JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING PROGRAM

TREND ANALYSIS OF RAINFALL AND STREAM FLOW; A CASE OF UPPER OF WABE SHEBELLE RIVER BASIN, ETHIOPIA

BY: DEBELA DIRIBSA DEBESA

A Thesis submitted to Jimma University, Jimma Inistitute of Technology, School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering Program.

June, 2022

Jimma, Ethiopia

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MAIN ADVISOR: Dr.-Ing. FEKADU FUFA (PhD)

CO-ADVISOR: SANYI MISGANA (M.Sc.)

June, 2022

Jimma, Ethiopia

DECLARATION

I, Debela Diribsa declare that this thesis is my original work and has not been presented for any degree in any university.

Candidate	Signature	Date
DEBELA DIRIBSA	………	……………

This thesis has been submitted for examination with our approval as a university supervisors.

Main-advisor:

Dr.-Ing. Fekadu Fufa (PhD)	Signature	Date
	……………	……………

Co-advisor

Sanyi Misgana (M.Sc.)	……………	……………

ABSTRACT

Trend analysis of rainfall and stream flow is essential for effective water resources planning and management. The objective of this research is to determine the trend of rainfall and stream flow time series in the upper of Wabe Shebelle River basin. The time series of seven rainfall stations and seven runoff stations were taken and analysed. The trend of rainfall and stream flow data was analysed individually for each station using Modified Mann-Kendall package called mmkh, which was installed in to the R software. Magnitude of trend was observed from Sen's slope value. From annual rainfall trend analysis, rainfall time series at Adaba, Assassa, Dodola and Meraro stations showed significant decreasing trend. From Spring season rainfall trend analysis rainfall time series at Adaba and Meraro stations showed significant decreasing trend. From summer rainfall trend analysis rainfall at Adaba, Assassa and Kofele stations showed significant decreasing trend. From Autumn season rainfall at Dodola and Meraro stations showed significant decreasing trend. From Winter season, rainfall at Adaba, Assassa, Dodola and Meraro stations showed significant decreasing trend. From monthly rainfall trend analysis most of the stations showed significant decreasing trend. The trend results of the average rainfall of the seven stations showed significant decreasing trend only during summer and winter seasons. The trend magnitude of the selected rainfall stations ranges from -1.29mm/annual up to -14.88mm/annual and the average of trend magnitude of the seven rainfall stations was -8.43mm/year. From runoff trend analysis; Leliso and Ukuma stations showed significant increasing trend during annual period and Winter season. Leliso station showed significant increasing trend during spring season. Ukuma and Wabi stations showed significant increasing trend during summer season. Leliso, Ukuma and Wayib stations showed significant increasing trend during Autumn season. From high flow trend analysis Assassa and stations showed significant decreasing trend and Ukuma station showed significant increasing trend. From low flow trend analysis results only Leliso station showed significant increasing trend. In this study the correlation between rainfall, runoff, high flow and low flow was evaluated using Linear regression model. The result demonstrated no correlation, weak correlation, moderate correlation and negative correlation at different stations. The result of this study can provide essential information for current and future plan in Wabe Shebelle River Basin.

Key Words: Correlation, Modified Man-Kendall, R software, Sen's slope, Trend Analysis, Upper of Wabe Shebelle River Basin.

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ACRONYMS

ANOVA: Analysis of Variance

IPCC: Intergovernmental Panel on Climate Change

Mk: Mann- Kendall

Mm3: Million-meter cube

MoWIE : Ministry of Water Irrigation and Electricity

m.a.s.l: mean above sea level

mmkh : Modified Mann-Kendall Test for Serially Correlated Data Using the Hamed and Rao (1998) Variance Correction Approach

NMSA: National Metrology Service Agency

mm: millimeter

UWSRB: Upper Wabe Shebelle River Basin

1. INTRODUCTION

1.1. Background

Trend is the way in which time series data of any parameter can be changed. Application of the trend analysis can be found in many disciplines. It involves in hydro meteorology as identifying trends of rainfall,temperature,streamflow,evaporation and wind speed (Rathnayake, 2019). Changes in rainfall usually results changes in the water cycle. Changes of water cycle results floods and droughts in many parts of the world. Flood and drought leading to an increasing number of people being affected globally (Krajewski et al., 2019).

Global long-term rainfall trends impacting the availability of water, with increasing occurrences of droughts and floods. That affects the agricultural productivity, loss of human life, and property damages over the world. It also affecting watershed development activities, the function, planning, and operation of existing and future planned water infrastructure (Panda, 2019). Information on the temporal patterns of rainfall and stream flow is obtained by carrying out an analysis of historical datasets. The results gives timely warnings to allow people to mitigate the negative effects of floods and droughts caused by climate change (Kimaru et al., 2019).

Rainfall is vital natural resources on the earth which can be seen as the major backbone of all the water resources. It is one of the key climatic variables that affect both the spatial and temporal pattern of water variability. The rainfall available in the watershed is also key factor for determining the availability of water resources. Understanding the changes in rainfall at local scales is very important for planning of required measurement (Mulugeta et al., 2019).The variability of rainfall can also pose a major risk to water resources and reservoirs due to flooding. The likelihood of extreme drought or flooding is determined by a temporal variability of rainfall (Kimaru et al., 2019).

Rainfall and river flows in Africa display high levels of variability across a range of spatial and temporal scales. Much evidence exists for high inter annual and decadal variability in rainfall and river flows in Africa. However, there are few detailed studies of their spatial and temporal variability (Conwayetal.,2009). In Ethiopia, several studies have been done on hydrological trends. Accordingly, there is a spatial and temporal trend of annual and seasonal rainfall in Ethiopia. It was stated that the rainfall trends are one of the more important factors in explaining various socio-economic problems such as food insecurity for the countries.

Stream flow is also a prerequisite for planning and management of water resources. It is important for the design of dams and other hydraulic structures. Assessments of different water demand mainly depends on availability stream flow (Fentaw et al., 2017). The temporal variability of rainfall and stream flow influences the agriculture, food security and energy. As a result, trend analysis of rainfall and stream flow is essential for enhancing water resource management, agriculture production, planning and designing hydraulic structures and mitigating the negative effects of flooding.

Trend analysis of rainfall time series includes determination of increasing, decreasing and magnitude of its change. Parametric and Non-parametric statistical methods used to analyse it. Trend analysis in various study shows that nonparametric methods mostly used. Mann-Kendall test is one of the best methods among them, which is preferred by various researchers. Mann-Kendall test does not require the datasets to follow normal distribution and show homogeneity in variance (Pal et al., 2017). However, non-parametric Mann-Kendall test is highly influenced by serially correlated data. When data is influenced by autocorrelation, Modified Mann-Kendall package can be used for trend detection studies since it can address the autocorrelation problem in time series.

Sen's slope estimation methods also used to determine the magnitude of trend. This method assumes the trend line is a linear function in the time series. In Sen's slope model, the slope value shows the rise and fall of the variable. Sen's slope is not affected when outliers and single data errors are present in the dataset (Pal et al., 2017). Package of Modified Man-Kendall in R software was used in this study to analyse rainfall and stream flow trend.

1.2. Statement of Problem

The rising temperature is widespread across the globe and cause the trends of water cycle across the world (Kimaru et al., 2019). The rainfall and stream flow in Ethiopia show high spatio temporal variability. According to various study no significant trend in annual and seasonal rainfall over the central, northern, and the northwestern areas. However, decreasing trends over the eastern and the southern areas of Ethiopia in the period from 1982 to 2002. Additionally, no significant trend in annual and autumn rainfall (February to May) in all individual watersheds in Ethiopia. However a significant decreasing trend for summer rainfall for some catchments over the period from 1960 to 2002 (Mulugeta et al., 2019).

Flood and drought have caused significant damage to human life, settlements and socio-economic systems in the country. Riverine floods usually occur in the lower part of major river basins of Awash, Baro-Akobo, Omo Gibe, and Wabeshebele. In 2006,flash and riverine floods killed more than 700 people and displaced over 242,000 people (Degefu et al., 2019).

The research on the Wabe-Shebele River basin demonstrated that the frequency, duration and severity of drought on water resource available and on land use land cover changes due to hydro-climatic drought at the upper and middle course of Wabe-Shebele River Basin especially around river banks. These reductions of rainfall and increasing of temperature increasing soil moisture evaporation) leads to the loss of different water resource available such as stream flow reduction and decreasing level of water table which in turn leads the problem for meeting water demands in agriculture, industry, households (Hayicho et al., 2019).

Wabe Shebelle River Basin was suffered with drought and caused loss of cattle and socio-economic activities of the area. During the dry season downstream river flows may be reduced to almost zero. Floods are a frequent problem during the wet season causing major problems mainly to downstream communities (Mohamed, 2013). As a result, it is necessary to consider and study rainfall and stream flow variability in the basin. This study was intended to analyse the trend of rainfall and stream flow in Upper Wabe Shebelle River Basin. Additionally, Modified Mankendall package was used to analyze trend of rainfall and stream flow time series to address the problem of autocorrelation of timeseries of rainfall and stream flow in the basin.

1.3. Objective

1.3.1. General Objective

The objective of this research is to analyze trends of rainfall and stream flow time series in the Upper of Wabe Shebelle River Basin.

1.3.2. Specific Objectives

The specific objectives of the study are :

- to analyze annual, seasonal and monthly trend of rainfall time series.
- to analyze annual, seasonal and monthly trend of rainfall time series
- to evaluate correlation of rainfall and streamflow by determining correlation coefficient between rainfall and runoff in the basin.

1.4. Research Questions

How the rainfall in the upper part of Wabe Shebelle River had been changed?

How the stream flow in the upper part of wabe shebelle river had been changed?

How is the correlation between rainfall and stream flow in the upper of Wabe Shebelle River Basin?

1.5. Significance of the study

Detection of trends in longtime series of hydrological data is of paramount scientific and practical significance. Water resources systems have been designed and operated based on the assumption of stationary hydrology. If this assumption is incorrect then existing procedures for designing levees, dams, reservoirs, etc. will have to be revised. Without revision there is a danger that systems are over or under designed (Kundzewicz & Robson, 2000)

Understanding the changes in long-term of annual and seasonal rainfall at local scales is very important for planning of required measurement. It helps to control damages caused by drought and flood. It also help policy makers and developers to give important decisions. Understanding of rainfall variability and trend is also crucial and necessary in order to figure out the impacts of climate change.

1.6. Limitation of the study

The time series data collected for this study was secondary data and these data contain missing value which could affect the accuracy of results of this study. Additionally, some stations in the study area has no long time collected data. In this study, the trend of stream flow and rainfall was assessed using Modified Mannkendall trend test which does not consider factors which affect these variables. However, in real world a number of variables directly affect stream flow and probably will affect the results of trend analysis. Some of these variables are rainfall,land use/land cover change, water diversion structures and wastewater discharge. Similarly different factors such as,temperature, evapotranspiration and evaporation can affect the trend of precipitation.

2. LITERATURE REVIEW

2.1. Hydro-Metrological change studies

The interactive relationships between hydro-meteorological elements and the environment are dynamic. Changes in temperature, precipitation, and runoff usually drive the evolution of ecosystems. Investigations on the changing properties of temperature, precipitation and fluctuations in river runoff have great importance. It helps to understand significant impacts of climate variations and human activities on the hydrological cycle and ecology (Krajewski et al., 2019).

According to various study Changes in hydrological series can take place in many different ways. A change may occur abruptly (step change) or gradually (trend) or may take more complex forms. Changes can be seen in mean values, in variability (variance, extremes, persistence) or within-year distribution. Abrupt changes can be expected because of a sudden alteration within the catchment. They can also inadvertently arise from changes to gauging structures, or to rating curves (stage-to-flow relationships), or to observation methods. Gradual hydrological changes typically accompany gradual causative changes such as urbanization, deforestation, climate variability, and other change. Climate change is often thought of in terms of progressive trend. However, it is possible for it to result in a step-like change. complex dependencies on non-linear dynamic processes that feature cumulative effects and thresholds (Kundzewicz & Robson, 2000)

There is a huge variety of hydrological data that it is possible to analyses for trend and step change. These may be collected at a range of temporal intervals: continuous, hourly, daily, monthly, annually, or sampled irregularly. Data records contain either instantaneous values or totals for a time interval. Studies of hydrological change are typically complicated by different factors. For instance, missing values, seasonal and other short-term fluctuations and lack of homogeneity. There are further problems because of censored data and data series that are not sufficiently long (Kundzewicz & Robson, 2000).

2.2. Causes of Hydro-metrological change

The water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above and below the earth surface (Han, n.d,2010). The hydrological cycle has been highly influenced by climate change and human activities. It is important to analyze the hydrological trends that occurred in past decades in order to understand past changes and to predict future trends. In a country whose economy is heavily dependent on rainfed agriculture, rainfall trends are often cited as one of the more important factors in explaining various socioeconomic problems such as food insecurity (Cong et al., 2009).

The hydrological cycle of a basin is a complex process influenced by climate, physical characteristics of the basin, and human activities. With the worsening of the water shortage problems and the increasing number of water-related disasters globally, the effects of climate variability and human activities on water resources have long been a focus of global hydrology research. Climate variability is believed to have led to global warming and changing patterns of precipitation, while human activities have changed the temporal and spatial distribution of water resources. In arid and semiarid regions, the effects of climate variability and human activities on runoff are significantly more sensitive, and these effects have resulted in reduction or increase in water yield. Evaluating these effects quantitatively is important for regional water resources assessment and management (Chen et al., 2012).

There are many factors that influence the underlying surface characteristics of a watershed, including land use change, hydraulic engineering, water resources development, and others. The underlying surface condition of a watershed has been reported to have a more important function than climate change on the hydrological cycle, and it contributed more than 50% to stream flow change. Anthropogenic interference mainly consists of land use/cover change (LUCC), urbanized and industrialized extension, and hydropower development and irrigation intensification, which greatly alter the underlying surface and water resource reapportionment. Quantification of streamflow changes and identification of the various contributing factors are also considerable (Rientjes et al., 2011)

The impact of climate change on the hydrological cycle will be a change in the global hydrology distribution. Precipitation and potential evapotranspiration are the most important for the determination of climate characteristics. Climate change is a global concern, particularly, with increase in the rate of mean temperature and decline of annual mean precipitation. Climate hazard grows with increase warming and vegetation production is declining in response to climate warming, particularly in desert vegetation. Long-term change in the average weather patterns may refer to climate change; the change might be quantitatively and qualitatively; however, the statistical analysis is the most suitable and commonly applied analysis to stress short- or long-term trend of precipitation and temperature changes (Ghebrezgabher et al., 2016).

Under the background of global warming, the expectation is that hydrological extremes would occur more frequently with greater severity because of changes in climate extremes. However, this has not been proven conclusively because of limited surface observations, complex watershed properties and limitations both in hydrological modeling and in the development of climate change scenarios. According to global-scale projections, hydrological variability will not change uniformly across the globe. For example, it is predicted that 30-year floods will occur more frequently over 50 % of the globe and that increased hydrological droughts will occur over 40 % of the analyzed land area. In addition to the effects of catchment properties, the spatial variations of hydrological variability changes are due to those of climate related changes. For example, drought increase is generally located where precipitation decreases; however, drought can still increase in some areas with increased precipitation if stronger evaporation is driven by temperature increase. Thus, the mechanisms by which climate variability influences hydrological variability should be analyzed (Ghebrezgabher et al., 2016).

Climate change is serious in the Horn of Africa (HOA); several researchers found that the annual mean temperature and precipitation were, respectively, raised and declined in the Sub-Saharan African countries in general and in the HOA in particular. Drought and flooding are serious natural disasters in this region, mainly, drought is severe since the 1970s. Above 50% of the population is living below the poverty line. Soil moisture lowers as a result of high rate of evaporation and soil erosion is serious with climate change, leading to decrease in vegetation cover (Ghebrezgabher et al., 2016)

Ethiopia has a tropical monsoon climate with wide elevation-induced variation. Three climatic zones can be distinguished: a cool zone in the central part crosscutting the western and eastern section of the high plateaus above 2400 up to 4620 meters above mean sea level a temperate zone between 1,500 and 2,400 m.a.s.l, and the hot lowlands below 1,500 m. Mean annual temperature varies from less than 7 - 12ºC in the cool zone to over 25ºC in the hot lowlands (NMSA 2001).

Rainfall in Ethiopia is highly erratic, and most rain falls as intensive, often convective storms, of very high intensity and varies extremely spatially and temporally. Such variability is a threat to an agricultural industry that relies heavily on rainfed agriculture since it will be very vulnerable to phenomena caused by rainfall extremes such as annual droughts and intra-seasonal dry spells as well as floods particularly in the lowland areas (FAO 1986).

Ethiopia is mainly an agricultural country with limited forest cover. (MoA, 1993) Less than 3% of the entire country is now covered with trees, compared to the 40% of a century ago and 16% in the early 1950s, prompting fears of an impending environmental disaster in this country which is home to coffee and one of the biodiversity hotspots of the world, now with large areas exposed to heavy soil erosion (MWR 2001). Ethiopian land which falls within the UNEP's definition of desertification is estimated to cover 71.5% of the country's total land area. Overgrazing, deforestation, poor farming practices and using dung for fuel are the major causes of land degradation in Ethiopia. The recorded annual soil erosion (surface soil movement) in Ethiopia ranges from low of 16 tons/ha/yr to high of 300 tons/ha/yr depending mainly on the slope, land cover, and rainfall intensities (UNEP 2008). The total estimated annual soil loss (surface soil movement) from the cultivated, range and pasture lands (780,000 km) in Ethiopia is estimated to range from low of 1.3 to an average of 7.8 billion metric tons per year (MEDaC, 1999).

The research on the Wabe-Shebele River basin demonstrated that the frequency, duration and severity of drought on water resource available and on land use land cover changes due to hydro-climatic drought at the upper and middle course of Wabe-Shebele River Basin especially around river banks. Riparian woodland and bush land occur along the riverbanks and on flood plains and are important in the semi-arid and arid parts of the basin where they used for grazing and browsing and, scattered seasonal crop cultivation on some of the flood plains that are highly affecting by drought (Awass, 2009). The drought that especially occurred at lower Wabe-Shebele River basin, in major caused by anomalies (deviation from the normal) in the weather or climate that lead to reduction in precipitation amount and distribution than normal. These reductions of rainfall and increasing of temperature increasing soil moisture evaporation) leads to the loss of different water resource available such as stream flow reduction and decreasing level of water table which in turn leads the problem for meeting water demands in agriculture, industry, households (Hayicho et al., 2019).

2.3. Trend Test Methods

Many tests for trend detection have been used in studies of long time series of hydrological data. Yet, every test requires a number of assumptions to be satisfied. When underlying test assumptions are not fulfilled, acceptance and rejection regions of the test statistic cannot be rigorously determined. Therefore, such tests should be treated as methods of exploratory data analysis rather than as rigorous testing techniques. Many approaches can be used to detect trends and other forms of non-stationery data in hydrology. In deciding which approach to take it is necessary to be aware of which test procedures are valid (the data meets the required test assumptions) and which procedures are most useful (likely to correctly find change when it is present).There are many approaches that can be used to detect trends and other forms of non-stationary in hydrological data. In deciding which approach to take, it is necessary to be aware of which test Procedures are valid and which procedures are most useful. (Hamed & Rao, 1998). Trends can be detected using either parametric or non-parametric tests.

2.3.1. Parametric Test

Parametric test is a test that involves estimation of parameters and it is not rank based. Parametric testing procedures are widely used in classical statistics. In parametric testing, it is necessary to assume an underlying distribution for the data (often the normal distribution), and to make assumptions that data observations are independent of one another. For many hydrological series, these assumptions are not appropriate. Firstly, hydrological series rarely have a normal distribution. Secondly, there is often temporal dependence in hydrological series particularly if the time series interval is short. If parametric techniques are to be used, it may be necessary to (a) transform data so that its distribution is nearly normal and (b) restrict analyses to annual series, for which independence assumptions are acceptable, rather than using the more detailed monthly, daily or hourly flow series

The parametric test is based on an assumption that the sample data come from a population. It follows a normal distribution(Kundzewicz & Robson, 2000).The parametric tests have higher efficiency and power than the non-parametric test for normally distributed data. However, they are rarely used for environmental data without adjustments for outlier and missing data. Further, uncertainties associated with using the model and difficulties in applying the methods make parametric tests less preferable (Mulugeta et al., 2019).The most widely used parametric method is linear regression.

As stated by Mc Cuen (1998), a parametric test is based on theory or concepts that require specific conditions about the underlying population and/or its parameters from which sample information will be obtained. Non-parametric test is a test that does not involve estimation of parameters and it is rank-based tests. In non-parametric and distribution-free methods, fewer assumptions about the data need to be made. With such methods, it is not necessary to assume a distribution. However, many of these methods still rely on assumptions of independence. More advanced approaches must therefore be used for daily or hourly series

2.3.2. Linear Regression

Linear regression is a very powerful statistical technique. Many people have some familiarity with regression just from reading the news, where graphs with straight lines are overlaid on scatterplots. Linear models can be used for prediction or to evaluate whether there is a linear relationship between two numerical variables (Edition, 2014). For linear regression, the data needs to be normally distributed and independent(Kundzewicz & Robson, 2000). Linear regression is severely affected by outliers, missing data, and the starting and ending values of the time series. However, linear regression based on ordinary least square (OLS)-based has been used for trend analysis in a number of studies(Mulugeta et al., 2019).

2.3.3. Non-Parametric Test

For the non-parametric tests, no assumption is made about the distribution of the population. They are simple to use and far less impacted by outlier and missing data than the parametric test. In addition, they represent a measure of monotonic dependence whether linear or not. The power of non-parametric tests rises with increasing sample size, and they can perform better than parametric tests when the data depart from normality. The non-parametric tests have been favored in hydrological time series analysis due to simplicity and suitability for data with outliers. Even for normally distributed data, non-parametric tests are preferred and safer because they can be applied without prior assumption about the population distribution of the data.

McKuen (1998) stated that, a nonparametric test is based on theory or concepts that have not required the sample data to be drawn from a certain population or have conditions placed on the parameters of the population. Even within the basic categories above it is necessary to choose tests that are appropriate for the situation. Some tests are very good at detecting a very specific type of change; other tests may be good at picking up any one of a broad range of possible changes. Since one does not know the pattern of variability beforehand, using a number of tests is sensible. The most commonly used non-parametric statistical tests in trend analysis are Pettitt's test ,Mann–Kendall's for trend test and Sen's Slope tests for slope estimation (Mulugeta et al., 2019) (Kuznetsov & Mohri, n.d.).

2.3.4. Pettitt's test

Pettitt's test is a nonparametric rank-based test developed by Pettitt (1979), which is used to detect the change point in time series data. The Pettitt method, which is a rank-based test method, has been widely used to detect change point in the mean value of observed series. Traditionally the rank-based test has been assumed to be distribution-free and not sensitive to outliers and skewed distributions. However, there has no evidence provided to prove this assumption. Based on the work of Yue and Wang (Stoch Environ Res Risk Assess 16:307–323,2002), this study defines the success rate of detecting the given change point as the ability of the Pettitt method, and investigates the ability in various circumstances by means of Monte Carlo simulation (Carlo, 2013)

Experiment results demonstrate that, the ability of the Pettitt method depends on not only the pre-assigned significance level, but also various properties of the sample data, including the sample size, the magnitude of a shift and the change point position. Besides, the distribution type and the distribution parameters such as the coefficient of variation, the coefficient of skewness and the shape parameter also seriously influence the ability. As expected, it is easier for the method to detect the change point when the sample size is larger, or the magnitude of a change point is bigger, or the variation of the sample data is smaller. And the highest ability is obtained when the change point occurs at the middle position of the series. These simulation results would provide users an extensive and detailed understanding about the use of the Pettitt method for the detection of change point (Carlo, 2013)

2.3.5. Mann-Kendall (MK) test

The Mann-Kendall (MK) test is a non-parametric approach for testing the significance of monotonic trends, linear or nonlinear, in time series data. The test is based on ranks of observations, not the actual values of the data series, making it uninfluenced by missing and outlier data. The MK test is strongly recommended by the World Meteorological Organization as a standard non-parametric procedure for testing trends. It is widely used in trend analysis of hydro-meteorological time series (Mulugeta et al., 2019).

In the Mann-Kendall trend test, the correlation between the rank order of the observed values and their order in time is considered. The null hypothesis for the Mann-Kendall test is that the data are independent and randomly ordered. There is no trend or serial correlation structure among the observations. However, in many real situations the observed data are auto correlated. The autocorrelation in observed data will result in mis-interpretation of trend test results. Positive serial correlation among the observations would increase the chance of significant answer, even in the absence of a trend (Hamed & Rao, 1998).

A closely related problem that has been studied is the case where seasonality exists in the data. By dividing the observations into separate classes according to seasons. Performing the Mann-Kendall trend test on the sum of the statistics from each season. The effect of seasonality can be eliminated. This modification is called the seasonal Kendall test. Although the seasonal test eliminates the effect of dependence between seasons, it does not account for the correlation in the series within seasons. The same problem exists when yearly data are analyzed, since they are often significantly auto correlated (Storch, 1995).

2.3.6. Modified Mk

Power of non-parametric Mann-Kendall test and Spearman's Rho test is highly influenced by serially correlated data. To address this issue, trend tests may be applied on the modified versions of the time series data by Block Bootstrapping (BBS), Prewhitening (PW). Trend Free Prewhitening (TFPW), Bias Corrected Prewhitening and Variance Correction Approach by calculating effective sample size. Time series data is often influenced by previous observations. When data is not random and influenced by autocorrelation, modified Mann-Kendall tests may be used for trend detection studies. Hamed and Rao (1998) have proposed a variance correction approach to address the issue of serial correlation in trend analysis. Data are initially detrended and the effective sample size is calculated using the ranks of significant serial correlation coefficients which are then used to correct the inflated (or deflated) variance of the test statistic.

2.3.7. Sen's Slope estimator

Similar to Man Kendall test, Sen's Slope estimator has been widely used to estimate the slope of a linear trend for a time series**.** Sen's slope estimation, non-parametric method gives the magnitude of trend. This method assumes the trend line is a linear function in the time series. In Sen's slope model, the slope value shows the rise and fall of the variable. Another advantage of using Sen's slope is that it is not affected when outliers and single data errors are present in the dataset (Pohlert, 2020).

2.4. Software used for performing the statistical Mann-Kendall test

Software used for performing the statistical Mann-Kendall test are R, MATLAB, SAS, SPSS, Excel add-ins, Minitab. Differentiating between which of these softwares best fits the analysis of the data sets depends on a number of factors. Each statistical software has its own strengths and weaknesses. Finding the suitable software is important, because companies that employ the most efficient data analysis based on competition. They effectively accessing and using their stockpiles of data to make better decisions. There are numerous criteria which can be used for choosing the software required as the tools. These criteria are always project dependent, since every project has its own specific requirements and needs. Further, some criteria are also user depended, such as personal preference for graphical user interface, computer operation system, input/output management and structure or users add on expansibility. Based on the available criteria and personal preference, statistical R software was used for this study (Ozgur & Dou, 2017).

2.4.1. Statistical R Software

The open-source programming language R has gained a central place in the hydrological sciences over the last decade. R is driven by the availability of diverse hydro meteorological data archives and the development of open source computational tools. The statistical and graphical packages provided in R are particularly useful for the hydrological sciences. It includes techniques such as linear and non-linear modeling, statistical tests, time-series analysis, classification, or clustering. R was initially developed as a statistical computing language. Still it is 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. It is virtually impossible to give complete coverage of all possible packages that might be useful to hydrologists. The skimr package provides compact and flexible summaries of data. It can be used with pipes and displays nicely in the console. Many estimating procedures can be carried out using the base-R stats package. Which includes, Time series model, correlation analysis, Mann–Kendall testing, linear regression, Poisson regression and Gamma regression (Slater et al., 2019).

2.4.2. R Software versus Other Statistical Software

While SAS and SPSS have many things in common, R is different. It is software with personality. First of all, it is open-source, the cost of using it being related only with the training of users. Also, its numerous GUIs, IDEs and packages are freeware. R is working on various operating systems: Windows, Linux, Mac OSX and it is easy to install and configure. The fantastic use Rs community grows continuously. The users of R have a very enthusiastic behavior and they consider the knowledge exchange a real challenge. The user support is based on a very active mailing list, blogs and dedicated forums. R is used for statistical analysis, data manipulation, visualization and exciting applications in various fields.

One of its big advantages is the linkage with the way statisticians think and work (e.g.: keeping the track of missing values). It bears Excel integration via R Excel; SPSS has not this issue available. Use of mix-and-match models for best results and re-use and reproduce new discovered techniques on analytic operations that the user is going to perform this is difficult in SAS or SPSS. R functions can nest inside one another, creating nearly infinite combinations of output, in this way it gives the warranty for the best result(Dobre, 2013).

R is didactic, since you have to understand a statistical method before you can put it at use. It is very efficient once you master it: you will then be able to create your own tools, enabling you to operate very sophisticated data analyses. R is especially powerful for data manipulation, calculations and plots. Its features include: an integrated and very well-conceived documentation system (in English). Efficient procedures for data treatment and storage. Suite of operators for calculations on tables. A vast and coherent collection of statistical procedures for data analysis; advanced graphical capabilities; simple and efficient programming language, including conditioning, loops, recursion and input-output possibilities (Slater et al., 2019).

2.4.3. R packages in a typical hydrological workflow

R is an ever-growing environment, as can be seen in the number of R packages that are developed every year (Slater et al., 2019). There are now hydrological packages for every step of a standard hydrological workflow. Packages for retrieving hydro-meteorological data, Packages for reading, manipulating, and cleaning the data and Packages for extracting driving data, spatial analysis, and cartography. Packages for hydrological statistics. Setting up a repository with version control at the start of a research project has many advantages. A repository is a structured set of files that will track edits any team member makes to the project, similar to the track-changes function in common word processors. Once a project folder or repository has been set up, one might need to identify the most useful R packages and functions for the task at hand. CRAN Task Views were recently developed to provide thematic lists of the packages that are most relevant to specific disciplines (Slater et al., 2019).

3. MATERIALS AND METHODS

3.1. Study area

3.1.1. Location

The study was carried out in the UWSRB located in the South-Eastern part of Ethiopia. The basin is found in Arsi and Bale Zone of Oromiya regional state. Geographically, the study area is bounded between 6◦87′N and 9 ◦ 25′N latitudes and 38 ◦ 45 ′E to 43 0′E longitude with an area of 62,723.96 Km2.

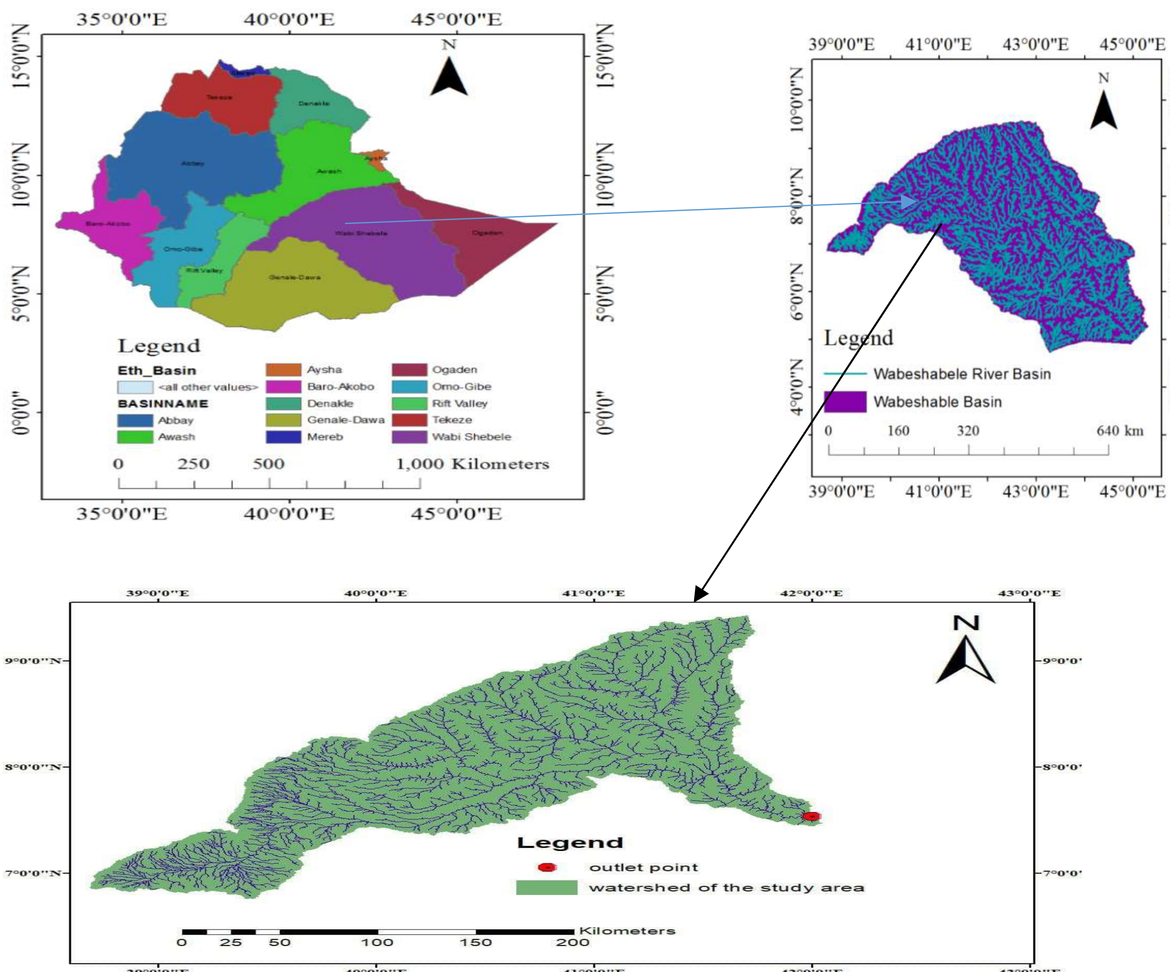

Figure 3. 1. Map of Upper Part of Wabe Shebelle River Basin

3.1.2. Topographic Feature

The study area is Upper part of Wabe-Shebelle River Basin, found in the south eastern plateau. The Arsi and Bale highlands, western plateaus are the margin that forms the north and northwestern watershed divide of the basin. Wabeshebele River emerges from the mountainous areas of the North Western borders of the river basin near a place called Hebeno. The physical condition and variation in altitude have resulted in great diversity of climate, soil and vegetation. The UWSRB has diverse topographic features with elevation range between 394 m and 4216 m above mean sea level (amsl) in the highlands of the Bale Mountain(Kebede, 2015).

3.1.3. Geologic Feature

The area is dominated by Mesozoic sedimentary formations, to some extent there are also volcanic rocks at the North West of the basin and isolated ridges and hills within the sedimentary basin. Metamorphic rocks outcrops in a small extent at the northern part of the study area. Alluvial deposits are also distributed linearly along the Wabi and fan deposits of seasonal floods and stream beds. The volcanic rocks of Arsi-Bale basalt bordering the rift valley are highly fractured.

3.1.4. Land use /Land cover

A small dense forest is found at the North Western portion of the basin. Dense shrub land is the predominant land cover in the basin. The shrub land occurs mainly on the semi- arid parts and often consists of patches of shrubs interspersing grasslands with some scattered low trees. Patches of exposed rock or sand surface are found in parts of Bale. Parts of central Arsi and northern Bale have afro-alpine and sub-afro alpine vegetation. These consist mostly of short shrub and heath vegetation used partly for sedentary grazing and browsing. Riparian woodland and bush land occur along the river banks and on floodplain sand are important in the semi-arid and arid parts of the basin where they are used for grazing and browsing and scattered seasonal crop cultivation on some of the flood plains. Areas of intensively cultivated land are found on the highlands of Arsi and northern Bale.

3.1.5. Soils

Cambi soil is distributed in the upper most parts of the watershed, especially areas on hills where the land is too steep. They are inevitably high-risk soils and occur wherever conditions are not favorable for other soil processes than weathering to take place. They are brown in color and shallow to moderately deep soil, phaeozems comprises 19.7% of the basin covering significant areas of the middle belt and downstream of the basin.

3.1.6. Climate

The climate of Wabe-Shebelle River Basin is depend on the basin altitude. The highland areas are cool and suitable for people settlement while the lowland areas are arid and not suitable for settlement (Adane, 2009). There are some meteorological stations placed around the basin very few of them are located within the basin and most are located around the cities of the basin. The rainfall amount within the Wabe shebelle river basin ranges from 200 mm on the arid part of the basin to 1250 mm towards the upper part of the basin.

3.1.7. Hydrology

Most of the rivers in the area arise along the northern and north western margins of the Arsi and Bale. Currently some areas in the upper catchments have gauging station. According to MoWIE,in the upper catchment there are more than 15 stations, among these Lelisso, Hararo,Assassa, Weyib at Agarfa, Ukuma, Maribo near Adaba, Jewis near Bedesa, Wabi at bridge and Wabi at Melkawakena, Robe station at Robe town. For this study,Assassa, Furuna, Leliso, Maribo,Ukuma, Wabi and Wayib at Agarfa were selected. These stations were selected based on their length of recorded period and percentage of missing value.

3.1.8. Meteorology

The rainfall in Wabe-Shebelle River Basin varies from less than 200 mm in arid zones (the south east part) to 1250mm in upper catchment. This is due to altitude variations over the basin from about 73m above sea level in the south east border up to 4137m above mean sea level in the upper side or at Bale Mountain Massif (Tesema, 2015).

3.2.Data collection

It is very important to collect adequate and quality data to get the required results in any field of study. The data used for this study includes rainfall data of seven stations stream flow data and GIS

Data. These data were obtained from National meteorological Agency, Ministry of water, Irrigation and Energy, Basin Development Authority.

3.3. Data Quality Management

Before any analysis of data, it is very necessary to go through the collected raw data deeply. It helps to avoid any mis-behavior of the data such as, missing data, outliers and consistency. In particular, the following techniques were used in this study to improve the quality of the collected data.

3.3.2. Consistency checking

A consistent record is the one where the characteristics of the record have not changed with time. A hydrologic time series data may be inconsistent with time due to change in physical condition of the catchment, method of data collection and negligence of the observer. Adjusting for gauge consistency involves the estimation of an effect rather than a missing value. For this study the graph of cumulative of each rainfall stations versus cumulative of average rainfall of all stations were drawn and the result showed almost straight line, so they were taken as the consistent data.

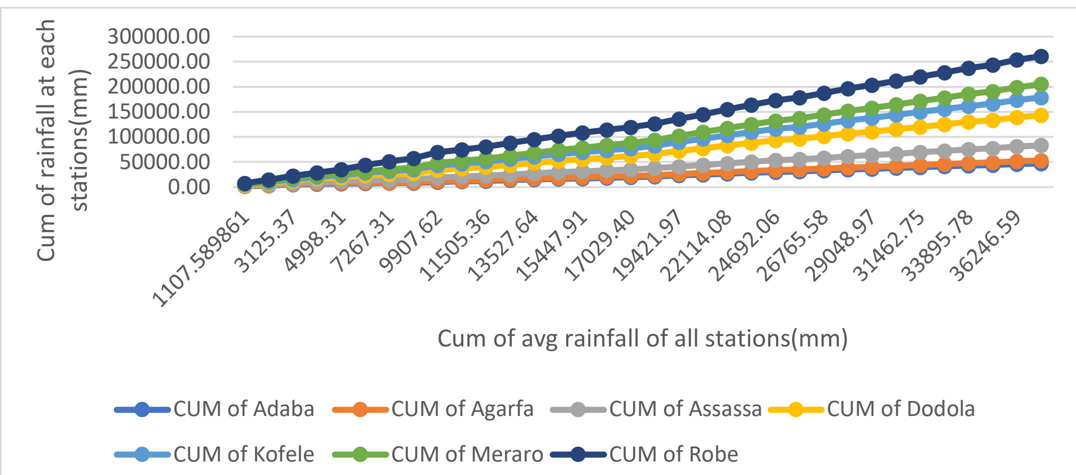

Figure 3.2. Graph of all rainfall stations**.**

3.3.1. Checking homogeneity of selected rainfall station.

Homogeneity is an important issue to detect the variability of the data. Generally, when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments. However, it is a hard task when dealing with rainfall data because it is always caused by changes in measurement techniques and observational procedures, environmental characteristics and structures, and location of stations. One of the methods to check homogeneity of the selected stations in the watershed is the non-dimensional rainfall records and plotted to compare the stations with each other. The homogeneity of the selected gauging stations rainfall records were carried out by non-dimensional equation.

$$p_i = \frac{\overline{p_i}}{\overline{p}} \qquad 3.1$$

Where,

p_i = Non dimensional value of precipitation for month i

$\overline{p_i}$ = Over years averaged monthly precipitation for the station i

$\overline{p}$ = Over year's average yearly precipitation of the station i

According to Homogeneity test analysis**,** the selected stations were plotted for comparison with each other. Figure below shows the result of homogeneity analysis plotted to check similarity between groups of stations. The same mode and pattern of the stations are observed and hence the group of stations selected is homogenous since all the value of Pi are less than 25%.

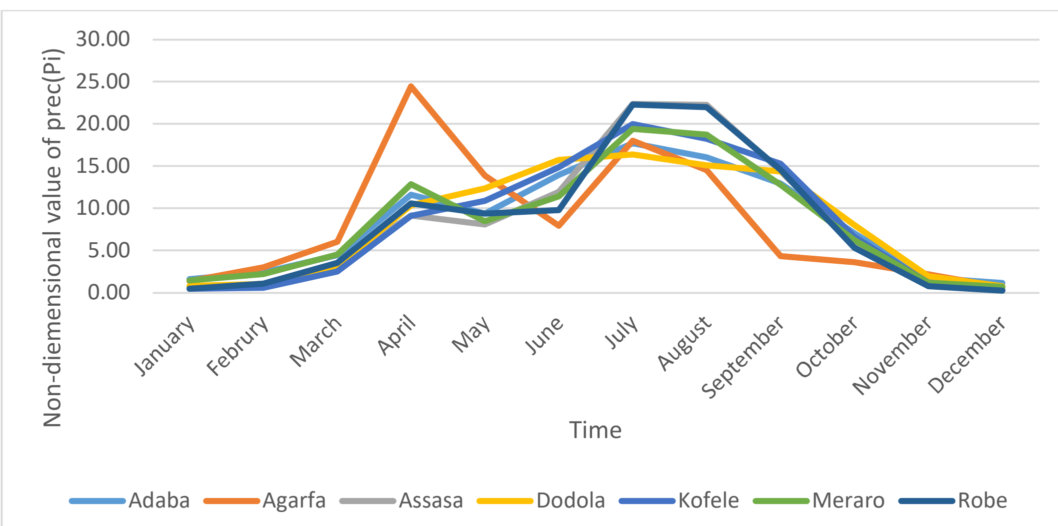

Figure 3.3. Homogeneity test analysis for all rainfall stations.

3.3.3. Filling missing observations.

Hydrological data records may be missed because of different reasons, including extreme natural phenomena and human induced phenomena such as mishandling of the observed data by field personnel, wars etc. Therefore, in any hydrological data analysis, filling the missed observation is the foremost work. Filling the missed observation can be done through numerous methods. These methods includes, a classical method of filling the hydrological data such as, Neighboring station, Arithmetic method, normal ratio method, weighted distance interpolation method, Time Series Analysis method and Regression method (Hastie et al., 2001). In this study, Neighboring and Arithmetic method was used by considering the percentage of missing rainfall data.

3.3.4. Test for Outliers

An outlier is an observation that deviates significantly from the bulk of the data, which may be due to errors in data collection, recording, due to natural causes etc. Outliers should have to be investigated because they can provide useful information about your data or process. Unless the outliers are detected and corrected, they may result in unreliable result in both trend test and time series modeling case.

3.4. Steps of trend analysis

The systematic approach that is adopted here in to determine the significance of detected trends can be summarized as the following procedure: Selection of variables to be studied. Selection of stations that have sufficient long record. Analysis and interpretation, which include checking for the presence of trend. Determine the significance of the detected trends.

a) Selection of variables

In the case of this study rainfall and run-off were taken as the variables of study for the trend analysis. These variables analysed annually, monthly and seasonally.

b) Selection of stations

In case of this study, Seven rainfall Stations and Seven stream flow stations were taken as the variables of study for the trend analysis.

c) Trend detection test

The time series of hydrologic variables were analyzed using the Modified Mann-Kendall test for trend analysis.

d) Significance of trend results

The results of trend test can be used to determine whether those observed collection of time series for hydrologic variable exhibits a number of trends that is greater than the number that is expected to occur by chance.

3.4.1. Mann-Kendall test

Mann Kendall test is a statistical non-parametric test and widely used for analysis of trend in climatologic and in hydrologic parameters. The Mann-Kendall test is applicable in cases when the data values xi of a time series can be assumed to obey the model of the form:

$$Xi = f(t) + \varepsilon i \qquad 3.3$$

Where, f(t) is a continuous monotonic increasing or decreasing function of time and the residuals εi can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. The non-parametric Mann-Kendall test is commonly employed to detect monotonic trends in series of environmental data, climate data or hydrological data. The null hypothesis, H0, is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, HA, is that the data follow a monotonic trend. The Mann-Kendall test statistic is calculated using the following formula.

$$S = \sum_{k=1}^{n-1} \sum_{k+1}^{n} sgn(xj - xk) \qquad 3.4$$

Where, xj and xk are the annual values in years j and k, j > k, respectively, and

$$Sgn(xj\text{-}xk) = \begin{cases} 1 \ if \ xj - xk > 0 \\ 0 \ if \ xj - xk = 0 \\ -1 \ if \ xj - xk < 0 \end{cases} \qquad 3.5$$

At certain probability level H0 is rejected in favor of HA, if the absolute value of S equals or exceeds a specified value Sα/2, where Sα/2 is the smallest S which has the probability less than α/2 to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend. However, if there are several tied values (equal values) in the time series, it may reduce the validity of the normal approximation. First, the variance of S is computed by the following equation, which takes into account that ties may be present.

$$\text{Var(S)} = \frac{n(n-1)(2n+5)-\sum_{i=1}^{m} ti(ti-1)(2ti+5)}{18} \qquad 3.6$$

The standardized test statistics Z is computed as follows

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}\ , \ for\ s > 0 \\ 0\ , \quad for\ s > 0 \\ \frac{S+1}{\sqrt{Var(S)}}\ , for\ s < 0 \end{cases} \qquad 3.7$$

Where, m is the number of tied groups and ti is the size of the i^{th} tie group. Also, Z_{MK} follows normal distribution. A positive Z_{MK} depicts an upward trend and negative Z_{MK} $d$epicts downward trend for the period. At significance level α, $Z_{MK} \geq$ Zα/2, then the trend of the data is considered to be significant. The above formula is valid when the number of observation n ≥ 10

3.4.2. Sen’s slope estimator

Sen’s slope estimation is another nonparametric method for trend analysis of hydro climatic data set. It is used to detect the magnitude of the trend. To estimate the true slope of an existing trend (as change per year), the Sen's non-parametric method is used. It can be used in cases where the trend can be assumed linear. This means that f (t) is calculated as:

$$f(t) = Qt + B \qquad 3.8$$

Where, Q is the slope and B is a constant. To get the slope estimate Q in equation, first calculate the slopes of all data value Pairs

where j>k

$$Q_i = \frac{x_j - x_k}{j - k} \quad 3.9$$

If there are n values, xj in the time series we get as many as N = n (n-1)/2 slope estimates Qi. The Sen's estimator of slope is the median of these N values of Qi. The N values of Qi are ranked from the smallest to the largest and the Sen's estimator is

$$Q = Q_{\left[\frac{N+1}{2}\right]}, \quad if\ N\ is\ odd \quad 3.10$$

$$Q = \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+1}{2}}\right) \text{ if N is even} \quad 3.11$$

3.5. Study Design.

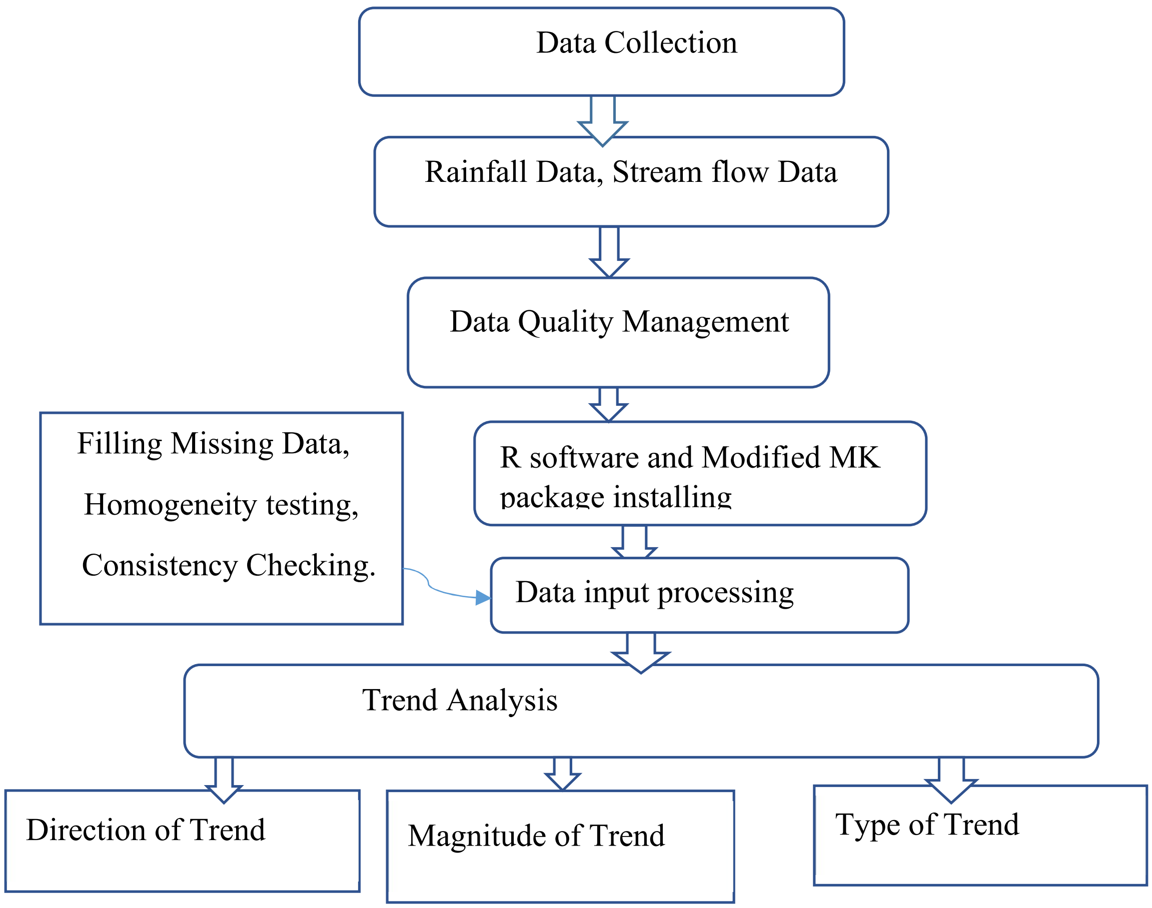

Figure 3.5. Study Design

4. RESULTS AND DISCUSSION

4.1. Annual rainfall trend

The trend analysis result for annual rainfall is given in Table 4.1. During 1985-2018 periods, Adaba, Assassa, Dodola and Meraro stations Showed significant decreasing trend annually at 0.05 significance level (95% confidence level) whith statistic (Z = - 3.32, -2.85, -2.19 & -3.23) and Sen's slope = (-2.25, -12.47, -13.13 & -14.88) respectively. This significant trend result indicated there was the cause of rainfall trend in the basin which could be the impact of climate variability and anthropogenic interference in the basin. The long-term change of climate associated with changes in rainfall patterns and variability (Edo et al., 2021). The human induced factors such as the rapid increase in deforestation and freshwater withdrawals can altering rainfall patterns (David et al., 2004). The result of some stations in this study agrees whith the previous study result in the basin. In the upper part of wabe shebelle the mean annual rainfall depicts a significant decreasing trend for some stations at a 5% significance level (Edo et al., 2021). From this study results, Agarfa and Kofele stations showed insignificant decreasing trend annually with statistic (Z = -0.95 & -1.75) and Sen's slope = (-1.29 & -8.92) respectively. Robe station showed insignificant increasing trend whith Z = 0.94 & Sen's slope = 7.98. This insignificant rainfall trend revealed that the cause of the trend is occurred randomly (by chance) rather than by other factors. This insignificant trend results of this study in agreement whith the previous study was conducted in this study area. In the upper part of wabe shebelle, some stations showed statically non-significant rising or declining trends annually at a 5% significance level.(Edo et al., 2021). From this annual rainfall trend result, some stations showed similar trend type and some stations showed difference trend type. Therefore, the similarity and variations of annual rainfall trend of the selected rainfall stations indicated both homogenous and heterogenous rainfall trend type through the spaces.

Table 4.1 Annual rainfall trend

Station	period	Z value	P value	significant level	Sen's slope
Adaba	1985-2018	-3.32	0.00	0.05	-2.25
Agarfa	1985-2018	-0.95	0.34	0.05	-1.29
Assassa	1985-2018	-2.85	0.00	0.05	-12.47
Dodola	1985-2018	-2.19	0.02	0.05	-13.13
Kofele	1985-2018	-1.75	0.08	0.05	-8.92
Meraro	1985-2018	-3.23	0.00	0.05	-14.88
Robe	1985-2018	0.94	0.35	0.05	7.98

4 .2. Seasonal rainfall trend

4.2.1. Spring season rainfall trend

The trend analysis results for spring rainfall is given in Table 4.2. Spring season consists of March, April and May months. For this season, Adaba & Meraro stations showed significant decreasing trend at significant level of 0.05 whith statistic Z = -2.25 & -2.58 and Sen's slope = -7.62 & -0.89 respectively. This significant trend result indicated there is the cause of rainfall trend in the basin which could be the impact of long-term climate variability in the basin. Climate change will cause changes in the patterns of water cycle and geographical distribution of water resources in the future where impacts will see in climatic factors such as precipitation and temperature. This result agrees whith the previous study conducted in the basin. Similarly, in the Belg season few rainfall stations displayed statistically significant trend in the upper part of wabe shebelle river basin(Edo et al., 2021). Assassa, Dodola and Kofele showed insignificant decreasing trend whith statistic Z = -1.60, -1.29, -1.06 and Sen's slope = -2.178, -0.693, -2.106 respectively. Agarfa and Robe stations showed insignificant increasing trend whith statistic Z = 0.32 & 1.12 and Sen's slope = 0. 21 & 5.72 respectively. This insignificant trend revealed the cause of the trend was occurred randomly rather than by other factors. Similarly, in the Belg season many rainfall stations displayed statistically insignificant trend in the UWSRB (Edo et al., 2021). From Spring season rainfall trend results of this study some stations showed similar trend type and direction within the same period, so this similarity showed homogenous spatial trend of rainfall in UWSRB. Other stations showed different trend type and direction within the same period and these variations showed heterogenous spatial trend of rainfall in UWSRB. Moreover, Spring season rainfall trend result of some stations showed similar trend type and direction whith Annual, Summer, Autumn and Winter rainfall trend result, so these similarities revealed homogeneity of temporal trend of rainfall in UWSRB. However, Spring season rainfall trend result of some stations showed difference trend type and direction from other seasons rainfall trend result, so these variations revealed heterogeneous temporal trend of rainfall in UWSRB.

Table 4.2. Spring Season rainfall trend

Station	period	Z value	P value	significant level	Sen's slope
Adaba	1985-2018	-2.25	0.02	0.05	-7.26
Agarfa	1985-2018	0.32	0.74	0.05	0.21
Assassa	1985-2018	-1.6	0.1	0.05	-2.17
Dodola	1985-2018	-1.29	0.2	0.05	-0.69
Kofele	1985-2018	-1.06	0.29	0.05	-2.10
Meraro	1985-2018	-2.58	0	0.05	-0.89
Robe	1985-2018	1.12	0.26	0.05	5.72

4..2.2. Summer Season rainfall trend

The trend analysis results for summer rainfall are given in Table 4.3. Summer season consists of June, July and August months. For this season Adaba, Assassa and Kofele stations showed significant decreasing trend at significant level of 0.05 with statistics Z = -3.2, -3.77, -3.17 and Sen's slope = -19.73, -8.14, -7.90 respectively. Agarfa and Robe showed insignificant increasing trend whith statistic Z = 1.48 & 0.74 and Sen's slope = 1.07 & 1.76 respectively. The results of two stations of this study are agree with other researchers' findings. The summer season mean rainfall in UWSRB was show insignificant trends with P-value of 0.522 and 0.048 and increased with inclined Sen's slope of 0.807 (Beker,2018). It can be understood that there is an increasing trend during the Kiremt season in majority of the rainfall stations in UWSRB (Edo et al., 2021). Dodola and Meraro showed insignificant decreasing trend whith statistic Z = -0.44 & -1.81 and Sen's slope = -0.67 & -3.56 respectively. From Summer season rainfall trend results of this study some stations showed similar trend type and direction within the same period, so this similarity showed homogenous spatial trend of rainfall in UWSRB. Other stations showed different trend type and direction within the same period and these variations showed heterogenous spatial trend of rainfall in UWSRB. Moreover, Summer season rainfall trend result of some stations showed similar trend type and direction whith Annual, Spring, Autumn and Winter rainfall trend result, so these similarities revealed homogeneity of temporal trend of rainfall in UWSRB. However, Summer season rainfall trend result of some stations showed difference trend type and direction from other seasons rainfall trend result, so these variations revealed heterogeneous temporal trend of rainfall in UWSRB.

Table 4.3. Summer Season rainfall trend

Station	period	Z value	P value	significant level	Sen's slope
Adaba	1985-2018	-3.2	0	0.05	-19.73
Agarfa	1985-2018	-1.48	0.13	0.05	-1.07
Assassa	1985-2018	-3.77	0	0.05	-8.14
Dodola	1985-2018	-0.44	0.66	0.05	-0.67
Kofele	1985-2018	-3.17	0	0.05	-7.9
Meraro	1985-2018	-1.81	0.07	0.05	-3.56
Robe	1985-2018	0.32	0.74	0.05	1.76

4..2.3. Autumn Season rainfall trend

The trend analysis results for Autumn precipitation is given in Table 4.4. Autumn season consists of September, October, and November months. For this season, Dodola and Meraro showed decreasing significant trend at significant level of 0.05 whith statistic Z = -3.82 & -3.26 and Sen's slope = -12.55 & -9.014 respectively. Adaba & Assassa showed insignificant decreasing trend whith statistic Z = -1.93 & -1.78 and Sen's slope = -1.72 & -6.32 respectively. Agarfa, Kofele & Robe showed insignificant increasing trend whith statistic Z = 0.44, 0.89 & 1.43 and Sen's slope = 0.06, 0.55 & 4.12 respectively. From Autumn season rainfall trend results of this study some stations showed similar trend type and direction within the same period, so this similarity showed homogenous spatial trend of rainfall in UWSRB. Other stations showed different trend type and direction within the same period and these variations showed heterogenous spatial trend of rainfall in UWSRB. Moreover, Autumn season rainfall trend result of some stations showed similar trend type and direction whith Annual, Spring, Summer and Winter rainfall trend result, so these similarities revealed homogeneity of temporal trend of rainfall in UWSRB. However, Summer season rainfall trend result of some stations showed difference trend type and direction from other seasons rainfall trend result, so these variations revealed heterogeneous temporal trend of rainfall in UWSRB.

Table 4.4. Autumn Season rainfall trend

Station	period	Z value	P value	significant level	Sen's slope
Adaba	1985-2018	-1.93	0.05	0.05	-6.32
Agarfa	1985-2018	0.44	0.66	0.05	0.06
Assassa	1985-2018	-1.78	0.07	0.05	-1.72
Dodola	1985-2018	-3.82	0	0.05	-12.55
Kofele	1985-2018	0.89	0.37	0.05	0.55
Meraro	1985-2018	-3.26	0	0.05	-9.01
Robe	1985-2018	1.43	0.15	0.05	4.12

4..2.4. Winter Season rainfall trend

The trend analysis results for winter precipitation is given in Table 4.5. Winter season consists of November, December and January months. For this season Adaba, Assassa, Dodola and Meraro stations showed significant decreasing trend at significant level of 0.05 whith statistic Z = -2.99, -2.046, -2.116 & -2.05 and Sen’s slope = -2.63, -0.469, -2.44 & -3.308 respectively. Agarfa and Kofele stations showed insignificant decreasing trend whith statistic Z = -0.09 & -1.46 and Sen’s slope = -0.01 & -0.19 respectively. Robe station showed insignificant increasing trend whith statistic Z = 0.19 and Sen’s slope = 0.08. According to other findings, in the Upper Part of Wabe Shebelle River Basin(UPWSRB) no significant trend was found in the Bega season(Edo et al., 2021). The winter season mean rainfall of (UPWSRB) showed the statistically insignificant trends with P-value of 0.119 and increased with inclined Sen’s slope value of 1.746 (Beker,2018). From Winter season rainfall trend results of this study some stations showed similar trend type and direction within the same period, so this similarity showed homogenous spatial trend of rainfall in UWSRB. Other stations showed different trend type and direction within the same period and these variations showed heterogenous spatial trend of rainfall in UWSRB. Moreover, Winter season rainfall trend result of some stations showed similar trend type and direction whith Annual, Spring, Summer and Autumn rainfall trend result, so these similarities revealed homogeneity of temporal trend of rainfall in UWSRB. However, Summer season rainfall trend result of some stations showed difference trend type and direction from other seasons rainfall trend result, so these variations revealed heterogeneous temporal trend of rainfall in UWSRB.

Table 4.5. Winter Season rainfall trend

Station	period	Z value	P value	significant level	Sen's slope
Adaba	1985-2018	-2.99	0	0.05	-2.63
Agarfa	1985-2018	-0.09	0.93	0.05	-0.01
Assassa	1985-2018	-2.05	0.04	0.05	-0.47
Dodola	1985-2018	-2.12	0.03	0.05	-2.44
Kofele	1985-2018	-1.46	0.14	0.05	-0.19
Meraro	1985-2018	-2.05	0.04	0.05	-3.31
Robe	1985-2018	0.19	0.85	0.05	0.08

4.3. Monthly rainfall trend

It was observed that there is significant changes in monthly rainfall data in different stations. For June month Adaba, Assassa, Dodola and Meraro stations showed significant decreasing trend with statistic Z = -3.57, -2.64, -2.97, -8.42 respectively and Sen’s slope = -6.91, -1.693, -4.57 & -2.74 respectively. For July month Adaba, Agarfa, Assassa, Dodola and Kofele stations showed significant decreasing trend whith statistics Z = -3.10, -2.061, -2.63, -2.46 & -1.986 and Sen’s slope = -7.67, -6.99, -0.669, -2.23, -3.58 & -2.088 respectively. For August month Adaba, Assassa, Kofele and Meraro stations showed decreasing significant trend whith statistics Z = -2.73, -3.56, -2.46 and -2.72 respectively whith Sen’s slope = -3.66, -2.816 & -3.39 respectively. For September month, Adaba, Assassa & Meraro stations showed significant decreasing trend whith statistics Z = -3.30, -2.98, -2.76 respectively and Sen’s slope = -6.42, -2.37 & -2.97 respectively. For November month Agarfa, Assassa and Kofele showed significant increasing trend whith Statistics Z = 2.65, 10.16 & 2.37 and Sen's slope = 2.94, 0.117 & 0.156 respectively. For December month Robe stations showed significant increasing trend with Statistics Z = 2.16 and Sen's slope = 5.72. For January month Meraro station showed significant decreasing trend whith statistics Z = -2.345 and Sen's slope = -0.138. For February month Adaba and Assassa stations showed significant decreasing trend with Z = -1.97, -2.077 and Sen's slope = -1.03, -0.197 respectively. For April month Robe station showed significant increasing trend whith Z = 2.31 & Sen's slope = 2.16. It was observed that there is no significant trend for October, March and May months during the period of 1985 up to 2.18. Monthly rainfall trend results in some stations showed some difference from annual precipitation trend and seasonal precipitation trend results in the same station. Therefore, monthly precipitation trend results showed heterogenous temporal trend of rainfall in the basin.

4.4. Trend of Average Rainfall of the selected stations

The trend analysis results for average Rainfall of the selected stations is given in Table 4.6. The result showed significant decreasing trend for Summer and Winter season whith statistics Z = -3.17, -2.115 and Sen's slope = -7.336, -0.539 respectively. These significant trend results indicated there was the cause of rainfall trend in the basin which could be the impact of climate variability and anthropogenic interference in the basin. However, there was insignificant decreasing trend for annual period, Spring and Autumn seasons whith statistics Z = -1.927, -0.237, -0.918 and Sen's slope = -8.434, -0.318, -0.695 respectively. This insignificant trend results revealed the trend was occurred randomly (by chance) rather than by other factors. Annual, Spring and Autumn seasons trends of average rainfall of the selected stations showed similar trend type. Summer and Winter seasons showed similar trend type so this similarity demonstrated homogenous temporal trend of rainfall in the UWSRB. Summer and Winter seasons showed difference trend type from annual, Spring and Autumn trend results. Therefore, these variations demonstrated the heterogeneous temporal trend of rainfall in the UWSRB.

Table 4.6. Trend results of Average rainfall of the selected stations.

Period	year	Z	P	Significant level	Sen's slope
Annual	1985-2018	-1.93	0.05	0.05	-8.43
Spring	1985-2018	-0.24	0.81	0.05	-0.32
Summer	1985-2018	-3.17	0.00	0.05	-7.34
Autumn	1985-2018	-0.92	0.36	0.05	-0.70
Winter	1985-2018	-2.12	0.03	0.05	-0.54

4. 5. Annual runoff trend

The trend analysis results for annual runoff is given in Table 4.6. Leliso and Ukuma showed significant increasing trend annually whith statistic Z = 2.75 & 3.02 and Sen's slope = 26.33 & 11.73 respectively. This significant trend showed there was changes in the spatial distribution and temporal variability of atmospheric precipitation, which are linked to climate change and land use land cover change in the basin. Factors that could affect runoff are mainly climate variability and human activities such as construction of water retention structures, deforestation,clearing of land cover, expansion of agricultural land and urbanization(Masih et al., 2011). Particular to hydrologic aspects, the land use and land cover type can affect both the infiltration and runoff amount by following mostly the declines of rainfalls in turn, the runoff of catchment determines the amount of sediment yields, rate of soil loss and erosion and collectively the land degradation of the catchment (Hayicho et al., 2019). Runoff, therefore, becomes a product of the interaction between climate changes and land use land cover change in a basin. The results of this study agree whith the previous study in the basin. The amount of surface runoff in the UWSRB generally increased from 1990 to 2010(Hayicho et al., 2019). From the results, Assassa, Maribo, Wabi & Wayib stations showed insignificant increasing trend whith statistic Z = 0.56, 1.61, 1.57 & 1.21 and Sen's slope = 2.26, 4.83, 1.31 & 1.51 respectively. Furuna station showed insignificant decreasing trend whith statistic Z = -0.79 & Sen's slope = -29.99. This insignificant trend revealed that the trends were occurred randomly rather than caused by other factors. The variations of runoff trend result for different stations showed there were variations of land use/land cover types and other factors in the basin. From annual runoff trend results, some stations showed similar trend type and direction within the same period, so this similarity showed homogeneity of spatial trend of runoff in UWSRB. Other stations showed different trend type and direction within the same period and this variation showed heterogeneity of spatial trend of runoff in UWSRB.

Table 4.7. Annual runoff trend

Station	Period	Z	p	significant level	Sen's slope
Assassa	1985-2015	0.56	0.57	0.05	2.26
Furuna	1989-2015	-0.79	0.43	0.05	-29.99
Leliso	2000-2015	2.75	0.01	0.05	26.33
Maribo	1985-2008	1.61	0.11	0.05	4.83
Ukuma	1985-2015	3.02	0	0.05	11.73
Wabi	1985-2015	1.57	0.12	0.05	1.31
Wayib	2000-2015	1.21	0.22	0.05	1.51

4. 5.1. Spring season runoff trend

The trend analysis results for spring runoff is given in Table 4.7. For this season Leliso showed increasing significant trend whith statistic Z = 2.026 and Sen's slope = 6.73. This significant trend of runoff in the station indicated there was climate variability and change of land use land cover in the basin. Assassa, Furuna, Ukuma and Wabi showed insignificant increasing trend whith statistics Z = 1.48,1.00,1.72 & 0.41 and Sen's slope = 1.22, 16.00, 0.98 & 0.082 respectively. Maribo and Wayib showed insignificant decreasing trend whith statistic Z = -0.62 & -0.40 and Sen's slope = -0.69 & -0.02 respectively. This insignificant trend revealed that the trend was occurred randomly rather than by other factors. The variations of runoff trend result for different stations showed there were variations of land use/land cover types and other factors in the basin. From Spring season runoff trend results, some stations showed similar trend type and direction within the same period, so this similarity showed homogeneity of spatial trend of rainfall in UWSRB. Other stations showed different trend type and direction within the same period and this variation showed heterogeneity of spatial trend of runoff in UWSRB. Moreover, Spring season runoff trend result of some stations showed similar trend type and direction whith Annual, Summer, Autumn and Winter runoff trend results, so these similarities revealed homogeneity of temporal trend of runoff in UWSRB.

However, Spring season runoff trend result of some stations showed difference trend type and direction from other seasons runoff trend result, so these variations revealed heterogeneous temporal trend of runoff in UWSRB.

Table 4.8. Spring season runoff trend

Station	Period	Z	p	significant level	Sen's slope
Assassa	1985-2015	1.48	0.14	0.05	1.22
Furuna	1989-2015	1	0.32	0.05	16
Leliso	2000-2015	2.03	0.04	0.05	6.73
Maribo	1985-2008	-0.62	0.54	0.05	-0.69
Ukuma	1985-2015	1.72	0.08	0.05	0.98
Wabi	1985-2015	0.41	0.68	0.05	0.08
Wayib	2000-2015	-0.4	0.69	0.05	-0.02

4.5.2. Summer season runoff trend

The trend analysis results for Summer runoff is given in Table 4.8. For this season Ukuma and Wabi showed increasing significant trend at significant level of 0.05 whith statistic Z = 2.12 & 2.18 and Sen's slope = 6.07 & 1.15 respectively. This significant trend of runoff in the station indicate there was climate variablity and a significant change of land use land cover in the basin. The Summer season runoff trend showed the same characteristics whith annual and other season trend results. Assassa, Leliso, Maribo & Wayib showed insignificant increasing trend whith statistic Z = 1.33,1.94,1.64 & 0.49 and Sen's slope =1.03,4.78, 3.39 & 0.25 respectively. Furuna showed insignificant decreasing trend whith statistic Z = -1.77 & Sen's slope = -50.42 respectively. This insignificant trend revealed that the cause of the trend is occurred randomly rather than by other factors. The variations of runoff trend result for different stations showed there were variations of land use/land cover types and other factors in the basin. From Summer season runoff trend results, some stations showed similar trend type and direction within the same period, so this similarity showed homogeneity of spatial trend of rainfall in UWSRB. Other stations showed different trend type and direction within the same period and this variation showed heterogeneity of spatial trend of runoff in UWSRB. Moreover, Summer season runoff trend result of some stations showed similar trend type and direction whith Annual, Summer, Autumn and Winter runoff trend results, so these similarities revealed homogeneity of temporal trend of runoff in UWSRB. However, Summer season runoff trend result of some stations showed difference trend type and direction from other seasons runoff trend result, so these variations revealed heterogeneous temporal trend of runoff in UWSRB.

Table. 4.9. Summer season runoff trend

Station	Period	Z	p	Significant level	Sen's slope
Assassa	1985-2015	1.33	0.18	0.05	1.03
Furuna	1989-2015	-1.77	0.07	0.05	-50.42
Leliso	2000-2015	1.94	0.05	0.05	4.78
Maribo	1985-2008	1.64	0.1	0.05	3.39
Ukuma	1985-2015	2.12	0.03	0.05	6.07
Wabi	1985-2015	2.18	0.03	0.05	1.15
Wayib	2000-2015	0.49	0.62	0.05	0.25

4.5.3. Autumn Season runoff trend

The trend analysis results for Autumn runoff is given in Table 4.9. For this season Leliso, Ukuma and Wayib showed significant increasing trend at significant level of 0.05 with statistic Z = 2.84, 6.43 & 2.073 and Sen's slope = 6.85, 3.02& 0.662 respectively. This result showed there were factors which caused this significant trend which could be climate variablity and a change of land use land cover in the basin. Furuna, Maribo & Wabi stations showed insignificant increasing trend whith statistic Z = 1.28, 0.97 & 0.25 and Sen's slope = 24.53, 1.61 & 0.00 respectively. Assassa station showed insignificant decreasing trend whith statistic Z = -0.66 and Sen's slope = -0.50. These insignificant trends revealed that the trend is occurred randomly rather than by other factors. The variations of runoff trend result for different stations showed there were variations of land use/land cover types and other factors in the basin. From Autumn season runoff trend results, some stations showed similar trend type and direction within the same period, so these similarities showed homogeneity of spatial trend of rainfall in UWSRB. Other stations showed different trend type and direction within the same period and this variation showed heterogeneity of spatial trend of runoff in UWSRB. Moreover, Autumn season runoff trend result of some stations showed similar trend type and direction whith Annual, Summer, Spring and Winter runoff trend results, so these similarities revealed homogeneity of temporal trend of runoff in UWSRB. However, Autumn season runoff trend result of some stations showed difference trend type and direction from other seasons runoff trend result, so these variations revealed heterogeneous temporal trend of runoff in UWSRB.

Table 4.10. Autumn Season Runoff trend

Station	Period	Z	p	Significant level	Sen's slope
Assassa	1985-2015	-0.66	0.5	0.05	-0.5
Furuna	1989-2015	1.28	0.2	0.05	24.53
Leliso	2000-2015	2.84	0	0.05	6.85
Maribo	1985-2008	0.97	0.33	0.05	1.61
Ukuma	1985-2015	6.43	0	0.05	3.02
Wabi	1985-2015	0.25	0.805	0.05	0
Wayib	2000-2015	2.07	0.038	0.05	0.66

4.5.4. Winter Season Runoff trend

The trend analysis results for Winter runoff is given in Table 4.10. For this season, Leliso and Ukuma showed significant increasing trend at significant level of 0.05 whith statistic Z = 2.93 & 3.02 and Sen’s slope = 5.48 & 0.495 respectively. These results showed there were factors which caused this significant trend which could be climate variablity and change of land use land cover in the basin. Furuna & Maribo showed insignificant decreasing trend whith statistic Z = 1.25 & 12.34 and Sen’s slope = 1.26 & 0.23 respectively. Assassa, Wabi & Wayib showed insignificant decreasing trend whith statistic Z = -0.22 -0.39 & -1.47 and Sen’s slope = -0.09 -0.40 & -0.01 respectively. These insignificant trends revealed that the trend is occurred randomly rather than by other factors. The variations of runoff trend result for different stations showed there were variations of land use/land cover types and other factors in the basin. From Winter season runoff trend results, some stations showed similar trend type and direction within the same period, so this similarity showed homogeneity of spatial trend of run off in UWSRB. Other stations showed different trend type and direction within the same period and these variations showed heterogeneity of spatial trend of runoff in UWSRB. Moreover, some stations showed similar trend type and direction whith Annual, Summer, Autumn and Spring runoff trend result, so these similarities revealed homogeneity of temporal trend of runoff in UWSRB. However, some stations showed difference trend type and direction from other seasons runoff trend result, so these variations revealed heterogeneity of temporal trend of runoff in UWSRB. From this Winter season runoff trend results, some stations showed similar trend type and direction within the same period, so these similarities showed homogeneity of spatial trend of rainfall in UWSRB. Other stations showed different trend type and direction within the same period and this variation showed heterogeneity of spatial trend of runoff in UWSRB. Moreover, Winter season runoff trend result of some stations showed similar trend type and direction whith Annual, Summer, Spring and Autumn runoff trend results, so these similarities revealed homogeneity of temporal trend of runoff in UWSRB. However, Winter season runoff trend result of some stations showed difference trend type and direction from other seasons runoff trend result, so these variations revealed heterogeneous temporal trend of runoff in UWSRB.

Table 4.11. Winter Season Runoff trend

Station	Period	Z	p	Significant level	Sen's slope
Assassa	1985-2015	-0.22	0.82	0.05	-0.39
Furuna	1989-2015	1.25	0.21	0.05	12.34
Leliso	2000-2015	2.93	0	0.05	5.48
Maribo	1985-2008	1.26	0.2	0.05	0.23
Ukuma	1985-2015	3.02	0	0.05	0.5
Wabi	1985-2015	-1.47	0.14	0.05	-0.1
Wayib	2000-2015	-0.4	0.68	0.05	-0.01

4.6. Monthly Run-off Trend

For January month Leliso & Ukuma showed significant increasing trend whith statistic Z = 2.17 & 3.20 and Sen's slope = 1.86 & 1.26 respectively. For February month Leliso showed significant increasing trend whith statistic Z = 4.097 & Sen's slope = 1.65. Wabi station showed significant decreasing trend whith statistic Z = -2.105 & Sen's slope = -0.064. For March month Wayib showed decreasing significant trend whith Z = -2.17 & S = -0.005. For April and May month all stations showed insignificant trend. For June month Assassa, Furuna & Leliso stations showed significant increasing trend whith statistic Z = 2.00, 4.607, 3.43 and Sen's slope = 5.74, 1.17, 2.509 respectively. For July month Leliso showed significant increasing trend whith statistic Z = 2.30 & Sen's slope = 3.05. For August month Ukuma station showed significant increasing trend whith statistic Z = 3.50 & Sen's slope = 2.6 and Wabi station showed significant increasing trend with Z = 2.21 & Sen's slope = 0.708. For September month Leliso, Ukuma & Wayib showed significant increasing trend whith statistic Z = 4.022, 3.40, 2.79 and Sen's slope = 2.61, 1.94, 0.231 respectively. For October month Furuna station showed significant increasing trend whith statistic Z = 2.151 & Sen's slope = 1.63. For November month Furuna, Leliso, Ukuma & Wayib showed increasing significant increasing trend whith statistic Z = 2.107, 4.022, 1.98, 2.95 and Sen's slope =1.17, 2.406, 0.28, 0.138. For December month Leliso & Ukuma showed significant increasing trend whith statistic Z = 0.138 & 3.42 and Sen's slope = 2.16 & 0.185 and Wabi station showed significant decreasing trend whith statistic Z = -4.306 and Sen's slope = -2.63. Monthly runoff trend results showed homogenous spatial trend, homogenous temporal trend, heterogenous spatial and temporal trend in the basin. Therefore, these variations trend result indicates trend must be analyzed temporally and spatially.

4.7. High flow Trend

The trend analysis results by Modified MK for high stream flow of the selected stations are given in table 4.11. From the results Assassa and Furuna stations showed significant decreasing trend whith statistics Z = -3.38, -2.02 and Sen's slope = -0.035, -0.29 respectively. Ukuma station showed significant increasing trend whith statistics Z = 2.31 and Sen's slope = 0.02. These results showed there were factors which caused this significant trend which could be climate variablity and change of land use land cover in the basin Furuna, Leliso, Maribo, Wabi and Wayib stations showed insignificant trend. These insignificant trends revealed that the trend is occurred randomly rather than by other factors. From high flow trend results, some stations showed similar trend type and direction within the same period, so this similarity showed homogeneity of spatial trend of runoff in UWSRB. Other stations showed different trend type and direction within the same period and this variation showed heterogeneity of spatial trend of high flow in UWSRB.

Table 4.12. High flow trend

Year	station	Z	P	Significant level	Sen's slope
1985-2015	Assassa	-3.38	0	0.05	-0.035
1989-2015	Furuna	-2.02	0.01	0.05	-0.29
2000-2015	Leliso	0.859	0.39	0.05	0.23
1985-2008	Maribo	1.63	0.1	0.05	0.14
1985-2015	Ukuma	2.31	0.02	0.05	0.066
1985-2015	Wabi	0.51	0.608	0.05	0.103
2000-2015	Wayib	1.75	0.079	0.05	7.52

4.8. Low Flow trend

The trend analysis results by Modified MK for low stream flow of the selected stations are given in table 4.12. From the results Leliso station showed significant increasing trend with statistics Z = 3.16 and Sen's slope = 0.036. The all other stations showed insignificant trend of low flow. These insignificant trends revealed the trend was occurred randomly in each station rather than by other factors. From low flow trend results, some stations showed similar trend type and direction within the same period, so this similarity showed homogeneity of spatial trend of runoff in UWSRB. Other stations showed different trend type and direction within the same period and this variation showed heterogeneity of spatial trend of low flow in UWSRB.

Table 4.13. Low flow trend

Year	station	Z	P	Significant level	Sen's slope
1985-2015	Assassa	1.76	0.078	0.05	0.012
1989-2015	Furuna	1.085	0.27	0.05	0.008
2000-2015	Leliso	3.16	0	0.05	0.036
1985-2008	Maribo	-0.193	0.84	0.05	0
1985-2015	Ukuma	0.25	0.79	0.05	0
1985-2015	Wabi	-0.268	0.78	0.05	0
2000-2015	Wayib	-1.8	0.07	0.05	-0.01

4.9. Evaluation of Correlation between rainfall and stream flow

The correlation between rainfall, runoff, high flow and low flow at different stations was evaluated using linear regression model. The correlation coefficient value between rainfall and runoff is given in table 4.13. From the results different correlation coefficient (r) value was obtained for different stations. The result demonstrated no correlation (r = 0.00 – 0.10), weak correlation (r = 0.10 - 0.39) and moderate correlation (r = 0.40 -0.69). The correlation between mean annual rainfall and runoff was, moderate correlation (0.40 < r < 0.69) at Furuna and Wabi station. Weak correlation (0.10 < r < 0.39) at Leliso, Maribo and Wabi stations. No correlation (0.00 < r < 0.10) at Ukuma station and negative correlation at Assassa station. The correlation between Spring mean rainfall and runoff was moderate correlation at Furuna and Wayib stations, weak correlation at Leliso, Maribo and Wabi stations, no correlation at Ukuma station and negative correlation at Assassa station. The correlation between summer rainfall and runoff was moderate at Furuna and Maribo, weak correlation at Leliso, no correlation at Wayib and negative correlation at Assassa, Ukuma and Wabi stations. The correlation between autumn rainfall and runoff was moderate at Furuna station, weak correlation at Assassa and Leliso, no correlation at Ukuma and Wayib station and negative correlation at Wabi station. The correlation between mean winter rainfall and runoff was moderate at Maribo station and Wabi station, weak correlation at Assassa and Leliso, no correlation at Furuna, negative correlation at Ukuma and Wayib station. The correlation between mean annual rainfall and high flow was moderate at Wayib station, weak at Assassa, Furuna, Leliso and Maribo station, no correlation at Ukuma station and negative correlation at Wabi station. The correlation between mean annual rainfall and low flow was weak at Furuna, Leliso and Wabi station, negative correlation at Assassa, Maribo, Ukuma and Wayib station. The weak and moderate correlation in the basin showed some percentage of stream flows in the basin affected by rainfall in the basin. The none correlation between rainfall and stream flow in the basin showed stream flows in the basin hadn't been affected by rainfall in the basin. This result revealed there were other factors which had affected stream flow in the basin which could be land use/ land cover change,soil moisture content, hydraulic structures in the basin and other factors.

Table 4.14. Correlation coefficient between rainfall and runoff

Station	Correlation coefficient of mean rainfall and low flow (r)	Correlation coefficient of mean rainfall and high flow (r)	Correlation coefficient of mean rainfall and runoff				
			Annual	Spring	Summer	Autumn	Winter
Assassa	-0.2918	0.2657	-0.1299	-0.193	-0.197	0.1396	0.1331
Furuna	0.1839	0.2812	0.5476	4.387	0.480	0.5443	0.0169
Leliso	0.1849	0.3375	0.3053	0.364	0.327	0.1740	0.1777
Maribo	-0.1945	0.1627	0.3576	0.201	0.440	0.3975	0.6492
Ukuma	-0.0570	0.0629	0.0019	0.029	-0.112	0.0738	-0.2738
Wabi	0.1632	-0.0445	0.1908	0.349	-0.103	-0.1012	0.7222
Wayib	-0.1979	0.5875	0.4462	0.452	0.048	0.0372	-0.3652

5. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSIONS

In this study, trends of rainfall, runoff, high stream flow and low stream flow was analysed individually for each station using Modified Mann-Kendall statistical method. The trends were analysed temporally (annually, seasonally and monthly). Seven rainfall stations Adaba, Agarfa, Assassa, Dodola, Kofele, Meraro and Robe were selected as the rainfall stations. From Modified Mann-Kendall trend results significant decreasing of rainfall observed annually, seasonally and monthly. For November month only, the three stations Agarfa, Assassa and Kofele showed significant increasing trend and only Robe station showed significant increasing trend for December and November month. Annual and seasonal average rainfall of the selected rainfall stations was estimated and its trend was analysed. Accordingly, there was significant decreasing trend of rainfall in Summer and Winter seasons. However, there wasn't significant trend for annual, Spring and Autumn seasons. Rainfall in the study area showed heterogenous trend temporally. From Modified Mann-Kendall Runoff trend analysis, significant increasing trend of runoff observed annually, seasonally at different station. From high flow trend analysis two stations showed significant decreasing trend and one station showed significant increasing trend. From Modified Mann-Kendall low flow trend analysis only one station showed significant trend. The significant trend results showed there are the cause of trend of rainfall and stream flow in the basin which could be the impact of climate variability and other factors in the basin. The insignificant trend results, revealed that the trend was occurred randomly and not caused by other external factors. In this study the correlation of rainfall, runoff, high flow and low flow was evaluated using Linear regression model to figure out the impact of rainfall on stream flow in the basin. The result demonstrated no correlation r = (0.0 - 0.10), weak correlation (r = 0.10 - 0.39) and moderate correlation (r = 0.40 – 0.69) between mean rainfall and streamflow annually and seasonally at different stations, where r is correlation coefficient value. None correlation of rainfall and stream flow demonstrated stream flow in the basin had been affected by other factors rather than rainfall in the basin. The moderate correlation showed some percentage of stream flow had been affected by rainfall contributed to the basin. It was concluded that as the basin has stored water and this stored water has to be exploited for different demand in the basin

5.2. RECOMMENDATIONS

In this study significant decreasing of rainfall was observed. This significant decreasing of rainfall may cause Drought and water shortage problem in the basin. Therefore, water basin management sector has to consider this problem to take the important remedy. High flow at Furuna station showed significant increasing trend and this increasing of high flow has negative impact on the water infrastructure and other property available in the basin. Therefore, this issue also has to taken into consideration by the organization it concerns. Since, Annual, seasonal and monthly rainfall and stream flow are studied using few stations, it is essential to increase the spatial coverage by including more number of stations. Factors that affect the hydrological time series like; land use/land cover change, water diversion structrures, wastewater discharge in the basin etc. must have to be considered and the sensitivity analysis has to be done to get the degree of effect of each factor. Additionally, the stations in the basin showed heterogenous characteristics, so it is essential to divided the basin in to sub basin to study hydro metrological trend in the basin.

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Appendixes

Appendix A: Rainfall observed at each station

A-1. Annual rainfall observed at each station

Year	Adaba	Agarfa	Assassa	Dodola	Kofele	Meraro	Robe	Average
1985	1491.41	118.88	1030.96	1661.92	1087.06	917.91	1233.31	1077.35
1986	2005.30	358.80	1168.57	2104.70	1227.75	1252.62	1642.29	1394.29
1987	1195.75	75.84	797.05	1634.60	1106.46	611.36	1274.55	956.51
1988	1664.13	269.62	1135.17	2008.12	1228.05	1007.59	1657.53	1281.46
1989	1556.36	271.80	1010.44	1793.91	1016.14	1006.56	1405.80	1151.57
1990	1589.86	179.41	1017.94	2010.26	1087.75	933.54	1416.88	1176.52
1991	1783.25	122.31	1099.12	2097.82	1262.59	1000.11	1295.53	1237.25
1992	1374.58	61.48	827.06	1638.62	868.05	761.36	1325.63	979.54
-+1993	1753.58	112.72	1207.44	2084.12	1305.61	1079.88	1583.63	1303.85
1994	1671.79	252.99	1070.11	1988.82	1160.44	976.98	1480.31	1228.78
1995	1151.02	46.54	665.31	1515.52	795.63	599.90	1139.28	844.74
1996	1660.40	180.45	1162.22	2009.40	1359.52	958.23	1549.57	1268.54
1997	1638.76	261.85	1102.54	2065.78	1340.22	1022.41	1734.49	1309.44
1998	1934.73	286.09	1264.41	2127.68	1324.91	1141.03	1778.04	1408.12
1999	1741.03	155.41	1121.05	2199.08	1156.83	1001.94	1612.49	1283.97
2000	2127.34	170.86	1079.04	2762.42	1404.03	1049.17	1260.17	1407.58
2001	1484.04	59.04	769.03	1848.54	902.33	730.01	1102.01	985.00
2002	1144.04	90.79	530.41	1471.43	642.54	594.54	716.75	741.50
2003	1130.06	70.68	703.67	1325.28	722.52	677.44	1250.27	839.99
2004	1070.90	99.74	659.69	1315.88	698.06	671.18	1308.50	831.99
2005	1332.66	200.67	893.33	1726.39	1011.94	843.79	1609.19	1088.28
2006	1295.09	103.89	788.65	1496.37	921.78	764.63	1287.23	951.09
2007	1453.87	117.47	844.08	1730.52	993.62	835.92	1522.82	1071.18
2008	1062.42	100.35	627.54	1418.20	725.27	598.33	1255.29	826.77
2009	920.66	134.29	667.23	1190.80	646.58	611.16	1226.08	770.97
2010	920.66	431.94	1465.39	2422.17	1588.51	1408.03	2498.93	1533.66
2011	309.69	32.52	671.99	1268.02	1193.67	162.03	3009.06	949.57
2012	363.42	40.35	644.13	1440.00	974.93	237.73	3141.50	977.44
2013	551.62	101.17	921.12	1907.12	1161.51	298.22	4100.25	1291.57
2014	324.07	64.54	538.63	1266.01	797.56	209.39	2712.51	844.67
2015	493.89	238.84	840.99	1574.36	957.70	183.89	1451.92	874.62
2016	325.07	217.32	816.36	1304.50	859.44	757.48	1495.04	908.36

2017	411.61	172.73	735.81	1806.48	685.92	804.21	1438.69	940.64
2018	326.07	139.16	647.38	1845.09	1117.55	800.27	1461.88	1001.89

A-2. Mean monthly Rainfall

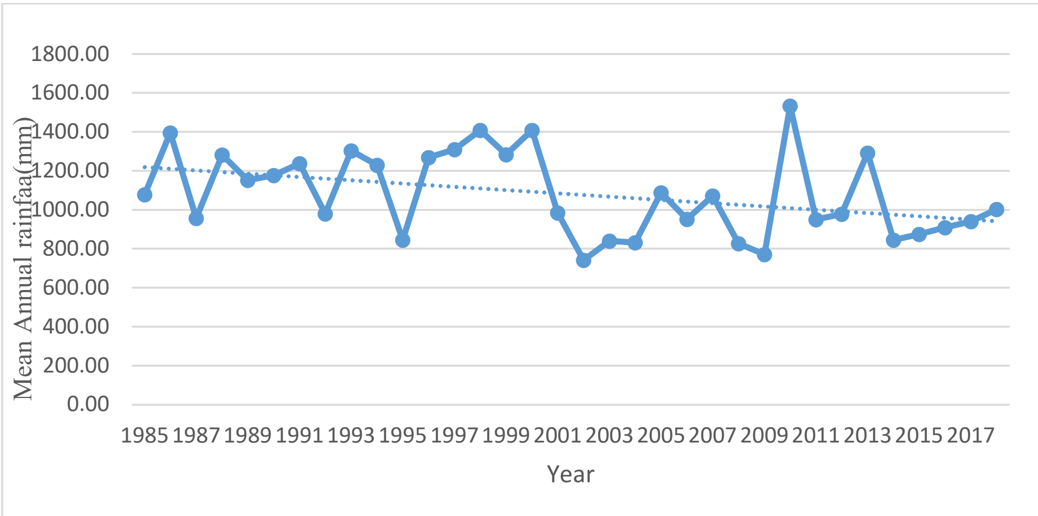
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	16.7	1.5	21.4	88.3	194.5	196.3	178.9	161.4	128.3	78.4	11.7	0.1
1986	1.1	27.7	20.0	232.5	153.3	210.6	237.9	273.2	201.9	29.0	4.3	2.8
1987	2.3	38.7	53.8	15.6	155.4	209.1	163.6	128.3	117.9	62.0	8.4	1.6
1988	3.4	9.9	12.4	228.0	28.1	155.5	219.4	241.4	265.7	114.2	1.2	2.3
1989	23.7	15.9	65.9	248.9	45.7	145.4	197.4	178.8	158.8	45.8	13.3	11.6
1990	3.4	42.9	37.9	198.1	43.5	131.9	248.5	250.6	168.5	36.4	4.1	10.1
1991	7.1	18.9	75.6	37.3	44.6	167.3	262.6	391.5	188.3	24.4	4.3	14.2
1992	52.7	10.5	20.4	39.0	37.6	111.7	275.3	189.0	154.7	60.2	18.7	9.2
1993	19.9	39.9	4.2	73.2	182.5	154.6	255.8	239.6	187.2	137.0	7.0	2.9
1994	0.1	1.8	18.3	113.7	131.0	301.1	256.8	212.8	148.7	26.2	15.8	2.5
1995	1.5	17.0	26.9	60.8	82.7	47.1	181.5	151.9	223.6	38.1	3.4	10.1
1996	19.6	4.5	32.5	61.6	142.6	179.7	289.8	241.4	236.1	41.0	16.7	3.2
1997	17.3	0.0	62.3	147.1	43.6	110.3	251.4	333.7	92.1	154.4	88.3	8.9
1998	40.2	29.1	26.9	78.3	222.4	161.1	264.5	219.6	165.1	191.7	6.1	3.2
1999	3.4	2.8	94.5	92.2	108.9	167.5	298.2	195.7	121.1	180.8	8.5	9.8
2000	0.4	1.6	3.4	110.4	221.4	139.7	319.1	269.9	163.4	150.8	22.6	3.8
2001	4.3	6.6	49.5	61.3	97.8	141.3	217.0	245.6	110.4	41.4	5.4	4.4
2002	16.4	2.3	35.5	88.1	51.7	96.1	112.4	213.2	68.8	34.7	2.4	19.8
2003	4.2	4.1	9.9	141.7	15.5	142.9	229.1	163.5	93.0	16.7	5.4	8.9
2004	19.3	4.3	35.4	146.8	20.4	114.0	163.5	161.1	66.0	74.5	16.6	9.7
2005	5.6	8.1	16.5	161.3	240.1	103.9	178.9	134.8	190.3	37.8	10.5	0.5
2006	1.9	11.8	17.7	156.5	28.1	127.1	182.3	221.5	82.5	101.4	8.9	10.6
2007	6.8	11.3	17.8	129.2	120.4	196.3	203.0	106.3	259.1	13.6	7.1	0.2
2008	1.4	1.1	1.3	43.2	50.5	177.5	207.4	149.9	87.9	47.2	58.1	1.3
2009	21.3	4.5	63.7	105.1	37.3	39.1	136.6	117.1	76.5	135.6	8.0	24.0
2010	7.1	108.7	203.1	266.1	260.2	104.1	218.6	274.4	187.9	48.3	4.8	7.1
2011	2.4	2.0	17.5	34.1	188.8	120.1	213.8	177.2	157.6	20.9	13.3	0.4
2012	0.5	0.0	9.6	140.9	74.6	99.7	205.2	197.7	177.4	55.7	14.1	0.8
2013	1.3	0.8	92.9	141.4	184.2	154.8	218.6	166.4	166.1	107.7	53.8	1.7
2014	3.2	18.3	44.9	55.3	104.3	72.4	142.0	164.0	148.2	66.3	23.1	1.9
2015	4.1	7.4	13.1	90.5	90.7	126.2	140.7	118.5	110.4	40.0	7.8	0.7
2016	4.3	6.5	18.7	102.2	80.2	116.6	146.6	119.2	117.9	47.9	13.3	5.6

2017	4.1	11.0	32.0	112.0	93.2	85.4	139.8	140.5	114.7	56.2	11.3	6.3
2018	4.2	14.0	44.7	111.0	117.4	90.4	142.8	148.8	114.8	59.6	8.0	3.3

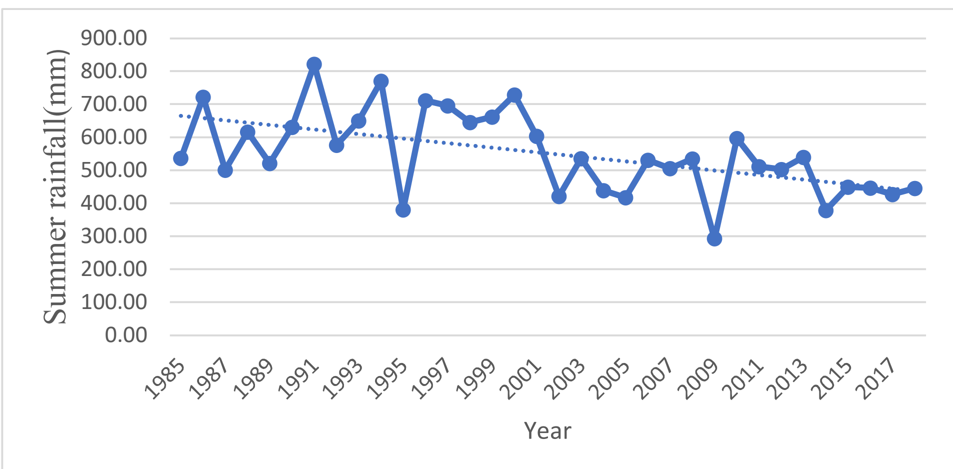
A-3. Annual and seasonal mean rainfall

year	Annual	spring	summer	Autumn	Winter
1985	1077.35	271.15	536.59	218.35	28.89
1986	1394.29	376.02	721.70	235.09	43.95
1987	956.51	202.97	500.96	188.24	14.86
1988	1281.46	258.18	616.27	381.02	41.94
1989	1151.57	345.02	521.53	217.93	58.36
1990	1176.52	263.47	630.92	209.02	36.72
1991	1237.25	147.56	821.51	216.96	78.49
1992	979.54	86.94	576.03	233.59	69.46
1993	1303.85	207.75	650.06	331.16	4.76
1994	1228.78	221.87	770.65	190.61	21.09
1995	844.74	154.00	380.48	265.15	34.20
1996	1268.54	209.14	710.85	293.76	20.51
1997	1309.44	239.13	695.38	334.73	78.30
1998	1408.12	286.56	645.16	362.89	9.43
1999	1283.97	260.09	661.29	310.38	12.57
2000	1407.58	268.57	728.79	336.81	15.68
2001	985.00	177.12	603.85	157.17	23.06
2002	741.50	153.03	421.59	105.86	28.41
2003	839.99	156.96	535.54	115.07	37.68
2004	831.99	191.44	438.63	157.08	23.64
2005	1088.28	363.66	417.61	238.59	14.27
2006	951.09	188.76	530.89	192.82	29.43
2007	1071.18	231.30	505.58	279.83	2.65
2008	826.77	75.26	534.82	193.18	27.20
2009	770.97	185.78	292.80	220.13	141.90
2010	1533.66	661.43	597.12	241.07	11.83
2011	949.57	203.71	511.05	191.86	2.36
2012	977.44	208.58	502.57	247.19	4.12
2013	1291.57	387.01	539.82	327.56	25.12
2014	844.67	190.44	378.42	237.59	17.10
2015	874.62	194.08	449.61	184.53	13.00
2016	908.36	211.33	446.09	208.83	23.82
2017	940.64	225.16	426.60	212.51	28.45
2018	1001.89	257.58	445.66	212.85	22.42

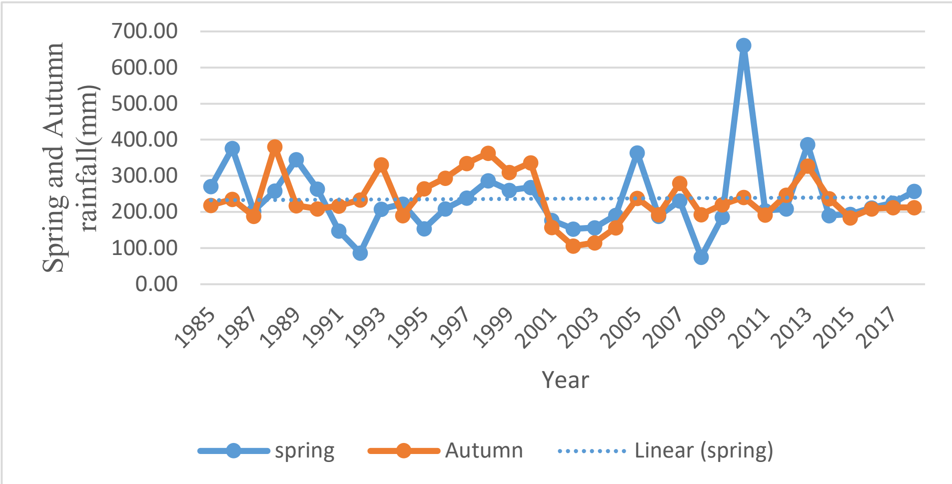
A-4. Mean annual rainfall



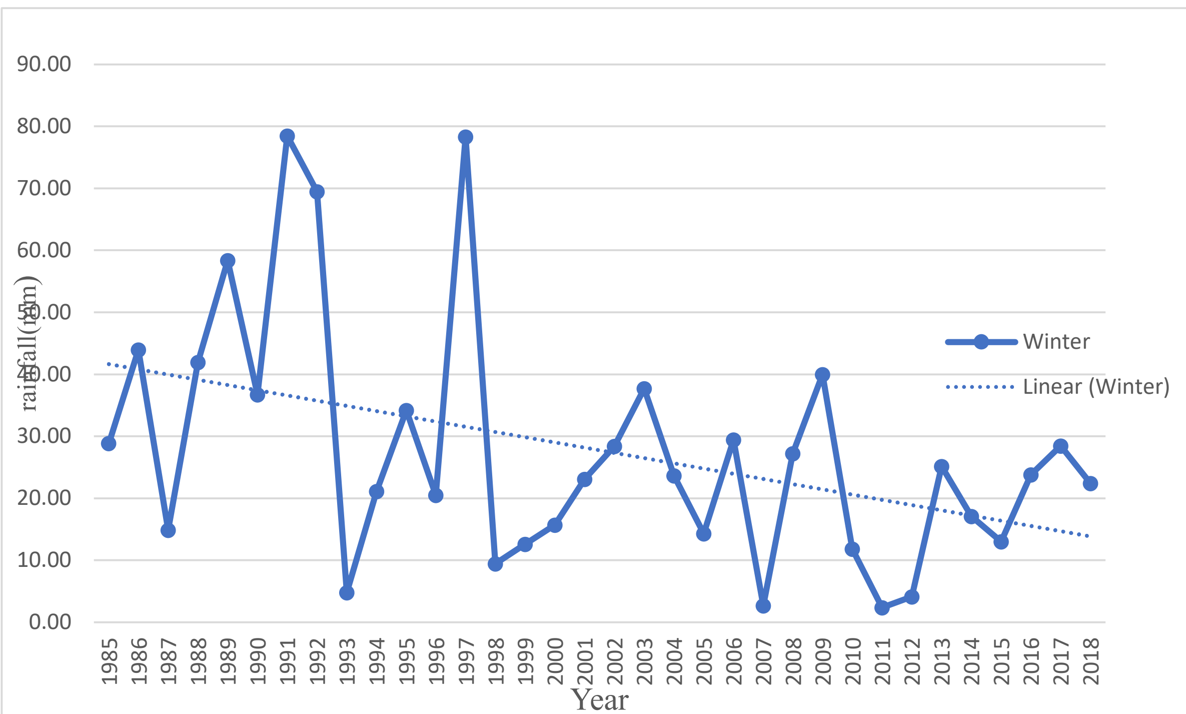
A-5. Summer mean rainfall



A-6. Spring and Autumn mean rainfall



A-7. Winter mean Rainfall



Appendix B: Annual and Seasonal rainfall trend

Station	Time	Type of trend	Direction
Adaba	Annual	significant	Decreasing
	Spring	significant	Decreasing
	Summer	significant	Decreasing
	Autumn	Insignificant	Decreasing
	Winter	Insignificant	Decreasing
Agarfa	Annual	Insignificant	Decreasing
	Spring	Insignificant	Increasing
	Summer	Insignificant	Increasing
	Autumn	Insignificant	Increasing
	Winter	Insignificant	Decreasing
Assassa	Annual	Significant	Decreasing
	Spring	Insignificant	Decreasing
	Summer	Significant	Decreasing
	Autumn	Insignificant	Decreasing
	winter	Significant	Decreasing
Dodola	Annual	Significant	Decreasing
	Spring	Insignificant	Decreasing
	Summer	Insignificant	Decreasing
	Autumn	Significant	Decreasing
	winter	Significant	Decreasing
Kofele	Annual	Insignificant	Decreasing
	Spring	Insignificant	Decreasing
	Summer	Significant	Decreasing
	Autumn	Insignificant	Increasing
	Winter	Insignificant	Decreasing
Meraro	Annual	Significant	Decreasing
	Spring	Significant	Decreasing
	Summer	Insignificant	Decreasing
	Autumn	Insignificant	Decreasing
	Winter	Significant	Decreasing

Appendix C: Annual runoff (Mm3)

Year	Assassa	Maribo	Ukuma	Wabi	Furuna	Leliso	Wayib
1985	9.95	77.37	41.21	238.57			
1986	27.03	79.78	34.78	218.72			
1987	32.85	88.11	36.97	269.67			
1988	41.62	88.85	31.68	257.80			
1989	35.24	83.48	36.82	163.07	97.20		
1990	37.71	83.14	41.83	207.70	107.98		
1991	36.42	113.85	24.21	127.53	110.66		
1992	48.99	113.44	35.16	269.60	106.18		
1993	32.14	149.94	41.54	283.89	107.72		
1994	33.37	99.38	44.34	245.30	107.61		
1995	38.55	67.82	33.04	190.32	119.65		
1996	38.04	107.77	45.10	284.59	111.38		
1997	37.64	125.53	29.96	201.10	87.61		
1998	39.01	140.54	59.16	285.39	124.22		
1999	37.53	94.21	25.95	190.07	97.53		
2000	38.86	90.26	39.53	196.83	89.35	52.28	132.30
2001	39.13	123.10	40.55	205.28	96.01	40.53	93.71
2002	40.11	62.64	19.63	140.41	76.21	26.30	52.49
2003	39.61	94.35	29.95	149.25	96.74	47.39	127.21
2004	42.51	83.86	40.29	223.78	87.33	40.05	111.31
2005	42.03	113.91	53.85	233.52	91.53	62.33	182.40
2006	41.40	129.11	54.15	298.21	94.19	67.02	278.12
2007	41.56	111.68	65.02	343.20	87.90	53.69	209.49
2008	41.25	97.53	55.05	315.82	80.61	44.57	270.32
2009	30.71	0.00	43.78	193.53	72.96	31.14	243.84
2010	30.78	0.00	87.25	273.65	143.58	64.12	1324.43
2011	31.19	0.00	83.02	192.94	111.90	86.35	25.24
2012	33.10	0.00	69.52	189.49	103.88	82.64	73.95
2013	36.55	0.00	105.49	358.92	122.25	96.76	476.88
2014	32.87	0.00	96.71	277.91	101.78	94.93	143.73
2015	32.76	0.00	93.22	232.65	107.11	77.17	170.20

Appendix D : Annual and seasonal runoff trend

Station	Time	Type of trend	direction
Assassa	Annual	Insignificant	Increasing
	Spring	Insignificant	Increasing
	Summer	Insignificant	Increasing
	Autumn	Insignificant	decreasing
	Winter	Insignificant	decreasing
Furuna	Annual	Insignificant	decreasing
	Spring	Insignificant	Increasing
	Summer	Insignificant	decreasing
	Autumn	Insignificant	Increasing
	Winter	Insignificant	Increasing
Leliso	Annual	Significant	Increasing
	Spring	Significant	Increasing
	Summer	Insignificant	Increasing
	Autumn	Significant	`Increasing
	winter	Significant	`Increasing
Maribo	Annual	Insignificant	Increasing
	Spring	Insignificant	decreasing
	Summer	Insignificant	Increasing
	Autumn	Insignificant	Increasing
	Winter	Significant	Increasing
Ukuma	Annual	Significant	`Increasing
	Spring	Insignificant	Increasing
	Summer	Significant	Increasing
	Autumn	Significant	Increasing
	Winter	Significant	decreasing
Wabi	Annual	Insignificant	Increasing
	Spring	Insignificant	Increasing
	Summer	Significant	Increasing
	Autumn	Significant	decreasing
	Winter	Insignificant	decreasing

Appendix E. High Flow (m3/s)

year	Assassa	Furuna	Leliso	Maribo	Ukuma	Wabi	Wayib
1985	0.46			11.20	10.63	41.38	
1986	6.05			13.82	9.08	54.27	
1987	1.31			18.62	7.80	59.48	
1988	12.91			19.38	8.89	49.24	
1989	1.96	16.19		14.07	7.95	31.68	
1990	1.81	15.24		14.07	9.89	46.13	
1991	2.43	15.41		19.76	6.46	22.92	
1992	2.82	19.02		24.83	9.85	55.21	
1993	2.23	14.06		20.65	6.53	38.87	
1994	1.44	13.94		19.15	9.04	43.08	
1995	1.74	16.26		19.65	8.99	36.41	
1996	1.64	13.40		20.07	9.79	62.39	
1997	1.67	6.09		27.45	10.21	39.28	
1998	1.99	12.55		20.32	11.20	62.88	
1999	1.82	6.56		27.58	7.06	58.52	
2000	1.49	12.11	15.18	17.35	9.50	39.70	78.93
2001	2.17	9.98	8.94	21.81	10.32	38.87	27.39
2002	1.73	3.34	4.72	12.06	5.87	37.23	16.78
2003	1.46	11.12	18.94	17.79	7.03	29.39	36.57
2004	1.55	7.67	10.34	19.73	8.35	72.43	28.71
2005	1.43	7.33	20.29	19.28	7.75	34.81	61.33
2006	1.56	9.06	12.37	18.46	9.69	46.57	65.15
2007	2.22	6.64	11.59	21.06	11.22	36.01	111.42
2008	1.66	10.42	16.38	20.00	10.69	68.35	97.98
2009	1.13	5.14	13.19		9.72	66.34	134.74
2010	1.13	13.17	16.05		10.55	39.91	268.08
2011	1.10	13.45	16.05		11.19	66.54	4.30
2012	1.26	6.11	15.75		9.79	25.21	9.15
2013	1.33	12.85	16.05		10.64	68.68	176.28
2014	1.18	13.07	14.30		10.05	34.33	92.41
2015	1.23	11.37	14.30		11.55	50.07	134.34

Appendix F. Low Flow(m3/s)

year	Assassa	Furuna	Leliso	Maribo	Ukuma	Wabi	Wayib
1985	0.225			0.103	0.003	1.293	
1986	0.281			0.205	0.005	1.293	
1987	0.882			0.179	0.021	1.42	
1988	0.882			0.155	0.009	1.293	
1989	0.808	1.973		0.079	0.015	1.42	
1990	0.79	2.026		0.163	0.037	1.551	
1991	0.757	1.616		0.103	0.005	1.42	
1992	0.8254	1.905		0.176	0.006	1.42	
1993	0.818	2.005		0.138	0.025	1.293	
1994	0.949	2.005		0.1	0.007	1.42	
1995	1.046	1.672		0.044	0.034	1.42	
1996	1.152	1.672		0.079	0.048	1.42	
1997	1.078	2.031		0.018	0.009	1.293	
1998	1.13	2.201		0.095	0.057	1.42	
1999	0.986	2.087		0.046	0.01	1.293	
2000	1.027	1.882	0.202	0.029	0	1.17	0.16
2001	1.172	2.143	0.202	0.06	0.002	1.42	0.205
2002	1.2025	2.087	0.269	0.06	0	1.42	0.273
2003	1.197	2.15	0.269	0.123	0.002	0.152	0.288
2004	1.213	2.087	0.479	0.205	0	1.42	0.356
2005	1.286	1.934	0.479	0.176	0.028	1.42	0.34
2006	1.223	1.975	0.479	0.148	0.009	1.293	0.163
2007	1.213	1.928	0.432	0.205	0.036	1.293	0.256
2008	1.052	1.761	0.345	0.158	0	1.17	0
2009	0.89	1.159	0.237		0.153	1.42	0.178
2010	0.89	1.928	0.389		0.26275	1.456	0.146
2011	0.908	2.692	0.876		0.252	1.326	0
2012	0.917	2.559	0.8765		0.003	1.2	0.063
2013	0.935	2.437	1.09575		0	1.326	0.011
2014	0.99	0.253	0		0.376	1.326	0.206
2015	0.981	2.377	0.795		0	1.456	0.1095

Appendix G. Percentage of station showed Significant trend Annually and Seasonally

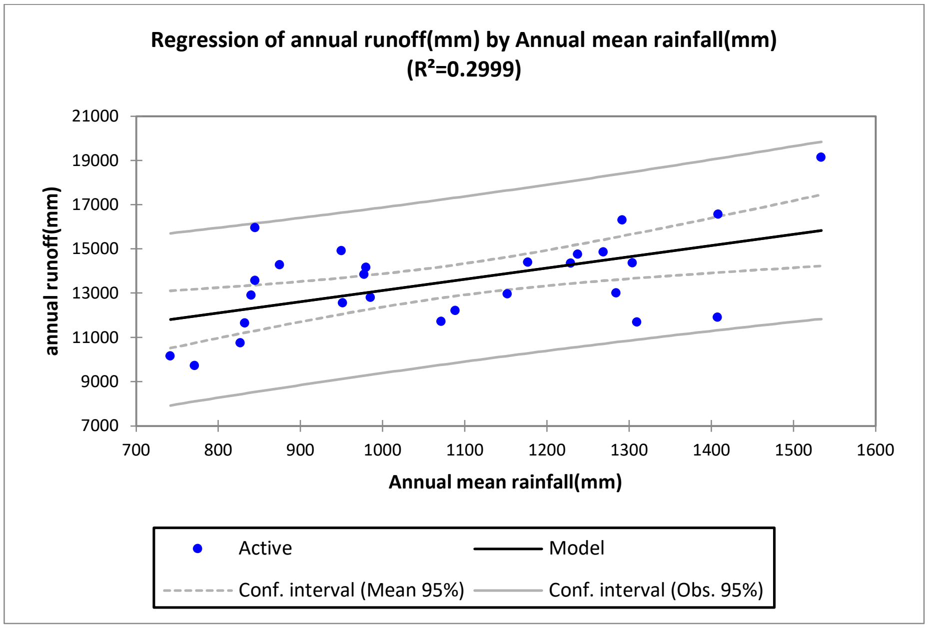
Parameters	Percentage of stations showed Significant trend				
	Annual	Spring	Summer	Autumn	Winter
Precipitation	57%	28.6	43	28.6	57
Runoff	28.57	14.28	28.57	42.85	28.57
Max flow	28.57				
Mini flow	57.14				

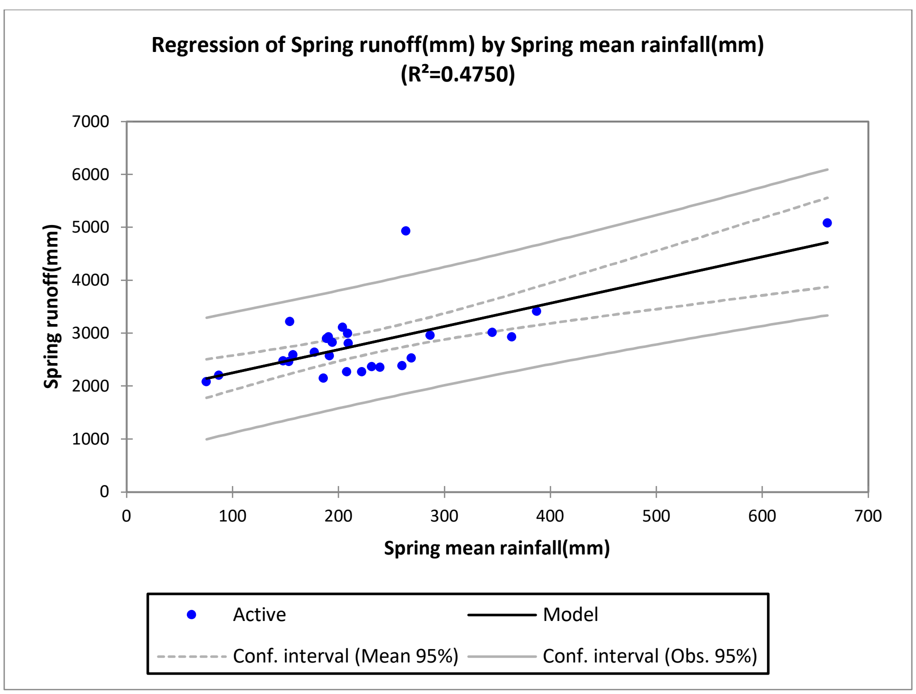
Appendix H. Percentage of station showed Significant trend monthly

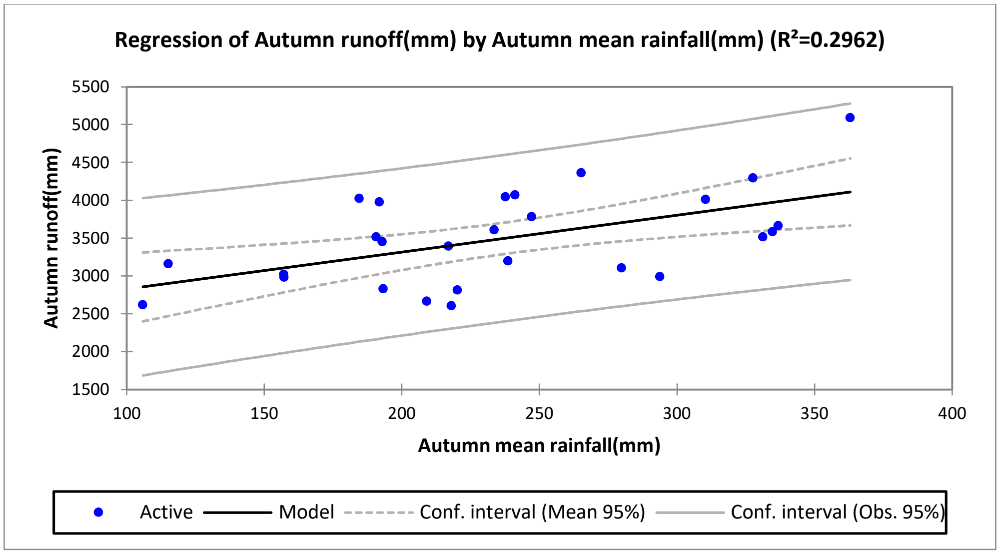
Parameters	Percentage of station showed Significant trend											
	Jan	Feb	March	April	May	June	July	August	Septe	Octo	Nov	Dece
Rainfall	16.66	16.7	0%	0%	0	50%	83	50%	33	0%	50%	33%
Runoff	28.6%	28.6	16.67	16.7	16.7	42.85	28.6	28.57	42.85	14	7.14	28.57

Appendix I. Linear Regression of Rainfall and Runoff

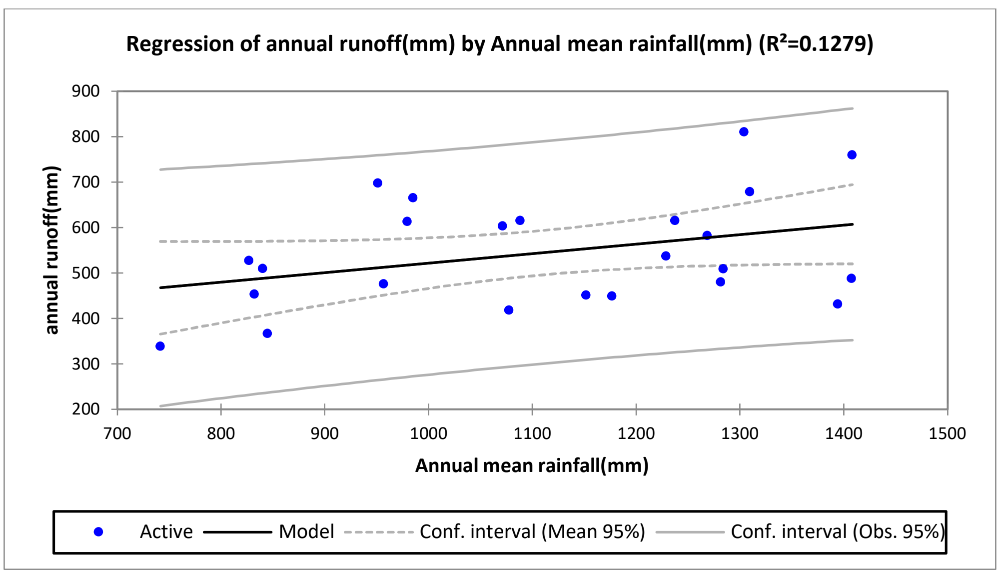
I-1. Linear Regression of Rainfall and Runoff at Furuna station

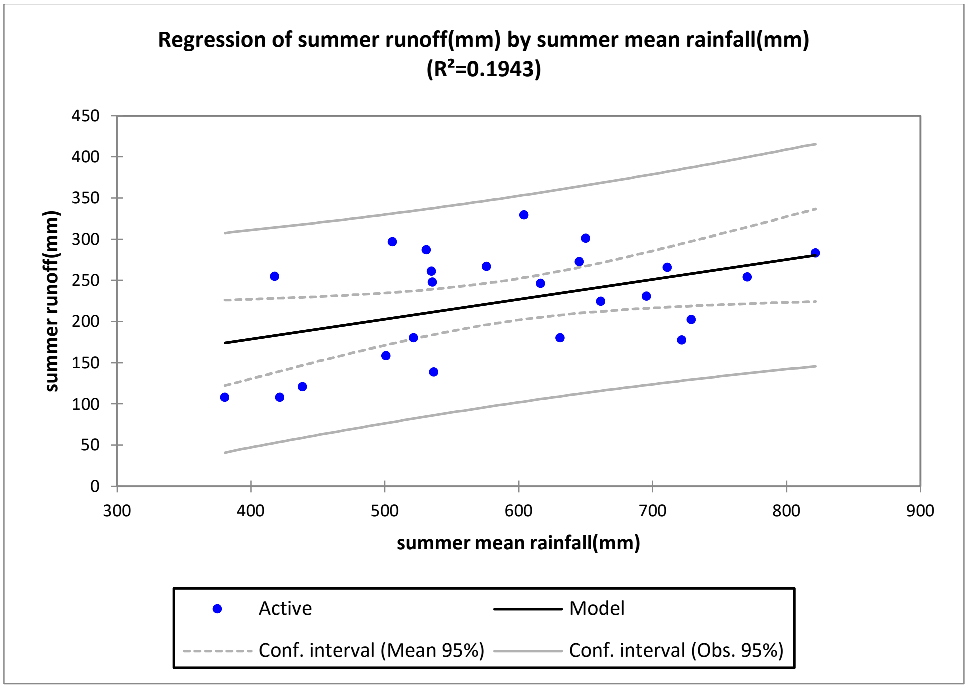




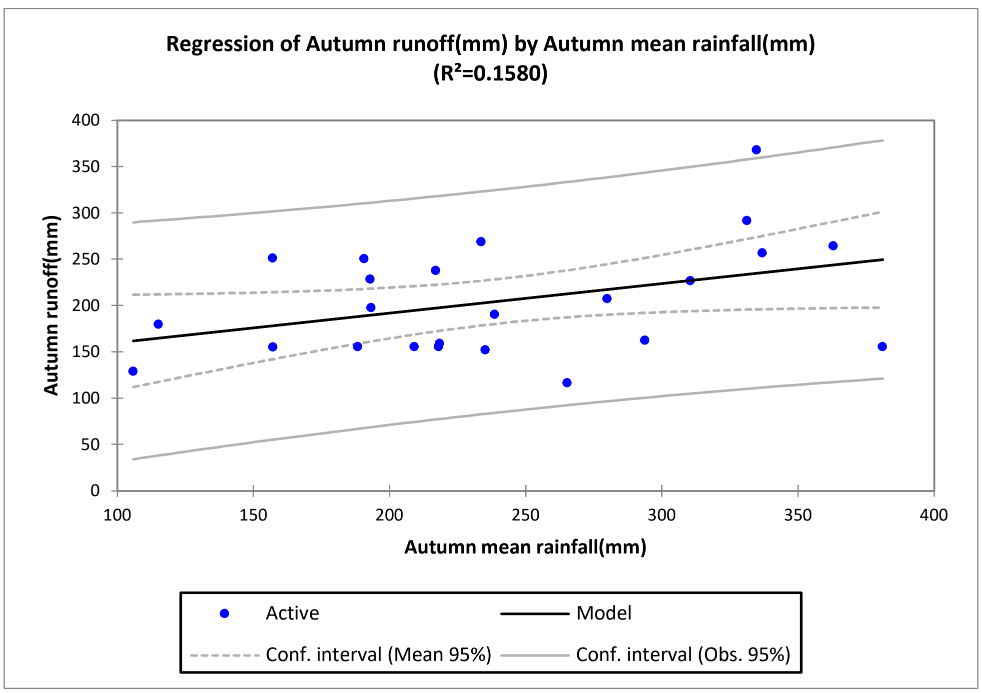


I-2. Linear Regression of Rainfall and Runoff at Maribo station

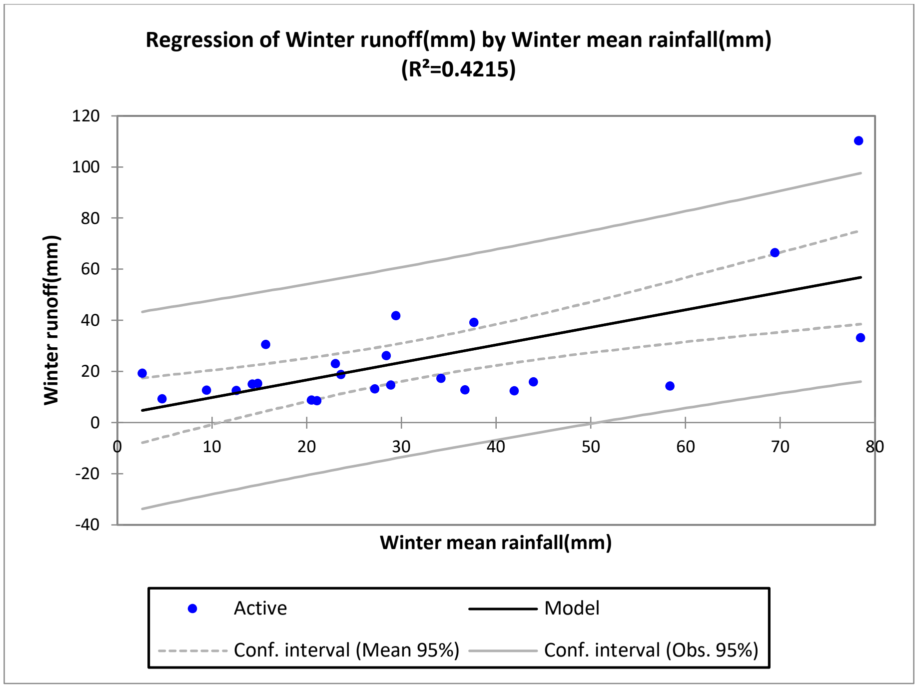




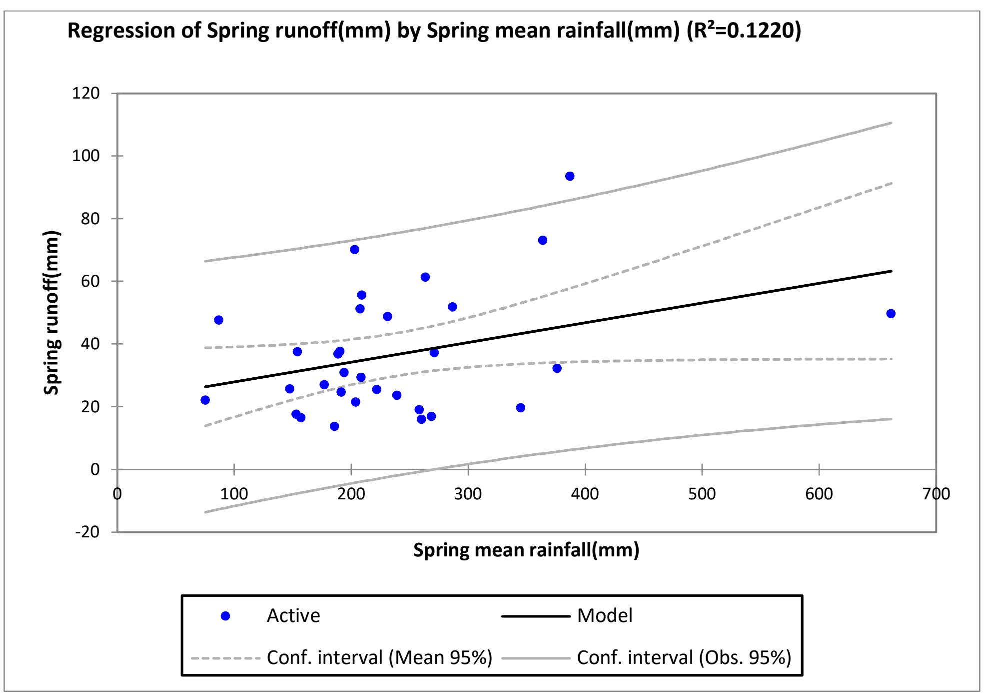
Regression of summer runoff(mm) by summer mean rainfall(mm)
(R²=0.1943)
summer runoff(mm)
summer mean rainfall(mm)
0
50
100
150
200
250
300
350
400
450
300
400
500
600
700
800
900
Active
Model
Conf. interval (Mean 95%)
Conf. interval (Obs. 95%)

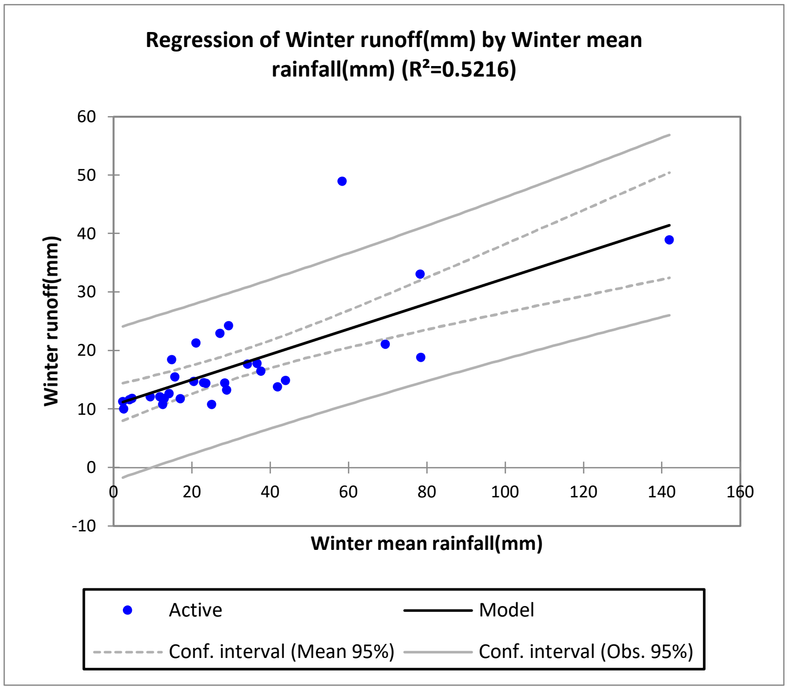


Regression of Autumn runoff(mm) by Autumn mean rainfall(mm)
(R²=0.1580)
Autumn runoff(mm)
Autumn mean rainfall(mm)
0
50
100
150
200
250
300
350
400
100
150
200
250
300
350
400
Active
Model
Conf. interval (Mean 95%)
Conf. interval (Obs. 95%)

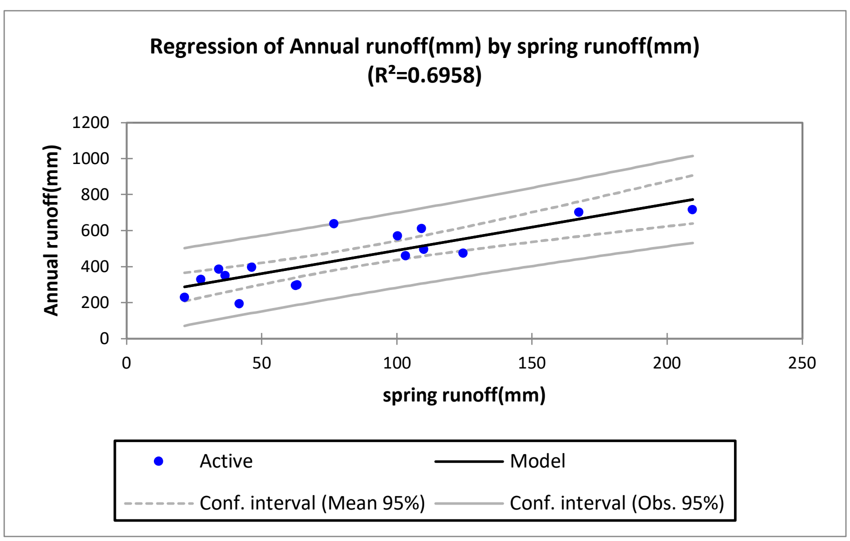


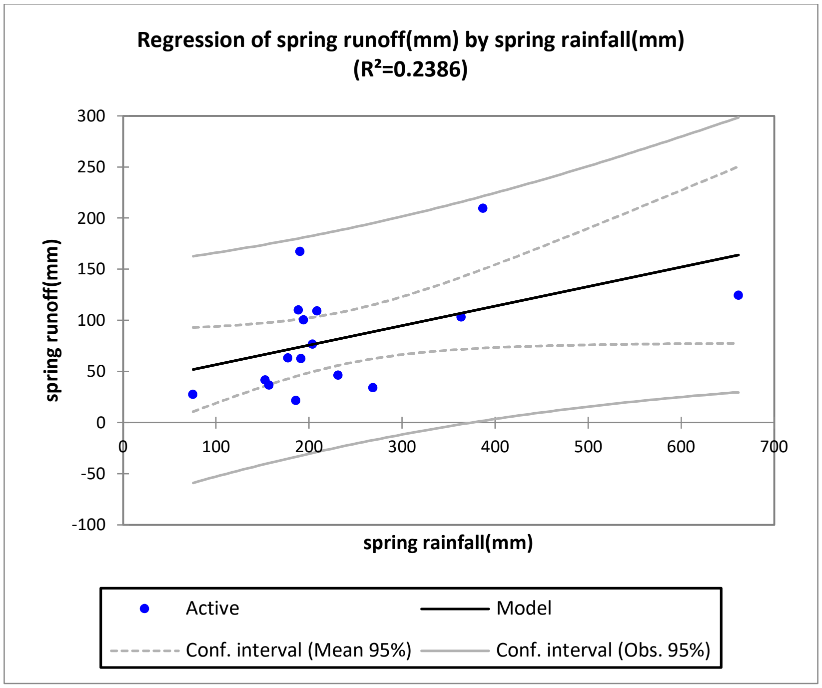
I-3. Linear Regression of Rainfall and Runoff at Wabi Station

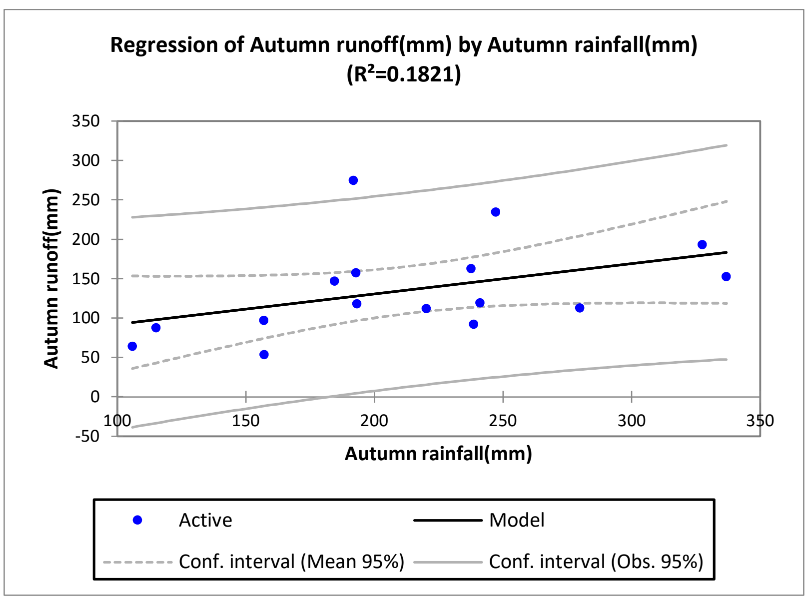




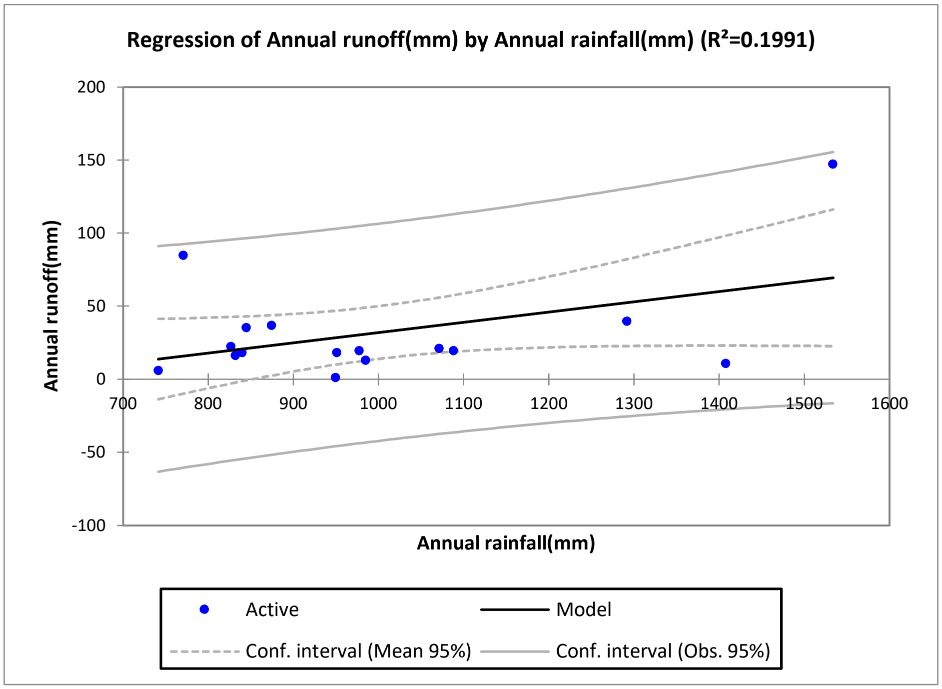
I-4. Linear Regression of Rainfall and Runoff at Leliso

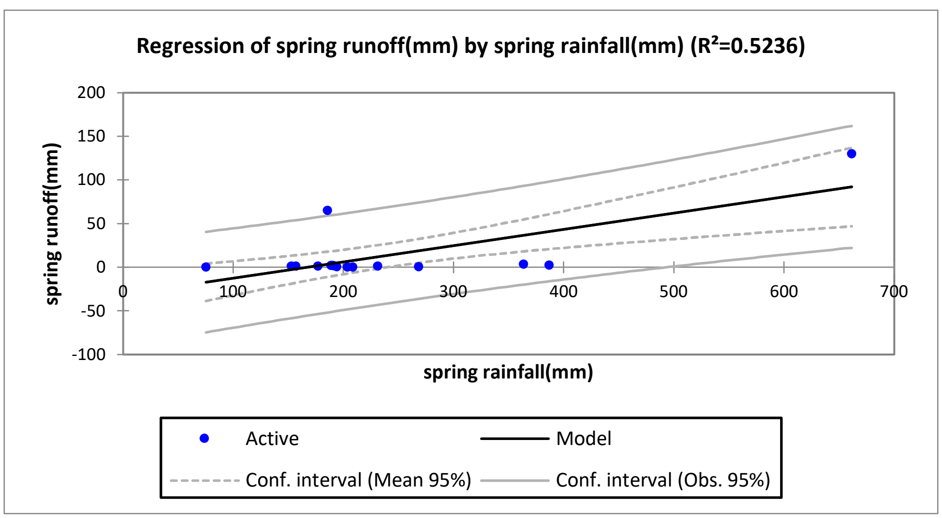


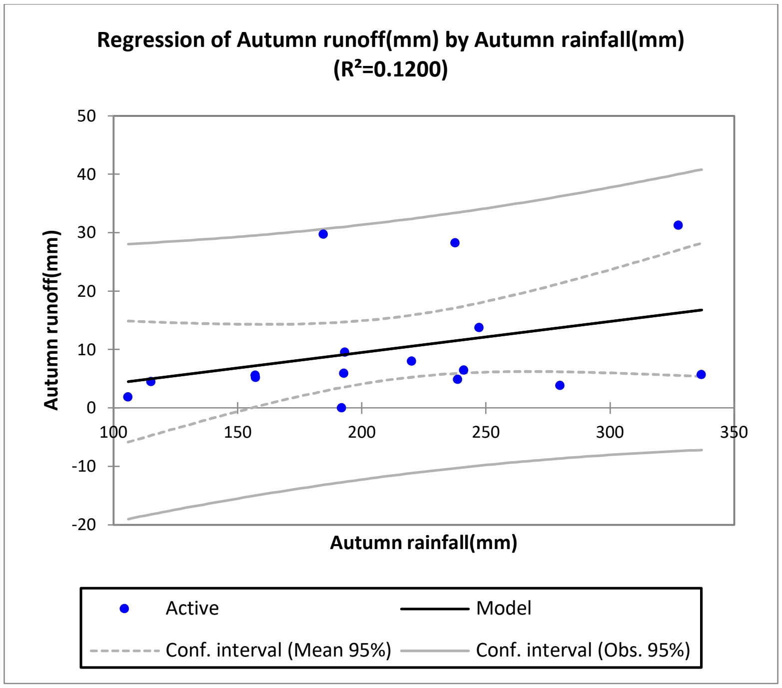

Regression of spring runoff(mm) by spring rainfall(mm)
(R^2=0.2386)
spring runoff(mm)
spring rainfall(mm)
300
250
200
150
100
50
0
-50
-100
0
100
200
300
400
500
600
700
Active
Model
Conf. interval (Mean 95%)
Conf. interval (Obs. 95%)


Regression of Autumn runoff(mm) by Autumn rainfall(mm)
(R^2=0.1821)
Autumn runoff(mm)
Autumn rainfall(mm)
350
300
250
200
150
100
50
0
-50
100
150
200
250
300
350
Active
Model
Conf. interval (Mean 95%)
Conf. interval (Obs. 95%)

I-5. Linear Regression of Rainfall and Runoff at Wayib






Regression of Autumn runoff(mm) by Autumn rainfall(mm)
(R²=0.1200)
50
40
30
20
10
0
-10
-20
100
150
200
250
300
350
Autumn runoff(mm)
Autumn rainfall(mm)
Active
Model
Conf. interval (Mean 95%)
Conf. interval (Obs. 95%)