	209.90	82.70	277.40	232.40	289.90	196.70	237.30	69.80	44.60	12.50
1997	52.70	1.80	49.80	142.20	340.10	307.30	220.70	304.20	231.80	309.00	37.60	4.40
1998	13.10	14.60	87.00	56.90	202.60	331.17	313.90	326.50	290.80	244.60	58.50	0.90
1999	28.00	2.90	13.00	148.00	430.90	440.60	318.80	241.60	323.60	328.10	8.10	38.90
2000	0.80	0.60	3.90	123.10	255.70	419.50	185.90	273.20	285.60	242.40	29.30	7.80
2001	0.30	33.00	87.00	68.80	322.50	390.40	297.10	329.30	369.50	210.50	29.20	27.40
2002	15.60	3.80	62.60	37.70	169.30	298.30	296.20	201.90	252.70	62.60	2.80	46.00
2003	7.10	66.00	83.90	130.70	36.90	320.00	278.10	257.90	196.80	52.30	13.20	2.60
2004	6.30	2.60	46.30	80.90	248.00	447.00	298.70	268.10	273.30	168.00	60.10	15.30
2005	5.00	2.20	112.20	65.30	153.00	354.20	349.00	405.80	485.80	137.80	83.00	0.00
2006	0.20	39.00	90.60	75.30	230.10	438.80	381.30	330.00	343.70	230.40	104.00	94.90
2007	4.60	69.30	78.70	135.00	174.20	396.60	320.20	288.10	404.70	82.00	29.00	0.00
2008	41.20	0.00	0.00	222.90	381.40	230.40	412.20	294.10	227.80	149.80	29.60	19.52
2009	0.00	42.50	102.10	282.90	69.20	291.20	267.10	206.30	218.00	253.80	0.60	43.10
2010	18.50	38.80	13.50	37.50	234.70	352.40	318.60	268.00	500.10	72.70	53.90	57.40
2011	55.80	0.00	62.80	56.00	259.00	290.40	196.00	282.30	243.40	17.10	82.00	0.40
2012	2.50	0.00	97.60	58.80	256.30	270.00	283.70	333.30	395.00	60.50	25.50	0.00
2013	16.20	6.00	28.80	32.10	276.40	316.70	196.30	410.40	305.50	253.80	17.40	0.00
2014	2.30	2.80	71.07	99.00	276.40	335.46	292.47	300.40	293.19	145.99	36.52	3.76
2015	1.90	21.66	72.87	97.83	230.15	343.80	369.90	292.36	288.29	144.72	33.80	26.90
2016	15.01	0.70	63.40	80.80	270.50	263.30	370.40	223.36	150.00	6.56	4.37	23.21
2017	15.91	21.66	72.87	96.98	236.90	278.65	300.43	296.62	288.29	144.72	33.91	23.29

Didessa Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	3.71	13.87	28.94	50.17	197.70	327.10	675.20	400.80	186.40	107.40	31.50	2.02
1984	0.00	7.37	8.90	19.50	221.00	306.20	286.80	308.50	281.07	0.00	8.20	13.60
1985	1.00	0.00	47.30	89.30	218.90	361.20	373.00	296.40	168.20	145.50	26.80	22.70
1986	0.00	5.40	11.80	73.10	90.00	184.20	339.40	286.67	220.20	94.30	5.10	0.50
1987	3.50	3.00	25.00	28.50	141.20	399.00	425.60	295.60	214.80	97.20	54.40	0.50
1988	0.60	41.14	31.90	0.00	275.30	339.90	296.17	442.40	380.10	241.00	8.00	0.00
1989	0.00	0.00	159.60	38.10	242.90	319.00	336.90	289.40	304.80	120.00	22.00	50.01
1990	4.20	7.33	36.67	4.00	111.70	279.60	401.80	227.20	141.20	47.10	19.20	0.00
1991	6.60	17.40	33.20	110.35	250.36	279.87	345.80	303.60	193.43	10.30	0.50	9.70
1992	3.60	0.30	70.17	109.42	80.80	196.60	152.90	206.70	317.00	183.20	64.90	6.00
1993	0.00	7.90	26.30	95.00	188.60	223.60	306.60	263.80	170.10	132.40	15.30	0.00
1994	0.10	0.00	1.20	73.40	193.90	236.40	236.40	280.70	91.40	50.60	16.50	0.30
1995	0.00	0.00	33.60	19.30	80.90	112.60	272.90	244.20	176.00	89.40	9.70	4.50
1996	21.40	4.20	78.90	60.00	239.00	310.70	380.30	369.70	370.00	31.40	9.90	7.93
1997	13.00	0.00	13.30	154.10	183.80	203.20	277.40	282.50	147.40	290.16	60.20	0.00
1998	0.00	0.00	13.20	12.30	281.00	398.10	195.60	370.60	253.70	190.70	29.00	0.40
1999	17.60	0.20	0.00	47.90	177.80	305.80	141.40	273.80	351.10	141.00	16.80	11.30
2000	0.00	0.00	0.40	154.20	240.80	448.20	132.40	347.30	300.30	191.90	21.10	0.00
2001	0.00	10.90	27.10	30.80	142.90	184.00	196.30	223.70	253.90	127.80	39.80	33.10
2002	6.00	14.50	30.00	31.10	76.70	233.00	252.10	125.50	111.80	16.50	0.20	7.80
2003	0.00	35.10	50.00	0.00	73.10	392.90	417.20	302.30	192.80	67.00	36.00	5.50
2004	0.00	5.20	5.50	34.80	105.70	251.70	427.80	317.50	139.50	147.10	36.20	1.20
2005	6.00	0.40	107.30	18.80	110.00	373.30	347.80	173.40	251.80	123.70	15.81	3.63
2006	0.40	2.03	10.20	13.20	236.80	193.80	294.00	261.40	344.60	346.30	37.00	29.50
2007	0.00	15.40	23.20	68.40	156.70	432.40	168.50	172.00	305.20	62.70	62.70	0.00
2008	11.10	0.00	5.00	118.50	307.30	404.70	479.50	367.60	268.40	78.30	54.70	3.00
2009	0.00	13.90	25.50	129.40	61.40	299.70	192.40	324.30	276.30	95.30	5.60	23.20
2010	1.70	0.40	0.00	18.10	256.70	514.90	351.90	139.00	254.10	100.80	3.00	1.10
2011	29.40	0.00	19.10	25.70	173.50	374.70	138.90	185.70	282.20	65.50	10.00	0.00
2012	0.00	0.00	0.80	53.71	137.00	227.90	148.30	364.50	308.70	38.50	41.60	13.00
2013	0.00	0.00	13.80	26.76	273.80	231.20	271.00	197.40	243.00	101.50	135.20	0.00
2014	0.00	9.90	129.28	144.80	204.30	260.50	336.70	232.80	389.80	192.40	1.80	0.00
2015	1.90	21.66	72.87	97.83	230.15	343.80	369.90	292.36	288.29	144.72	33.80	26.90
2016	15.01	0.70	63.40	80.80	270.50	263.30	370.40	223.36	150.00	6.56	4.37	23.21
2017	15.91	21.66	72.87	96.98	236.90	278.65	300.43	296.62	288.29	144.72	33.91	23.29

Gidayana Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	8.00	3.40	35.70	2.90	255.50	217.60	395.30	343.70	429.60	209.00	58.20	7.66
1984	0.00	0.00	20.70	32.90	186.10	418.20	373.20	325.30	315.70	70.48	1.40	14.35
1985	0.00	0.00	9.20	64.60	99.10	474.40	307.90	469.60	171.00	76.60	42.30	0.00
1986	0.00	18.30	38.70	38.10	49.60	382.40	465.80	332.30	378.80	165.90	12.86	37.70
1987	2.20	0.00	84.60	84.40	282.20	278.40	472.40	198.40	179.30	209.00	65.90	0.90
1988	2.60	19.80	30.80	0.30	119.40	329.00	325.30	283.20	280.20	232.90	0.50	0.80
1989	0.37	0.00	129.60	50.50	211.70	373.90	332.80	269.10	319.80	113.50	4.00	77.30
1990	5.00	5.10	15.40	55.20	127.20	326.80	415.50	450.50	219.00	95.90	17.70	0.00
1991	0.00	20.30	62.60	127.90	83.80	217.40	217.80	206.80	169.40	30.00	0.00	24.60
1992	0.00	0.00	14.00	104.20	99.10	202.60	186.20	207.40	153.70	209.90	26.50	62.60
1993	0.00	3.60	51.80	118.20	208.90	270.50	331.80	314.50	312.70	207.83	24.00	0.00
1994	4.30	3.90	4.70	78.70	321.00	284.59	402.70	422.60	191.10	8.90	80.20	14.70
1995	0.00	0.00	22.60	190.30	254.60	225.50	272.50	321.10	398.10	43.30	20.30	17.40
1996	0.00	2.30	136.50	79.00	240.80	370.50	416.80	229.30	311.90	112.40	31.40	5.20
1997	4.50	0.00	62.00	106.50	302.20	263.20	320.70	364.70	345.70	279.00	69.40	1.10
1998	12.90	0.30	71.70	24.60	306.20	306.20	382.40	367.80	305.30	265.10	38.40	0.00
1999	17.00	0.50	0.00	96.90	249.70	265.20	317.70	332.90	250.40	353.10	5.00	21.40
2000	0.00	0.00	1.30	112.90	221.60	265.90	343.00	252.70	314.40	197.60	36.50	18.80
2001	0.00	17.40	60.70	29.80	257.00	358.20	273.10	290.80	215.30	153.00	9.50	15.20
2002	18.30	12.60	71.20	63.20	82.77	350.58	328.10	235.20	214.60	62.00	7.70	41.40
2003	0.00	35.80	38.10	27.00	16.10	348.60	279.00	299.61	418.70	42.90	37.80	5.70
2004	5.50	31.90	16.10	45.00	82.90	505.80	375.70	264.50	333.90	100.90	68.20	4.00
2005	0.70	0.00	139.90	22.50	131.60	349.10	314.20	373.70	361.20	163.40	41.80	0.00
2006	10.70	0.00	13.50	23.20	220.50	386.00	373.70	297.00	341.95	142.10	56.90	27.90
2007	0.00	15.10	12.60	93.90	338.00	438.10	309.20	242.60	313.69	88.68	1.30	0.00
2008	16.60	0.00	0.00	250.80	379.60	155.30	249.90	240.60	378.40	58.70	35.10	3.57
2009	1.00	29.40	18.50	72.80	24.00	361.90	290.60	350.40	181.90	89.70	2.50	0.00
2010	4.70	7.00	0.00	32.90	357.90	262.20	477.40	245.60	280.90	58.70	28.10	0.00
2011	16.90	0.00	64.70	12.50	318.30	285.00	189.60	288.20	229.70	34.10	55.00	1.20
2012	0.00	0.42	51.90	10.20	95.40	531.90	430.20	344.60	176.40	49.90	62.00	1.40
2013	0.00	0.00	14.50	17.70	270.20	265.40	298.80	451.90	228.80	204.60	62.70	0.00
2014	0.00	6.50	82.82	146.67	351.37	269.97	278.50	386.70	376.10	319.30	14.70	7.07

Gimbi Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	2.78	7.66	25.62	62.50	198.39	364.08	589.71	398.91	328.10	159.10	15.70	0.00
1984	0.00	0.00	11.60	10.50	196.42	384.27	349.96	361.22	400.40	13.50	0.00	0.00
1985	0.00	0.00	45.50	107.70	71.00	334.50	248.90	235.60	353.80	68.10	17.30	4.50
1986	0.00	25.00	6.00	56.10	8.60	305.10	479.50	296.60	213.60	93.60	37.60	0.00
1987	0.00	0.00	54.90	61.40	249.40	307.90	474.50	347.30	187.90	136.50	10.00	0.00
1988	0.00	31.60	20.00	0.00	268.40	400.70	308.40	322.20	452.60	174.20	2.20	0.00
1989	0.00	0.00	68.10	43.50	236.20	329.90	428.40	404.80	433.00	138.40	14.63	12.04
1990	0.00	6.00	4.50	5.20	93.00	348.41	389.88	440.00	396.00	21.20	0.00	0.00
1991	0.00	11.23	25.70	126.27	242.57	283.47	456.00	375.40	111.00	103.30	0.40	0.00
1992	0.00	0.00	37.70	110.55	164.98	233.70	372.10	454.90	518.80	140.60	122.00	10.80
1993	0.00	10.30	30.50	98.50	134.50	306.90	381.30	367.80	290.40	130.20	6.40	0.00
1994	9.50	0.00	2.40	99.63	390.31	330.06	272.29	303.18	186.87	50.25	41.70	1.83
1995	0.80	0.00	29.70	86.40	165.70	308.00	202.70	310.10	208.30	63.10	0.00	1.00
1996	12.50	0.00	14.20	49.70	252.00	248.00	401.90	303.80	246.20	37.60	9.30	0.80
1997	2.80	0.00	18.50	107.30	184.80	317.50	351.10	232.00	242.50	351.70	48.80	0.00
1998	0.00	0.00	0.00	43.20	152.90	390.10	262.30	363.32	484.90	189.30	14.60	0.00
1999	0.00	1.00	0.00	88.20	291.10	340.40	187.60	327.70	366.90	361.50	10.60	5.70
2000	0.00	1.00	0.80	192.70	297.50	362.40	302.00	326.10	287.10	225.10	33.40	0.60
2001	0.00	0.00	32.50	27.30	231.00	280.80	331.40	336.30	167.50	141.40	20.90	34.50
2002	13.00	0.80	6.90	59.20	86.30	375.20	297.30	409.00	321.90	78.90	0.00	2.50
2003	0.00	89.60	49.20	3.50	120.70	404.80	492.20	333.70	343.90	59.20	40.30	9.20
2004	0.00	8.90	3.70	53.70	164.50	325.10	439.00	366.90	365.60	126.20	18.70	1.00
2005	2.00	1.30	115.60	24.20	176.50	398.20	368.80	255.30	383.00	79.40	1.60	2.30
2006	0.70	4.40	2.90	10.00	256.30	488.30	461.00	297.20	398.80	211.60	18.20	41.60
2007	0.50	26.70	36.50	67.10	214.70	296.40	255.90	383.00	352.00	54.00	38.67	0.00
2008	8.10	0.00	0.00	199.10	371.60	346.90	494.90	340.90	266.00	60.90	27.90	0.00
2009	0.00	7.03	28.40	155.30	97.30	399.70	190.10	357.70	196.60	144.70	0.70	59.20
2010	30.80	0.00	17.90	59.10	298.90	320.50	448.00	298.80	286.30	131.90	1.60	6.30
2011	0.00	0.30	30.70	44.60	181.10	400.20	210.70	332.80	293.70	43.70	12.20	0.00
2012	0.00	0.00	5.43	95.20	268.20	340.80	329.90	390.10	297.40	32.70	48.60	3.20
2013	0.00	0.00	8.90	1.60	443.60	344.30	314.00	228.00	303.80	129.00	53.70	0.00
2014	0.00	5.61	193.13	349.36	399.82	471.70	478.98	435.70	312.00	248.60	9.80	5.00
2015	2.88	0.60	22.99	25.90	338.20	270.80	308.80	313.06	437.90	145.60	21.40	305.95
2016	2.88	8.05	25.23	5.30	221.57	336.61	356.56	343.85	332.00	466.00	9.10	387.67
2017	2.88	7.96	22.99	59.18	212.09	338.27	354.65	344.60	315.98	145.60	21.40	287.90

Kone Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	16.80	21.90	49.40	63.10	182.60	246.90	315.00	304.50	260.50	81.30	26.50	0.00
1984	0.10	5.00	16.00	71.10	255.20	157.50	308.00	160.00	159.60	9.20	11.10	1.40
1985	8.20	0.00	17.70	95.30	158.40	242.80	250.80	196.60	223.90	132.40	22.10	30.30
1986	0.00	19.70	62.00	140.30	86.60	580.00	705.10	336.20	346.10	120.40	31.50	0.20
1987	0.00	12.80	96.00	131.80	226.50	308.50	385.20	299.50	289.60	175.20	25.30	4.30
1988	5.90	99.00	44.30	13.80	290.30	485.10	272.00	292.70	371.50	218.10	37.50	3.40
1989	1.00	6.20	115.80	90.80	107.10	312.30	202.20	284.40	198.80	94.60	44.50	161.20
1990	5.10	29.40	45.50	68.90	151.70	336.90	338.70	308.30	223.70	69.30	17.80	2.00
1991	5.30	21.80	51.50	118.00	139.00	247.00	475.30	401.90	172.30	73.10	1.20	23.20
1992	8.40	3.10	56.00	156.60	127.10	250.70	217.80	311.00	208.00	226.90	119.10	1.90
1993	1.20	39.20	73.70	115.70	189.00	410.60	222.30	476.50	201.60	266.40	3.50	0.00
1994	15.60	0.00	21.50	81.40	191.00	184.30	273.00	404.70	285.90	36.20	54.60	0.00
1995	1.50	3.00	187.60	89.60	157.40	298.80	321.80	309.70	331.80	69.50	9.10	26.60
1996	100.80	2.10	158.90	117.80	288.80	256.10	271.70	264.70	238.50	113.30	19.40	16.70
1997	8.30	14.64	76.00	101.10	220.70	154.80	165.20	279.30	112.10	29.40	42.73	3.17
1998	11.40	24.17	88.80	28.50	275.00	337.60	334.10	294.80	180.60	282.60	0.00	18.24
1999	20.80	4.50	2.40	57.90	335.20	328.50	257.10	264.90	191.90	460.20	15.80	37.60
2000	0.00	0.00	14.80	160.90	188.40	307.90	221.50	237.00	432.00	216.00	29.60	17.50
2001	0.50	23.70	63.20	81.60	256.90	311.10	250.60	272.90	230.60	174.90	11.00	53.00
2002	16.00	1.40	39.20	62.20	160.90	172.60	272.60	180.00	205.90	43.40	7.30	39.90
2003	0.00	83.60	59.30	85.40	44.09	249.50	238.10	169.60	219.20	19.10	13.20	6.50
2004	4.90	1.40	18.90	60.70	204.50	325.20	299.80	298.20	287.20	188.20	60.70	3.70
2005	12.50	0.00	102.50	60.50	169.50	476.04	343.90	258.90	270.70	92.70	118.20	0.00
2006	0.07	10.80	50.00	50.30	179.30	285.40	412.40	311.60	308.90	166.30	14.60	101.10
2007	8.60	38.50	67.40	88.70	169.50	400.50	420.50	397.20	404.20	152.00	9.50	0.00
2008	32.00	0.00	9.90	183.70	357.20	441.94	532.50	388.70	191.30	96.20	89.20	3.80
2009	67.50	25.20	67.50	185.80	102.40	215.10	409.80	515.40	166.40	269.03	13.94	43.57
2010	25.10	13.90	1.20	28.50	275.80	397.90	357.93	245.70	251.80	42.80	25.00	33.90
2011	44.70	1.90	52.30	69.60	568.30	587.10	299.60	633.70	706.50	0.00	68.20	4.70
2012	0.83	0.00	62.30	17.60	274.60	479.54	144.90	356.17	254.30	48.00	37.40	2.80
2013	0.00	3.20	26.80	53.37	297.17	808.50	757.40	381.27	329.70	455.52	31.31	2.67
2014	12.99	16.39	59.48	92.32	216.71	338.26	332.00	319.78	339.63	363.20	56.66	0.00

Nekemte Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	6.65	26.10	37.90	18.30	189.10	263.20	481.90	307.40	248.87	281.50	85.90	6.07
1984	1.60	21.80	23.23	22.64	259.05	393.50	374.63	319.20	248.70	10.90	21.90	16.12
1985	0.81	0.00	72.20	114.10	279.79	322.10	356.50	416.50	287.40	104.20	40.65	33.80
1986	0.00	24.52	19.80	58.40	76.52	278.80	429.50	339.41	228.40	45.40	0.00	5.80
1987	2.72	4.50	178.20	56.11	182.80	464.10	398.20	316.80	267.30	126.10	29.40	0.00
1988	6.00	110.20	17.30	0.00	373.47	444.39	308.30	281.80	414.82	198.80	76.20	0.00
1989	0.00	0.00	234.32	38.05	261.00	363.50	380.40	295.30	378.09	67.10	35.60	120.80
1990	5.90	2.30	84.40	25.00	119.30	333.50	408.60	476.40	311.90	78.00	41.50	2.90
1991	5.20	20.70	65.70	106.20	286.82	325.35	477.50	457.70	290.00	66.80	11.50	31.30
1992	13.50	0.90	97.50	92.70	292.10	400.40	500.70	432.20	272.90	242.40	105.70	28.10
1993	0.00	35.80	38.60	211.60	257.70	567.20	515.10	441.20	238.10	190.30	15.00	0.00
1994	4.00	3.50	69.90	62.60	383.70	357.20	469.10	430.90	186.70	55.90	64.90	1.60
1995	4.40	4.30	66.70	65.60	207.00	385.20	388.70	484.00	306.00	87.60	50.50	13.30
1996	40.30	4.30	104.00	143.10	292.30	391.90	563.50	344.30	272.00	97.00	45.20	23.00
1997	13.50	0.90	68.10	244.20	256.30	406.10	445.80	226.60	156.10	229.10	137.10	6.20
1998	10.10	0.00	56.10	40.90	275.80	549.80	486.60	347.70	432.50	291.60	48.60	11.70
1999	42.40	2.40	0.60	57.13	382.00	331.10	194.90	250.90	238.20	338.70	23.80	20.98
2000	0.30	0.41	2.90	107.20	224.90	509.30	332.20	540.90	240.80	138.80	47.14	19.70
2001	0.00	26.40	50.80	83.60	240.80	349.60	336.20	352.40	267.40	168.80	16.00	50.20
2002	24.90	21.10	74.30	106.20	77.40	376.80	427.30	260.30	186.90	117.60	0.20	33.00
2003	0.30	47.50	54.90	21.30	55.10	422.90	429.70	439.00	312.90	18.90	25.50	9.50
2004	7.20	6.90	12.70	76.60	206.30	286.60	409.90	433.00	248.90	71.90	20.20	11.90
2005	9.50	0.00	131.50	60.30	241.00	387.40	346.20	438.80	355.60	219.90	58.50	0.00
2006	0.50	4.80	56.60	71.30	209.40	350.60	476.00	339.10	278.30	213.80	50.40	88.60
2007	4.70	54.40	47.80	141.70	217.50	462.60	355.60	447.40	297.80	86.70	56.80	0.00
2008	13.10	0.00	0.10	227.40	368.30	416.70	412.10	384.90	301.70	235.00	82.00	0.00
2009	0.00	22.70	35.50	173.00	97.90	314.50	251.50	395.70	412.10	286.20	15.30	18.40
2010	7.10	25.60	3.50	27.60	532.70	518.30	450.90	318.70	366.80	133.60	81.30	16.00
2011	42.00	2.00	51.70	77.80	265.40	403.40	259.30	418.20	349.40	82.10	57.40	1.70
2012	0.00	0.00	26.90	32.20	251.90	307.40	399.80	593.80	314.00	99.40	68.80	15.10
2013	11.70	3.30	23.40	5.90	404.10	357.10	392.70	293.90	301.50	91.90	79.80	0.00
2014	0.00	3.80	145.26	149.50	536.40	435.60	360.20	414.17	276.60	209.60	31.40	0.00
2015	9.37	14.32	53.12	90.24	253.22	401.19	399.19	383.37	280.76	149.80	50.51	18.46
2016	9.37	15.04	53.63	92.79	260.79	400.33	406.69	375.32	278.55	146.45	47.64	16.94
2017	0.00	14.32	53.12	28.80	253.22	505.37	388.40	297.90	137.00	140.10	131.70	15.00

Shambu Station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	11.13	18.07	34.89	8.03	184.69	202.83	375.50	308.39	313.12	201.73	54.80	5.64
1984	0.62	12.87	24.48	25.65	195.80	258.80	443.80	406.40	265.37	38.86	41.00	14.95
1985	42.00	3.10	56.30	110.60	192.00	345.10	304.61	397.24	194.63	80.03	26.88	27.09
1986	30.70	152.30	31.68	113.00	57.11	310.83	381.87	269.59	226.26	91.60	7.12	20.41
1987	5.11	0.00	39.50	106.20	243.50	232.70	320.80	340.20	129.40	58.50	2.20	14.20
1988	19.00	23.90	26.60	18.90	262.50	324.80	302.00	323.10	281.60	109.70	5.30	1.20
1989	1.10	35.30	100.90	134.40	95.60	186.90	348.10	310.20	272.20	62.80	28.70	112.70
1990	7.00	43.20	66.20	45.60	128.30	220.00	380.80	609.50	243.00	7.20	20.80	1.05
1991	3.40	2.20	56.80	101.73	198.74	263.92	342.40	394.50	196.50	23.30	11.30	4.10
1992	16.00	14.80	57.50	143.30	137.60	259.40	278.10	293.00	346.90	115.60	76.30	96.30
1993	5.50	23.30	56.90	166.00	163.60	249.60	345.60	402.20	236.80	152.40	19.70	0.00
1994	5.80	9.20	28.20	67.50	174.40	257.60	286.10	242.20	176.20	4.80	22.10	1.70
1995	0.00	32.40	49.30	66.00	187.30	180.30	250.70	292.50	229.50	28.00	10.90	49.30
1996	36.60	6.00	77.00	83.70	301.20	182.20	355.20	294.20	198.60	88.53	71.80	14.30
1997	3.10	2.50	60.30	113.20	235.80	280.50	336.10	295.70	153.50	237.00	84.10	7.50
1998	12.00	11.60	47.30	30.10	176.90	269.50	263.60	232.40	222.50	189.30	32.27	0.00
1999	29.20	0.00	0.50	36.20	219.80	303.50	189.30	250.20	241.20	256.00	2.50	19.71
2000	6.30	0.00	3.30	115.20	146.80	228.40	294.90	279.70	195.40	168.37	36.10	36.20
2001	0.00	12.00	106.60	54.60	217.10	175.20	324.20	198.00	145.10	77.40	31.10	9.50
2002	11.90	13.50	97.90	57.20	107.00	243.10	544.70	361.20	197.70	23.80	4.50	23.90
2003	6.50	33.40	67.20	7.40	1.40	351.00	248.30	238.10	326.40	3.80	35.10	30.70
2004	12.20	5.40	18.00	96.90	126.80	271.40	314.90	229.40	241.70	134.80	19.80	18.00
2005	12.90	3.00	145.40	58.30	96.40	279.90	316.00	315.60	222.40	59.30	21.10	0.00
2006	0.50	50.20	52.70	21.10	198.30	305.30	328.70	187.20	335.90	98.80	11.50	29.60
2007	14.90	80.90	25.40	98.20	205.00	246.40	358.60	281.10	257.70	88.40	0.00	0.00
2008	0.50	2.00	0.00	81.70	293.10	259.90	379.30	344.90	191.20	118.17	92.80	10.30
2009	13.00	17.10	55.10	95.50	17.00	229.40	339.90	337.03	126.10	179.30	22.70	11.00
2010	29.10	2.20	29.00	80.30	290.60	185.60	299.30	289.40	189.40	12.60	10.40	13.80
2011	5.90	1.20	45.90	23.50	229.00	197.00	362.90	210.60	292.10	7.30	44.60	1.90
2012	25.50	0.00	93.20	9.70	113.20	271.50	397.40	324.30	248.40	37.70	15.80	4.10
2013	2.50	1.20	12.80	29.00	270.90	291.90	369.50	222.50	188.20	85.10	69.80	0.00
2014	11.50	17.00	50.60	157.00	314.20	205.90	217.10	363.10	226.00	85.80	85.50	21.20
2015	0.30	20.86	37.90	11.60	186.66	159.10	325.40	347.10	200.40	21.30	40.70	19.79
2016	9.70	21.43	49.43	78.56	354.80	248.66	315.00	310.84	229.84	79.95	8.25	17.79
2017	3.40	20.86	19.30	125.90	204.90	273.50	289.20	340.30	235.24	82.40	37.00	19.79

Appendices III: Temperature data for selected station after filling of missing data (Tmax in °C)

Nekemte station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	25.70	27.10	25.30	26.40	24.68	21.40	19.50	20.88	20.60	23.30	24.30	24.70
1982	24.80	26.40	26.60	25.90	24.40	21.60	19.70	19.20	21.70	22.70	23.60	25.00
1983	25.80	26.70	28.00	28.20	24.90	22.60	21.10	19.80	22.27	22.50	23.40	24.97
1984	25.00	26.80	27.51	26.77	24.68	22.16	20.79	22.40	21.40	24.10	23.90	24.97
1985	25.87	26.20	27.20	25.10	24.68	21.00	19.90	20.10	21.80	23.10	24.34	24.30
1986	25.50	26.40	26.30	25.60	27.30	20.90	20.50	20.88	22.27	23.70	24.34	25.10
1987	25.87	27.40	24.10	26.60	24.10	22.30	22.60	21.60	23.60	24.30	24.40	25.30
1988	25.87	26.20	27.51	26.77	24.68	22.16	20.79	20.88	22.27	23.20	24.50	24.97
1989	25.87	26.00	27.51	26.77	23.80	21.70	21.10	21.00	22.27	23.30	25.00	24.00
1990	25.50	25.70	27.51	26.80	25.20	22.40	20.50	20.80	21.80	23.80	25.10	26.30
1991	27.40	28.40	27.40	26.77	24.68	22.16	20.79	20.88	22.27	23.50	24.10	24.00
1992	24.80	26.10	27.40	25.70	23.70	21.50	19.90	19.80	21.20	22.00	22.50	23.90
1993	24.70	24.90	26.70	23.50	23.00	21.10	20.20	21.10	22.00	23.30	24.70	25.50
1994	26.90	27.37	27.51	26.77	24.68	21.00	19.90	19.90	21.80	24.80	23.90	25.70
1995	25.87	27.80	27.40	26.50	24.30	22.80	20.50	21.20	22.70	24.60	24.60	25.50
1996	25.60	28.10	27.00	26.20	23.30	21.50	20.80	20.60	21.90	23.50	24.10	24.90
1997	25.60	27.70	27.50	24.90	23.20	22.20	20.90	21.50	23.80	23.90	23.60	24.20
1998	25.60	27.40	27.90	29.10	25.20	23.10	21.00	21.30	22.50	23.10	24.40	25.60
1999	26.10	28.40	28.20	27.60	23.20	22.50	20.10	20.70	22.70	22.50	24.60	24.90
2000	26.70	28.30	29.20	25.50	24.10	22.30	20.60	20.60	22.60	23.30	24.34	25.20
2001	25.30	27.40	26.50	26.90	24.80	21.60	21.10	20.70	23.00	23.70	24.40	25.70
2002	25.50	27.90	27.40	27.10	26.30	22.70	22.20	21.10	22.90	24.20	24.90	25.00
2003	26.30	28.20	27.20	27.70	28.00	21.80	20.40	20.80	22.20	24.70	25.30	25.70
2004	26.70	27.70	28.40	26.90	26.10	22.20	20.80	21.50	22.70	23.80	24.70	25.30
2005	26.10	29.60	28.20	27.50	25.30	22.50	21.00	21.90	22.50	24.00	24.40	25.50
2006	26.10	28.00	27.90	26.90	24.40	22.70	21.30	20.60	22.30	24.00	23.80	24.10
2007	25.00	26.60	27.70	26.50	24.50	22.40	20.70	20.40	22.20	24.10	24.90	25.20
2008	26.40	27.20	28.80	25.00	23.30	22.20	20.30	20.50	22.10	23.40	23.50	24.80
2009	25.70	27.30	28.20	26.80	25.80	23.50	21.00	21.40	22.70	23.90	25.20	24.70
2010	26.50	27.40	28.50	28.40	24.20	23.30	20.50	20.90	22.40	24.10	24.60	24.00
2011	24.90	28.00	27.10	28.00	24.70	22.70	22.10	21.00	22.40	24.50	24.20	25.30
2012	27.30	29.40	29.40	28.40	25.20	22.30	21.20	21.30	22.40	24.80	24.60	25.20
2013	26.60	29.00	29.20	29.80	24.70	22.60	21.50	20.90	22.60	24.00	24.40	24.80
2014	26.20	27.50	27.10	26.77	24.00	22.50	21.60	21.90	21.30	24.00	24.80	24.80

Bedele Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	27.11	28.44	33.30	28.10	23.80	22.70	22.10	23.30	23.80	24.10	24.40	25.90
1984	27.11	26.70	27.20	28.10	24.90	22.60	21.70	22.30	22.50	24.40	25.00	26.20
1985	27.30	28.00	29.40	27.70	23.70	23.00	21.70	21.70	22.30	23.70	25.10	25.20
1986	26.90	27.70	27.60	27.70	28.70	23.00	22.20	22.70	22.70	23.70	24.80	25.30
1987	26.40	27.90	28.68	28.02	25.88	23.68	22.26	22.58	23.60	24.10	24.20	25.90
1988	27.10	26.80	27.70	28.50	25.10	22.70	20.70	21.50	22.20	23.90	24.60	25.20
1989	25.50	26.10	25.90	25.30	24.60	22.90	21.30	22.00	22.90	23.70	24.40	24.00
1990	25.40	24.70	26.40	26.40	25.40	23.90	21.90	22.20	23.10	24.60	25.60	26.50
1991	26.90	28.00	27.50	28.02	25.88	23.68	21.30	21.80	23.60	25.20	25.90	26.70
1992	26.60	27.20	28.90	27.90	27.60	26.00	24.10	23.10	27.00	26.10	26.50	26.16
1993	27.11	28.44	28.68	28.02	25.88	23.68	22.26	22.58	23.89	24.85	25.48	26.16
1994	27.11	29.10	29.70	28.30	25.50	23.68	22.26	22.00	23.60	26.30	26.40	27.50
1995	28.80	28.50	29.50	27.90	25.70	25.30	22.20	23.00	24.10	25.10	25.40	26.30
1996	26.30	28.90	27.30	26.90	24.60	23.30	22.30	22.80	24.00	24.90	25.30	25.80
1997	26.50	28.50	28.90	26.20	24.90	24.10	22.40	23.20	25.00	25.10	25.20	26.50
1998	27.80	29.50	28.80	31.00	27.10	25.20	22.60	22.90	24.30	24.90	26.00	27.80
1999	27.90	30.60	30.40	29.60	25.80	24.50	21.80	22.90	24.70	23.70	26.10	26.60
2000	27.11	28.44	28.68	28.02	25.88	23.68	22.40	22.70	24.00	24.40	25.10	26.20
2001	27.20	29.00	27.40	28.00	26.20	23.10	22.20	22.30	24.60	24.80	25.10	26.20
2002	26.40	28.90	28.70	28.90	27.90	24.00	23.70	22.80	24.10	25.00	26.10	26.60
2003	27.70	29.40	28.00	27.80	29.00	24.20	21.80	22.40	24.10	25.40	26.60	27.20
2004	28.40	29.40	29.10	28.10	27.10	23.20	22.50	22.80	24.10	24.80	25.90	26.50
2005	27.50	30.70	29.20	28.90	26.40	24.10	22.20	23.40	23.90	24.80	25.80	26.60
2006	28.00	29.00	28.60	27.40	25.80	23.90	22.30	21.80	23.30	24.90	24.90	25.30
2007	26.30	27.30	28.60	27.20	25.60	23.00	21.70	21.90	23.10	24.70	25.50	26.80
2008	27.50	28.00	29.60	26.30	24.60	23.50	21.80	22.20	23.80	24.50	24.70	26.16
2009	26.60	27.90	28.40	28.02	25.88	23.68	22.80	23.40	24.90	24.50	25.90	25.30
2010	27.11	28.44	28.68	28.02	26.00	24.50	21.60	22.40	24.20	25.80	26.10	25.70
2011	26.20	29.10	28.20	29.80	26.70	24.30	23.10	22.20	23.90	26.30	25.50	26.60
2012	28.00	29.90	28.80	28.20	26.30	23.10	22.20	22.10	23.40	25.70	25.20	26.16
2013	27.80	29.70	29.40	30.20	26.00	23.50	21.70	22.00	24.40	24.70	25.80	26.80
2014	27.50	28.90	28.68	28.02	25.00	23.68	22.26	22.58	23.89	24.85	25.48	26.16
2015	27.60	28.44	28.68	28.02	25.88	23.68	24.20	23.60	23.89	24.85	25.48	25.20
2016	27.11	29.40	30.40	28.10	24.80	22.20	23.20	24.50	25.40	26.70	26.70	26.16

Alibo Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	24.80	26.10	24.80	25.80	23.40	22.00	18.90	19.80	20.20	21.50	22.80	23.60
1982	24.20	24.90	24.90	25.60	23.70	21.90	19.40	18.80	21.20	21.20	22.90	23.60
1983	24.70	25.40	26.70	27.30	25.00	22.20	20.30	18.90	21.00	21.30	22.30	24.10
1984	25.00	26.70	26.80	27.20	24.10	20.30	19.90	17.20	20.50	21.80	22.70	23.70
1985	23.50	26.40	26.40	25.50	22.20	20.10	18.30	19.50	20.60	21.40	23.50	23.20
1986	25.80	26.20	26.10	24.40	26.60	20.10	19.30	20.30	20.60	22.00	23.90	25.10
1987	25.50	26.70	25.60	26.10	22.40	21.80	21.80	21.60	23.50	23.70	24.00	24.70
1988	25.60	25.50	27.80	28.50	25.90	21.50	17.60	19.30	20.30	21.50	23.70	24.40
1989	25.10	25.10	24.40	25.65	23.70	23.00	20.50	20.40	21.40	21.67	21.50	22.10
1990	22.70	24.80	25.40	25.80	24.90	22.00	20.20	20.90	21.10	21.50	23.50	24.30
1991	24.23	25.49	25.80	24.80	24.20	21.40	19.80	20.40	21.60	22.00	23.40	23.00
1992	23.60	25.49	26.50	25.90	23.60	22.30	21.20	20.80	21.30	21.10	21.60	22.40
1993	23.10	23.60	25.40	23.10	23.20	21.40	19.90	20.20	20.50	21.20	22.40	23.90
1994	24.30	25.90	26.50	26.10	24.10	21.40	20.10	19.20	20.60	22.00	22.80	24.00
1995	24.23	26.00	26.10	25.80	23.20	22.60	19.80	20.40	20.70	21.10	22.77	23.40
1996	24.23	25.49	23.80	24.20	22.40	20.40	20.10	19.91	21.07	21.67	22.77	23.40
1997	23.70	24.60	25.75	25.65	23.20	22.00	20.80	20.40	22.00	22.00	22.77	23.40
1998	24.23	25.49	25.75	25.65	25.00	22.50	20.50	20.40	21.30	21.30	21.70	22.40
1999	23.20	25.70	26.60	25.80	23.80	21.71	19.00	19.70	20.60	19.70	21.70	23.40
2000	24.40	25.60	26.80	23.10	23.70	21.50	19.80	20.00	21.00	20.70	22.60	21.80
2001	24.00	25.40	24.40	25.40	23.80	20.50	19.80	19.80	20.80	21.90	22.30	22.40
2002	24.00	25.80	25.10	25.80	26.00	21.50	21.10	20.10	21.10	22.10	23.20	23.20
2003	24.50	25.70	25.75	26.20	27.40	21.71	19.30	19.80	20.30	21.70	22.20	23.20
2004	24.70	25.40	25.80	25.30	25.00	20.80	19.90	19.70	20.40	20.90	23.40	23.20
2005	24.10	25.40	24.20	25.80	24.20	21.71	20.10	19.91	21.07	21.67	22.77	23.40
2006	24.80	26.40	25.90	25.65	23.90	21.40	20.10	19.00	20.80	21.90	22.77	23.40
2007	24.50	25.49	26.40	25.30	24.10	21.71	20.10	19.50	21.07	21.10	22.60	23.50
2008	24.10	25.49	25.75	25.65	23.10	22.70	21.50	20.60	22.00	21.80	22.10	23.10
2009	24.10	25.20	25.80	25.30	24.80	23.40	20.10	20.50	22.20	21.40	22.80	23.60
2010	23.30	25.40	26.40	25.40	24.10	21.40	20.00	19.10	20.60	21.90	22.10	22.10
2011	23.30	24.80	23.60	25.40	23.50	21.20	19.70	19.60	20.70	21.80	22.70	23.20
2012	25.10	26.40	25.90	25.80	24.90	21.71	21.50	19.50	20.40	21.00	22.50	23.30
2013	23.30	24.50	26.00	26.30	24.40	20.90	20.20	20.30	21.30	22.00	22.20	23.00
2014	24.60	24.80	25.20	25.30	25.00	25.00	22.50	20.50	22.80	23.40	23.80	23.70
2015	23.70	24.80	25.30	25.30	22.10	21.20	20.50	20.80	20.90	22.50	22.50	22.60
2016	24.00	25.70	27.70	27.70	23.10	22.60	20.10	19.91	21.07	22.70	24.60	25.50

Appendices III: Temperature data for selected station after filling of missing data (Tmin in °C)

Nekemte Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	13.90	14.20	12.90	14.30	13.65	12.50	11.70	12.57	12.20	12.50	12.20	12.20
1982	12.50	12.80	13.70	13.80	13.70	12.50	12.60	12.57	12.53	12.10	12.00	12.10
1983	11.10	13.20	14.20	14.70	14.10	12.10	12.10	12.80	12.53	12.30	11.90	11.63
1984	11.60	13.20	13.95	14.25	13.65	12.60	12.40	11.90	11.80	12.20	12.40	12.30
1985	12.24	12.10	13.95	13.50	13.65	12.40	11.80	11.50	11.60	11.90	12.51	12.10
1986	12.40	12.70	13.10	13.80	12.30	10.50	12.10	12.30	12.53	`12.58	12.51	10.20
1987	12.24	12.10	11.70	12.40	11.70	10.10	9.60	9.10	8.90	9.20	11.30	11.10
1988	12.24	11.40	12.90	14.25	13.65	12.60	10.10	12.57	12.53	12.20	12.10	11.10
1989	12.24	11.70	13.95	14.25	12.90	11.90	11.90	12.10	12.53	12.30	12.50	12.20
1990	12.70	12.60	13.95	14.40	14.20	12.60	12.70	12.50	12.40	13.00	13.20	13.10
1991	12.40	13.00	14.30	14.25	13.65	12.60	12.40	12.57	12.53	12.20	12.20	11.50
1992	11.80	12.60	14.40	14.60	13.90	12.50	12.00	12.50	12.40	12.60	12.10	11.60
1993	11.50	11.90	13.60	13.10	13.50	12.90	12.50	12.50	12.40	12.70	12.80	12.70
1994	13.00	13.07	13.95	14.25	13.65	12.70	12.40	12.50	12.40	12.40	12.60	11.70
1995	12.24	13.40	13.60	14.50	13.80	13.30	12.70	12.90	12.70	12.60	12.80	12.50
1996	11.80	13.70	13.60	14.20	13.10	12.90	12.60	12.40	12.70	12.70	12.40	12.50
1997	12.50	12.20	14.40	13.70	13.30	12.90	12.70	12.90	13.00	13.40	13.20	12.60
1998	12.30	13.00	14.70	16.00	14.70	12.90	13.20	13.20	13.20	13.30	12.10	11.60
1999	12.60	14.20	13.70	14.50	12.90	12.50	12.30	12.30	12.60	12.60	11.70	11.63
2000	12.40	12.60	14.50	13.60	13.30	12.40	12.40	12.20	12.50	12.80	12.51	12.20
2001	11.40	13.50	13.70	14.50	13.60	12.40	12.80	13.10	12.90	13.00	12.70	13.10
2002	11.80	13.90	14.00	14.70	14.60	13.10	13.00	13.00	12.90	13.40	13.50	12.20
2003	12.80	14.40	14.60	15.00	15.20	12.80	12.40	13.00	12.60	13.10	13.40	12.50
2004	13.10	12.90	15.10	15.00	14.10	12.80	12.20	12.60	12.40	12.50	13.10	12.40
2005	11.70	15.20	14.50	15.40	14.20	13.00	12.60	12.70	13.10	12.60	12.10	12.30
2006	12.70	13.90	13.90	14.20	13.50	12.60	13.00	12.90	12.90	13.20	12.70	11.50
2007	11.30	12.20	14.10	14.10	13.80	13.00	13.00	13.00	12.70	12.30	12.50	12.00
2008	12.40	12.60	14.90	13.00	12.40	12.10	11.90	12.80	12.90	12.80	12.50	12.50
2009	12.30	14.00	14.10	13.80	14.40	13.00	12.90	13.20	13.00	12.50	12.20	12.60
2010	12.70	13.70	14.00	15.20	14.10	13.30	13.20	13.20	13.10	13.10	13.00	12.40
2011	11.70	12.90	13.80	14.50	13.80	13.30	13.00	13.00	13.00	12.80	12.20	10.90
2012	11.80	13.30	14.20	14.50	14.00	13.00	13.40	13.00	12.80	12.70	12.90	11.90
2013	12.20	13.50	14.60	14.90	13.50	13.30	12.90	13.20	13.00	13.00	12.80	11.30
2014	12.6	12.8	13.8	13.4	13.6	13.5	13.1	12.7	12.7	13.3	12.7	11.7

Bedele Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	11.94	12.99	13.90	11.60	11.40	11.90	12.96	13.30	13.50	13.80	14.30	15.60
1984	11.94	16.00	15.10	15.80	14.50	13.40	12.10	12.10	12.20	12.70	12.70	12.90
1985	13.50	12.90	13.40	13.30	13.50	13.00	12.70	12.40	12.30	11.60	12.50	12.50
1986	12.80	13.40	13.90	14.00	14.10	13.00	12.50	12.90	12.70	12.70	12.60	11.50
1987	11.90	13.60	13.93	14.26	13.63	12.96	12.96	12.83	12.10	12.10	12.40	12.00
1988	12.30	13.70	13.90	14.60	14.00	13.40	13.30	13.10	12.80	12.50	11.70	10.50
1989	10.10	11.40	12.70	13.20	13.30	12.60	12.70	12.60	12.50	11.90	11.50	11.90
1990	11.50	12.60	12.60	13.90	13.20	13.10	12.90	12.60	12.50	11.70	12.10	11.60
1991	12.10	12.20	13.80	14.26	13.63	12.96	13.20	12.80	12.70	11.60	11.50	11.40
1992	11.40	12.80	13.70	14.30	13.70	12.90	12.60	12.80	12.10	12.10	11.10	11.82
1993	11.94	12.99	13.93	14.26	13.63	12.96	12.96	12.83	12.64	12.43	12.05	11.82
1994	11.94	12.50	14.20	14.26	13.50	12.96	12.96	13.30	12.80	11.60	12.70	11.40
1995	12.00	13.10	13.00	14.80	14.10	13.40	13.00	13.20	12.80	12.40	12.40	12.50
1996	12.10	13.10	13.80	14.40	13.50	13.40	13.20	13.10	12.60	12.00	11.70	11.50
1997	11.90	11.20	14.00	13.60	13.20	13.00	13.10	12.80	12.60	12.43	12.05	11.82
1998	11.94	12.99	14.40	15.40	14.70	13.20	13.50	13.70	13.40	13.40	11.10	10.50
1999	11.30	12.80	12.70	13.80	12.20	12.80	12.70	12.40	12.50	12.80	10.60	11.70
2000	11.94	12.99	13.93	14.26	13.63	12.96	12.90	13.00	13.00	12.80	11.90	11.60
2001	10.90	12.70	13.90	14.30	13.60	12.90	12.70	13.10	12.50	13.10	12.20	12.20
2002	11.90	13.30	14.50	14.60	14.40	13.00	12.80	12.20	12.00	11.30	11.10	11.20
2003	12.40	13.50	14.20	14.50	14.70	13.10	13.40	13.70	13.00	12.50	12.60	11.90
2004	13.20	12.50	15.00	14.90	13.90	13.30	13.10	13.30	13.00	12.50	12.30	12.60
2005	11.60	15.00	14.60	15.30	14.20	13.30	13.10	12.70	13.00	12.40	11.60	11.10
2006	12.30	13.20	13.80	14.10	13.40	12.60	13.00	12.90	13.00	12.90	12.50	11.50
2007	11.50	12.20	13.60	14.00	13.80	13.00	13.00	12.60	12.40	11.40	11.60	10.90
2008	12.10	12.20	14.20	13.30	12.80	12.90	12.00	12.60	12.70	12.40	11.70	11.82
2009	11.70	13.20	13.20	14.26	13.63	12.96	12.20	12.70	12.30	12.40	11.50	11.90
2010	11.94	12.99	13.93	14.26	14.10	12.90	12.70	12.90	12.60	12.60	12.00	11.70
2011	11.40	12.00	13.50	13.90	13.60	12.50	12.40	12.30	12.60	12.20	12.30	11.70
2012	11.40	12.80	14.60	14.70	13.80	12.80	12.60	12.80	12.30	12.40	12.80	11.82
2013	13.50	14.10	14.80	14.90	14.00	12.50	12.40	12.10	12.40	12.50	12.80	11.00
2014	12.60	12.60	13.93	14.26	13.00	12.96	12.96	12.83	12.64	12.43	12.05	11.82
2015	11.10	12.99	13.93	14.26	13.63	12.96	12.80	12.80	12.64	12.43	12.05	12.40
2016	11.94	13.20	15.30	15.30	14.00	13.20	12.50	13.00	12.90	11.90	11.90	11.82

Alibo Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	10.50	10.50	10.90	11.60	11.10	10.70	10.10	10.30	10.00	10.10	9.90	10.10
1982	11.00	11.10	11.70	11.40	11.90	10.70	9.60	10.30	9.90	10.20	10.60	10.00
1983	10.40	11.40	12.60	13.00	12.60	11.50	10.50	10.70	10.10	11.00	10.60	10.60
1984	10.40	11.20	12.90	13.70	11.90	10.30	10.10	10.20	9.90	10.30	11.00	10.50
1985	10.70	10.50	12.20	12.30	11.00	11.20	9.90	9.80	10.20	10.10	10.50	10.70
1986	10.80	11.90	12.60	11.70	12.90	11.20	10.50	10.50	10.50	10.50	10.90	10.40
1987	10.90	12.50	12.70	13.00	12.20	11.40	10.80	10.50	10.60	9.70	9.80	9.30
1988	11.00	11.50	12.70	14.30	12.90	11.10	10.70	10.00	10.00	10.20	10.50	10.70
1989	10.40	10.80	11.30	12.95	11.40	11.70	9.90	10.00	10.40	11.50	10.60	10.50
1990	10.30	10.70	11.20	12.30	12.70	10.90	10.70	10.40	10.00	10.70	11.40	11.00
1991	11.42	11.91	12.00	12.00	11.60	11.00	10.30	10.00	10.20	10.40	10.60	10.00
1992	10.60	11.91	11.20	11.00	10.30	10.40	10.50	10.50	10.90	11.00	10.50	10.20
1993	9.70	10.50	11.70	11.30	10.90	11.00	10.20	9.80	9.60	10.30	10.50	10.50
1994	10.30	15.80	16.40	17.80	12.30	15.50	15.40	15.50	15.50	16.20	15.10	15.00
1995	11.42	15.60	16.10	17.00	16.40	17.00	16.90	17.00	17.00	16.70	16.90	16.40
1996	16.50	11.91	16.00	15.40	16.50	11.53	11.10	11.18	11.25	11.50	11.45	11.08
1997	11.42	11.91	12.65	12.95	12.30	11.53	11.10	11.18	11.25	11.50	11.45	11.08
1998	11.42	11.91	12.65	12.95	12.30	11.53	11.10	11.18	11.25	11.50	11.45	11.08
1999	11.42	11.91	12.65	12.95	12.30	11.53	11.40	13.30	14.20	13.80	12.70	11.08
2000	13.50	13.40	13.00	12.20	12.30	12.70	13.80	14.20	15.60	15.90	16.60	15.80
2001	15.50	11.60	12.20	13.30	12.00	11.00	10.80	11.70	11.00	11.30	10.90	10.90
2002	15.50	12.10	12.00	13.10	13.10	11.70	11.10	11.20	10.80	11.30	11.50	11.00
2003	11.20	12.10	12.65	12.70	14.10	11.53	11.10	11.10	11.00	11.40	11.60	11.00
2004	11.50	11.40	12.90	12.90	12.70	11.20	10.50	10.60	10.90	10.70	11.20	11.40
2005	11.10	12.80	12.80	13.50	12.80	11.53	11.10	11.18	11.25	11.50	11.45	11.08
2006	12.20	12.70	12.90	12.95	11.90	11.10	11.10	11.00	10.60	11.50	11.45	11.08
2007	10.60	11.91	12.00	12.50	12.00	11.53	11.10	11.00	11.25	10.70	11.30	10.90
2008	10.90	11.91	12.65	12.95	11.30	11.10	10.50	10.60	11.60	11.30	11.00	10.90
2009	11.20	12.00	13.30	12.90	12.90	11.40	11.00	11.10	11.20	11.00	9.90	10.30
2010	11.00	12.80	13.10	13.10	12.90	11.90	10.90	11.40	11.40	11.50	11.60	11.00
2011	11.00	12.40	12.60	13.10	12.60	11.70	11.10	11.00	11.10	11.60	10.70	10.80
2012	11.70	12.80	13.10	13.70	13.00	11.53	11.60	11.20	11.00	11.30	11.30	10.70
2013	11.90	12.60	13.50	13.40	11.50	11.40	10.90	10.80	10.50	10.90	11.00	10.40
2014	10.9	11.1	11.3	11.4	10.9	11	10.8	10.6	11.5	12	12.7	10.8
2015	10.5	11.3	12	11.8	10.7	10.9	10.5	10.5	10.5	12	10.9	10.6
2016	10.4	10.7	11.5	11.3	10.8	10.3	11.1	11.18	11.25	11.1	10.7	10.1

Appendices IV: Streamflow data for the selected station after filling of missing data and quality check

Didessa Nr. Dembi (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	6.837	35.452	28.768	8.751	3.683	20.085	93.935	210.519	139.624	47.178	8.076	3.500
1991	2.687	2.595	2.457	4.812	11.000	29.456	113.760	194.777	101.491	52.288	5.173	3.305
1992	2.922	6.308	4.812	3.400	13.655	30.797	94.273	121.513	105.477	80.605	44.663	14.100
1993	5.339	7.124	6.201	14.497	30.177	97.094	124.720	131.793	105.477	80.605	44.663	14.100
1994	5.974	5.594	6.276	8.699	14.105	43.152	102.262	142.383	108.618	22.106	10.271	6.123
1995	4.821	4.984	6.165	9.191	18.183	33.576	70.863	101.528	127.723	37.862	12.555	12.590
1996	4.821	5.163	6.165	9.191	18.133	33.542	71.012	101.697	127.723	37.862	12.555	12.590
1997	7.927	5.702	8.670	11.623	20.621	54.910	81.895	128.033	78.787	97.957	72.489	20.956
1998	10.485	5.628	7.586	4.901	11.619	42.481	101.623	155.004	115.380	122.697	34.276	7.885
1999	4.854	2.703	3.106	3.684	20.511	57.177	90.448	91.361	82.617	112.754	18.658	6.819
2000	3.801	2.299	1.691	3.749	15.379	45.753	108.245	115.264	93.346	78.083	31.646	8.174
2001	4.735	3.960	4.163	5.580	20.723	87.377	123.191	120.131	114.108	79.242	22.986	8.390
2002	8.107	3.505	2.967	4.334	2.917	28.897	78.440	101.135	81.860	30.651	13.426	7.086
2003	3.376	1.877	4.283	11.409	3.043	26.189	96.661	89.917	129.059	35.710	9.967	4.675
2004	2.936	2.377	1.170	1.131	6.425	32.105	89.439	81.629	97.264	55.106	14.152	6.350
2005	3.489	1.607	2.697	2.013	8.635	43.757	66.763	131.444	114.905	52.207	16.714	6.145
2006	3.264	1.996	2.534	2.897	8.546	45.941	131.033	173.178	144.170	69.682	37.219	13.622
2007	6.038	3.647	2.712	6.998	26.411	58.508	125.785	160.476	128.430	61.667	17.052	8.465
2008	6.730	4.480	2.740	10.050	33.500	71.957	86.707	139.128	98.636	32.235	49.503	12.810
2009	5.667	3.771	3.521	10.094	5.024	25.213	69.477	111.399	80.533	77.754	14.733	7.292
2010	6.529	7.091	4.305	2.939	23.688	92.511	115.980	138.932	159.041	78.867	21.942	15.604
2011	7.818	5.964	4.884	6.217	21.671	59.603	101.073	119.016	161.289	42.738	21.528	10.216
2012	3.710	1.205	0.838	2.903	18.595	40.813	82.583	103.828	173.209	59.102	26.726	14.729
2013	9.075	4.886	2.594	0.534	9.399	53.694	81.107	130.665	113.121	81.095	21.770	8.482
2014	4.463	2.121	4.412	14.556	42.356	57.287	110.913	124.657	95.041	110.633	16.350	8.711
2015	3.162	1.343	1.334	0.815	12.749	47.110	116.607	120.406	107.223	30.512	30.820	14.600

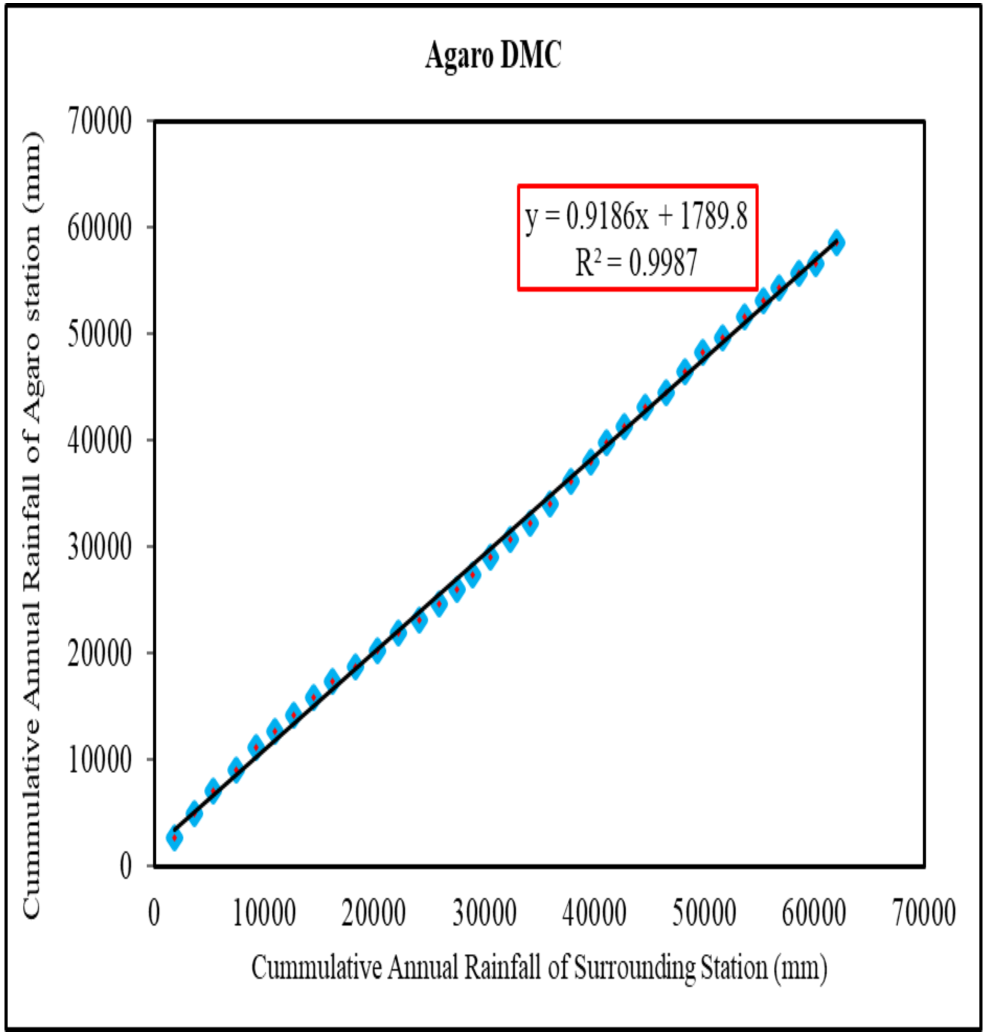
Didessa Nr. Arjo (m^3/s)

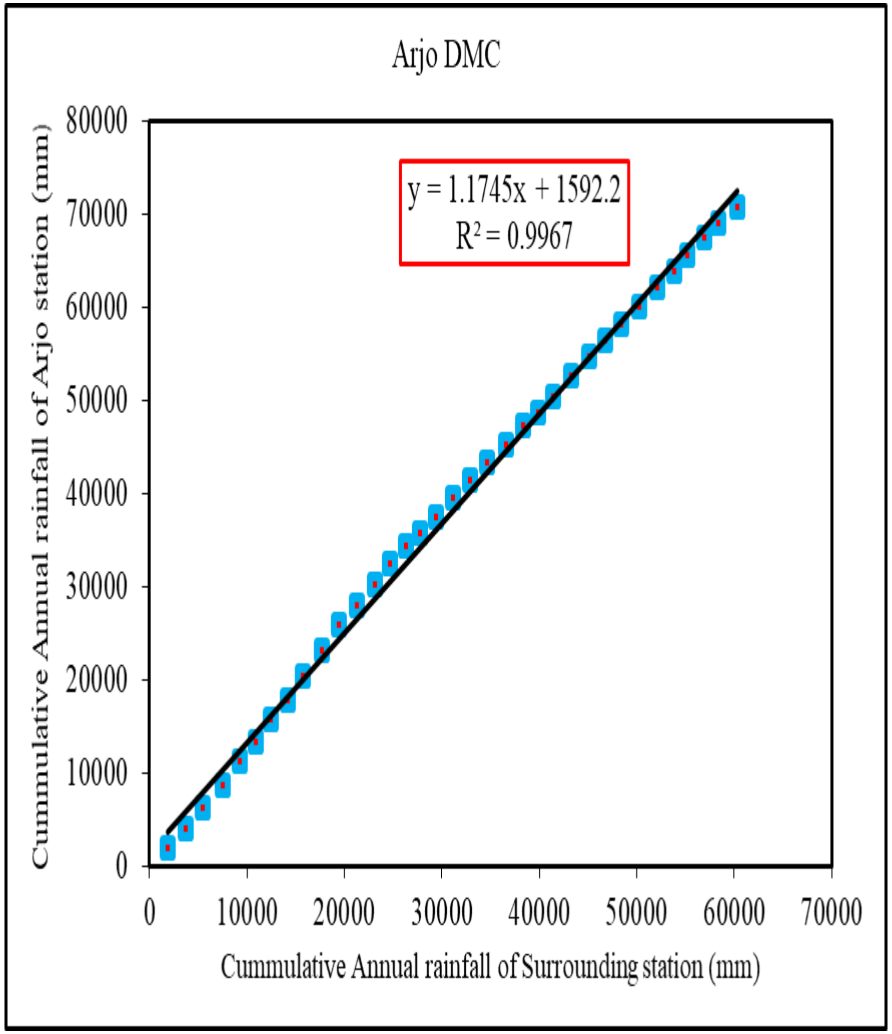
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	19.96681	12.41729	12.62235	23.49627	15.69535	60.7157	128.1604	414.4243	342.5469	124.7302	43.72513	30.948
1991	19.62764	13.76518	12.81974	16.46141	36.55911	94.68267	202.8692	426.6701	249.3092	158.4274	32.23322	14.22987
1992	9.142968	9.89575	5.134935	7.985033	21.07861	61.98013	137.3646	307.8273	217.7768	300.9671	63.31443	27.39865
1993	15.88245	11.51807	9.108484	21.10963	39.28416	120.4249	223.8639	432.6205	243.3273	151.9472	68.26513	23.65097
1994	14.58139	8.089893	5.782581	6.048533	22.29374	84.945	199.4426	455.8625	331.0331	58.37723	26.2579	13.79239
1995	7.602419	5.061286	5.525548	7.502867	14.28313	32.023	83.99884	212.4192	187.4569	58.31861	23.12173	25.10331
1996	19.62764	14.18681	15.52858	11.71873	52.95406	143.9586	270.0347	319.0117	230.5772	129.9654	59.56185	32.53969
1997	15.46374	7.869607	12.58949	16.46141	36.55911	116.8581	225.3637	352.7829	315.8383	158.4274	57.11072	30.948
1998	19.62764	13.76518	12.81974	16.46141	36.55911	116.8581	225.3637	352.7829	315.8383	158.4274	57.11072	30.948
1999	19.62764	13.76518	12.81974	16.46141	36.55911	116.8581	225.3637	352.7829	315.8383	158.4274	57.11072	30.948
2000	19.62764	14.18681	12.966	16.63291	37.71493	120.7328	229.582	355.4994	310.9455	198.7043	93.3698	50.65219
2001	31.76897	24.60657	24.66258	22.65337	47.89371	154.6459	276.4034	390.2686	387.8716	251.6643	82.80017	41.70674
2002	36.956	23.64371	20.63197	24.4657	17.26716	67.40097	170.696	220.6516	222.8666	78.66416	44.448	31.308
2003	21.0509	14.98275	20.9679	28.6806	17.909	46.37753	194.1418	243.4855	267.4699	158.4274	57.11072	30.948
2004	19.51032	16.60761	11.30103	11.06213	24.33497	77.89697	196.514	238.5069	247.8839	200.9071	54.0997	33.84058
2005	23.15555	14.43368	16.54694	13.774	31.10068	87.70313	159.4949	320.7133	382.9627	147.7041	62.79327	35.19652
2006	23.10516	17.10036	15.43658	16.9924	27.17126	89.7225	252.2145	540.8791	395.1995	172.2585	90.22577	51.68374
2007	34.07077	26.30136	19.12874	25.08907	45.01294	113.373	313.0121	357.5647	369.1709	181.9054	47.9515	33.9659
2008	25.692	17.47639	9.182419	22.11127	65.43587	207.1291	250.3892	406.2715	283.1969	89.25494	112.6828	45.19603
2009	28.86555	20.21682	20.12658	30.62003	33.81319	52.0597	119.844	249.8982	198.4813	181.863	53.6964	35.97948
2010	26.71077	21.792	19.92732	18.00213	49.41668	195.4836	310.9281	351.2382	502.2736	144.7626	23.16017	6.571419
2011	3.106194	0.394321	0.328	0.044667	24.69713	120.6088	170.1316	313.0115	419.2065	140.0651	36.57917	5.586387
2012	0.910613	0.008143	0.000258	0.1031	3.481	98.0758	172.3633	325.7274	482.506	131.0684	56.4035	39.00916
2013	6.916774	2.068571	1.515355	0.321233	41.31716	281.8902	396.7704	391.9453	336.9033	243.1076	56.5432	36.54335
2014	28.09339	21.78996	23.52465	38.01853	142.3333	275.7761	525.6343	501.4755	315.8383	158.4274	57.11072	30.948
2015	19.62764	13.76518	12.81974	16.46141	36.55911	116.8581	225.3637	352.7829	315.8383	158.4274	57.11072	30.948

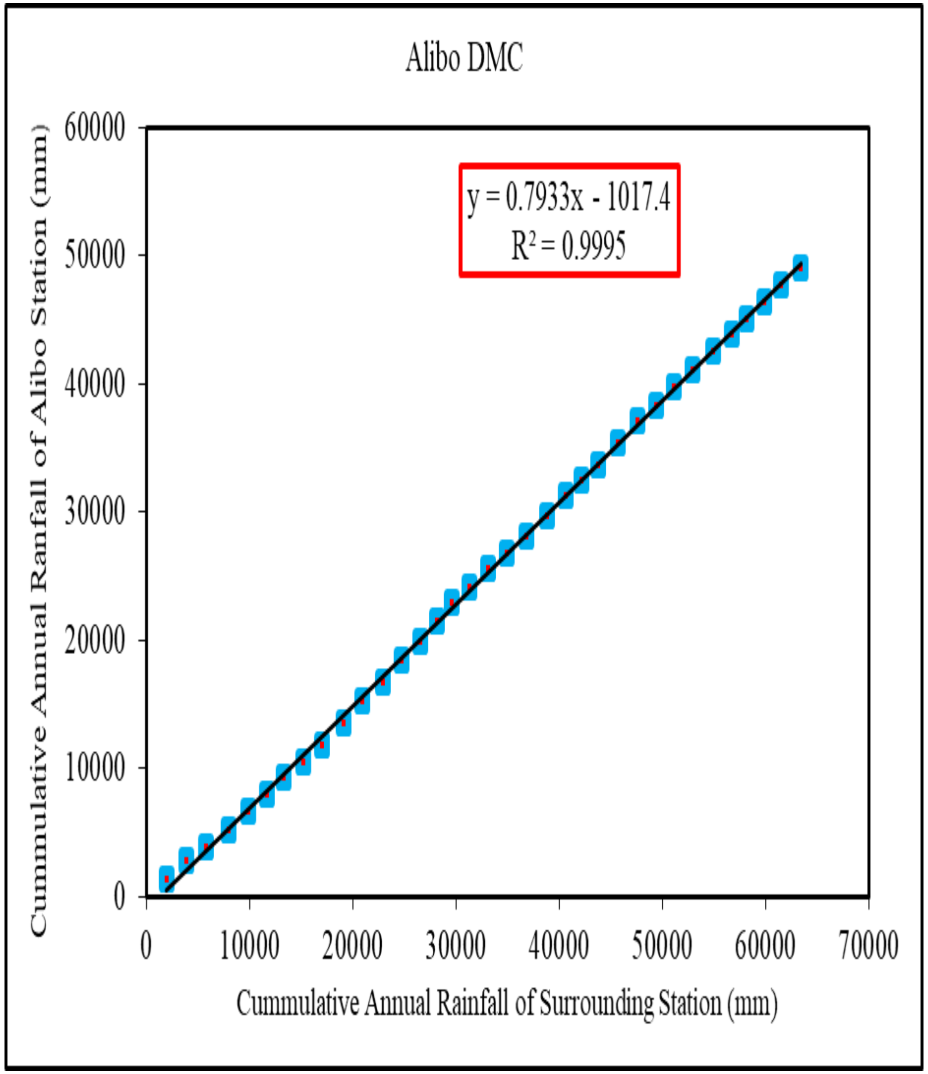
Uke Nr. Nekemte (m^3/s)

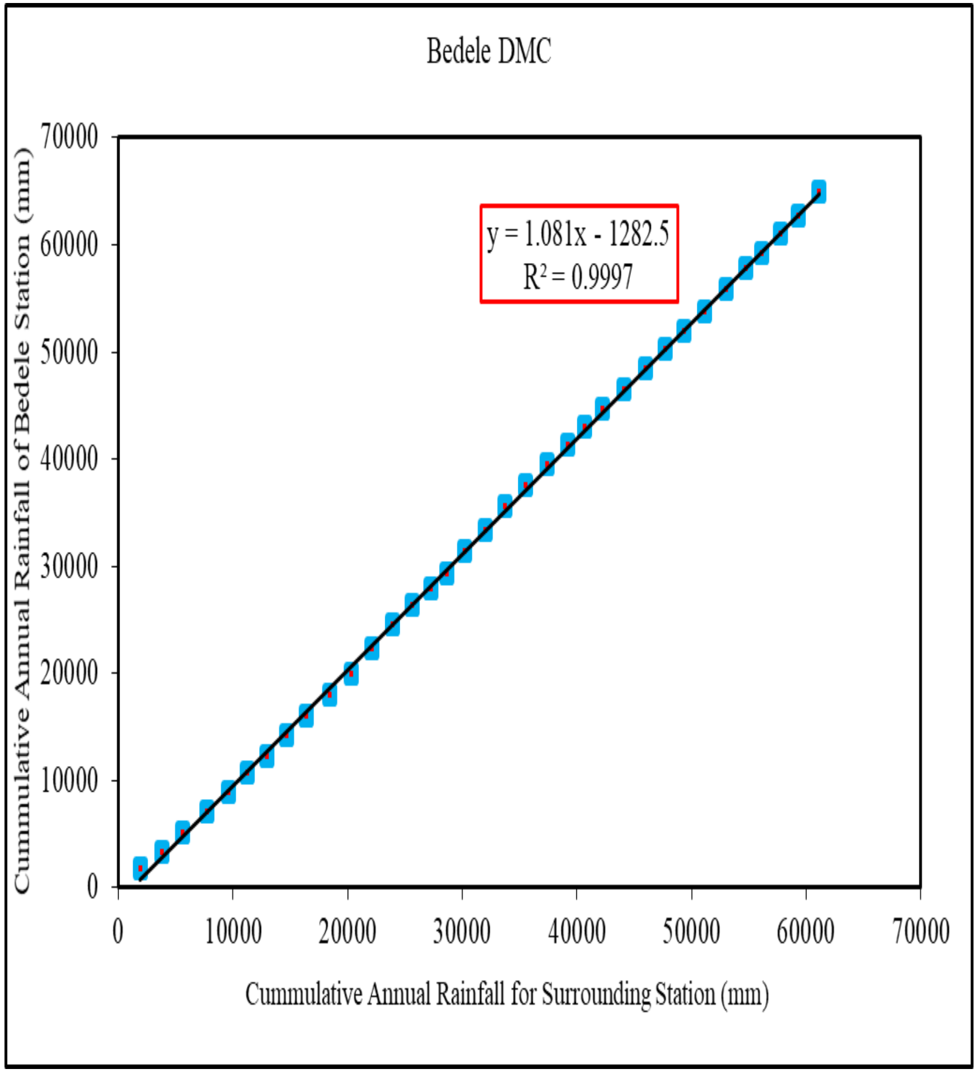
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	3.493839	1.875214	1.145968	0.944033	1.263839	4.853567	42.35368	96.94558	69.9103	35.70116	11.3992	4.797935
1991	2.334871	1.23575	0.920774	2.066867	1.585742	20.61783	60.81323	90.73548	86.4994	30.11348	9.1256	3.964355
1992	2.282129	1.247607	0.927258	0.987733	4.102484	14.82343	40.6039	44.74981	54.4759	53.5379	24.6136	9.392419
1993	4.310419	1.887643	1.10771	2.753367	3.493581	28.73947	89.43916	133.0675	73.4497	40.286	15.45973	6.46229
1994	3.057387	1.552286	1.044226	1.432867	6.294065	20.33057	61.24029	116.7119	67.9257	21.00519	9.715467	4.607839
1995	2.24471	1.082536	1.112806	1.220733	1.491065	7.302033	19.59329	111.7124	67.45187	22.28816	10.3894	4.846484
1996	2.968871	1.241393	1.452903	1.275	4.89371	23.46793	68.38323	69.48113	69.72407	29.51761	12.4558	6.192065
1997	3.221806	1.4025	1.246226	2.0017	4.814355	22.32147	57.63142	75.86706	57.12	41.38194	37.46573	13.02884
1998	5.903548	2.561929	1.870065	0.974767	2.47029	20.8622	59.63742	82.62777	59.42637	31.63503	17.3036	8.255839
1999	2.979355	0.951643	0.806839	0.8919	6.113194	8.7299	18.53458	53.38645	50.50483	86.54903	20.89847	6.938161
2000	3.481742	1.568536	0.780903	1.358367	2.786581	17.03803	33.044	84.71958	58.28837	42.11045	12.74723	5.666677
2001	3.275518	1.274219	1.026597	1.107118	4.582533	26.06641	56.12354	69.20382	66.33122	40.36051	12.54693	5.986114
2002	3.369323	1.575179	0.972806	1.039167	0.953581	4.171467	19.57826	27.56784	36.8607	19.59919	6.487367	3.426
2003	1.885355	0.762357	0.773452	0.3315	0.123194	7.075	30.19084	64.37323	95.5302	49.5571	4.261333	0.452677
2004	0.041581	0.053893	0.445452	0.501067	2.368032	6.511133	26.35616	49.71226	37.3279	21.70768	7.3764	3.60929
2005	1.856355	0.868857	1.185161	0.5693	1.277968	11.10737	31.37087	45.68358	72.99287	29.45458	10.87027	3.939194
2006	2.736806	1.166071	0.539452	0.4667	1.16929	10.18217	35.0111	52.31671	48.93287	37.79584	19.02443	8.572161
2007	3.688903	1.787179	1.171742	1.568667	3.212387	23.2927	55.70935	55.74745	75.8002	32.60981	8.5108	4.166839
2008	2.487032	1.119464	0.553194	2.8226	8.10971	27.57023	77.24348	79.36494	51.85867	27.60097	16.6087	6.532613
2009	3.250355	1.492143	1.306097	1.456233	1.399355	5.159	10.76635	34.92203	57.33447	31.59058	8.966367	4.315258
2010	2.382935	0.972179	0.473742	0.620833	5.864677	20.0804	49.21655	66.2719	131.2958	52.9529	6.9663	4.572774
2011	3.048194	1.251464	0.90529	0.780267	4.587903	13.73787	21.5271	54.4659	83.0854	32.18226	9.187033	4.315258
2012	2.389871	1.11575	0.436323	0.5239	7.929677	9.9569	22.11484	124.1584	94.7095	23.84877	8.063933	4.43671
2013	2.585516	1.137964	0.648097	0.427833	5.090194	10.2017	37.432	51.65623	53.884	30.50855	11.34983	5.491677
2014	3.546548	1.590929	3.267387	2.900333	11.79316	34.09527	69.57016	52.44942	56.24465	49.74525	10.07836	5.087156

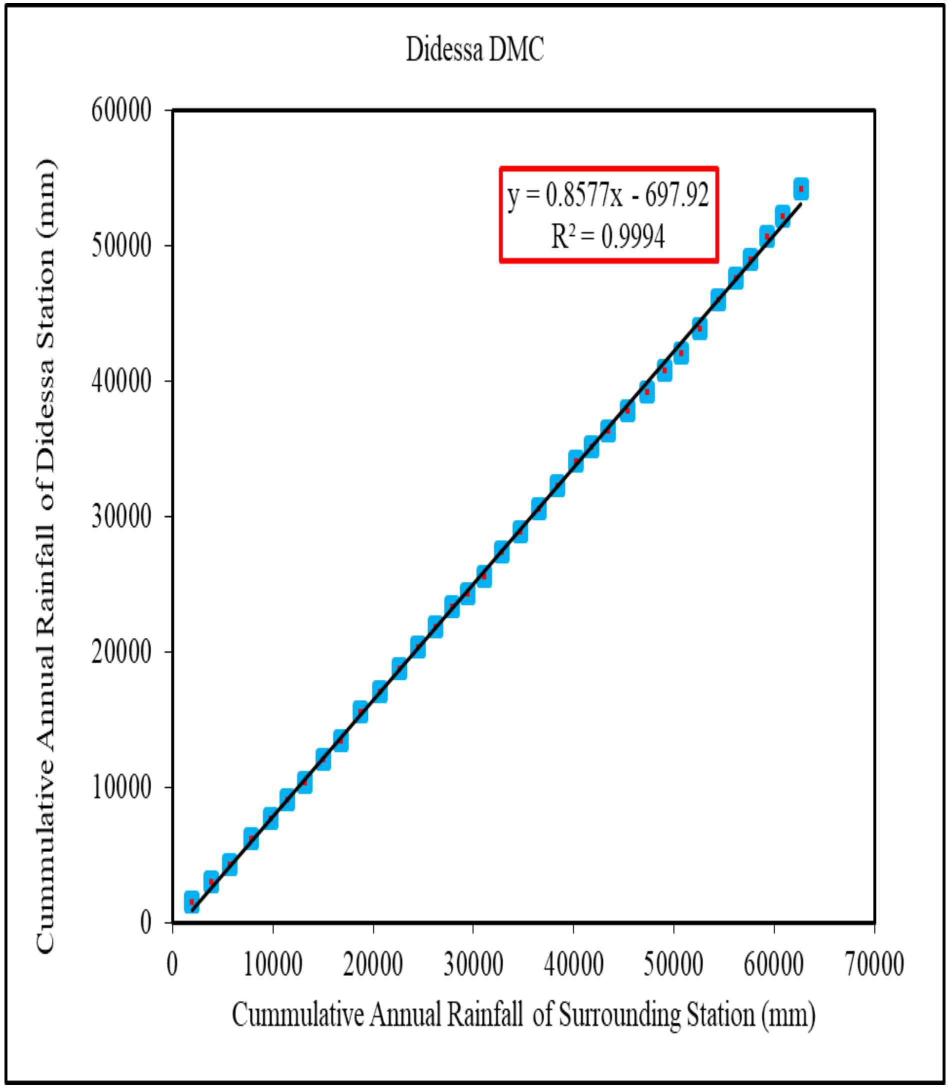
Appendices IV: Double mass curve for Consistency check for selected Rainfall Stations

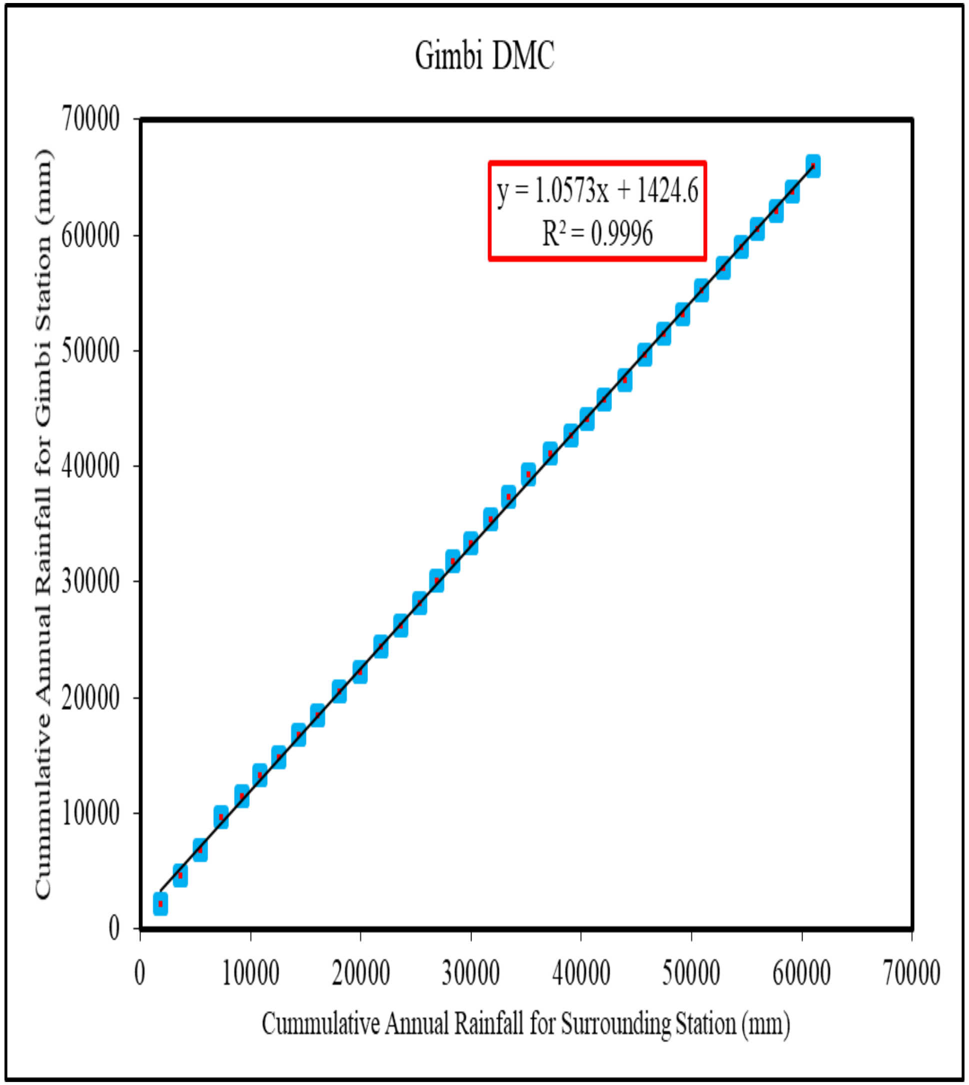


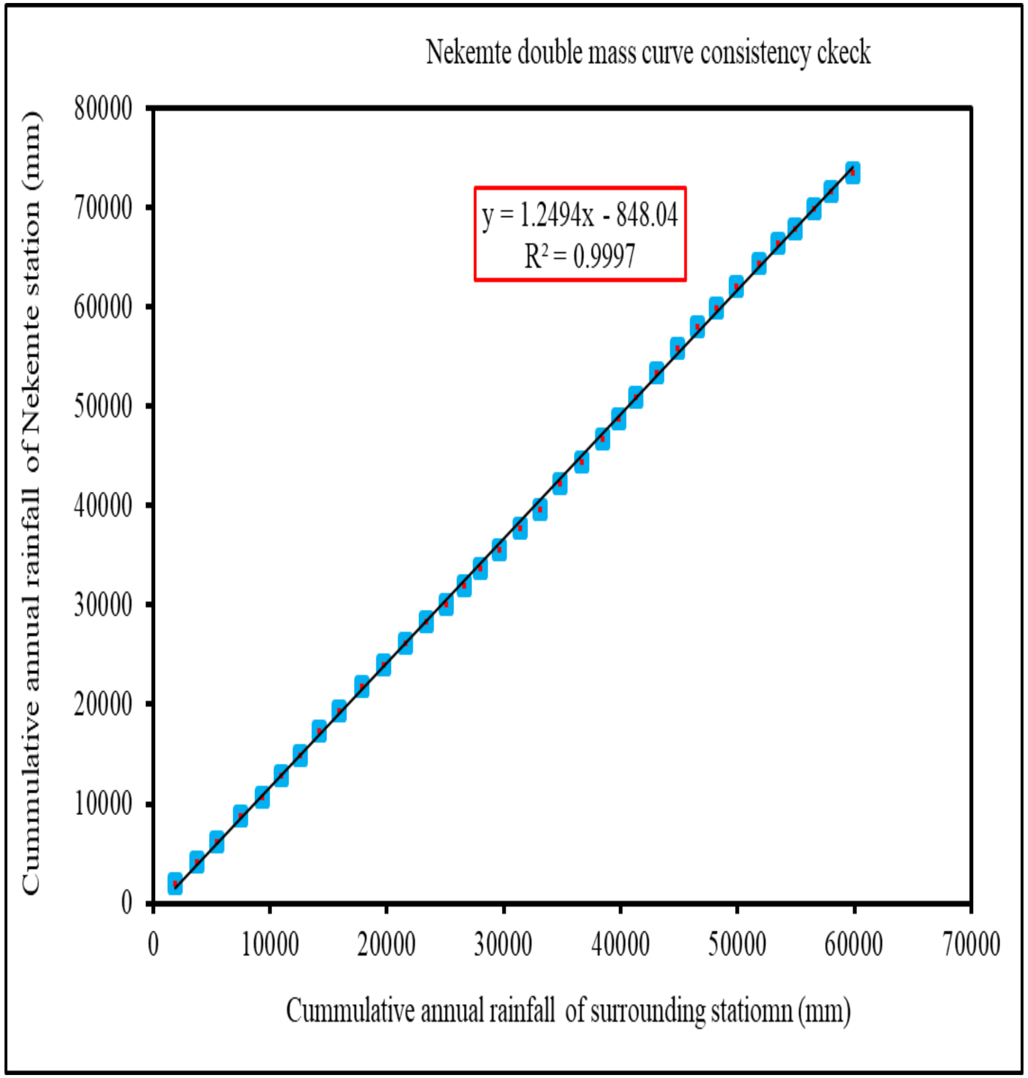


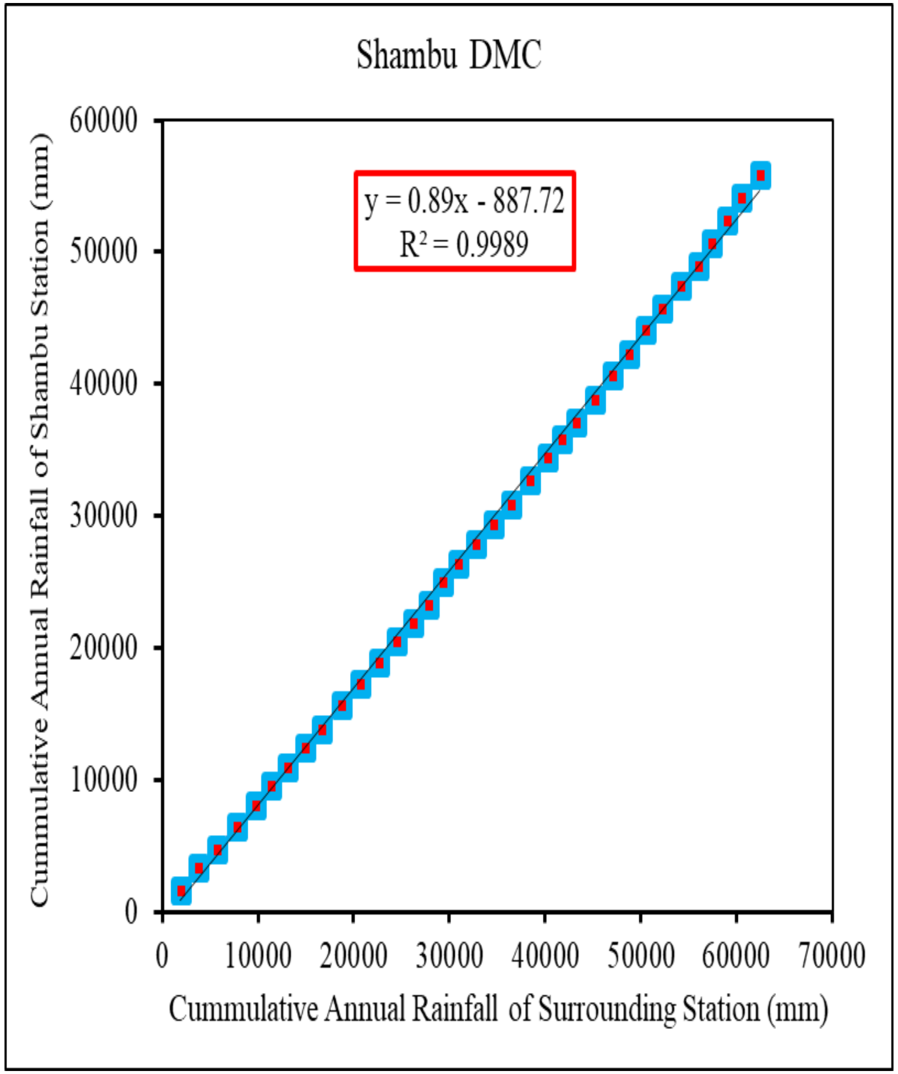

Alibo DMC
y = 0.7933x - 1017.4
R² = 0.9995
Cummulative Annual Rainfall of Alibo Station (mm)
0
10000
20000
30000
40000
50000
60000
70000
Cummulative Annual Rainfall of Surrounding Station (mm)

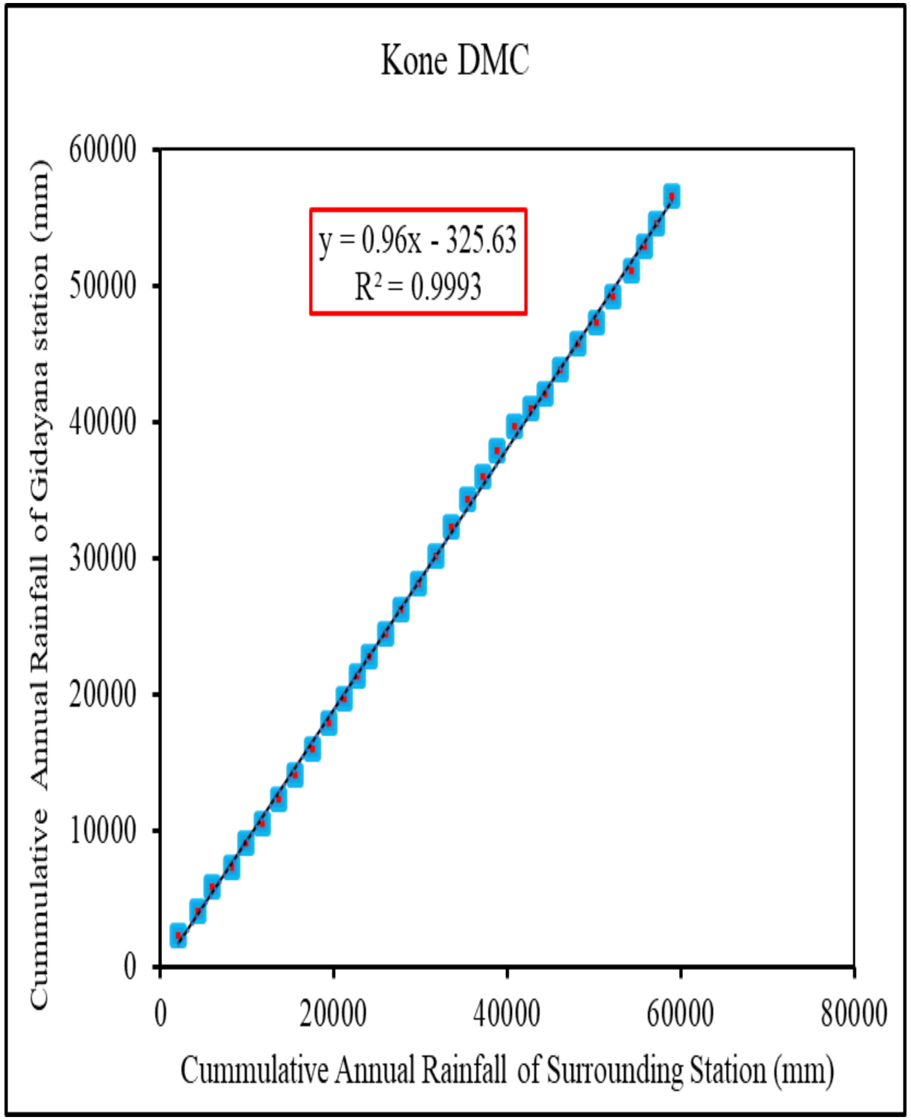

Bedele DMC
y = 1.081x - 1282.5
R² = 0.9997
Cummulative Annual Rainfall of Bedele Station (mm)
0
10000
20000
30000
40000
50000
60000
70000
Cummulative Annual Rainfall for Surrounding Station (mm)

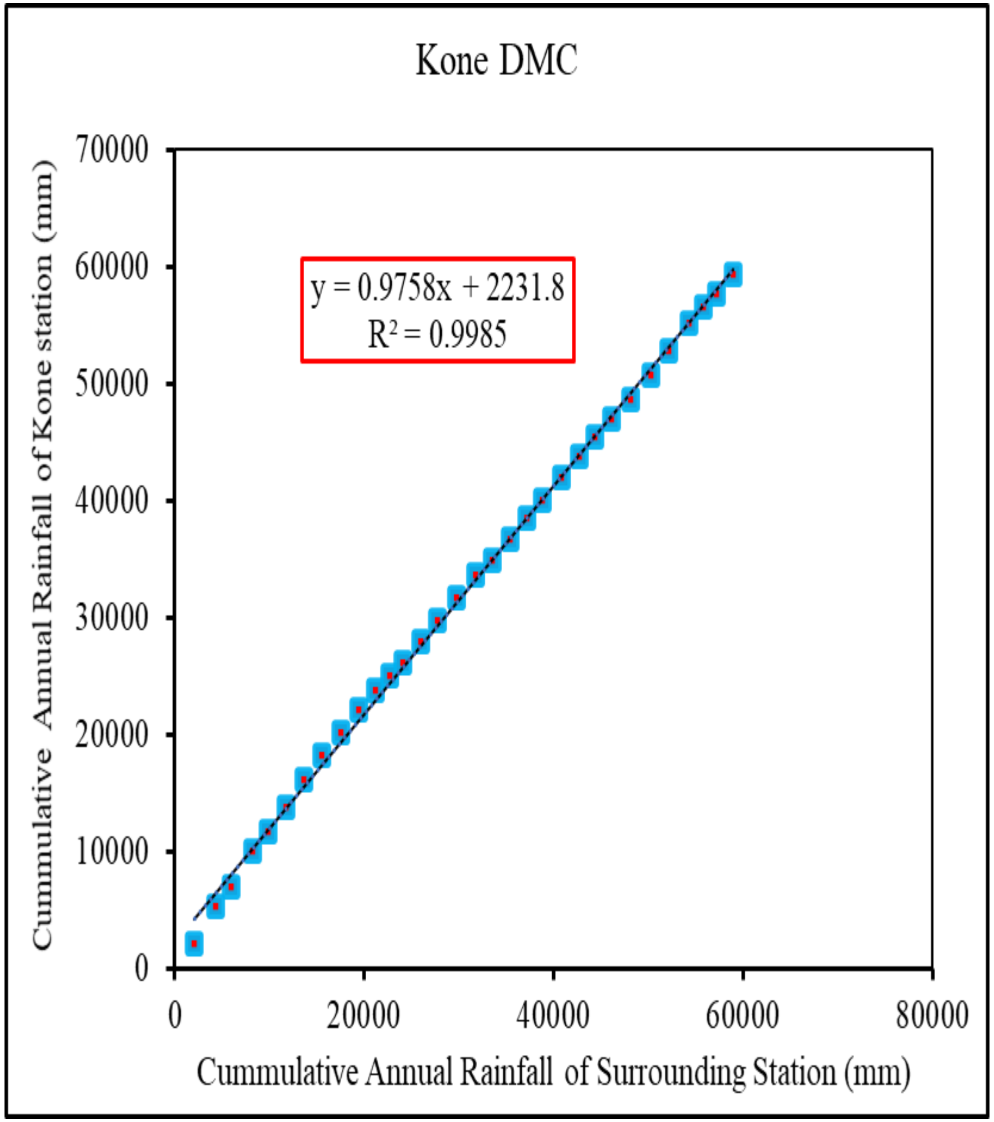

Didessa DMC
y = 0.8577x - 697.92
R² = 0.9994
Cummulative Annual Rainfall of Didessa Station (mm)
Cummulative Annual Rainfall of Surrounding Station (mm)
0
10000
20000
30000
40000
50000
60000
70000

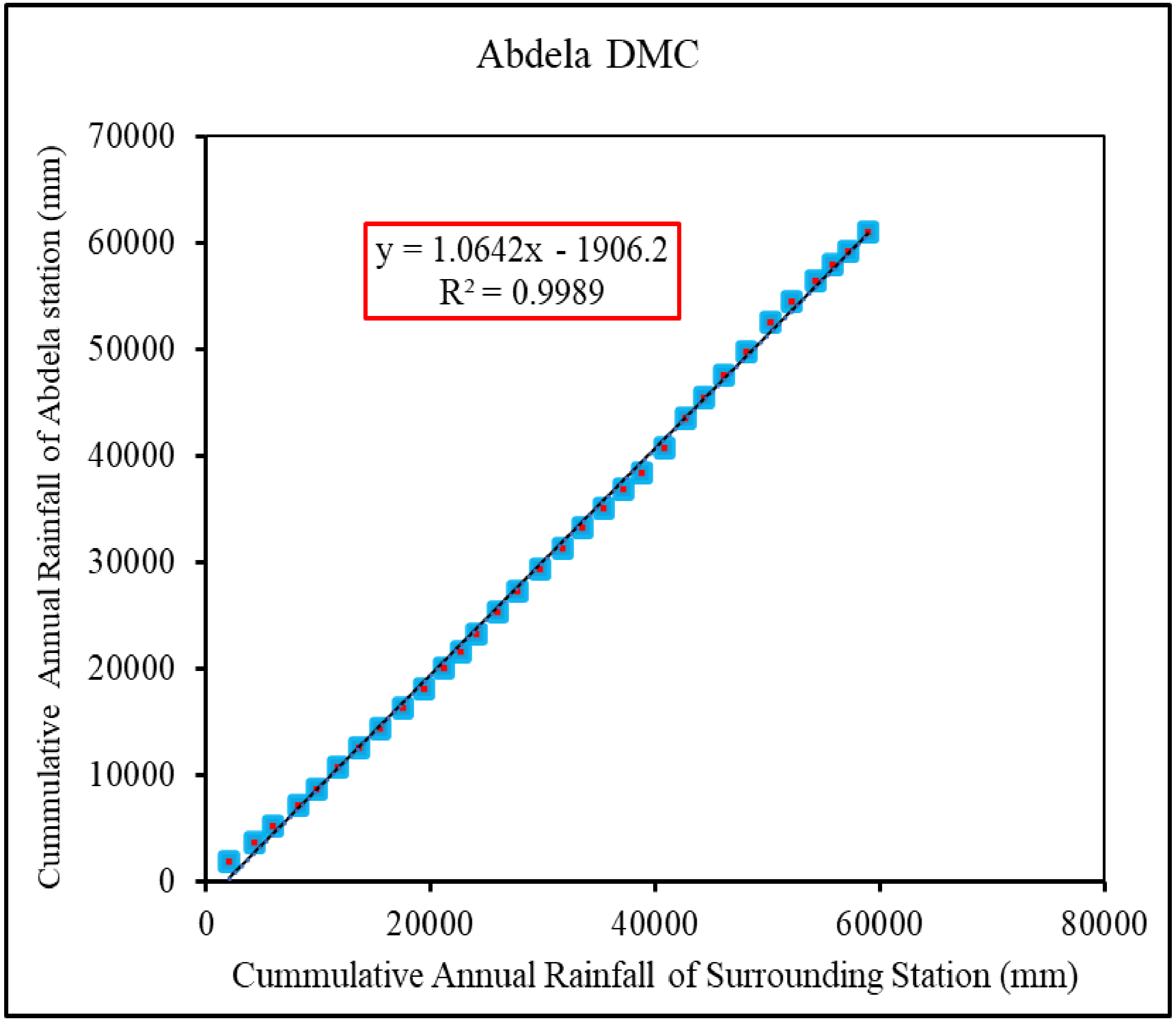

Gimbi DMC
y = 1.0573x + 1424.6
R² = 0.9996
Cummulative Annual Rainfall for Gimbi Station (mm)
Cummulative Annual Rainfall for Surrounding Station (mm)
0
10000
20000
30000
40000
50000
60000
70000


Nekemte double mass curve consistency ckeck
y = 1.2494x - 848.04
R² = 0.9997
Cummulative annual rainfall of Nekemte station (mm)
Cummulative annual rainfall of surrounding statiomn (mm)
0
10000
20000
30000
40000
50000
60000
70000
80000


Shambu DMC
y = 0.89x - 887.72
R² = 0.9989
Cummulative Annual Rainfall of Shambu Station (mm)
Cummulative Annual Rainfall of Surrounding Station (mm)
0
10000
20000
30000
40000
50000
60000
70000


Kone DMC
y = 0.96x - 325.63
R² = 0.9993
Cummulative Annual Rainfall of Gidayana station (mm)
Cummulative Annual Rainfall of Surrounding Station (mm)
0
10000
20000
30000
40000
50000
60000
0
20000
40000
60000
80000


Kone DMC
y = 0.9758x + 2231.8
R² = 0.9985
Cummulative Annual Rainfall of Kone station (mm)
Cummulative Annual Rainfall of Surrounding Station (mm)
0
10000
20000
30000
40000
50000
60000
70000
0
20000
40000
60000
80000


Abdela DMC
y = 1.0642x - 1906.2
R² = 0.9989
Cummulative Annual Rainfall of Abdela station (mm)
Cummulative Annual Rainfall of Surrounding Station (mm)
0
10000
20000
30000
40000
50000
60000
70000
0
20000
40000
60000
80000