

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING



SPATIO-TEMPORAL ANALYSIS OF RAINFALL TREND

A Thesis in Hydraulic Engineering

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A Thesis

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

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ABSTRACT

This study examined spatio-temporal trend and variability of rainfall time series in the Upper Awash Basin. Rainfall records from twenty three stations for the period (1965-2016) of the major stations having longer observation period is used. The variability and trend significance (at $\alpha = 5\%$ of two tailed) were studied at monthly, seasonal, and annual time scales. Data quality was checked by cumulative deviation and RAINBOW Software. Rainfall descriptive statistics is calculated by SPSS Software. Prewhitening has been applied to the Mann-Kendall test in the trend-detection of time series to eliminate the effect of serial correlation.

Non-parametric Mann-Kendall test for trend significance analysis and Sen's slope estimator for trend magnitude in MAKESENS Excel template were used in determining the trend in rainfall. ArcGIS 10.2.2 is used to investigate the spatial interpolation. The coefficient of variation was used for rainfall variability analysis. As far as trend and variability analysis is concerned in space and time, the study area exhibited different trend and variability.

Trend analysis with Mann-Kendall test show that, there is statistically significant increasing trend in annual total rainfall at Zequala station only where as statistically significant decreasing trend were found at Welenkomi, Addisalem, Bole, Akaki and Asgori stations. No significance trend was found for the remaining stations. For the trend magnitude with Sen's Slope Estimator, maximum rise in rainfall magnitude is 5.69mm/year while maximum decline is -5.1mm/year at Zequala and Welenkomi stations respectively.

To observe spatial distribution of rainfall magnitude, trend and variability; four interpolation methods (IDW, Kriging, Spline and Trend) have been used. Performance of each method is assessed by MAE, MSE, RMSE, MARE, MBE and MRE. Result obtained by IDW (less than 0.15 at all) gets minimum value and considered as high performance for this study.

From the test statistics distribution map, western area show statistically significant decreasing whereas most parts of eastern shows statistically significance increasing trends. An even spatial distribution of trend is observed at central part of the study area.

These findings provide valuable information on the distribution, variability and trend of rainfall necessary for the design of sustainable water resource management strategies and to reduce the impact of droughts and floods in the study area.

Keywords: RAINFALL; TREND; MANN-KENDALL; SEN'S SLOPE; SPATIO-TEMPORAL;; UPPER AWASH BASIN

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LIST OF ABBREVIATIONS

AA	Addis Ababa
AAIT	Addis Ababa Institute of Technology
AR (1)	Autocorrelation one
BR	Buishand Range
CV	Coefficient of Variation
DMC	Double Mass Curve
GIS	Geographic Information System
IDW	Inverse Distance Weighting
IQR	Inter quartile Range
IPCC	Intergovernmental Panel on Climate Change
LCL	Lower Confidence Limit
MAD	Median Absolute Deviation
MAKESENS	Mann-Kendall Sen's Slope.
Max	Maximum
MAE	Mean Absolute Error
MRE	Mean Relative Error
MBE	Mean Biased Error
Min	Minimum
NMA	National Meteorological Agency
PW	Pre-Whitening
RMSE	Root Mean Square Error
SPSS	Statistical Package for the Social Sciences
UCL	Upper Confidence Limit
WMO	World Metereological Organization

CHAPTER ONE

1 INTRODUCTION

1.1 General

Rainfall is one of the key hydro-climatic variables that affect both the spatial and temporal patterns of water availability [36] and it governs the hydrologic cycle and availability of water resources. Importance of investigating long-term trends and variability of hydro-climatic variables is becoming crucial for sustainable water resources management in different parts of the world [75]. As such, detection of trend in long time series of rainfall data is an important and challenging issue in hydro-meteorological studies [75]. Moreover, the climate change issues are exacerbating the spatio-temporal variability of rainfall. Therefore, it is becoming essential to deal with rainfall trends in water resources planning and management. Rainfall and temperature trend analysis is frequently used to trace extent and magnitude of climate change [40].

The spatio-temporal knowledge of rainfall trend is essential to deal with issues associated with flood plain zoning, economic evaluation of flood protection projects, drought assessment [8; 80] and early warning systems. Flood frequency analysis, flood hazard mapping, hydrological modelling, water resource assessments [7] and allocation [33] are all associated with spatial trends of rainfall. Improving the understanding such characteristics of rainfall is therefore the key to the country's water resources development.

Variability and trends in rainfall is one of the important aspects of climate change studies and worldwide several attempts have been made to study both spatial and temporal variation of the rainfall [1; 7; 10; 46;60;61;62;65;71;79]. Different studies were conducted to assess the variability and trend of rainfall at different parts of Ethiopia [14; 22;25; 31;53;54;67; 79, 82;83]. Almost all studies depicted that variations of rainfall existed in every month in different stations. However, the variability of trend is quite significant both in space and time. Such issues are highly linked with the dynamic nature of rainfall and indicated that there is a need for assessment in localized scale studies.

Out of the 12 river basins in Ethiopia, the Awash River Basin is the most important, intensively utilized and environmentally vulnerable [6;35].It is also one of the basins well studied in water resources development aspect. Specifically, the Upper Awash Basin provides consistent irrigation water to a large and productive agricultural area. It is also used for generating hydropower energy and the fresh water supply for big towns and cities like Addis Ababa and

Adama, and many other small towns along its course. Thus knowledge of rainfall characteristics in this basin will have immense contribution for the sustainable water resources development of the area. Up to now, no research has been performed about the trend of rainfall variation in the Upper Awash River Basin with localized assessment aspect.

1.2 Statement of the Problem

Impacts of rainfall change are increasingly becoming a challenge for global society in tackling food security and water problems. Such issues are more pronounced due to changes in rainfall magnitude and intensities in different geographic locations. Changes in annual and seasonal rainfall affect water resources for agriculture production and overall economic growth. Water resource development which is essential to bring about sustainable growth of agriculture, rural development and overall economic progress is unexpected without rainfall. The availability of water resources, as well as their management and use within the basin, is impacted by the spatiotemporal variability of rainfall. In recent years, the frequent occurrence of extreme climatic events such as flooding and drought became a local concern. Since these phenomena negatively affect societies, water resources, ecosystem and the economy at large, destruction of hydraulic structure and unsuccessful services of infrastructure such as bridge, road drainage ditch. Rainfall variability is directly related to the occurrence of the aforementioned issues. In recent time, the flood occurred in Addis Ababa on Akaka River which contribute the flow to the basin is one of the problems found in the upper awash basin. Therefore, rainfall is the key variable that affects both the spatial and temporal patterns of water resources. Furthermore, the upper part of basin is also exposed to flooding due to orographic, location, water driver area and closure to tropical region [6].

1.3 Objective of the Study

1.3.1 General Objective

The general objective of this study is the spatial and temporal analysis of rainfall trend in the upper awash basin.

1.3.2 Specific Objective

- ☞ To evaluate the spatial and temporal variation of rainfall at different time scale;
- ☞ To explore station-based trend analysis at different time scale;
- ☞ To quantify and map rainfall magnitude, trend and variability distribution by spatial interpolation techniques;

- ☞ To predict future rainfall scenarios and thereby assess their implication in planning of effective and sustainable water resources management for the basin.

1.4 Research Questions

The research will be expected to answer the following research question.

- ☞ Why it is important to analysis of rainfall trends within the Upper Awash Basin?
- ☞ Why the spatio-temporal distribution of rainfall is necessary in the basin?
- ☞ What is the coefficient of variation for the spatio-temporal analysis of rainfall within the Upper Awash Basin at different weather/meteorological station?
- ☞ What the rainfall trend looks like on the different upper basin meteorological station?

1.5 Significance of the Study

The significance of this study is to provide information on rainfall descriptive statistic and spatio-temporal variability; trend significant, magnitude and distribution of rainfall on different time scale to water resource planner, design professional (urban drainage, bridge and Dam) designer, agricultural sector and urban planner. This helps to have good information about a disturbing flooding or drought if there will be any in the future. In addition to this, the outcome of this study will give the updated information for the downstream users about the nature of the trend in rainfall in the Upper Awash catchment so that they will have good information on the future water availability in the catchment.

1.6 Limitation of the Study

The study focuses on the upper awash basin to evaluate the trend and distribution of rainfall and variability at different stations on different time scale. Aiming at the objective, this study did not take into account the trend of other parameter; rather than rainfall trend at spatial and temporal. Moreover, it was beyond the scope of this study to identify the problem of flood and drought if it may be happened under future scenarios difficulty. The study also did not take into account the effect of trend change on the water availability.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Hydrology of River Basin and Rainfall Characteristics

River basin which is important from hydrological, economic and ecological points of view depends on rainfall. It is expected that the response of hydrological systems, erosion processes and sedimentation could significantly alter due to rainfall variability. An understanding of the hydrological response of a river basin under different rainfall conditions would help solve problems associated with floods, droughts and allocation of water for agriculture, industry, and hydropower generation, domestic and industrial use [2; 3].

Given recognizance to the rainfall distribution and its extreme variability, an understanding of temporal and spatial characteristics of rainfall is crucial to planning and management of water resources especially on a basin-scale. Such information is important in agricultural planning, flood frequency analysis, flood hazard mapping, hydrological modelling, water resource assessments, climate change impacts and other environmental assessments [73].

2.2 Rainfall Change and River Basin Management

Rainfall change is one of the most critical issues for scientists from many areas, owing to its potentially serious global effects on both natural environment and human life. The spatial and temporal distribution is crucial for advancing our ability to model and predict rainfall change. Its distribution is also important for basin management, agriculture, electrical power, flood control, drought and flood monitoring on all spatial scales [48]. The impact of rainfall variability on water resources is felt worldwide but its effects are more overwhelming in places where flooding or drought takes place [64]. However, the foremost influences are witnessed on the water cycle and its effect on domestic use, flood control, irrigation [64]. In this study, the upper awash basin is a very important area, since it is a sensitive area, which is severely threatened by rainfall variability, especially increasing rainfall and downstream flooding processes.

Analysis of rainfall trends is important in studying the impacts of climate change for water resources planning and management [34]. It is also relevant for future development and sustainable management of water resources in a given basin.

The increasing trend in rainfall totals may pose significant danger to areas that are prone to flooding as reservoirs could easily overflow leading to loss of lives and properties. This study therefore, examines the spatio-temporal distribution of rainfall in upper awash basin, for a long

period of years in order to point out the implications associated with such recent trend and distribution pattern.

2.3 Rainfall Trend and Fluctuation Effects

Changes in rainfall patterns might affect future planning in terms of housing and other urban facilities, proposed irrigation projects, land use, insurance and other activities that assume the climate will not change over scheme life. In addition, increase in rainfall may lead to increased frequency of floods, landslides, soil loss, and sediment transport, and would have consequences for aquifer recharge and the general water quality situation [64]. Rainfall is a key factor in water supply and water resource planning and its change affects the function and operation of existing water infrastructure including hydropower, structural flood defences, drainage and irrigation systems as well as water management practices. Rainfall is one of the most important hydrological variables of the basin. In particular, it greatly influences the amount of water flowing through the water cycle and water availability. The higher the rainfall, the more water is available; low rainfall and drought generally reduce water supply [2]. In general, higher or lower rainfall or changes in its spatial and seasonal distribution would influence the spatial and temporal distribution of runoff, soil moisture and groundwater reserves, and would affect the frequency of droughts and floods. Further, temporal change in rainfall distribution will affect cropping patterns and productivity [42].

2.4 Needs of Rainfall Trends Analysis and Evaluation

Quantitative estimates of hydrologic effects of rainfall variability are essential for understanding and solving the potential water resource management problems associated with water supply for domestic and industrial water use, power generation, and agriculture as well as for future water resource planning, reservoir design and management, and protection of the natural environment. Trend analysis has proved to be a useful tool for effective water resources planning, design, and management since trend detection of hydrological variables such as stream flow and precipitation provides useful information on the possibility of change tendency of the variables in the future [86].

Rainfall is a prime input for various engineering design and hence proper rainfall trend result is important for the operation of engineering structure and essential to estimate the relevant input value for design and analysis of engineering structures and also for crop planning [47].

Due to the importance of rainfall on social, economic and environmental issues, several studies were focusing on its analysis in Western Africa [24]. Indeed, the rainfall is the most determining climatic variable for the life of the populations. Rainfall reduction led to the decrease of water resources, the modification of the natural ecosystems and the socioeconomic systems [24].

2.5 Rainfall Variability

Rainfall in Ethiopia shows large variations across time and space, due to the complex topography and varying latitude of the country [21]. Temporally, rainfall varies from days to decades, with the magnitude and direction of historic rainfall trends varying from region to region and season to season [17; 23; 44; 54; 82]. Spatially, the amount, seasonal cycle, onset and cessation times of rainfall as well as the length of growing season, are all variable across the country [60]. The mean, standard deviation and coefficient of variation of monthly and annual rainfall was calculated to check the rainfall variability [47; 43].

2.6 Previous Studies of Rainfall Trends and Variability in Ethiopia

Many studies have attempted to determine the trend in rainfall on both country and regional scales in different parts of Ethiopia. Yilma and Zanke [82] have studied the trend analysis on annual and seasonal rainfall amounts. They have found that:

1. There is no significant trend in the annual and seasonal rainfall totals in the central, northern and northwestern.
2. Significant declines of annual and the Kiremt total rainfall at the eastern, southern and southwestern stations over the period 1965–2002.

Convay [18] in the northeastern Ethiopian highlands found that there is no significant and clear trend in the annual rainfall pattern. Bewket and Convay [2004] found that there is no major shift or trend in annual and seasonal rainfall during the periods 1898–1950, 1951–2002 and 1898–2002. Cheung and Senay [2008] showed that there are no significant changes or trends in annual rainfall at the national or watershed level. Also analysis of trends in seasonal rainfall for different parts of the country found that while the highly variable Belg rain did not display any significant changes over the study period, the Kiremt rain was decreasing in most watersheds located in the southwestern and central parts of Ethiopia.

Dereje and Kindie [23] also investigated variability and trends of long term rainfall in a time series in Amhara region of Ethiopia. They found that, there was no any increasing and decreasing trend rather it fluctuates around the mean. Spatio-temporal variability and trends of

rainfall in central highlands of Ethiopia studied [Alemayehu and Bewket 2017] and showed that annual and kiremt rainfall exhibited statistically not significant increasing trends in most parts while belg rainfall shows significant increasing trends. Conway and Bewket [19] studied temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia and showed that there are no consistent significant trends in daily rainfall. Osman [26] on long term variability of rainfall, a declining trend was observed for the central highlands. Mengistu [53] observed that statistically non-significant increasing trends of the total annual rainfall seasonal except on spring which was declining trends. Moges [54] investigates spatial and temporal variability of rainfall at seasonal and annual time scales at Tekeze River Basin, exhibited highest rainfall distribution at the southwest part of the river basin and decrease to other directions in annual and kiremt season.

CHAPTER THREE

3 DESCRIPTION OF THE STUDY AREA

3.1 Location of Study Area

Awash River basin is one of the main river basins of Ethiopia. The river originates over the highlands of Central Ethiopia, about 150 km west of Addis Ababa, at an elevation of about 3,000 m above mean sea level and flows north-eastwards, where it eventually drains into the Lake Abe. The total length of the river is about 1,200 km and its catchment area is 110,000 km². According to the master plan study by MoWIE, the Awash River Basin has been divided into three distinct zones: Upper Basin (upstream from Koka Dam Station), Middle Basin (Between Koka and Awash Station), and Lower Basin (between Awash station and Tendaho station) on the basis of various inter-related factors such as location, altitude, climate, topography, agricultural development, inhabitants, and administrative boundaries.

The Upper Awash Basin was chosen as a case study area in the present research. It is approximately between latitudes 8°10'0" and 8°90'0"N, and longitudes 37°90'0" and 38°90'0"E in the Central Part of Ethiopia, at an altitude of 1548 – 3050 m above the sea level and it covers an area of about 10615 km².

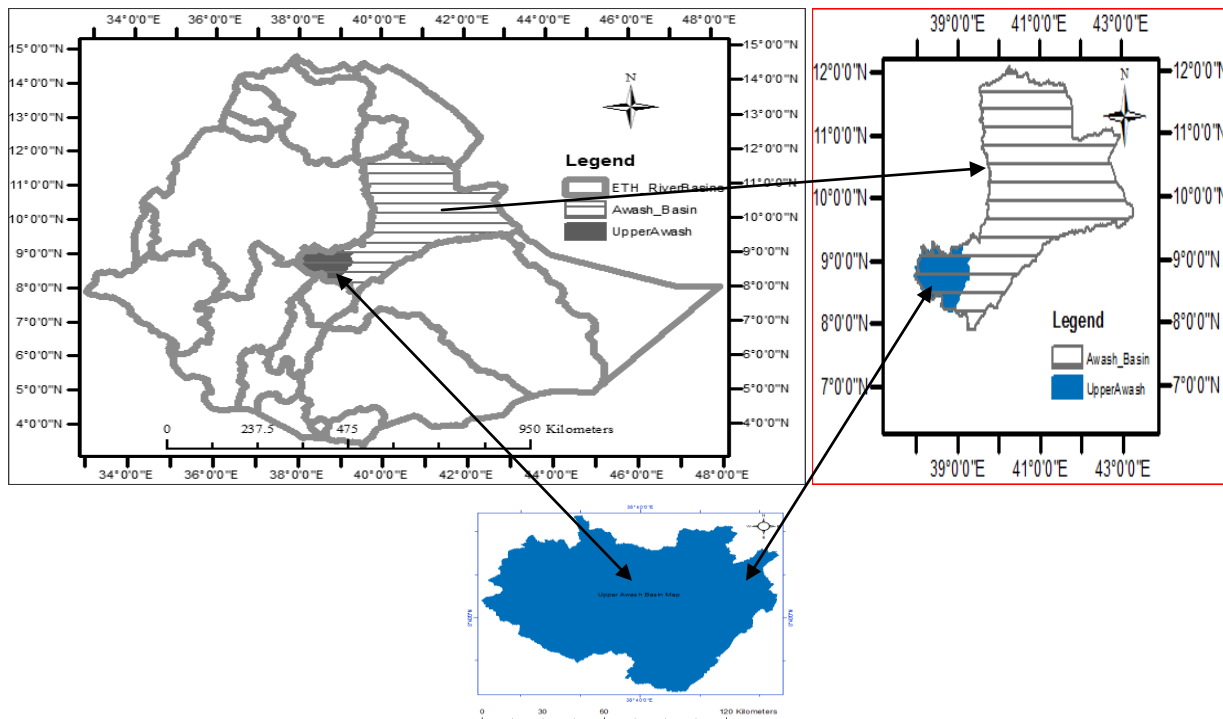


Figure 3-1: Location Map of the Upper Awash Basin

3.2 Rainfall Networking

The responsibility to monitor weather and climate in general and rainfall gauging station as particular in all measurable forms in Ethiopia lies with the National Meteorological Agency (NMA). The spatial distribution of rainfall stations within the Upper Awash basin can be viewed on the rainfall network map as shown in Figure 2-2(a). Based on data availability, the optimization of station densities and observation period length, 23 rainfall gauging stations were selected as shown in Figure 2-2(b).

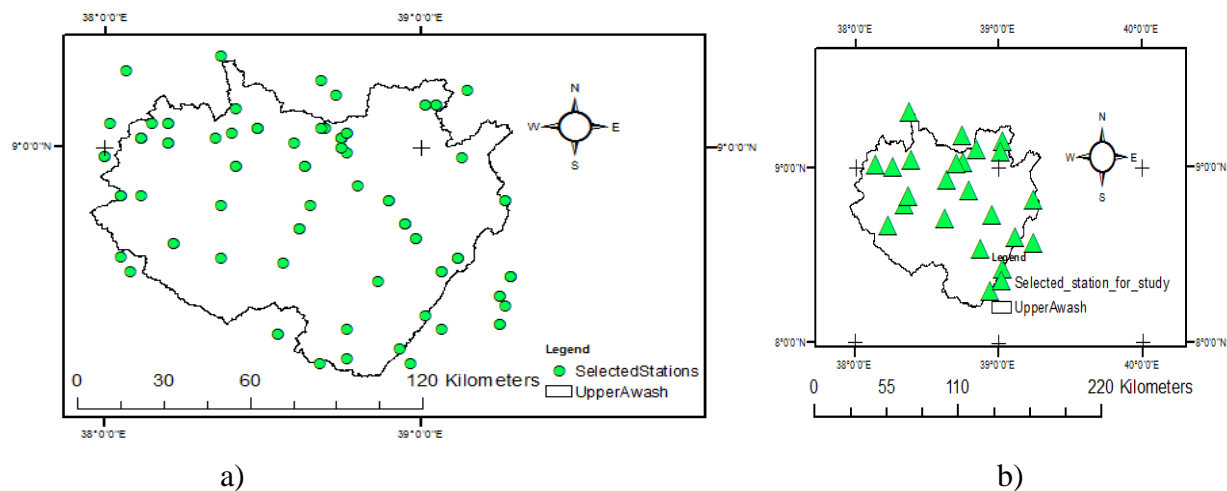


Figure 3-2: Available Rainfall Gauging Stations (a) and Selected Stations (b) in the Upper Awash Basin

3.3 Climate

The climate of the Awash Basin is influenced by the Inter-Tropical Convergence Zone (ITCZ), a zone of low pressure that characterizes the convergence of dry tropical easterly and moist south easterly winds. This convergence is responsible for seasonal rainfall distribution within the basin. As a result of annual migration of the inter-tropical convergence between May and November, the major rainfall in Ethiopia occurs. The Upper Awash area gets its main rainy season in July and August when the ITCZ is positioned in Northern Ethiopia. A weak high pressure system over Ethiopia has a south-east and North West axis, which depresses the movement of the ITCZ southward from the Upper Awash area and runs parallel to it. Therefore, the region from July to August is under the influence of the dry north east or the wet south-west winds; this makes rainfall in the Middle Awash region smaller than the rest of Ethiopia and irregular.

3.4 Temperature

Temperature is moderate as a result of high elevation; there is a poorly defined period of “small rains”, a well defined wet season, and a dry season comprising the remaining portion of the year. Monthly average maximum and minimum temperature are estimated to be 21.4 °C to 26.1 °C and 9.1 °C to 14 °C, respectively, relative humidity is about 45% during the dry seasons.

3.5 Rainfall Data of the Awash Basin

The mean annual rainfall of the basin varies from about 1,600 mm, in the highlands north east of Addis Ababa, to 160 mm, in the northern point of the basin. Rainfall distribution is generally bimodal in the Middle and Lower Awash and unimodal in the Upper Awash. The mean annual rainfall over the entire Western catchment is 850 mm and over the headwaters of the Awash, it is 1,216 mm. Over the Eastern catchment the mean annual rainfall is estimated to be 465 mm. Minor rains normally occur in March and April and major rains from July to August. As such, the occurrence of rainfall is highly erratic. The total amount of rainfall also varies greatly from year to year, resulting in severe droughts in some years and flooding in others.

3.6 Land Use and Land Cover

The major land use land cover in Awash river basin are bare land, cultivated land, dense bush shrub land, forest, open shrub land and shrub land are exists in Awash river basin. The land use condition in the Upper Awash catchments includes mainly of cultivated agricultural land, grassland, and forestland, rural and urban settlements. It is estimated that 67% is intensively cultivated, 25.5% is moderately cultivated, 4.5% is bush land or shrub land or wooded grassland, and 3% is urban area and alpine vegetation

3.7 Physiography and Geology

The two main physiographic components of the Awash River Basin: The Ethiopian plateau and the rift valleys. The topography of the plateau is generally flat to undulating land form with elevations ranging generally from 2500m down to 2000m .The lowest elevation of the plateau, or up lands, is commonly considered to be at 1500m. Geologically the plateau comprises the denuded surface of the Precambrian basement rocks on which lies the near horizontal Mesozoic sediments, covered in turn by the tertiary flood basalt extrusions. Exceptions on this plateau area are the deeply incised river valleys and the volcanic masses, the latter rising to over 3000m. Thus

at the broadest level 6 subdivisions exist, which are related to the general physiographic character of the landforms of the study area.

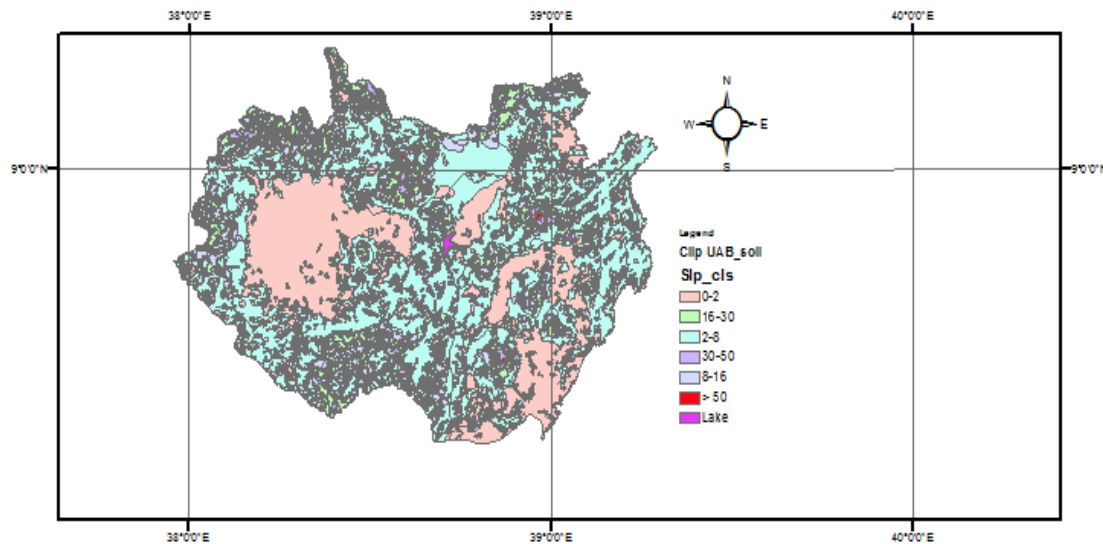


Figure 3-3: Topographical location of the study area

3.8 Soil

The major soils classified in the upper awash basin are Vertisols, Luvisols, Cambisols, Nitisoils, Andosols, Fluvisols, Regosols, and Leptosols, the list of the major soil groups and their area coverage, their geographic distribution is shown in a map. Vertisols are the most extensive soils of the sub basin; they cover about 40 % of the total. The distribution of Vertisols is mainly in the central highland plateaus, or surrounding Finfinnee zone and these areas are known by intensive cultivation of Teff, Wheat, etc.

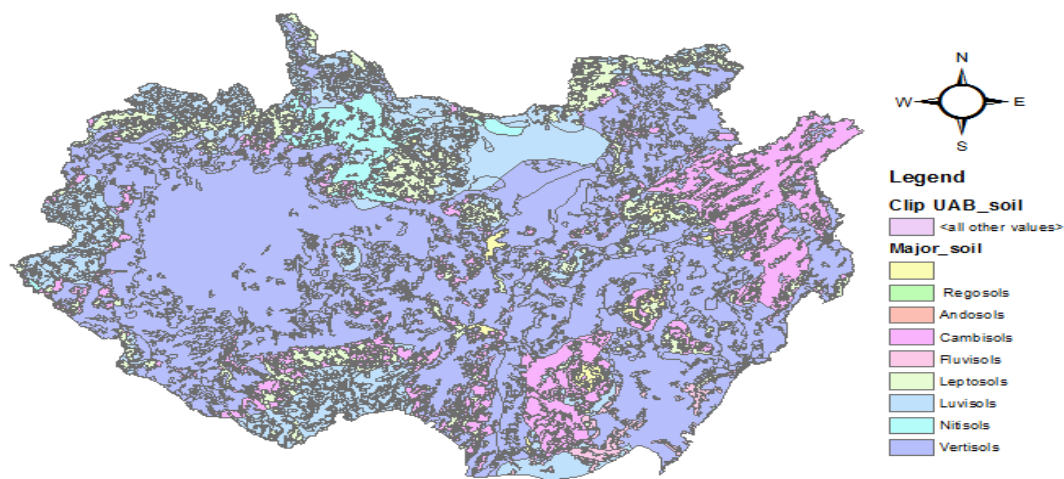


Figure 3-4: Soil Distribution Map of Upper Awash Basin

CHAPTER FOUR

4 MATERIALS AND METHODS

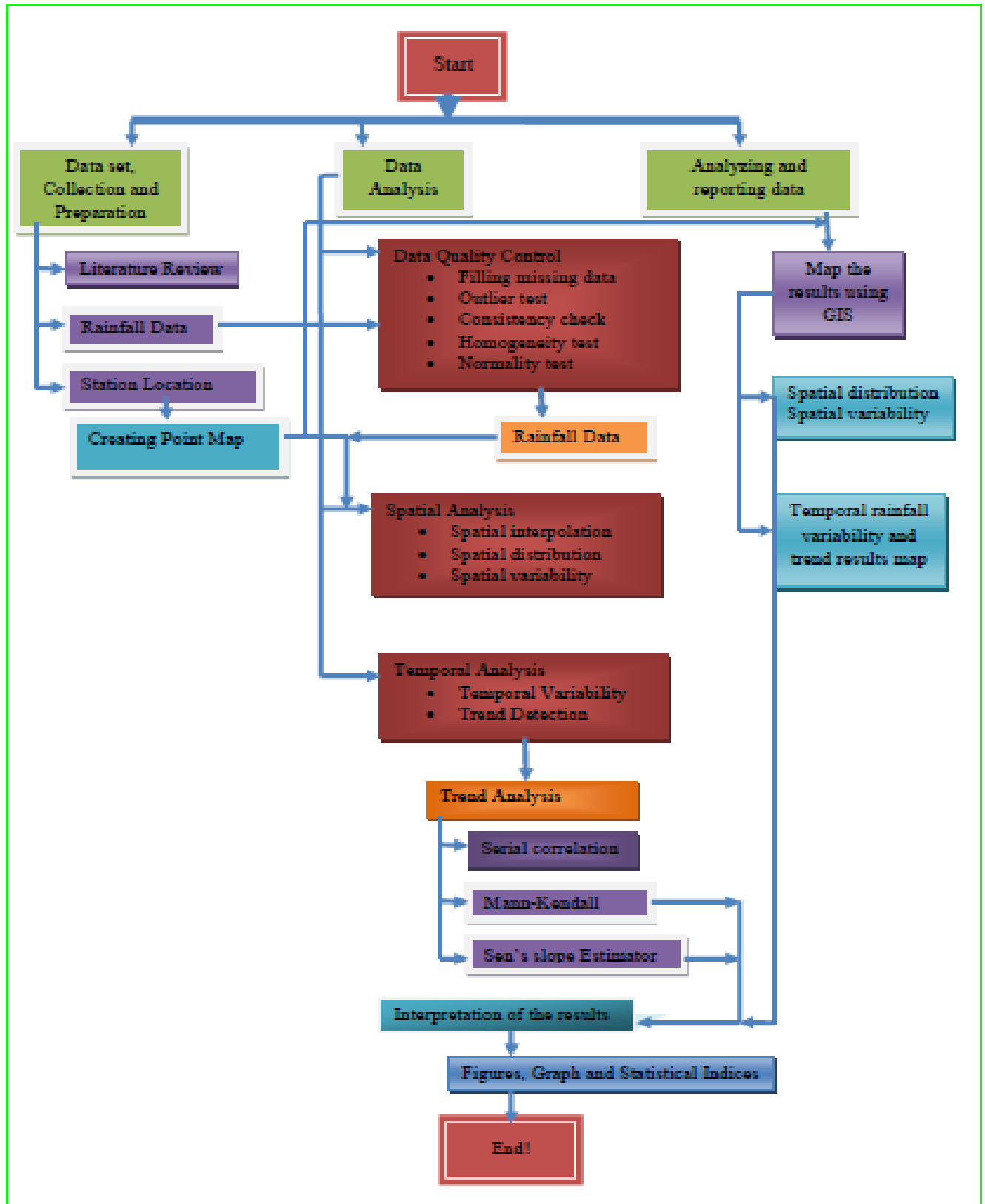
4.1 General

In this study, the spatial and temporal variability of the rainfall over Upper Awash Basin is examined for the period of (1965-2016) for the major stations having longer observation period. The rainfall data was collected from the National Meteorological Agency of Ethiopia (NMA). The long term daily rainfall data has been used to generate monthly, seasonal and annual time series for detecting spatio-temporal trends in rainfall. The general characteristics of the rainfall trends are analyzed by non-parametric test of statistical analysis. Trend analysis is used to investigate whether the trend is increasing, decreasing, or no trend in data value points. A statistical analysis defines trend as a significant change over time which is detectable by non-parametric and parametric tests. Trend analysis of a time series consists of the magnitude of trend and its statistical significance. Using rigorous quality controlling procedures, representative stations were selected for the study area. Then, the rainfall trend analysis has been conducted for the selected stations on monthly, seasonal and annual basis.

4.2 Materials and Tools Used

For an appropriate implementation of the study the following materials are required for data collection, data analysis, and data analysis and reporting. Among those materials and software's some of them are as follow:

- ☞ Arc GIS (software) for the spatial interpolation from point rainfall to the surface [54].
- ☞ Location map to determine geographic location [32: 52:54].
- ☞ Statistical Package for the Social Sciences (SPSS), is used for statistical data analysis [<https://ibm-spss-statistics-base.en.uptodown.com/windows/download>].
- ☞ An Excel template MAKESENS [67] (Mann-Kendall test for trend significance and Sen's slope estimates for trend magnitude) is used for detecting and estimating trends in the time series of the monthly, seasonal and annual time series of rainfall.
- ☞ Microsoft Office Excel 2007 to interpret graphically the trend direction



Source: Own Study

Figure 4-1: Conceptual framework of methodology

4.3 Description of Tools

Geographic information systems (GIS) is employed for implementation of spatial-interpolation techniques such as inverse distance weighted (IDW), Spline and Kriging. Also, the GIS is used for the development of a spatial database, spatial processes, and visualization of the results.

SPSS is short for Statistical Package for the Social Sciences, and it's used by various kinds of researchers for complex statistical data analysis. The software is freely available (for academic purpose) on the web and downloaded from <https://ibm-spss-statistics-base.en.uptodown.com/windows/download>.

4.4 Methods of Trend Analysis

Two popular trend analysis methods are commonly used in the present study: (i) the Mann–Kendall's test and (ii) Sen's slope estimator. Both tools are available as MAKESENS Microsoft Excel add-in software developed by the Finnish Meteorological Institute [67]. Long-term changes in the monthly, seasonal and annual rainfall indices were computed using the tool.

Mann Kendall test is a statistical test widely used for the analysis of trend in climatologic and in hydrologic time series. There are two advantages of using this test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series. Whereas, trend analysis using linear regression assumes normality and homogeneity of variance throughout the series and may be adversely affected by outliers and missing data. However, the nonparametric statistics are usually much less affected by the presence of outliers, and missing values, and they represent a measure of monotonic dependence whether linear or not. Therefore, the nonparametric Mann–Kendall trend test is robust since trends in climatic series are rarely linear. The data of the selected stations were subjected to trend analysis using Mann-Kendall test. The presence of a monotonic increasing or decreasing trend was tested with the nonparametric Mann-Kendall test and the true slope of the existing linear trend was estimated with the nonparametric Sen's method [70]. The Sen's method uses a linear model to estimate the slope of the trend.

4.4.1 Data Acquisition and Processing

Rainfall's Station Data: Many rainfall stations are available in the study area. However, rainfall records are often incomplete at most stations because of missing rainfall data in the measured period. Therefore, in order to maximize station densities and length, stations' having missing

data of less than 30 % (twenty three stations) has been selected for this study. Of the selected rainfall stations, sixty five percent has missing data less than ten percent whereas thirty one percent has between ten and twenty. The remaining four percent has been twenty to thirty percent (Table 4-2).

Rainfall Data: The rainfall data for some stations were available from different observation period to optimize stations densities and length. Observed daily rainfall data were obtained from the National Meteorological Agency of Ethiopia (NMA). At the beginning, historical records of daily rainfall were examined in all meteorological stations found in Upper Awash Basin. Unfortunately, some of the stations had records only over a short period or had many discontinuities. Stations for final study were selected based on representativeness within a length of record period. Twenty three meteorological stations were chosen and they are distributed over the study area as shown in table4-1 and figure 4-1. All the stations have daily rainfall data which were obtained from the National Meteorological Agency of Ethiopia (NMA). And the meteorological station's detailed information is shown in Table 4-1.

Table 4.1: Metrological station of the study area

Station Name	Basin	Lat.	Long.	Elevation(m)
Bole	Upper Awash	9.03	38.75	2354
Addis Alem	Upper Awash	9.04	38.38	2372
Akaki	Upper Awash	8.87	38.79	2057
Ginchi	Upper Awash	9.02	38.13	2132
Mojo	Upper Awash	8.61	39.11	1763
Sebeta	Upper Awash	8.93	38.63	2240
Sendafa	Upper Awash	9.15	39.02	2569
Tulu Bolo	Upper Awash	8.67	38.22	2100
Welenkomi	Upper Awash	9	38.25	2165
A.A Obs.	Upper Awash	8.22	39.4	2400
Debrezeit	Upper Awash	8.21	38.33	2020
Nazaret	Upper Awash	9.09	39.3	1622
Shola	Upper Awash	9.09	39.01	2560
Zequala	Upper Awash	8.32	38.52	3050

Asgori	Upper Awash	8.79	38.33	2072
Sululta	Upper Awash	9.18	38.73	2610
Teji	Upper Awash	8.83	38.37	2091
Koka Dam	Upper Awash	9.00	38.45	1618
Intoto	Upper Awash	9.08	38.72	2903
Enchinni	Upper Awash	9.32	38.37	2690
Awash Melka	Upper Awash	8.71	38.64	2030
Ejere	Upper Awash	8.77	39.26	2100
Alem Tena	Upper Awash	8.29	38.91	1656

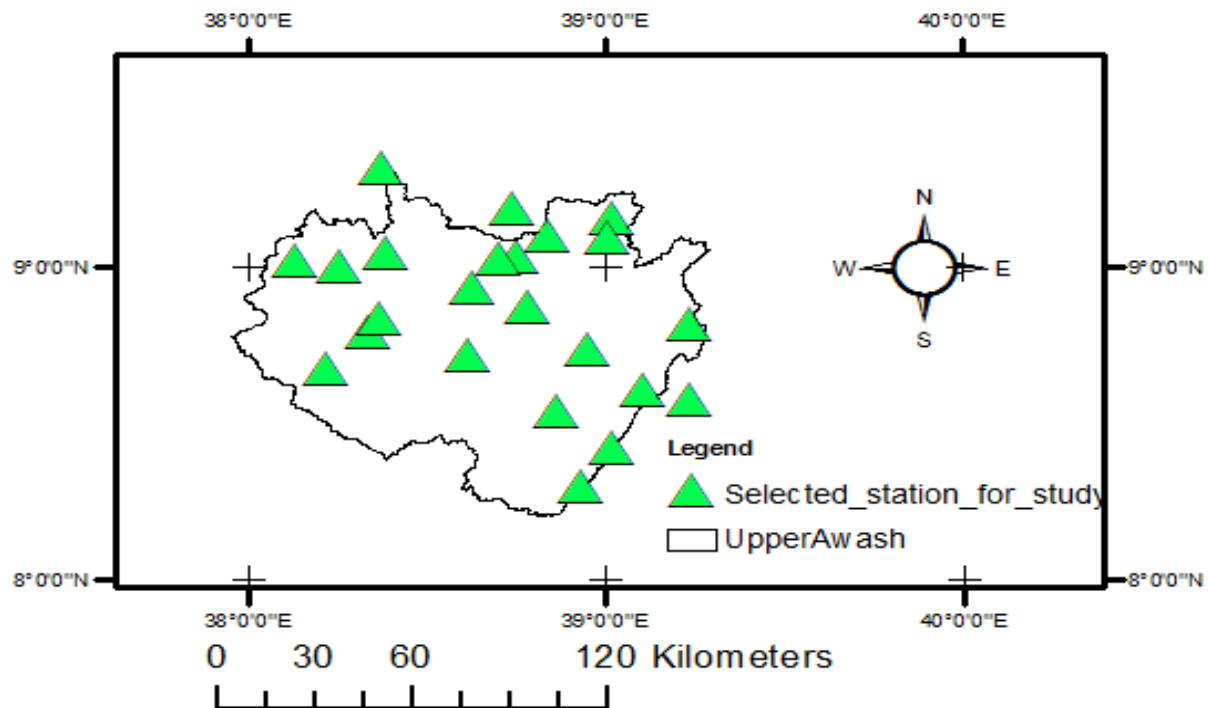


Figure 4-2: Selected Stations Map in the Upper Awash Basin

4.4.2 Data Quality Control

The rainfall data must be checked for consistency before it is used for further analysis. The quality control can be done by visual inspection, filling of missing data if there is any, accumulated plot and double mass curve. This will help identify if there are any gaps or unphysical peaks (spikes and negatives) in data series and correct them before the data is used.

Otherwise, using the inaccurate data will give erroneous output from the trend direction and magnitude.

Screening and Visual Inspection: After the rainfall data is collected from any source it must be checked for its quality. Visual inspection is the first step in data quality control. This can be done by checking if date and time record is complete, unphysical values (negatives), flat regions (sensor or transfer system fall out) and unphysical variation patterns (sensor malfunctioning). At first, the series were inspected for outlier's test that could appear due to typing. Visual inspection was applied to the data both in tabular and in graphical form. The visual inspection was done by plotting the time series data against time. The percentage of missing data points for all rainfall stations is shown in table 4-2.

Table 4.2 : Availability of rainfall data and Percentage of missing

Station Name	Observation Period	Missing Days (%)	Rank
Bole	1965-2016	2.5	2
Addis Alem	1965-2016	8.1	5
Akaki	1965-2016	5.4	4
Ginchi	1965-2016	4.3	3
Mojo	1965-2016	12.8	7
Sebeta	1965-2016	7.5	4
Sendafa	1965-2016	18.9	10
Tulu Bolo	1965-2016	12.9	8
Welenkomi	1965-2016	16	9
A.A Obs.	1965-2016	0.8	1
Debrezeit	1965-2008	15.1	5
Nazeret	1965-2016	8.9	6
Shola	1965-2016	8.9	6
Zequala	1965-2008	3.2	2
Asgori	1980-2016	19.1	3
Sululta	1980-2016	26.5	4
Teji	1980-2016	4.8	1
Koka Dam	1980-2016	10.1	2
Intoto	1987-2008	9.1	1
Ejere	1976-2016	15.9	2

Enchinni	1976-2016	8.6	1
Awash Melka	1987-2016	13.2	1
Alem Tena	1987-2016	13.3	2

Filling Missing Data: Rainfall is an important part of the hydrological cycle. One of the first steps in any hydrological and meteorological study is accessing reliable data. However, rainfall data is frequently incomplete. The incompleteness of rainfall data may be due to damaged measuring instruments, measurement errors and change in the measurement site, a change in data collectors, and the irregularity of measurement.

In rainfall data analysis, the big problem is missing of the observed daily data. However, in many sites there are no consistent data records, data may exist for short periods, with long periods of missing data [27]. The gap in the data should be filled before the data are subjected to the analysis. The missing data are estimated by using the data of the neighboring stations. The simple average rainfall is used as a standard of comparison. The normal rainfall is the average value of rainfall at particular date, month or year over a specified observation period of years [72]. Missing data of one day or two days were filled in by average values of neighboring days [39]. If consecutive days had missing data, the missing values were calculated by using normal ratio equation from the mean days of non-missed days of the whole year after excluding of the missing days of the time series in the observation period by the help of this formula.

$$P_x = \frac{1}{n} \sum_{i=1}^{i=n} \frac{N_x}{N_i} P_i$$

Where n = the number of nearby station

P_x = missing precipitation

P_i = precipitation at i^{th} station/surrounding station

N_x = mean daily precipitation for station x

N_i = mean daily precipitation for station i or surrounding station

Consistency Check: To perform trend analysis, the filled data still need to be checked for consistency. The accumulated total of the individual gauge having low missing data is compared with the corresponding totals for a representative group of nearby observation period. If a decided change in the regime of the curve is observed, it should be corrected. However, as all the

selected stations in this study were consistent and there is no need of further correction. Double mass curve for AA Obs station is presented and used as showed on figure4-3 below.

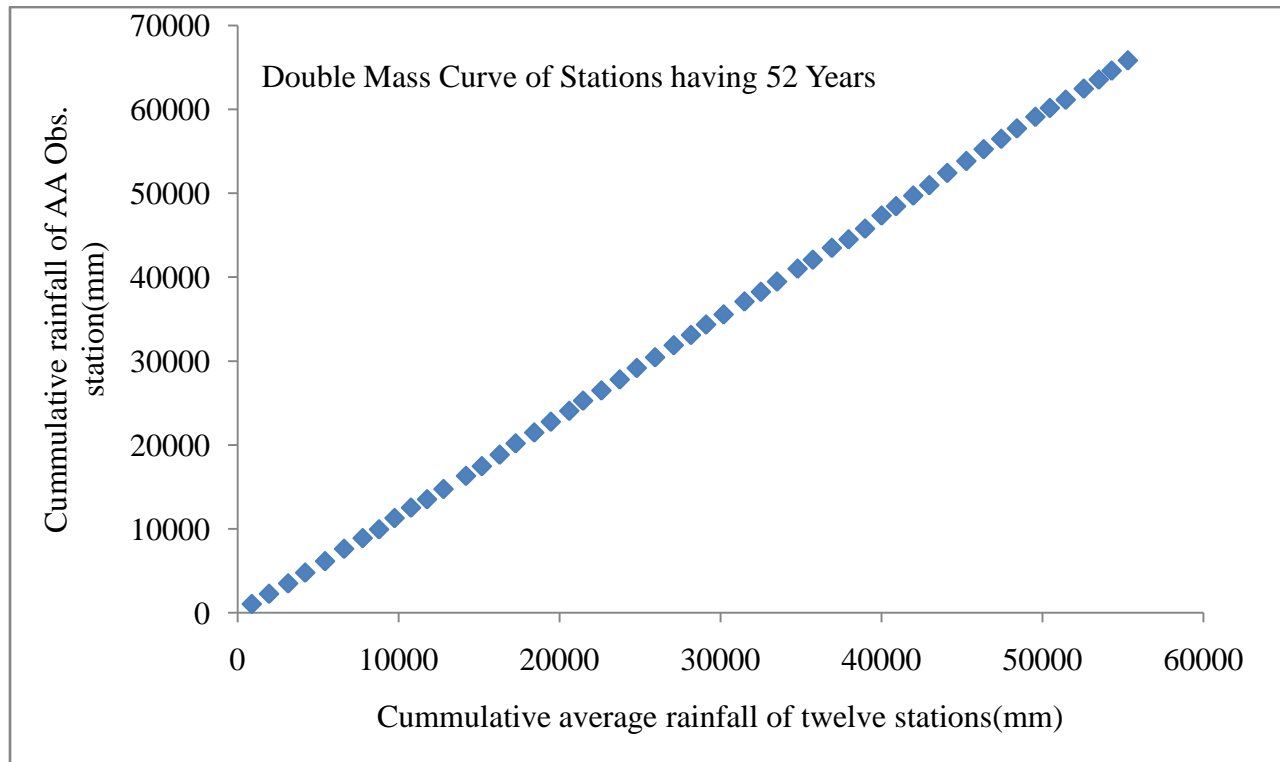


Figure 4-3 : Double Mass Curve (DMC) for checking data consistency

Outliers Test: An outlier in a data series is the data that is significantly or statistically detached from the rest of the series [30]. Outliers in data series affects sample statistics like mean, standard deviation, coefficient of variation and coefficient of skewness and so the distribution model parameters and convenience level [59]. To make a reliable frequency analysis, it is necessary to carefully detect and remove the outliers. In this study, the outliers in annual total series of 23 rainfall stations in the study area are analyzed by labeling rule method and SPSS statistical software.

1. **Labeling rule method:** Labeling rule is the one method which was employed to detect the presence of outlier in the rainfall data. It is the statistical method of detecting the presence of outliers in data sets using the 25th percentile (Q_1) and the 75th percentile (Q_3). The underlying mathematical equation based on the lower and the upper bound is presented as follows:

$$\text{Lower Bound: } Q_1 - (2.2 * (Q_1 - Q_3))$$

$$\text{Upper Bound: } Q_3 + (2.2 * (Q_3 - Q_1))$$

At 0.05 degree of freedom, any data lower than lower bound or greater than upper bound were considered as an outlier [14] and they removed from the data series to below and above the upper and lower value to the maximum of ten percent.

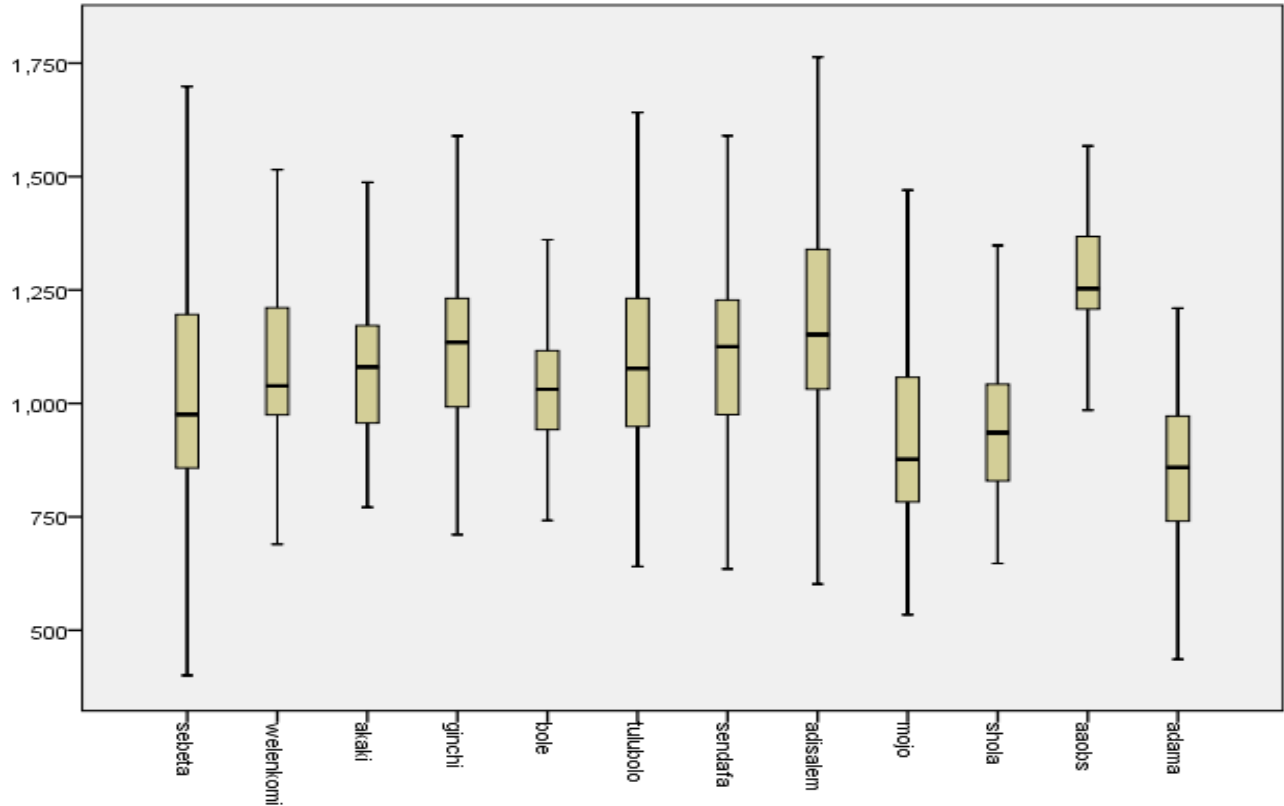


Figure 4-4: Station wise outlier output by box plot method in SPSS

Test of Randomness and Persistence: Testing the time series for absence of persistence is the basic data screening procedure by computing the first serial-correlation coefficient [20]. The data analysis procedures for trend detection used require that the data should be random and persistence free, that is, not influenced by rainfall in the previous time step. The autocorrelation function was used to test for such randomness and independence [78;20]. This serial-correlation coefficient is given as:

$$r_k = \frac{\sum_{i=1}^{n-k} [x_i - \bar{x}][x_{i+k} - \bar{x}]}{\sum_i^n [x_i - \bar{x}]^2}$$

Where r_k is the lag-k autocorrelation coefficient, \bar{x}_m is the mean value of a time series x_i , n is the number of observations, and k is the time lag.

Random series have autocorrelations near zero for all time lag separations, except the zero lag coefficients which is always 1. In that case, statistical tests are directly applied to the series. Non-random series have one or more significantly non-zero autocorrelation values and statistical tests in this case are applied to a pre-whitened series to account for the non-randomness. To accept the hypothesis $H_0: r_1 = 0$, the value of r_1 should fall between the upper confidence limit (UCL) and the lower confidence limit (LCL). The lower and upper confidence limits are given as:

$$LCL = [(-1-1.96(n-2)^{0.5}) / (n-1)]$$

$$UCL = [(-1+1.96(n-2)^{0.5}) / (n-1)]$$

Applying this condition to the time series, the condition: $LCL < r_1 < UCL$ (r_1 = lag-1 correlation coefficient) is satisfied for 78% of the selected stations and for the remaining 22% of stations Pre-whitened autocorrelation lag-1 of time series data has been carried out. Thus, no correlation exists between successive observations. The data are independent, and there is no persistence in the time series.

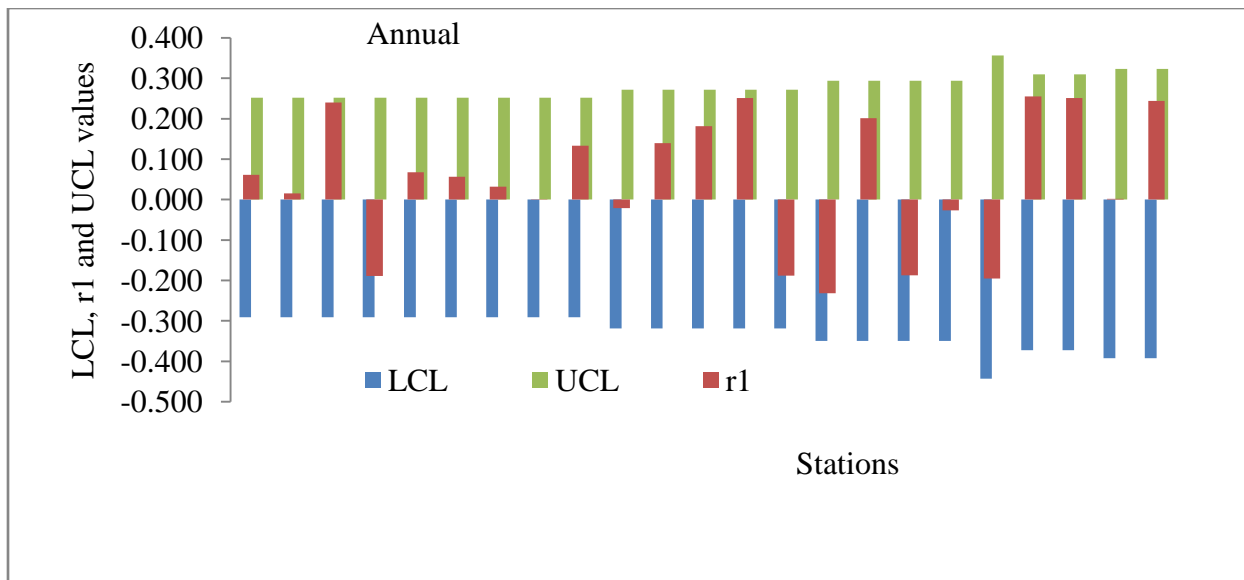


Figure 4-5: Station wise tests for the absence of persistence

4.4.3 Descriptive Statistics

The rainfall data analysis was undertaken to describe, quantify and validate the variability and trend in the basin. The variability and trend can be tested using different statistical and graphical methods. In this study, the coefficient of variation (CV) and graphical methods were used. The

CV is a statistical measure that shows the variation of data about the mean; it is the ratio of standard deviation to the mean. Most studies uses the CV to describe the variability of rainfall [5; 19; 49;54;82].

4.4.4 Temporal Rainfall Trend Analysis

Mann-Kendall Test: Trend detection and analysis are performed through parametric and non-parametric tests only for consistent data. Normality and homogeneity of variance throughout the series may be adversely affected by outliers and missing data in parametric tests. The advantage of non-parametric statistical test over the parametric test is that the former is more suitable for non-normally distributed, outlier, censored and missing data, which are frequently encountered in hydrological time series [85;88]. As a result, Mann- Kendall (MK) test is widely used to detect trends of meteorological variables (82; 75; 5]. This method has been widely used to assess trends in hydroclimatic data; hence, it was adopted to explore the trends of rainfall in the Upper Awash River Basin. Mann-Kendall trend test is used by [5;51; 45]:

$$S = \sum_{i=1}^{n-1} \cdot \sum_{j=i+1}^n \text{sgn}(X_j - X_i)$$

Where S is a statistic, x_i and x_j are the sequential data values, n is the length of the time series, and $\text{sgn}(X_j - X_i)$ is defined as;

$$\text{Sgn}(x_j-x_i) = \begin{cases} 1, & \text{if Sgn}(x_j-x_i) > 0 \\ 0, & \text{if Sgn}(x_j-x_i) = 0 \\ -1, & \text{if Sgn}(x_j-x_i) < 0 \end{cases}$$

Since the data is independent and normally distributed, the variance of the S statistic is given by

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

The values of S and $\text{Var}(S)$ are used to compute the test statistic Z as follows:

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

The trend is said to be decreasing if Z is negative and the computed probability is greater than the level of significance. The trend is said to be increasing if the Z is positive and the computed probability is greater than the level of significance. If the computed probability is less than the level of significance, there is no trend. The null hypothesis is rejected at the significance level of α if $|Z| \geq Z_{\alpha/2}$, where $Z_{\alpha/2}$ is the critical value of the standard normal distribution with a probability exceeding $\alpha/2$, and it shows that the trend is significant. If $|Z| < Z_{\alpha/2}$, the null hypothesis is accepted, and the trend is not significant. A trend is considered to be statistically significant if it is significant at significance level α ($\alpha = 5\%$) level, in this study significance level of 5% is adopted. Moreover, significant trends at 0.05 significance levels exist when the $|Z| > 1.96$ [31; 88; 101]. For S to be significant and different from zero, H_0 should be rejected considering the level of significance adopted, pointing to the existence of a trend in the time series, and thus accepting H_1 . In this thesis, 0.05 significance level was considered to analyse the hypothesis.

Sen's Slope Estimator: The magnitude of the trend at a given time can be found from Sen's slope estimator [77;70]. The test is widely used in assessing the trend magnitude for rainfall series over the time [42; 56]. Slope for all data pairs can be calculated by

$$T_i = \frac{X_j - X_i}{j - i} \text{ for } i = 1, 2, 3$$

Where, x_j and x_k are data values at time j and k ($j > k$) separately. When there is one data point in each time period, then $N = n(n-1)/2$, where n is the number of time periods. But, if there are more data points then, $N < n(n-1)/2$, where n is the total number of observations. The values of N are arranged from smallest to biggest. Then, median of these „ n “ values of T_i are represented by Sen's slope of estimation which is calculated using the following equation,

$$Q_i = \begin{cases} \frac{T(N+1)}{2} & \text{for } N \text{ odd observations} \\ \frac{1}{2} \left(\frac{T(N)}{2} + \frac{T(N+1)}{2} \right) & \text{for } N \text{ even observations} \end{cases}$$

A positive value of Q_i indicates increasing magnitude and a negative value of Q_i represents decreasing magnitude.

Modified Mann–Kendall test: Effect of Serial Correlation for Trend Detection

Usually, in trend detection tests, it is assumed that the observed time series is serially independent. However, data such as annual mean or annual maximum rainfall may show significant correlation. In situations when significant serial correlation is present in the time series, the MK test has high chances of showing significant trends, while no trend exists in reality [87]. Due to the results of the MK test are heavily affected by serial correlation of the time series, prewhitening has been applied to the MK test in the trend-detection studies of hydrological time series to eliminate the effect of serial correlation. In other words, the existence of serial correlation leads to an increase in the probability of disproportionate rejection of the null hypothesis.

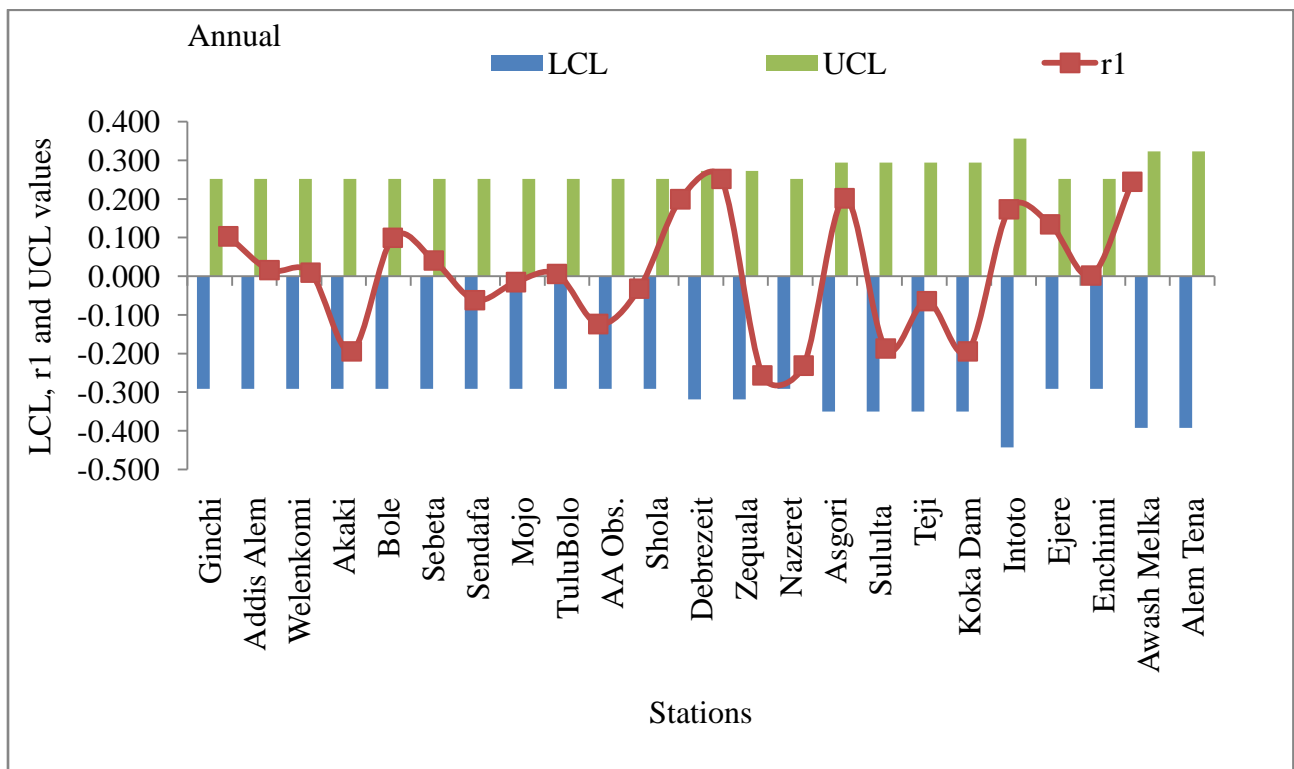
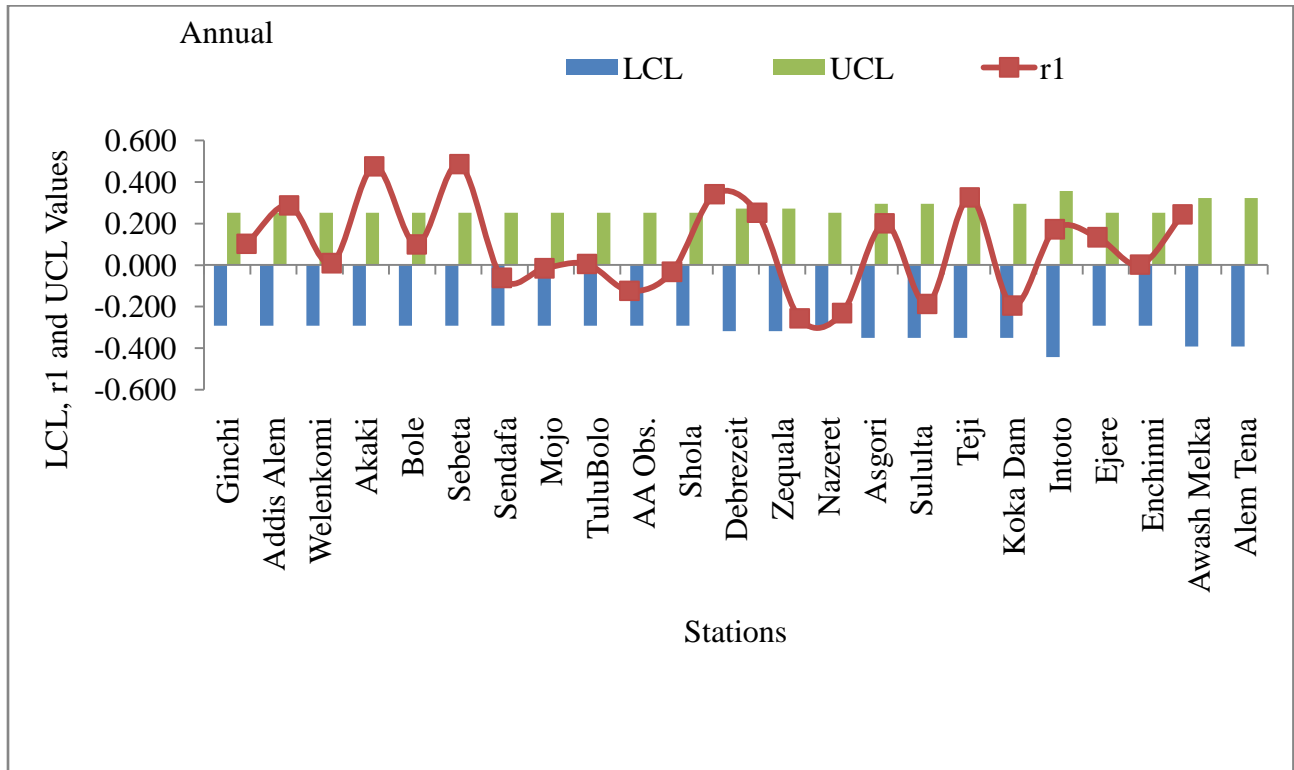
Pre-Whitening (PW): To reduce the effect of serial correlation [85;84;57] proposed prewhitening of the time series before the application of the trend detection test. This approach has been applied by [89] for the detection of trends in rainfall records. Computation of other time series models could be fitted more closely to the rainfall data [66]; however, the PW approach assumes that time series can be appropriately described by an autoregressive process of order one, AR(1). The PW approach makes it possible to modify the original time series, and apply the trend test on the reduced sample. Modification in the original time series is mainly done by computing the lag-1 serial correlation coefficient r_1 . For a significance level α if the value of r_1 is non-significant, then the trend test is applied to the original time series (x_1, x_2, \dots, x_n); otherwise, it is applied to the pre-whitened time series ($x_2 - r_1 x_1, x_3 - r_1 x_2, \dots, x_n - r_1 x_{n-1}$). Where $x_1, x_2, \dots, x_{n-1}, x_n$ are observational value of time series data, n is number of observation and r_1 is autocorrelation. The pre-whitening removes serial correlation from the data by means of the following formula:

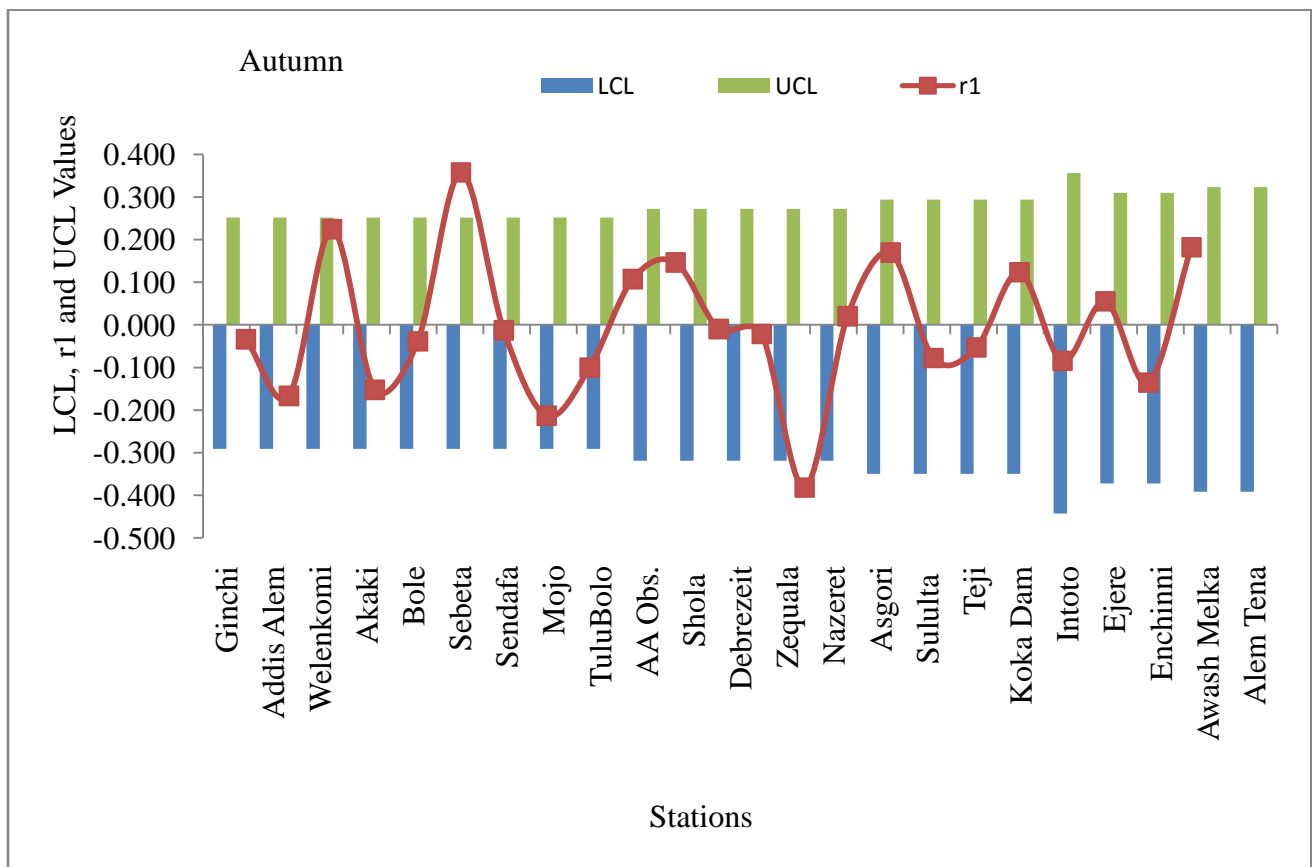
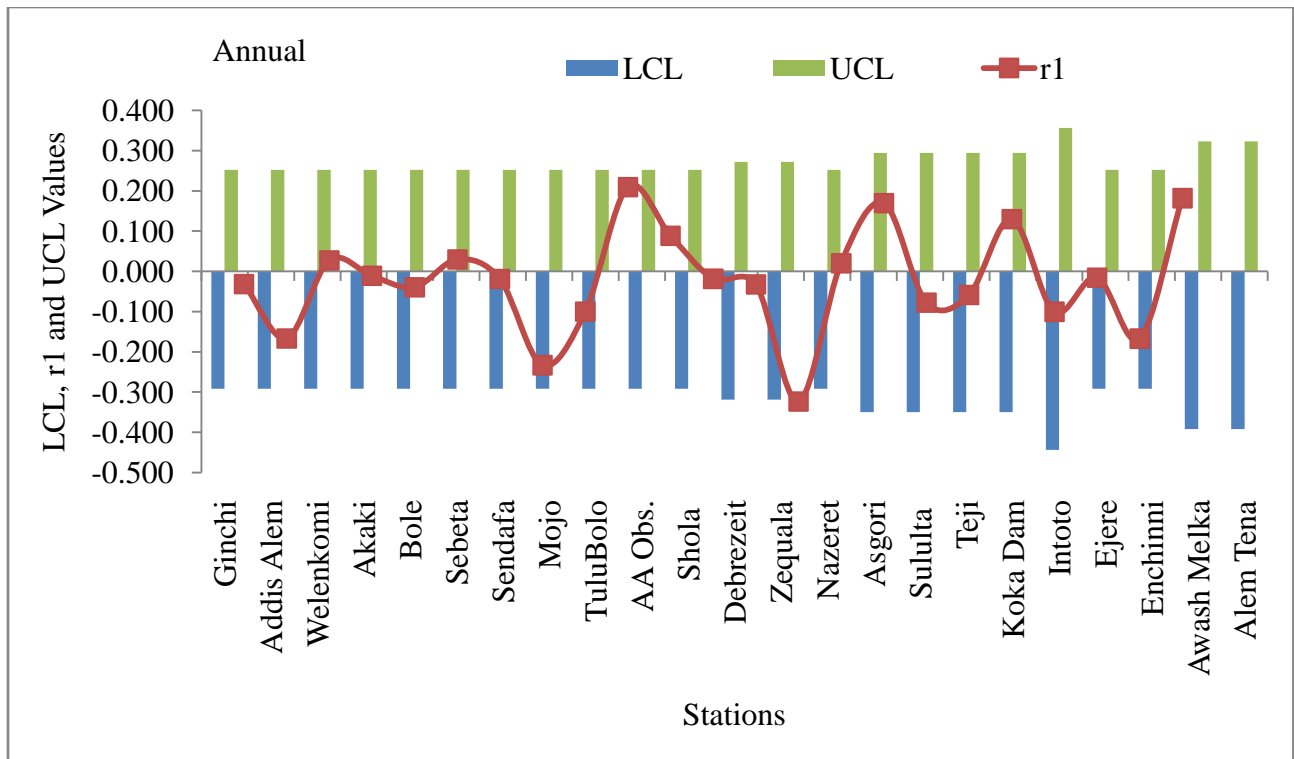
$$X'_i = x_i - r_1 * x_{i-1}$$

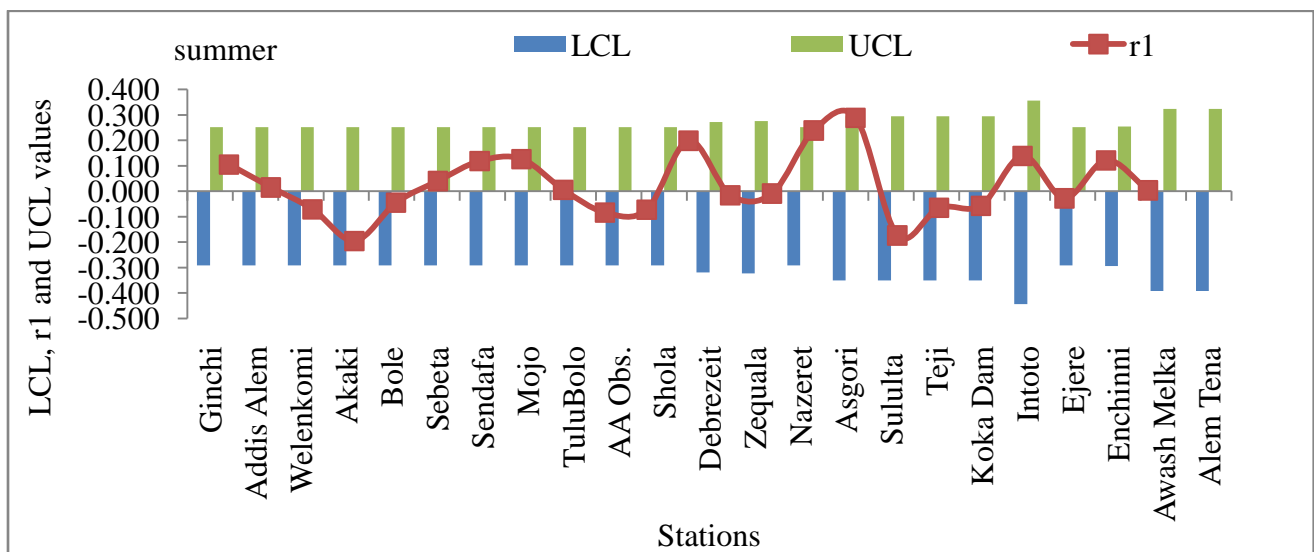
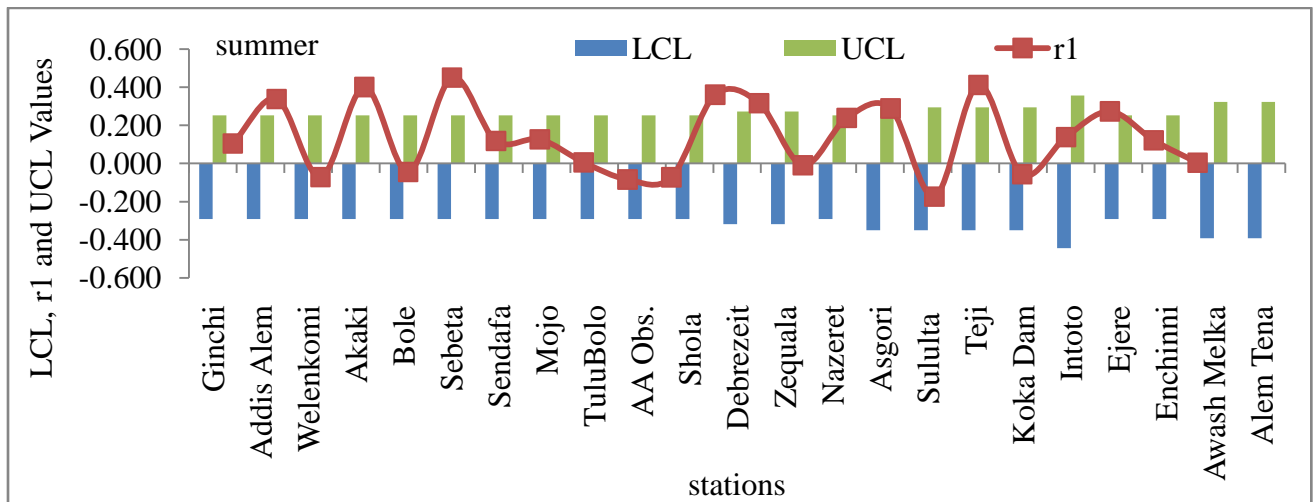
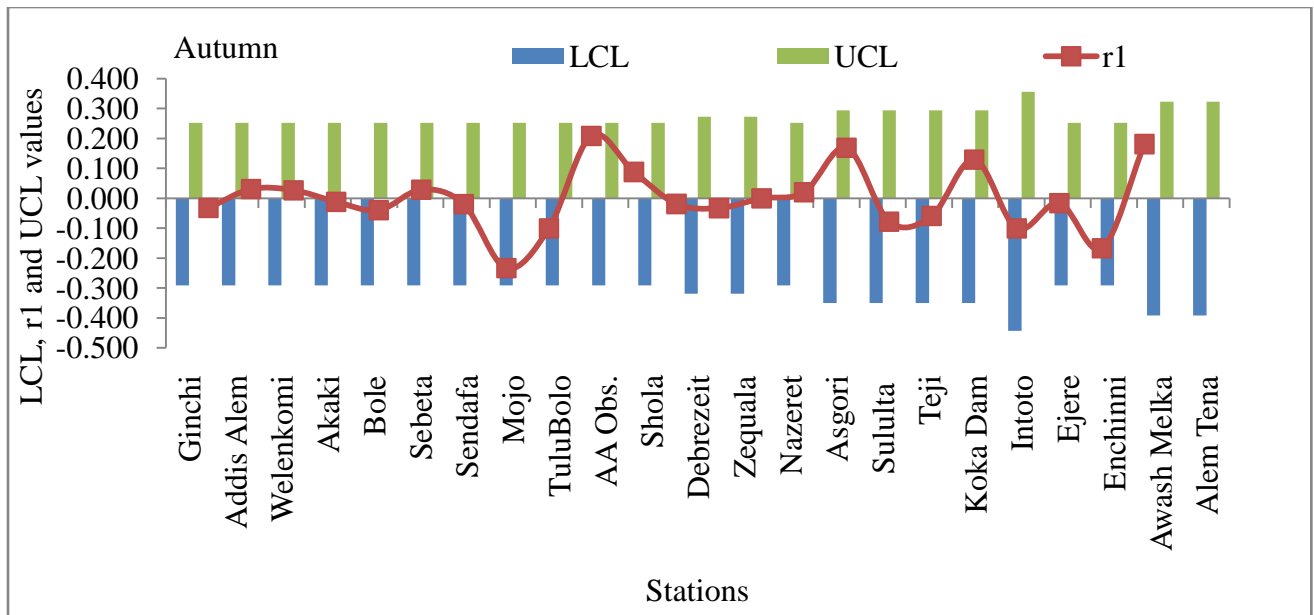
Where x_i is the original time series value for time interval i , X'_i is the pre-whitened time series value, \bar{x} is the mean of the sample data and r_1 is the lag -1 autocorrelation coefficient that can be expressed as:

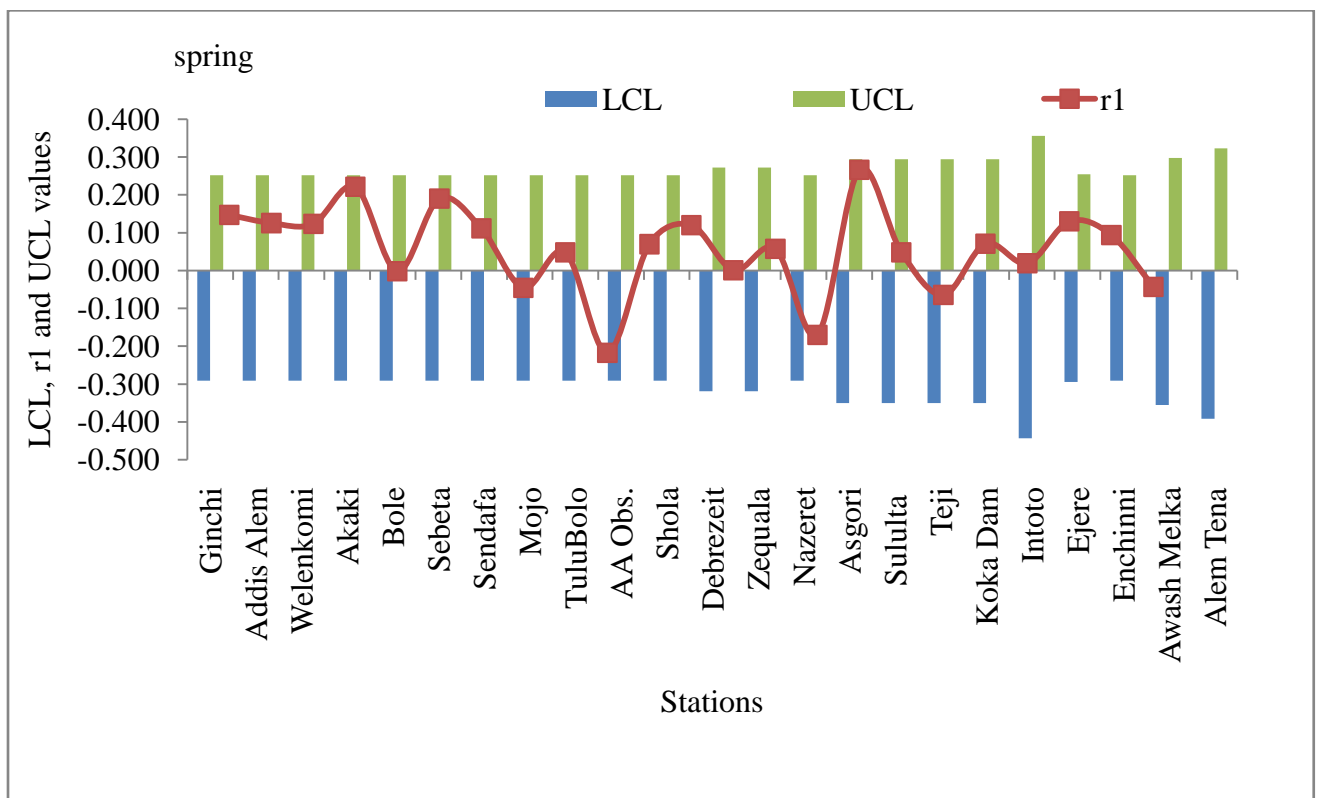
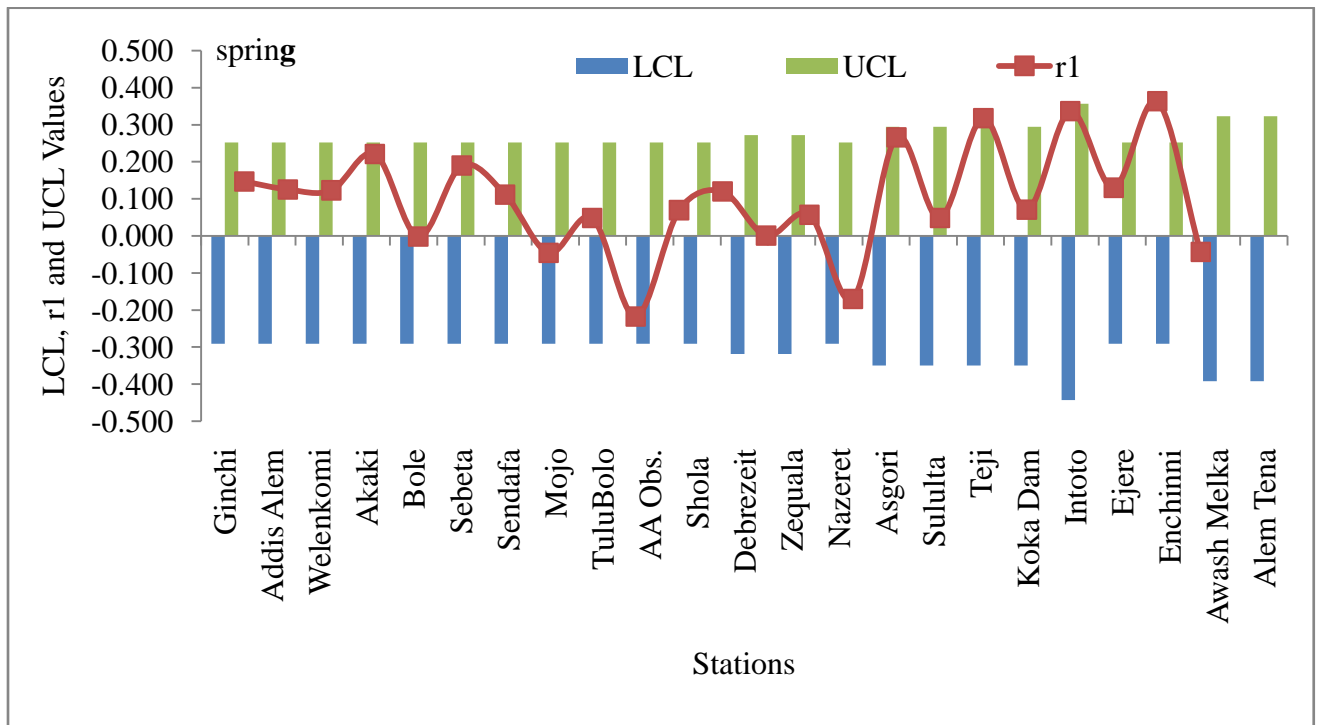
$$r_1 = \frac{\frac{1}{n-1} \sum_{i=1}^{n-1} [x_i - \bar{x}][x_{i+1} - \bar{x}]}{\frac{1}{n} \sum_{i=1}^n [x_i - \bar{x}]^2}$$

For this study Mann-Kendall test was used in conjunction with the widely used method of pre-whitening for eleven stations after removal of serial correlation.









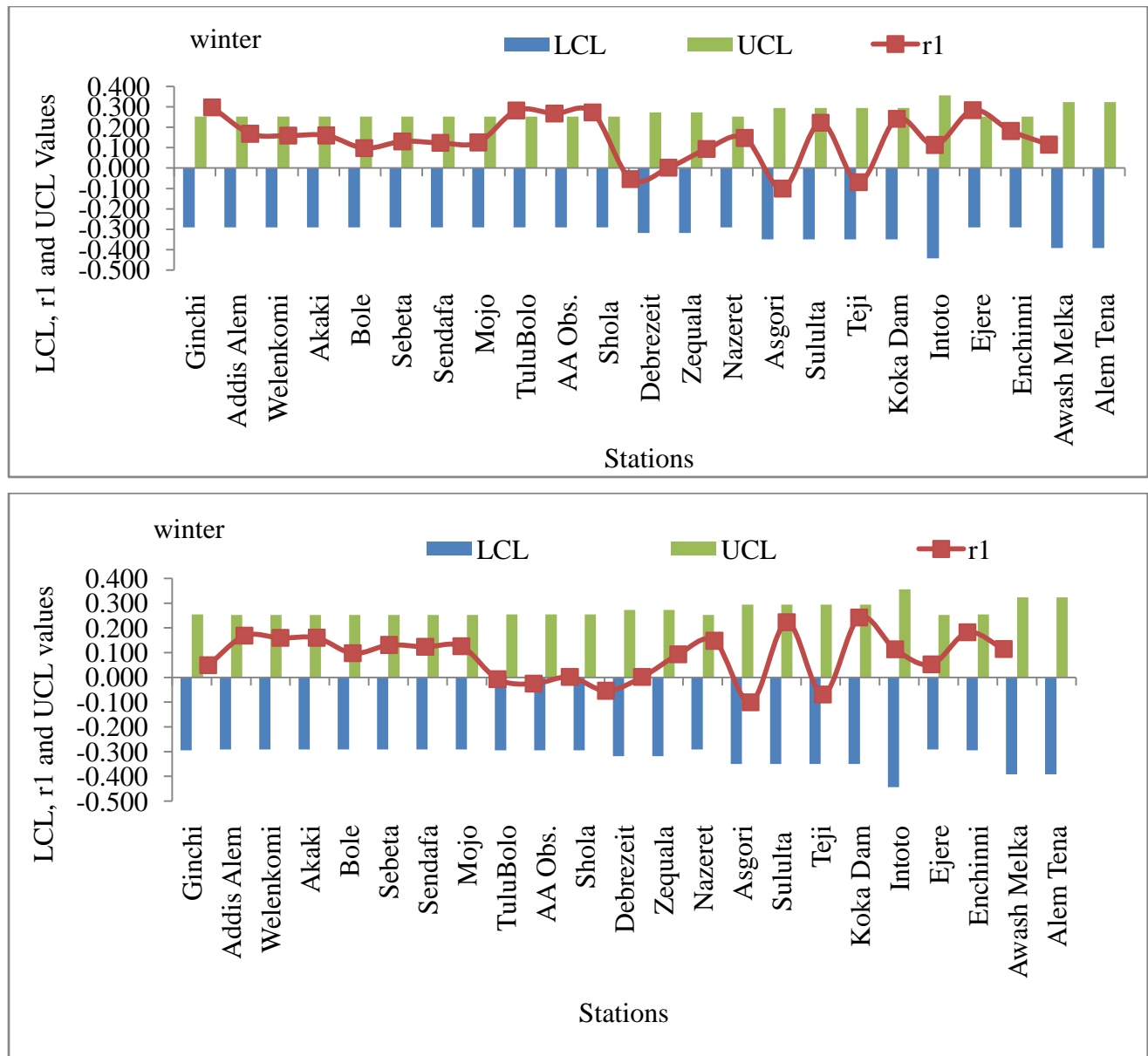


Figure 4-6: Annual and seasonal rainfall before and after serial effect (autocorrelation) analysis

4.5 Spatial Analysis of Rainfall Data

Rainfall process is known to exhibit a high degree of variability both in space and time. Using point measurements at selected locations it has always been found to be a challenge to the scientific community to get the spatial distribution. This calls for a procedure of estimation called interpolation. Spatial interpolation refers to the estimation of values at unsampled points based on known values of surrounding points in space and well developed and widely adopted in various GIS applications. It is commonly used in a Geographic Information System (GIS) to

generate a continuous layer of data from a set of point data taken at sample locations, in order to estimate elevation, rainfall, temperature or other spatially-based continuously changing phenomena [12; 55].

Before the analysis of rainfall data, the base map of the study area and the map showing the spatial distribution of the rain gauge stations were prepared using the software ArcGIS10.2.2

4.5.1 Interpolation Methods

Four different interpolation methods (Inverse Distance Weighting, Kriging, Spline, and Trend) were used in this study. These methods were used as they are representative of available interpolation procedures, widely used in rainfall interpolation, and easy to implement in GIS (e.g. Arc Map GIS)[12]

Inverse Distance Weighting Method: Inverse Distance Weighting (IDW) interpolation determines cell values using a weighted combination of a set of sample points. The weight is a function of the inverse distance/inversely proportional to the distance between the observations and the interpolated location. The surface being interpolated should be that of a locational dependent variable. Nearby data will have the most influence in the interpolation, and the surface will have more detail (be less smooth). IDW function in ArcGIS was used for IDW interpolation with a moderate weighting value (2) to control the significance of known points upon the interpolated values, based upon their distance from the output point. Inverse Weight Distance [81] was employed to determine the spatial pattern of rainfall at different time scale..

IDW produce surfaces by establishing a neighborhood search of points and weighting these points by a power function. Often, with the increase of power the effect of the points that are farther diminishes. Lesser power distributes the weights more uniformly between neighboring points. The advantage of IDW is that it is intuitive and efficient and it works best with evenly distributed points and it is sensitive to outliers. Unevenly distributed data clusters result in introduced errors. Equation below presents how the IDW interpolation technique calculates the value for an unknown location.

$$P_x = \frac{\sum_{i=1}^k \frac{P_i}{D_i^n}}{\sum_{i=1}^n \frac{1}{D_i^n}}$$

Where P_x is the estimated value at point x , P_i is the P value at known point i , D_i is the distance between point i and point x , k is the number of known points used in estimation, and n is the specified power which controls the degree of local influence.

Spline Method: Spline interpolation is another type of deterministic interpolation method. A mathematical function is utilized that produces a surface with continuous rainfall and minimum curvature; thus, these are gradual interpolators. This method performs best when the surface is relatively smooth and a large number of measured data points are available. It will not perform as well when there are large changes in the surface within short distances. This interpolation method is local in that a subset of record values can be used to generate each prediction, with the actual search area being flexible. Allowing more recorded values in the calculation will result in a smoother predicted surface. Unlike IDW methods, the values predicted by splines are not constrained to the range of recorded values, i.e., predicted values can be above the maximum or below the minimum measured value. The Regularized option was used in this analysis to produce a smoother prediction surface with values that may lie outside the sample data range. The smoothing spline function also assumes the presence of a measurement error in the data that needs to be smoothed locally [14].

Trend Method: Trend surface analysis is the most widely used global surface-fitting procedure. The mapped data are approximated by a polynomial expansion of the geographic coordinates of the control points, and the coefficients of the polynomial function are found by the method of least squares, insuring that the sum of the squared deviations from the trend surface is a minimum. Each original observation is considered to be the sum of a deterministic polynomial function of the geographic coordinates plus a random error. The polynomial can be expanded to any desired degree, although there are computational limits because of rounding error.

Kriging Method: Geostatistical interpolation methods are stochastic methods, with kriging being the most well-known representative of this category. Kriging methods are gradual, local, and may or may not be exact (perfectly reproduce the measured data). Also, they are not by definition set to constrain the predicted values to the range of the measured values. Similar to the IDW method, kriging calculates weights for measured points in deriving predicted values for unmeasured locations (Bilu 2016). With kriging, however, those weights are based not only on distance between points, but also the variation between measured points as a function of distance. Kriging is different from other methods (such as IDW), because the weight is no longer arbitrary [9]. The kriging process is composed of two parts — analysis of this spatial variation and calculation of predicted values.

Spatial variation is analyzed using variograms, which plot the variance of paired sample measurements as a function of distance between samples. An appropriate parametric model is then typically fitted to the empirical variogram and utilized to calculate distance weights for interpolation. Kriging selects weights so that the estimates are unbiased and the estimation variance is minimized. This process is similar to regression analysis in that a continuous curve is being fitted to the data points in the variogram.

After a suitable variogram model has been selected, kriging creates a continuous surface for the entire study area using weights calculated based on the variogram model and the values and location of the measured points. The analyst has the ability to adjust the distance or number of measured points that are considered in making predictions for each point. A fixed search radius method will consider all measured points within a specified distance of each point being predicted, while a variable search radius method will utilize a specified number of measured points within varying distances for each prediction. For this thesis a variable search radius method has utilized. There are two kriging methods: Ordinary and Universal. Ordinary Kriging (which was used for this thesis) is the most general and widely used of the kriging methods and is the default.

4.5.2 Comparison of Different Interpolation Methods and Accuracy Assessment

The primary use of cross validation technique is to compare the interpolated value with the ground truth (observed) value and evaluate the interpolation capacity (ability) of different interpolation model, and finally to decide the best interpolation technique for further use. The validation technique can also help as understand the approaches and limitation of interpolation techniques. The accuracy and the competence of the interpolation method can be tested through different statistical equation and the interpolation values are compared to the real. To compare observed and estimated values or to evaluate interpolation methods, statistical indices of MAE (Mean Absolute Error), MBE (Mean Bias Error) and RMSE (Root Mean Square Error) were used [9;50;32;42;85;52].

MAE is used for determining the degree of bias in the estimates often referred to as the bias [41]. Since positive and negative estimates counter act each other, the resultant MAE tends to be lower than the actual error prompting caution in its use as an indicator of accuracy [37]. RMSE provides a measure of the error size, but is sensitive to outliers as it places a lot of weight on

large errors [37]. Small MAE values indicate a model with few errors; whereas small RMSE values indicate more accurate estimates on a point-by-point basis. MSE suffers the same drawbacks as RMSE. Whereas MAE is less sensitive to extreme values and indicates the extent to which the estimate can be in error. MAE and RMSE are argued to be similar measures and they give estimates of the average error, but do not provide information about the relative size of the average difference and the nature of differences comprising them. Small MAE values indicate a model with few errors, whereas small RMSE values indicate more accurate estimates on a point-by-point basis. When MAE is 0.00 or near to naught, the applied method simulates the fact well. However, as far as its amount is farer than 0.00, it implies to less precise. Finally, MAE and RMSE used to evaluate model performances (performances of the IDW, Kriging, Spline and Trend interpolation methods). The smallest RMSE indicate the most accurate predictions. The mathematical formula for each parameter is described in the following.

$$\text{MAE} = \frac{\sum_{i=1}^n (I_i - O_i)}{n} \dots\dots\dots \text{i}$$

$$\text{MRE} = \frac{n * \text{MAE}}{n \sum_{i=1}^n O_i} \dots\dots\dots \text{ii}$$

$$\text{MSE} = \frac{\sum_{i=1}^n (I_i - O_i)^2}{n} \dots\dots\dots \text{iii}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^n (I_i - O_i)^2}{n}} \dots\dots\dots \text{iv}$$

$$\text{MARE} = \frac{\sum_{i=1}^n \left| \frac{I_i - O_i}{O_i} \right|}{n} \dots\dots\dots \text{v}$$

Where n is the number of observation, O_i is the observed rainfall value at a time (i), and I_i the estimated/interpolated rainfall value at a time (i). With these statistics above, the agreement between interpolated and observed values can be quantified and the best method among the four methods for interpolating rainfall can be used as the selected interpolation techniques.

CHAPTER FIVE

5 RESULTS AND DISCUSSIONS

5.1 Rainfall Characteristics of Upper Awash Basin

5.1.1 Monthly Characteristics of Rainfall

The mean monthly rainfall of the stations in the Upper Awash Basin varied from 1.8 to 302.1 mm in the period 1965–2016 (Figure 5-1). Comparatively, the monthly rainfall was low on December, October and from January to May, but started to increase in June (Figure 5-1). Moreover, relatively intensive rainfall was received between June and August, with the maximum mean monthly rainfall received in August at Sendafa station. The minimum monthly rainfall was recorded at Mojo station in December and in all stations the lowest rainfall occurred in November and December.

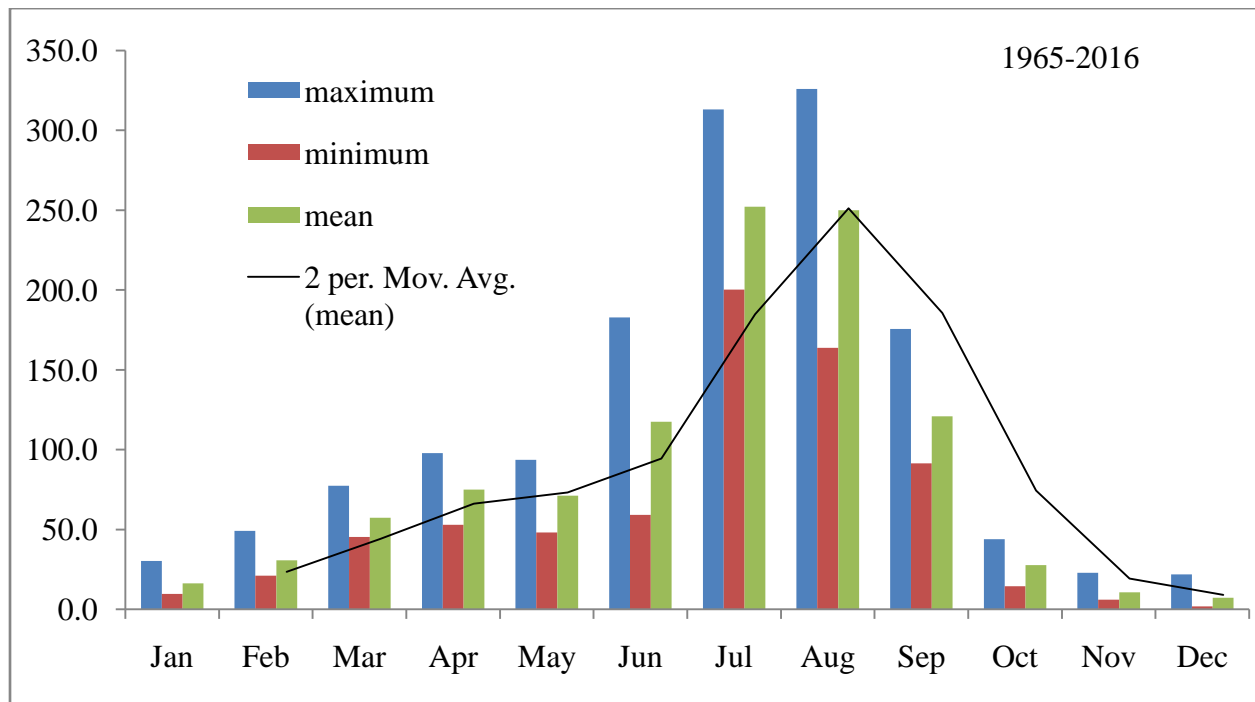


Figure 5-1 : The mean monthly rainfall (mm) at Upper awash basin for 52 year

5.1.2 Inter-Annual and Temporal Rainfall Variability

Figure 5-2 shows annual rainfall of the 22 rainfall stations in the Upper Awash Basin; the annual rainfall varied from 775.9mm to 1264.5mm. The AA Obs. and Alemtena stations recorded the highest and lowest annual rainfall, respectively. The catchment receives mean annual rainfall of 1057.67mm.

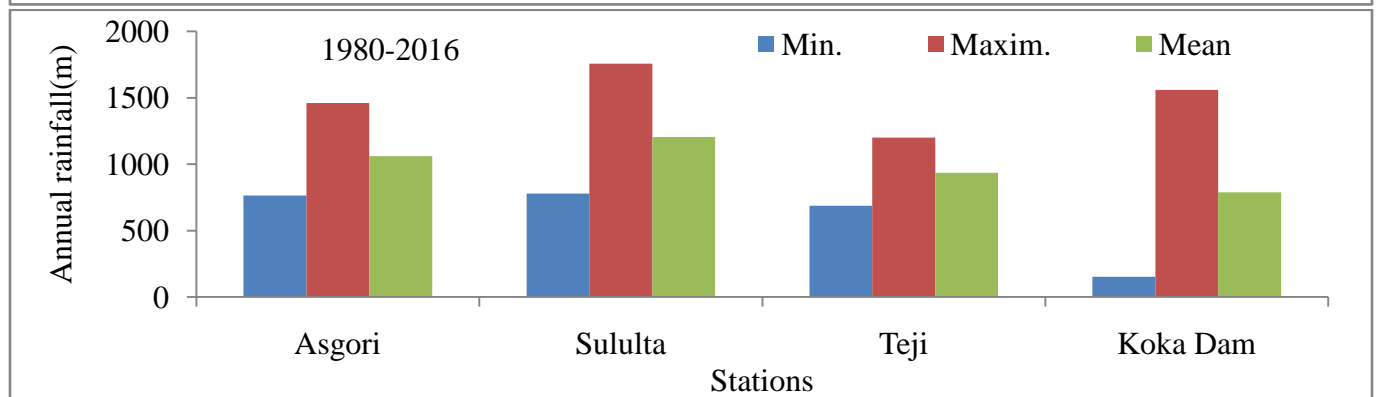
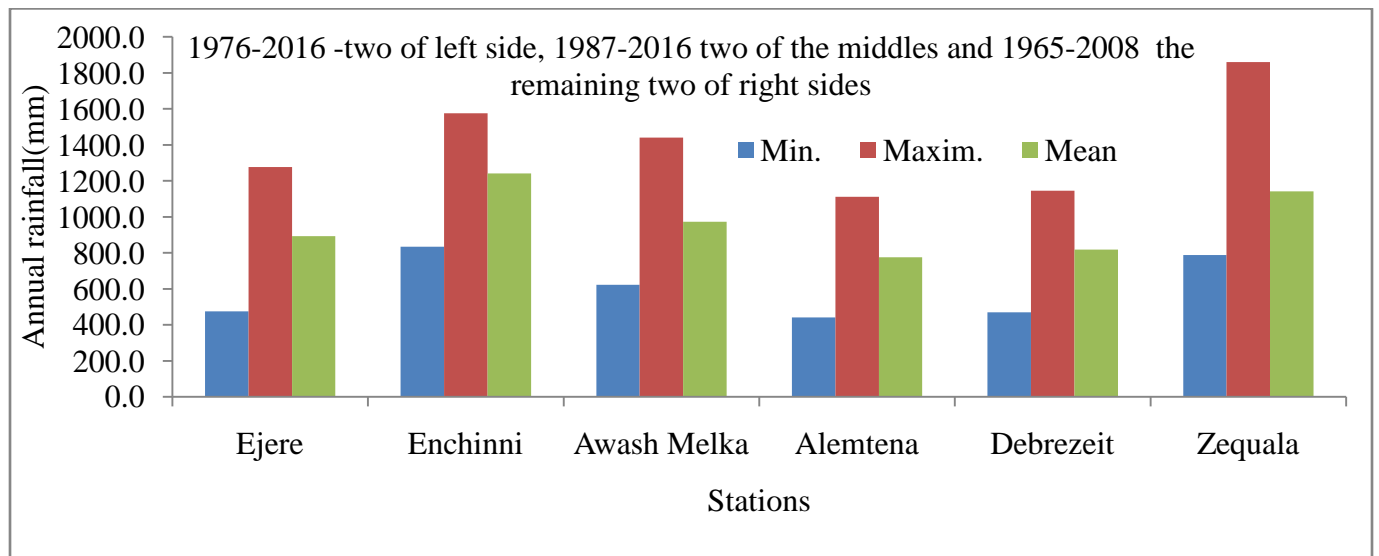
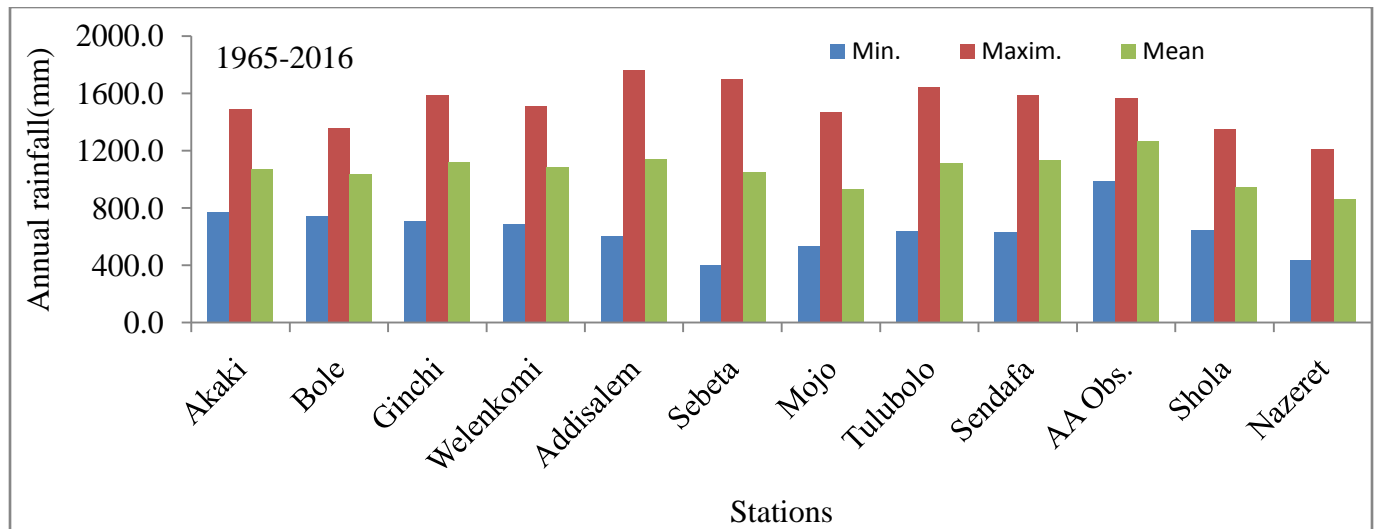


Figure 5-2 : Annual rainfall in Upper Awash Basin for the 22 rainfall stations.

Figure 5-3 shows the annual and seasonal rainfall trend in Akaki and Asgori stations. In 1965-2016, annual rainfall varied from 400.4 to 1763.5 mm at Sebeta and Addisalem. In 1965-2008, annual rainfall varied from 470.2 to 1144.1 mm at Debrezeit. In 1980-2016, annual rainfall

varied from 151 to 1756.5 mm at Koka Dam and Sululta. In 1976-2016, annual rainfall varied from 474 to 1276.1 mm at Ejere. In 1976-2016, annual rainfall varied from 474 to 1276.1 mm at Ejere. In 1987-2016, annual rainfall varied from 441.4 to 1111.8mm at Alemtena. The variability of annual rainfall at different stations showed a similar increasing and decreasing (at most stations) trend except for a few years with extremely high rainfall. High rainfall was recorded at Zequala in 1990 which is 1860mm. In 1965-2016, both the graphical and linear trend in annualrainfall indicated negative and positive trends.

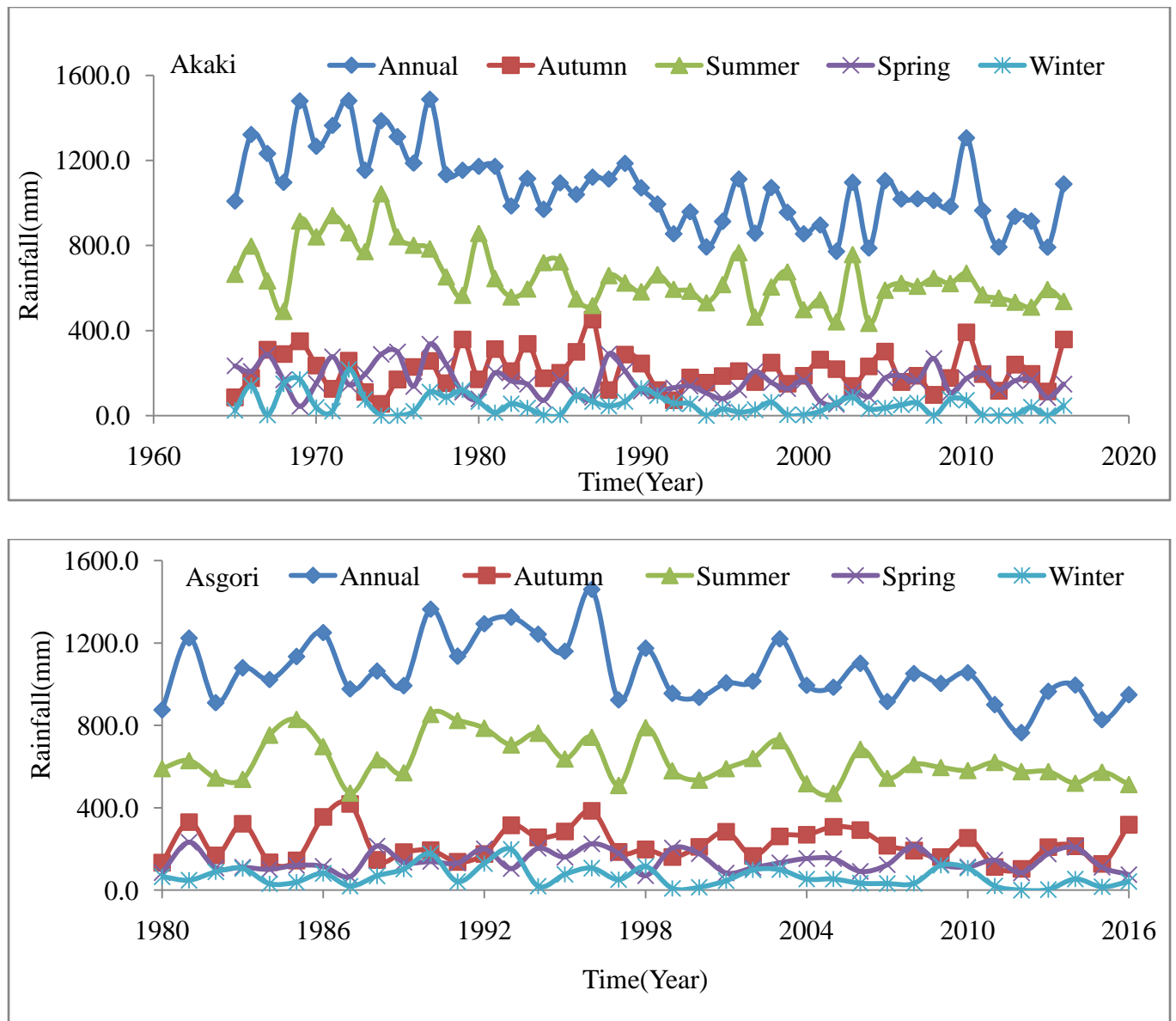


Figure 5-3 : Annual and seasonal temporal variability of rainfall in Akaki and Asgori stations

The temporal variability of annual rainfall indicated a similar pattern of rise and decline in a majority of the stations.

5.1.3 Rainfall Descriptive Statistics

The first stage in the analysis of the data was to look at the descriptive statistics of the rainfall records. This descriptive statistics were calculated by SPSS statistical software and presented in table 5-1. The details of the descriptive statistics are given in the appendices section.

The observable difference in the computed mean and median of the data is an indication of the variability of rainfall within the period under study. In addition, it is often said that rainfall data is not always normally distributed hence it is obvious that a high value of skewness and kurtosis as observed in Table 5-1.

From Table 5-1, the station with the highest mean annual rainfall was AA obs., which recorded an amount of 1265.4mm.

The variation of CV values indicates the existence of variability in the rainfall of the study area. In addition, the lowest mean annual rainfall occurred at Alemtena with an amount of 775.9mm. The rainfall range shows the difference between the maximum and minimum annual values. The standard deviation and the range indicate the variability of annual rainfall. A small value of standard deviation indicates that the data is tightly grouped about the mean. A high value indicates that the data is spread widely on either side of the mean. A high standard deviation also suggests that year-to-year fluctuations are high while a low standard deviation indicates that fluctuations are lower.

The lower the coefficient of variation of rainfall amount at any station, the lower the variability and the greater the dependability. Table 5-1 reveals that the rainfall variability is significantly low at most stations and therefore highly dependable for water resources development. Considering the coefficient of variation, Koka Dam and Sebeta stations shows the maximum variation from year to year, compared to the rest of the stations.

Table 5.1: Basic Descriptive statistics of annual rainfall of the study are

S.No	Stations	Mean	95% Confidence Interval for Mean		5% Trimmed Mean	Median	Variance	Std. Dev.	Min	Max	Range	IQR	Skewness	Kurtosis	CV
			Lower Bound	Upper Bound											
1	Bole	1038.4	996.9	1079.9	1037.2	1030.8	22256.4	149.2	741.8	1360.5	618.7	178.3	0.2	-0.3	0.17
2	Ginchi	1119.8	1063.2	1176.3	1118.9	1134.4	41262.7	203.1	710.9	1589.6	878.7	242.1	0.2	-0.2	0.23
3	Asgori	1060.4	1008.3	1112.6	1055.5	1013.8	24488.3	156.5	763.9	1460.5	696.6	215.2	0.6	0.0	0.15
4	Akaki	1075.7	1024.3	1127.0	1069.4	1080.3	33980.2	184.3	771.3	1487.3	716.0	215.4	0.4	-0.2	0.27
5	Koka Dam	788.1	670.2	906.1	780.3	778.7	125147.8	353.8	151.0	1559.7	1408.7	447.5	0.5	0.0	0.52
6	Mojo	929.3	870.9	987.6	921.4	876.9	43923.3	209.6	534.0	1470.2	936.2	279.0	0.6	0.5	0.23
7	Sebeta	1048.1	960.6	1135.7	1045.2	975.7	98937.5	314.5	400.4	1698.3	1297.9	342.5	0.5	-0.1	0.66
8	Sendafa	1134.1	1075.6	1192.7	1130.0	1125.1	44265.8	210.4	635.1	1590.0	954.9	259.2	0.3	0.0	0.24
9	Sululta	1204.6	1121.2	1288.0	1197.4	1181.3	62606.9	250.2	777.8	1756.5	978.7	375.8	0.3	-0.3	0.23
10	Teji	934.7	892.8	976.6	934.3	930.3	15801.2	125.7	686.8	1200.2	513.4	150.4	0.3	-0.2	0.16
11	Tulu Bolo	1115.8	1048.9	1182.6	1108.9	1076.9	57628.0	240.1	640.3	1641.2	1000.9	289.1	0.6	-0.2	0.25
12	Welenkomi	1082.9	1029.7	1136.1	1077.0	1038.6	36530.1	191.1	689.8	1515.0	825.2	236.8	0.6	-0.1	0.31
13	Addisalem	1143.0	1074.8	1211.2	1144.2	1151.5	60006.4	245.0	601.8	1763.5	1161.7	314.0	-0.1	0.1	0.21
14	Awash Melka	971.6	888.4	1054.8	964.3	886.3	49665.0	222.9	623.1	1440.7	817.6	341.7	0.7	-0.4	0.31
15	Alem Tena	775.9	717.8	834.0	777.8	806.1	24204.7	155.6	441.4	1111.8	670.4	191.1	-0.4	0.1	0.31
16	AA Obs	1265.4	1224.4	1306.4	1263.9	1252.9	21715.8	147.4	985.2	1567.4	582.2	161.9	0.1	-0.4	0.12
17	Shola	941.7	900.7	982.8	935.1	935.7	21760.2	147.5	647.2	1348.3	701.1	215.5	0.6	0.4	0.23
18	Debrezeit	819.3	774.1	864.6	821.3	855.9	22158.1	148.9	485.2	1144.1	658.9	196.6	-0.4	-0.3	0.19
19	Zequala	1140.5	1063.3	1217.8	1125.5	1099.0	64598.7	254.2	787.5	1860.0	1072.5	383.9	0.9	0.3	0.24
20	Nazeret	866.2	819.1	913.4	867.4	859.1	28720.1	169.5	436.0	1209.8	773.8	235.3	-0.1	-0.2	0.19
21	Ejere	892.9	839.2	946.6	890.6	917.2	28935.2	170.1	474.0	1276.1	802.1	245.7	0.2	0.1	0.2
22	Enchinni	1240.9	1183.2	1298.7	1241.9	1201.5	33445.8	182.9	834.2	1574.7	740.5	274.2	0.1	-0.6	0.21
23	Intoto	1240.5	1166.4	1314.5	1236.8	1213.4	30753.1	175.4	945.3	1601.0	655.7	191.7	0.4	0.0	0.16

5.1.4 Outliers Detection Results

Labeling Rule Method Results

From the results presented in Table 5-2, the 25th percentile (Q_1) was observed to be 951.5 while the 75th percentile (Q_3) was observed to be 1166.65 using the weighted average definition. The detail of percentile table is given in the appendices section.

Table 5.2 : Percentiles Value Weighted Average's annual rainfall data

	Asgori	Percentiles						
		5	10	25	50	75	90	95
Weighted Average		821.32	894.96	951.5	1013.8	1166.65	1299.2	1373.65

Adopting the labeling rule equation of the form:

$$\text{Lower Bound: } Q_1 - (2.2 \times (Q_3 - Q_1)) \text{ and Upper Bound: } Q_3 + (2.2 \times (Q_3 - Q_1))$$

The lower and upper bound statistics were calculated as follows:

$$\text{Lower bound} = 951.5 - (2.2(1166.65 - 951.5)) = 478.17\text{mm.}$$

$$\text{Upper bound} = 1166.65 + (2.2(1166.65 - 951.5)) = 1639.98\text{mm}$$

The extreme value statistics of the annual rainfall data which shows the highest and lowest case observation period is presented in Table 5-3.

Table 5.3 : Extreme value statistics of Asgori rainfall data.

Asgori	Highest		Lowest		Upper Bound	Lower Bound
	Case year	Value	Case Year	Value		
1	1996	1460.5	2012	763.9	1639.98	478.17
2	1990	1364.0	2015	827.7		
3	1993	1324.4	1980	875.2		
4	1992	1292.9	2011	899.9		
5	1986	1250.7	1982	910.3		

From the result of Table 5-3 it was observed that the highest rainfall value is 1460.5 which is less than the calculated upper bound of 1639.98mm. The lowest rainfall value was observed to be

763.9mm which are greater than the calculated lower bound of 478.17mm. Since no rainfall value was greater than the calculated upper bound or lower than the calculated lower bound, it was concluded that the annual rainfall data used in this study were free of possible outliers.

5.1.5 Normality Test

For normality, the skewness and kurtosis should be as close to zero as possible and result of Table 5-1 gave a skewness value of 0.678 with a kurtosis of 0.229 for Asgori, which is far from indicating that the data are not normally distributed. Moreover, the histogram of the rainfall data collected from the stations should assumed the bell shaped configuration otherwise, it is concluded that the data are not normally distributed. The histogram of the rainfall data collected from Asgori is presented in Figures 5-4 and it was observed that the rainfall data from Asgori is not normally distributed.

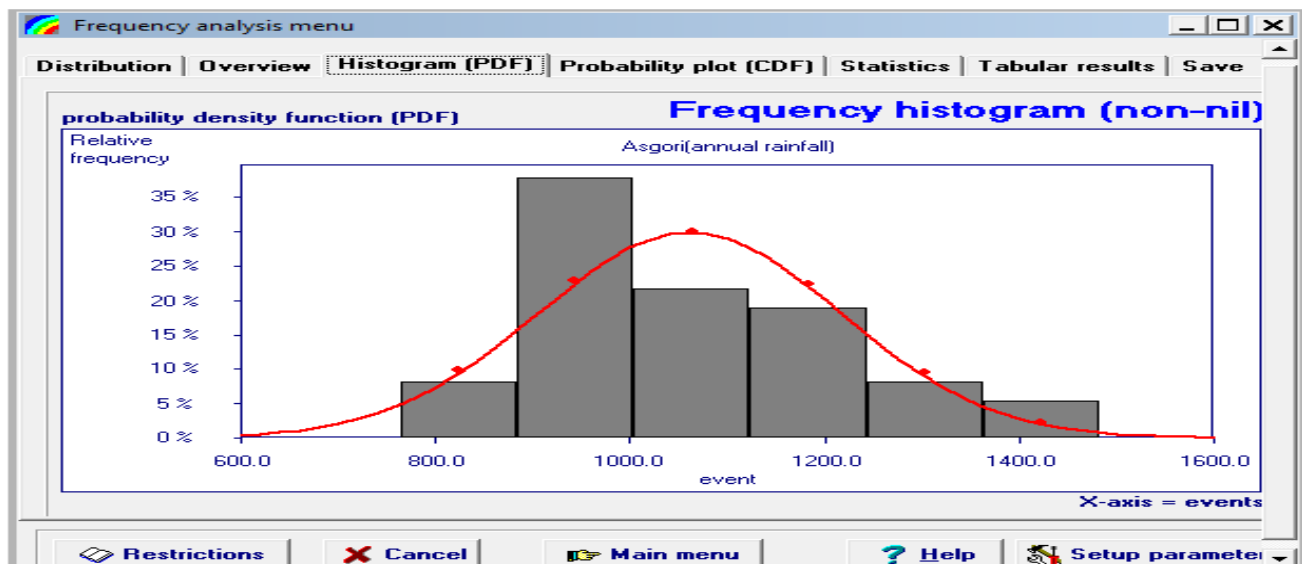


Figure 5-4: Histogram of Asgori rainfall data.

To conclude the assumption of normality, statistical hypothesis were formulated as follows:

H_0 : The data are normally distributed and H_1 : The data are not normally distributed

To validate the strength of the null hypothesis, normal probability analysis software was employed to test the normality behavior of the rainfall data at 99% confidence interval (0.01 degree of freedom). Result of the statistical analysis is presented in Figures 5-5, and revealed that rainfall data from Asgori station is not normally distributed at 99% confidence interval. The details for each station are presented in the appendices section. Only Sululta station is normally distributed at 99% confidence interval.

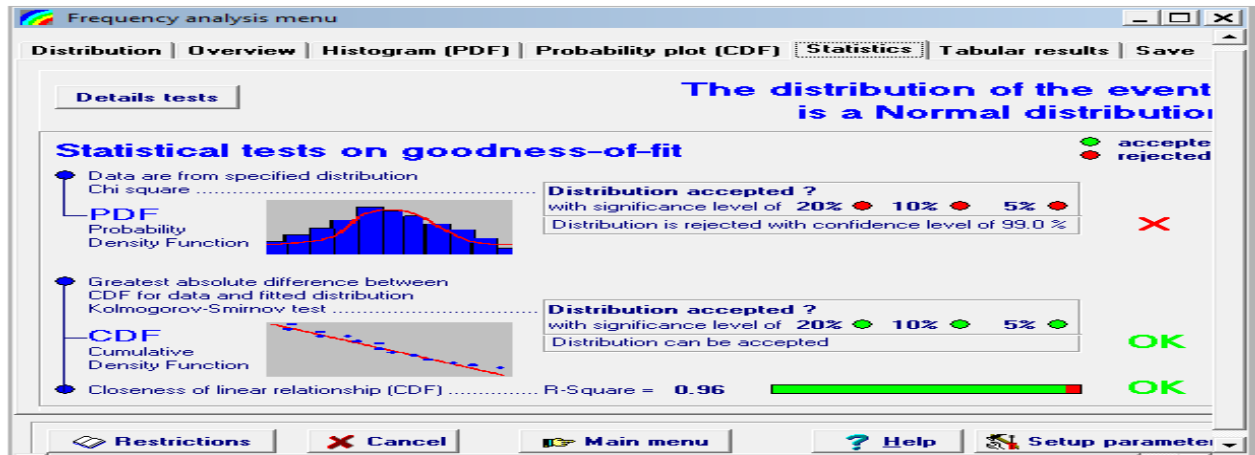


Figure 5-5: Statistical test of Asgori rainfall data

The implication is that non-parametric test will be most suitable in detecting and estimating the magnitude of trend associated with the data.

5.2 Spatial Distribution of Rainfall

From the analysis, it was observed that there is significant spatial variation in the mean annual rainfall received at twenty three meteorological stations of Upper Awash Basin [Table5-1]. The catchment receives mean annual rainfall of 1036.1mm. The highest rainfall occurs is 1265.4mm at Addis Ababa Obs station followed by Enchinni and Intoto stations having 1240.9 mm and 1240.5 mm where as the lowest rainfall of 775.9 mm received at Alem Tena station.

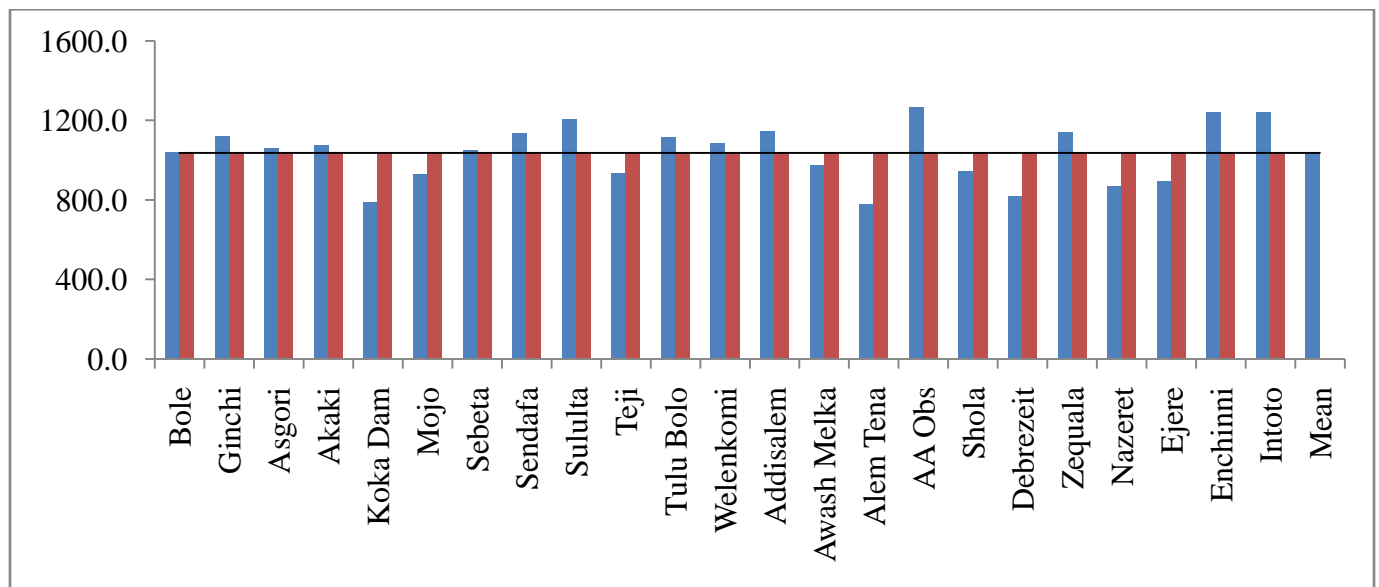


Figure5-6 : Station wise spatial distribution of annual rainfall

5.3 Temporal Rainfall Trend Analysis

This section presents the results of the non-parametric Mann–Kendall and Sen’s Slope Estimator tests at the 5% significance level in tabular and graphical form. In this study, trend analysis for monthly, seasonal, annual rainfall data in Upper Awash Basin has been carried out according to the observation period availability. Mann-Kendall and Sen’s Slope estimator were used for the determination of trend. In the non-parametric Mann-Kendall test, the trend of rainfall has been detected for each station individually with Sen’s magnitude of slope.

5.3.1 Monthly Trend Analysis Trend Significance

The Mann-Kendall (MK) test was applied on a monthly scale to detect trends in the rainfall series at different stations. Monthly trend tests showed a mix of positive and negative trends at different stations (table 5-5).

The rainfall trend during January showed that increasing trend at Welenkomi, Mojo, Nazeret, Zequala, Debrezeit, Intoto, Enchinni, Awash Melka, Koka Dam stations, but all are statistically insignificant. The rests of the stations are statistically insignificant decreasing trend.

The trend analysis discovered that statistically significant (95% confidence level) decreasing trends of the February rainfall appear in Akaki, Tulu Bolo, Welenkomi, Addis Ababa Obs., Shola, Teji, Asgori, Ejere, Alem Tena and Koka Dam. No trend indicated at Zequala station of the same month. The rests of the stations are statistically insignificant decreasing trend.

Rainfall in the station of Mojo, Nazeret, Zequala and Koka Dam shows insignificant increasing trends where as the remaining of the stations shows insignificant decreasing trends in the month of March. None of the station is statistically significant at 95% confidence level in March.

Similarly, rainfall in the station of Sebeta and Zequala shows insignificant increasing trends where as the remaining of the stations shows insignificant decreasing trends in the month of April except at Alem Tena station which is statistically significant at 95% confidence level.

Debrezeit, Intoto and Sululta stations shows insignificant decreasing trends in May. Rainfall at station of Sebeta, Tulu Bolo and Enchinni stations shows increasing trend which is statistically significant at 95% confidence level in this month. The rests of the stations are statistically insignificant increasing trend.

Statistically insignificant decreasing trend is found in the stations of Akaki, Sebeta, Welenkomi, Nazeret and Alem Tena where as statistically significant increasing trend were obtained for

Zequala, Teji and koka Dam stations of June month. For the remaining stations in the same month, statistical insignificant positive trend is obtained at 95% confidence level.

Rainfall during July at stations Sebeta, Sendafa, Welenkomi, Enchinni, Debrezeit, Sululta, Teji and Asgori shows negative trend and Akaki station show statistically significant decreasing trend where as Mojo, Ejere and Koka Dam were statistically significant increasing trend at 95% confidence level. The remaining stations were positive and statistically insignificant.

In the same manner, rainfall during August at stations Bole, Ginchi, Tulu Bolo, Mojo, Welenkomi, Debrezeit, Nazeret, Addis Ababa Obs., Shola, Enchinni and Teji shows negative trend and Akaki, Alem Tena, Addis Alem and Asgori stations shows statistically significant decreasing trend. The remaining stations were positive and statistically insignificant at 95% confidence level in August.

Statistically significant decreasing trend were found at 95% confidence level in September for Akaki station while statistically significant increasing trend was obtained for Koka Dam station. For Addisalem, Bole, Ginchi, Welenkomi, Mojo, Alem Tena, Zequala, Enchinni and Intoto stations, the trends were negative and not significant while for the other unmentioned stations during September the trends were positive and statistically insignificant.

None of the station was statistically significant decreasing and increasing trends at 95% confidence level during October. Tulu Bolo, Mojo, Nazeret, Zequala, Debrezeit, Intoto, Sululta and Teji shows positive trend while unmentioned stations were negative trend and both of them were statistically insignificant.

Rainfall during November at stations Akaki, Sebeta, Tulu Bolo, Nazeret, Zequala, Debrezeit, Shola, Ejere and Koka Dam shows Positive trend and Intoto, Sululta, Teji, Awash Melka and Alem Tena stations show statistically significant increasing trend. The remaining stations were negative and statistically insignificant.

None of the station was statistically significant decreasing and statistically significant increasing trend was observed at Debrezeit station at 95% confidence level during December. Akaki, Addis Alem, Enchinni, Bole, Ginchi, Sendafa, Addis Ababa Obs., Asgori, Ejere, Alem Tena and Koka Dam shows negative trend while the rest stations were positive trend.

Table 5.4: Station-wise Monthly Test Statistics (Z) Values.

S.No	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Akaki	-1.25	-2.27	-0.08	-1.43	0.26	-1.71	-3.20	-2.47	-2.26	-0.70	0.09	-0.66
2	Addis Alem	-0.62	-1.98	-0.73	-1.74	0.92	0.15	0.07	-2.45	-1.65	-1.45	-1.01	-0.44
3	Bole	-0.47	-1.71	-0.72	-1.61	0.81	0.59	1.21	-0.80	-0.84	-1.64	-1.05	-0.31
4	Ginchi	-0.64	-1.62	-0.18	-1.24	0.67	0.43	1.32	-0.32	-1.21	-1.71	-1.33	-0.09
5	Sebeta	-0.09	-1.10	-0.28	0.14	2.28	-0.97	-0.49	0.53	1.08	-0.58	0.29	0.36
6	Sendafa	-0.50	-1.83	-1.39	-0.12	0.91	1.03	-0.56	0.36	0.32	-0.81	-0.58	-0.91
7	Tulu Bolo	-0.87	-2.09	-0.78	-0.15	2.67	1.25	0.08	-0.59	0.06	0.24	0.86	0.12
8	Welenkomi	0.02	-2.49	-1.53	-1.55	0.22	-0.72	-0.24	-1.68	-0.89	-1.13	-0.27	0.27
9	Mojo	0.69	-1.09	0.83	-0.79	1.08	0.70	2.52	-0.28	-0.60	0.60	-0.30	0.00
10	Nazeret	0.87	-0.88	0.17	-0.24	0.13	-1.05	1.76	-0.48	1.22	0.09	1.60	1.47
11	Zequala	0.76	0.00	0.60	0.31	0.35	2.09	1.57	0.07	-0.25	0.74	0.53	0.76
12	Debrezeit	0.08	-0.63	-0.34	-0.69	-0.28	0.85	-0.62	-0.46	0.55	0.30	1.06	2.12
13	AA Obs.	-1.17	-2.65	-0.39	-0.39	0.71	1.76	0.84	-0.38	0.64	-0.67	-1.48	-0.14
14	Shola	-0.43	-2.65	-0.65	-0.58	0.24	0.27	1.48	-0.58	0.06	-0.27	1.12	0.26
15	Intoto	1.00	-1.49	-0.55	-0.77	-0.07	1.41	1.76	0.42	-0.82	1.51	2.22	1.29
16	Sululta	-0.19	-1.60	-1.84	-0.42	-0.07	1.06	-0.01	0.33	1.50	1.94	2.61	0.31
17	Teji	-0.62	-2.17	-0.52	-1.50	1.61	2.00	-1.66	-0.69	1.16	0.01	2.60	0.09
18	Asgori	-0.45	-2.25	-1.23	-1.53	1.95	0.61	-1.37	-2.97	0.51	-1.37	-0.05	-0.85
19	Koka Dam	0.21	-2.28	0.41	-0.24	1.67	2.15	3.44	1.22	2.29	-0.15	1.83	-1.00
20	Enchinni	0.17	-1.07	-0.11	-0.37	2.07	0.35	-1.83	-0.51	-0.03	-0.75	-0.24	-0.86
21	Ejere	-0.75	-2.31	-0.46	-0.46	0.74	0.82	2.68	1.34	1.68	-0.66	0.80	-0.98
22	Awash Melka	0.47	-1.98	-1.16	-0.54	1.78	0.25	0.43	0.18	1.18	-0.65	2.08	1.35
23	Alem Tena	-0.81	-2.25	-0.93	-2.46	1.91	-1.28	0.07	-2.53	-1.5	-0.39	2.14	-1.05

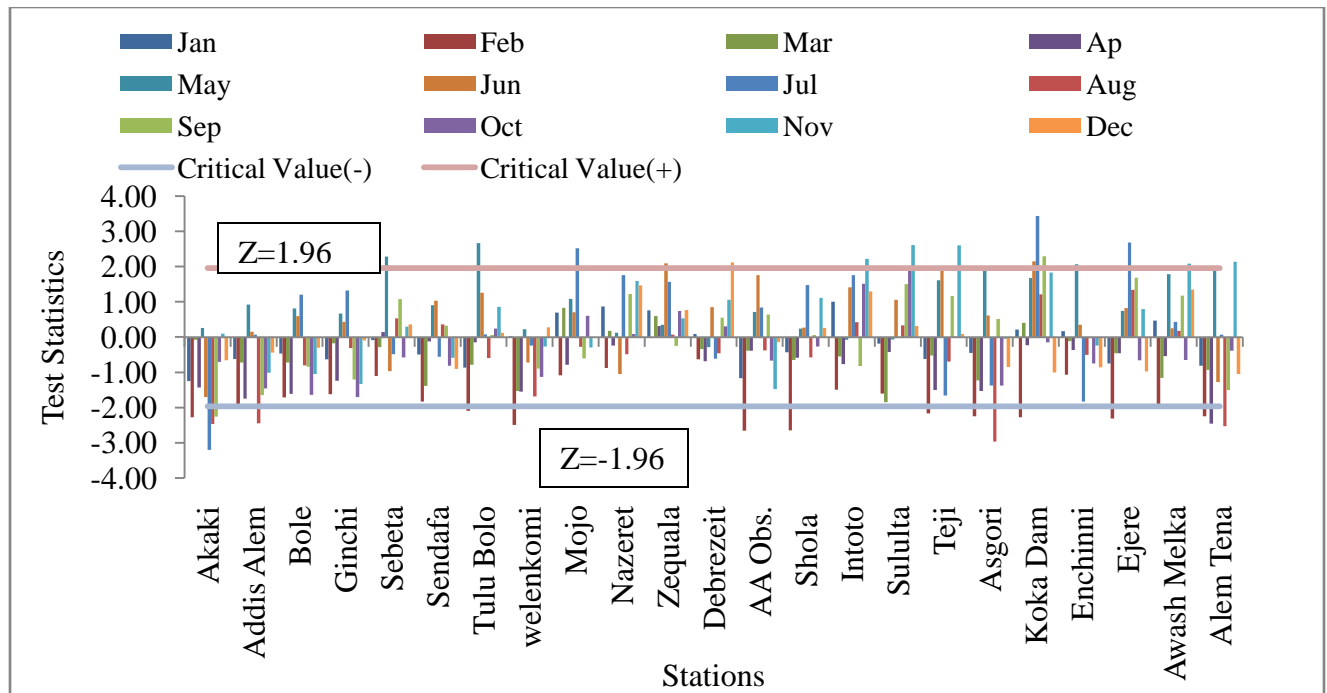


Figure 5-7 : Test Statistics Z for individual stations of monthly rainfall

Trend Magnitude

The magnitude of statistically significant trends on a monthly scale was determined using Sen’s slope estimator. The results show that trends at Intoto, Koka Dam, Ejere, Alemtena and Asgori were more rapid (e.g., sharper increases and decreases) compared to other stations. The Asgori station had the maximum negative decline in monthly rainfall (3.15 mm/month) during the month of August where as Koka Dam station had the maximum positive increase (5.34mm/month) during the months of July. Figure5-10 shows the trends in maximum monthly rainfall trend at the Koka Dam and Asgori station.

In January, the rainfall magnitude varies between -0.07mm to 0.00 mm/month range in some area of the Upper Awash Basin. For November and December month, the magnitude is ranged from -0.15mm in December to 0.2mm/month in November at Enchinni and Sululta stations respectively. The rainfall change has not existed in the most parts of the Upper Awash Basin on January, November and December. This indicated the absence of rainfall during these months (dry month). The highest rainfall increment has been occurred on July at Koka Dam. On February, the rainfall amounts have been decreased in all specified stations except at Nazeret; Zequala and Debrezeit stations (does not change).

Table 5.5: Station-wise Monthly Trend Magnitude (Q) Values

S.No	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Akaki	0.00	-0.80	-0.07	-0.62	0.10	-0.77	-2.11	-1.80	-1.52	-0.07	0.00	0.00
2	Addis Alem	0.00	-0.41	-0.22	-0.85	0.40	0.08	0.11	-1.40	-0.84	-0.28	0.00	0.00
3	Bole	0.00	-0.41	-0.24	-0.67	0.40	0.23	0.89	-0.39	-0.47	-0.32	0.00	0.00
4	Ginchi	0.00	-0.41	-0.08	-0.60	0.30	0.19	0.94	-0.13	-0.55	-0.36	0.00	0.00
5	Sebeta	0.00	-0.16	-0.09	0.11	1.07	-0.41	-0.31	0.59	0.67	-0.05	0.00	0.00
6	Sendafa	0.00	-0.21	-0.44	-0.03	0.42	0.55	-0.43	0.29	0.18	-0.09	0.00	0.00
7	Tulu Bolo	0.00	-0.46	-0.26	-0.09	1.30	0.98	0.03	-0.56	0.05	0.00	0.00	0.00
8	Welenkomi	0.00	-0.52	-0.49	-0.66	0.06	-0.34	-0.15	-1.13	-0.45	-0.14	0.00	0.00
9	Mojo	0.00	-0.01	0.36	-0.34	0.44	0.36	2.37	-0.13	-0.27	0.09	0.00	0.00
10	Nazeret	0.00	0.00	0.06	-0.08	0.05	-0.55	1.34	-0.42	0.54	0.00	0.00	0.00
11	Zequala	0.00	0.00	0.29	0.22	0.25	1.45	1.88	0.05	-0.16	0.10	0.00	0.00
12	Debrezeit	0.00	0.00	-0.08	-0.39	-0.25	0.53	-0.55	-0.32	0.26	0.01	0.00	0.00
13	AA Obs.	-0.19	-0.68	-0.14	-0.13	0.29	0.85	0.43	-0.19	0.28	-0.18	-0.08	-0.01
14	Shola	0.00	-0.38	-0.19	-0.19	0.06	0.12	1.03	-0.38	0.02	0.00	0.00	0.00
15	Intoto	0.36	-1.30	-0.81	-0.85	-0.17	2.50	3.23	0.72	-1.08	0.91	0.10	0.02
16	Sululta	0.00	-0.45	-1.05	-0.35	-0.10	1.13	-0.09	0.60	1.26	0.22	0.20	0.00
17	Teji	0.00	-0.80	-0.27	-1.30	1.13	1.78	-0.96	-0.39	0.76	0.00	0.00	0.00
18	Asgori	-0.07	-0.92	-0.73	-1.15	1.36	0.52	-1.40	-3.15	0.33	-0.27	0.00	-0.08
19	Koka Dam	0.00	-0.26	0.11	-0.09	1.21	1.59	5.34	2.17	1.87	0.00	0.00	0.00
20	Enchinni	0.04	-0.28	-0.06	-0.29	1.94	0.32	-2.21	-0.54	-0.04	-0.22	-0.01	-0.15
21	Ejere	0.00	-0.51	-0.26	-0.22	0.42	0.42	2.96	1.73	1.32	-0.05	0.00	0.00
22	Awash Melka	0.00	-0.99	-1.20	-0.90	2.34	0.40	0.99	0.19	1.42	-0.06	0.01	0.00
23	Alem Tena	0.00	-0.63	-0.64	-2.34	1.19	-1.20	0.21	-2.56	-1.59	-0.05	0.00	0.00

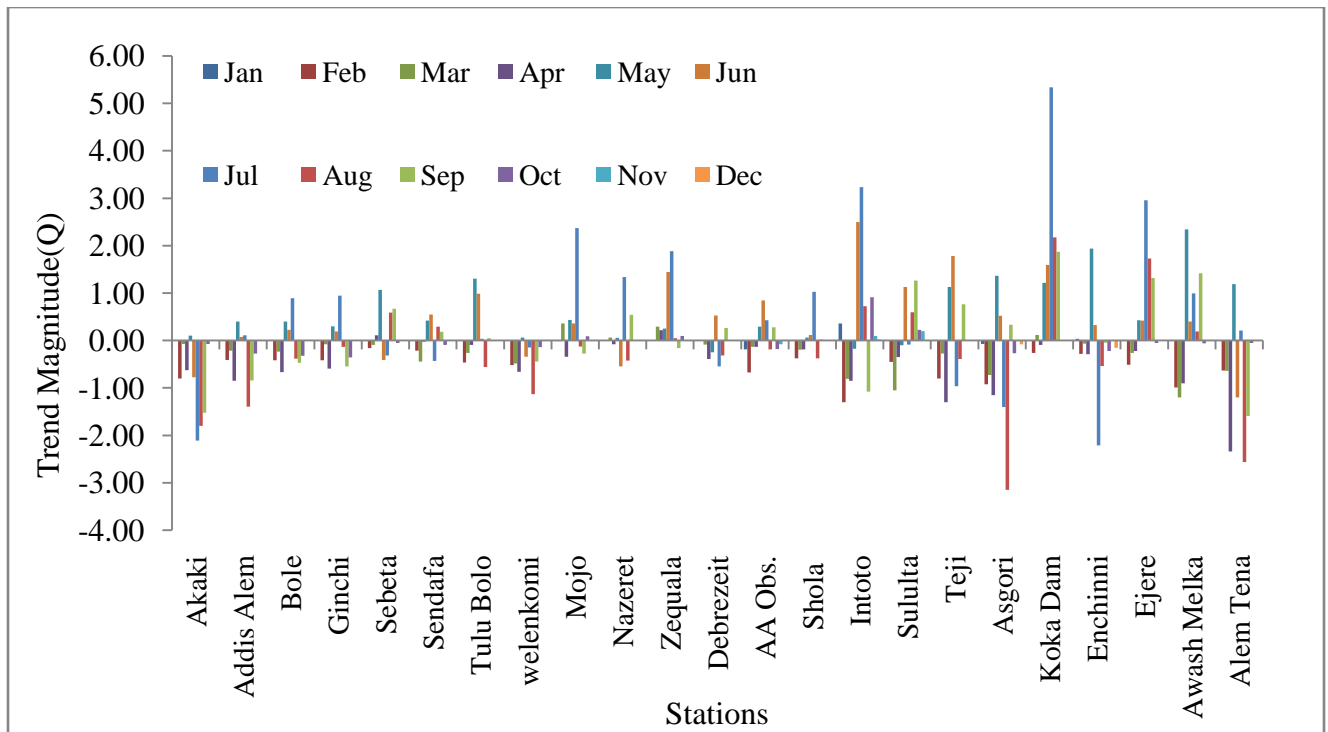


Figure 5-8 : Trend magnitude of the monthly rainfall

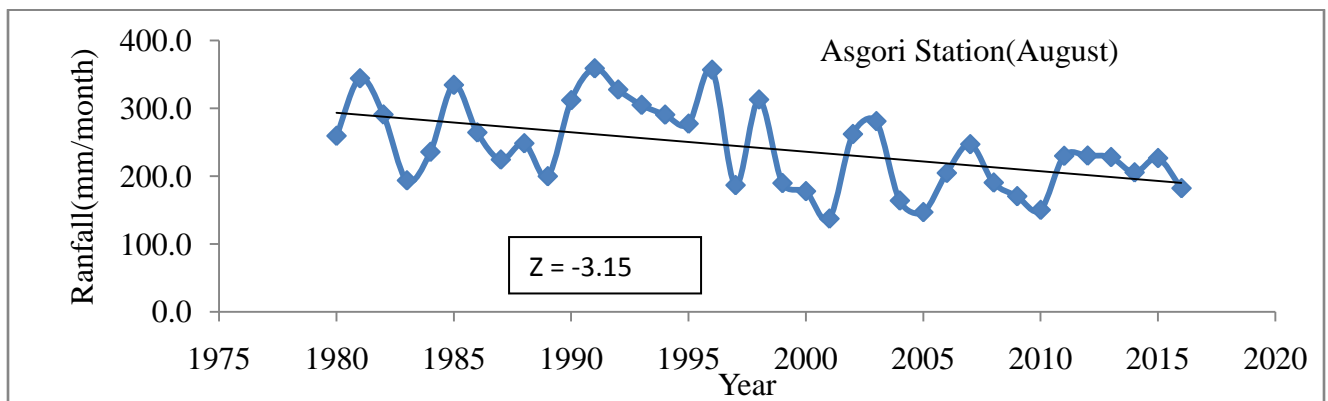
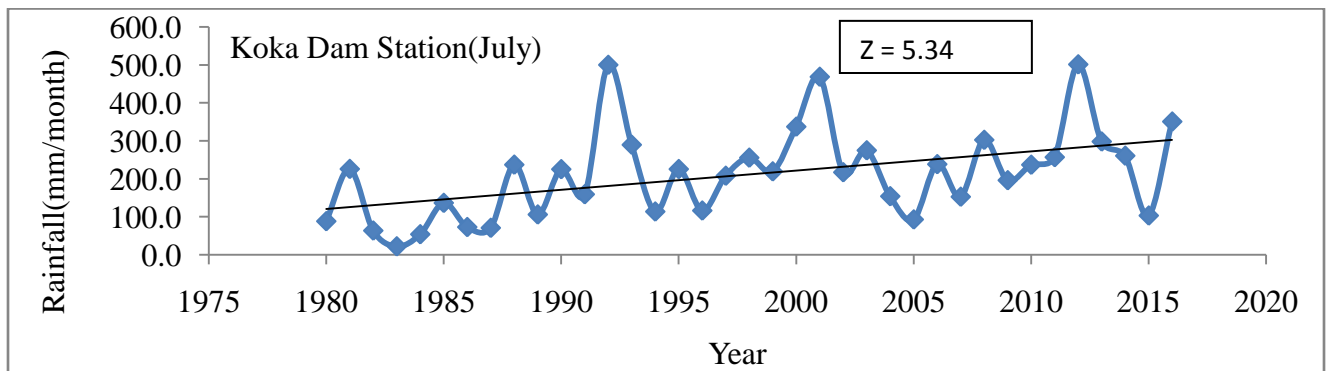


Figure 5-9: Variations of monthly rainfall time series in stations with most significant trends during 1980–2016.

5.3.2 Seasonal Trend Analysis

Trend Significance

Decreasing rainfall trend is found during Autumn Season at Sululta station while decreasing rainfall trend with statistically significant is not found at any stations.

Increasing rainfall trend with statistically significant at 95% confidence level is found during Summer Season at Mojo and Ejere stations while decreasing rainfall trend with statistically significant is found at Akaki, Welenkomi and Asgori stations. The rest of the station has statistically insignificant negative trends (Addis Alem, Bole, Ginchi, Tulubolo, Debrezeit, Enchinni, and Alemtena) and positive trends (Sebeta, Sendafa, Shola, Nazeret, Zequala, Addis Ababa Obs., and Awash melka, Sululta, Teji, Koka Dam and Intoto).

Rainfall during spring season at Akaki Station show decreasing trend and statistically significant where as none of station show statistically significant increasing trend. Addis Alem, Bole, Ginchi, Sebeta, Sendafa, Welenkomi, AA Obs., Koka Dam, Enchinni, Alemtena and Debrezeit stations shows negative trend and statistically insignificant. The rest of the station has statistically insignificant positive trends.

The trend analysis revealed that statistically significant (95% confidence level) decreasing trends of the winter rainfall appear in Akaki, Bole, Sendafa, Alemtena, Shola, Teji, Ejere and Tulu Bolo stations. The rest of the station has statistically insignificant negative trends in the season of winter.

Trend Magnitude

The trend magnitude varies between -3.37mm/year to 1.46 mm/year at stations Sululta and Koka Dam respectively in the autumn while -3.05mm/year and 7.54mm/year at stations Alemtena and Intoto in the summer which are decreasing and increasing. For the case of spring the rainfall magnitude has been decreased by -4.41 mm/year and increased by 2.53mm/year at Akaki and Awash melka stations. Winter season showed the rainfall magnitude of -1.38mm/year and -0.08mm/ at Alemtena and Nazeret stations. All the mentioned station here have been the maximum decline and rise rainfall trend magnitude.

In general, the results of trend magnitude Q showed decreased at Ginchi, Welenkomi, Addis Alem, Bole, Akaki and Debrezeit stations.

Table 5.6: Station-wise Seasonal Test Statistics (Z) and Trend Magnitude Values

S.No	Stations	Autumn		Summer		Spring		Winter	
		Z	Q	Z	Q	Z	Q	Z	Q
1	Akaki	-1.23	-1.20	-2.57	-2.97	-2.05	-4.41	-2.04	-0.75
2	Addis Alem	-1.12	-0.80	-1.15	-1.97	-1.66	-1.04	-1.29	-0.61
3	Bole	-1.17	-1.12	-0.73	-0.64	-1.00	-0.50	-2.09	-0.76
4	Ginchi	-0.03	-0.03	-0.59	-0.60	-1.55	-1.18	-1.70	-0.74
5	Sebeta	0.37	0.54	0.42	0.72	-0.80	0.52	-1.28	-0.46
6	Sendafa	-0.78	-0.58	1.02	1.39	-0.80	-0.57	-2.50	-0.91
7	Tulu Bolo	0.97	0.49	-0.18	-0.33	0.09	0.06	-2.21	-0.73
8	Welenkomi	-1.43	-1.02	-2.39	-2.18	-1.71	-1.23	-1.56	-0.59
9	Mojo	0.91	0.67	2.08	2.42	0.32	0.14	-0.99	-0.25
10	Nazeret	-0.15	-0.08	0.48	0.58	1.57	1.09	-0.28	-0.08
11	Zequala	0.64	0.77	1.80	3.00	0.70	0.56	-0.24	-0.13
12	Debrezeit	-0.90	-1.02	-0.05	-0.11	-0.17	-0.16	-0.87	-0.27
13	AA Obs.	-0.96	-0.86	1.27	1.19	-0.39	-0.28	-1.93	-0.92
14	Shola	-0.95	-0.53	0.51	0.68	0.36	0.19	-2.20	-0.65
15	Intoto	-1.66	-2.88	1.41	7.54	0.62	0.99	-0.82	-0.92
16	Sululta	-2.00	-3.37	0.27	1.11	1.87	2.08	-0.73	-0.20
17	Teji	-0.30	-0.24	0.48	0.50	1.36	1.10	-2.22	-1.15
18	Asgori	-0.17	-0.23	-2.11	-3.49	0.14	0.14	-1.66	-1.14
19	Koka Dam	1.06	1.46	1.78	5.35	-0.31	-0.34	-1.42	-0.59
20	Enchinni	0.58	0.93	-0.90	-1.62	-0.62	-0.56	-0.93	-0.72
21	Ejere	-0.36	-0.24	2.58	4.68	1.25	1.14	-2.62	-1.25
22	Awash Melka	0.11	0.44	0.75	1.79	0.92	2.53	-1.59	-1.18
23	Alem Tena	-0.96	-1.84	-1.50	-3.05	-0.75	-1.26	-2.08	-1.38

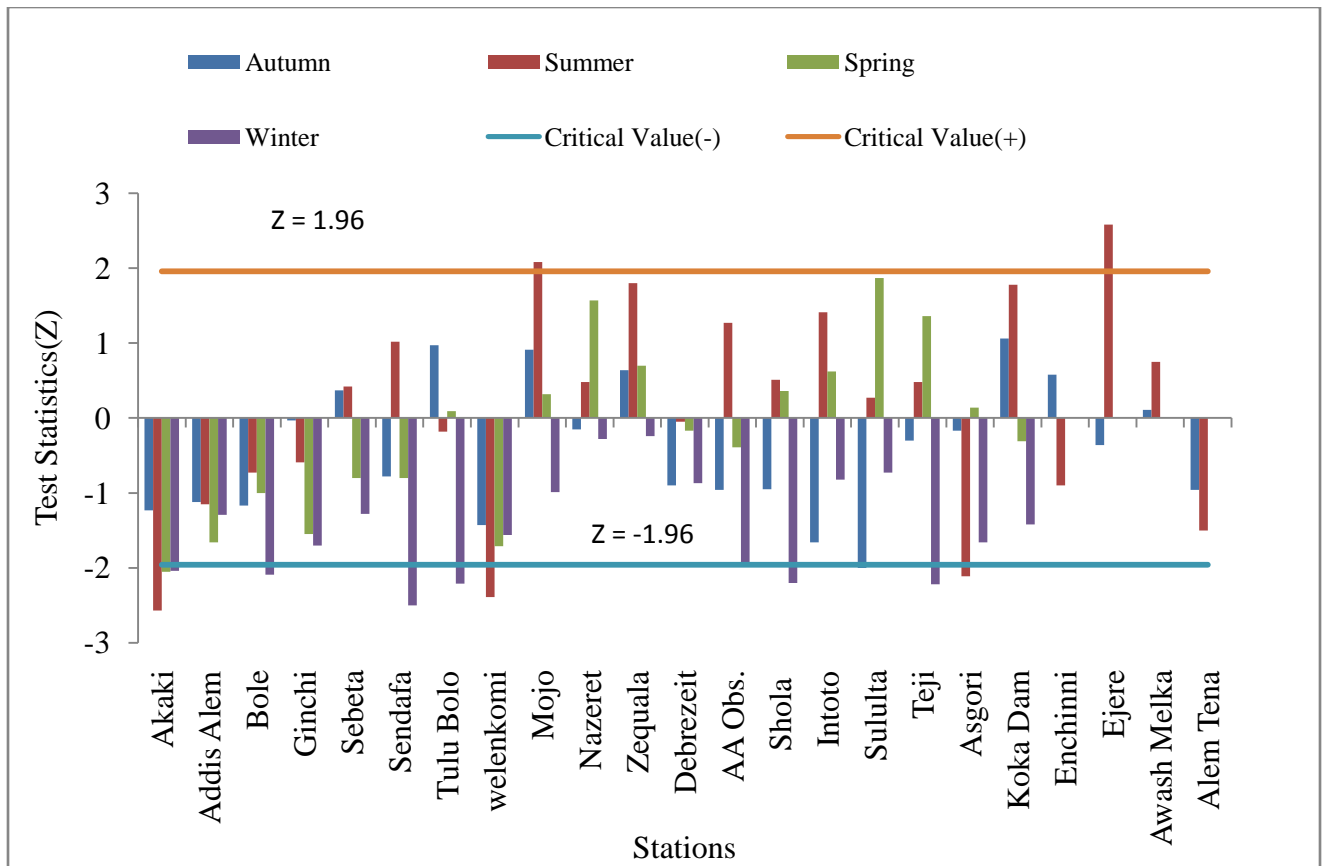


Figure 5-10 : Test Statistics Z for individual stations of seasonal rainfall

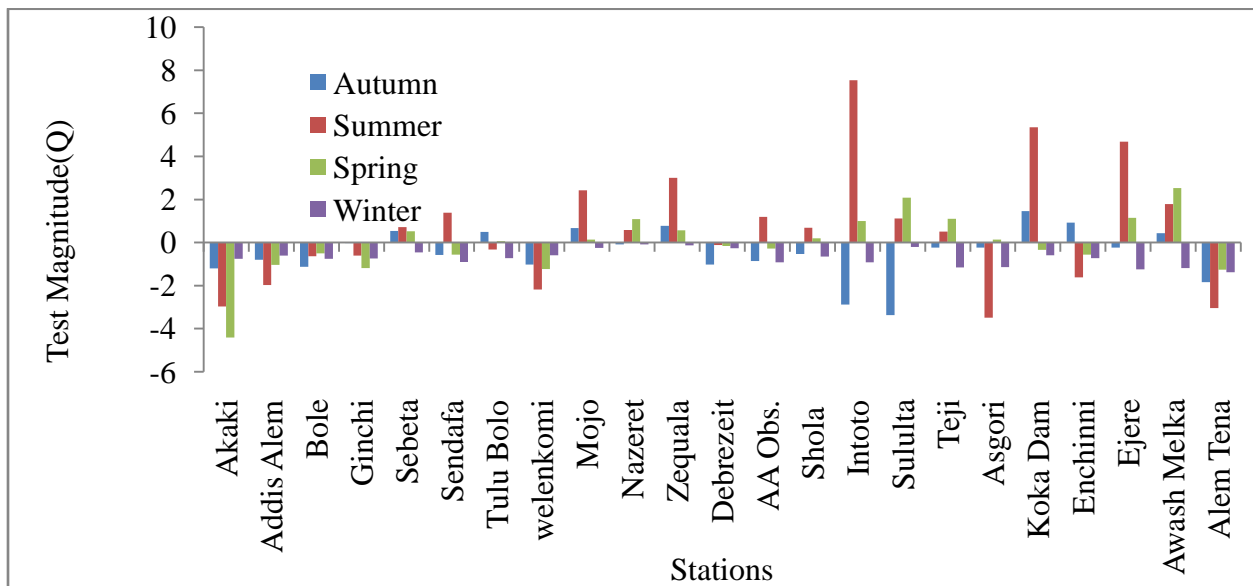


Figure 5-11: Trend magnitude of the seasonal rainfall

5.3.3 Annual Rainfall Temporal Trends Analysis

Trend Significance

The trend analysis revealed that statistically insignificant (95% confidence level) negative trends of the annual rainfall appear in Ginchi, Intoto, Shola, Akaki, Sendafa, Sululta, Asgori, Tulu Bolo, Debrezeit and Alemtena stations while Welenkomi, Addis Alem, Bole, Akaki and Asgori showed a statistically significant decreasing trend at 95% confidence level. The test statistics values of Z for Intoto, Awash, Mojo, Koka, Ejere and Nazeret stations showed an insignificant positive trend while Zequala station showed a statistically significant increasing trend at 95% confidence level. The results of annual test statistics Z, implying that 21.7% decreasing trend, 4.3% increasing trend and 73.9% exhibits no trend which was statistically significant over the observation period at 95% confidence level. The most important annual trends happen at Welenkomi station.

Table 5.7:-Station-wise annual rainfall trends using Mann-Kendall test and Sen's slope methods

S.No	Station name	Z	Trend	Significance level	Q
1	Ginchi	-1.68	Decreasing	Not significant	-3.05
2	Welenkomi	-3.15	Decreasing	Significant	-5.1
3	Addis Alem	-2.37	Decreasing	Significant	-5.06
4	Bole	-2.23	Decreasing	Significant	-3.56
5	AA Obs	-0.43	Decreasing	Not significant	-0.75
6	Intoto	0.62	Increasing	Not significant	2.75
7	Shola	-0.91	Decreasing	Not significant	-1.43
8	Akaki	-2.67	Decreasing	Significant	-4.64
9	Sendafa	-0.59	Decreasing	Not significant	-0.85
10	Sululta	-0.38	Decreasing	Not significant	-1.27
11	Sebeta	-0.03	Decreasing	Not significant	-0.06
12	Teji	-0.43	Decreasing	Not significant	-1.1
13	Asgori	-2.18	Decreasing	Significant	-4.93
14	Tulu Bolo	-0.64	Decreasing	Not significant	-1.43
15	Debrezeit	-1.02	Decreasing	Not significant	-1.69
16	Zequala	2.07	Increasing	Significant	5.69

17	Mojo	1.65	Increasing	Not significant	3.08
18	Nazeret	0.95	Increasing	Not significant	1.61
19	Koka Dam	1.43	Increasing	Not significant	7.67
20	Enchinni	-1.27	Decreasing	Not significant	-3.55
21	Ejere	0.66	Increasing	Not significant	1.7
22	Awash Melka	0.29	Increasing	Not significant	1.58
23	Alem Tena	-1.75	Decreasing	Not significant	-6.03

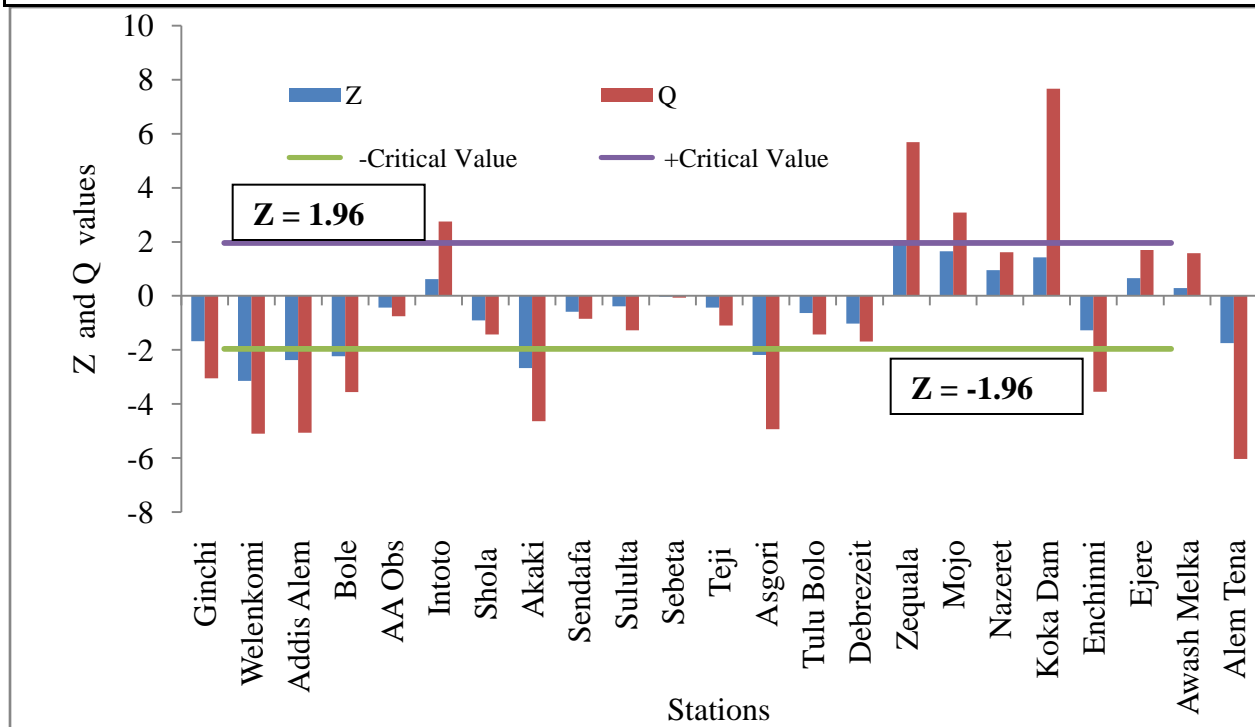
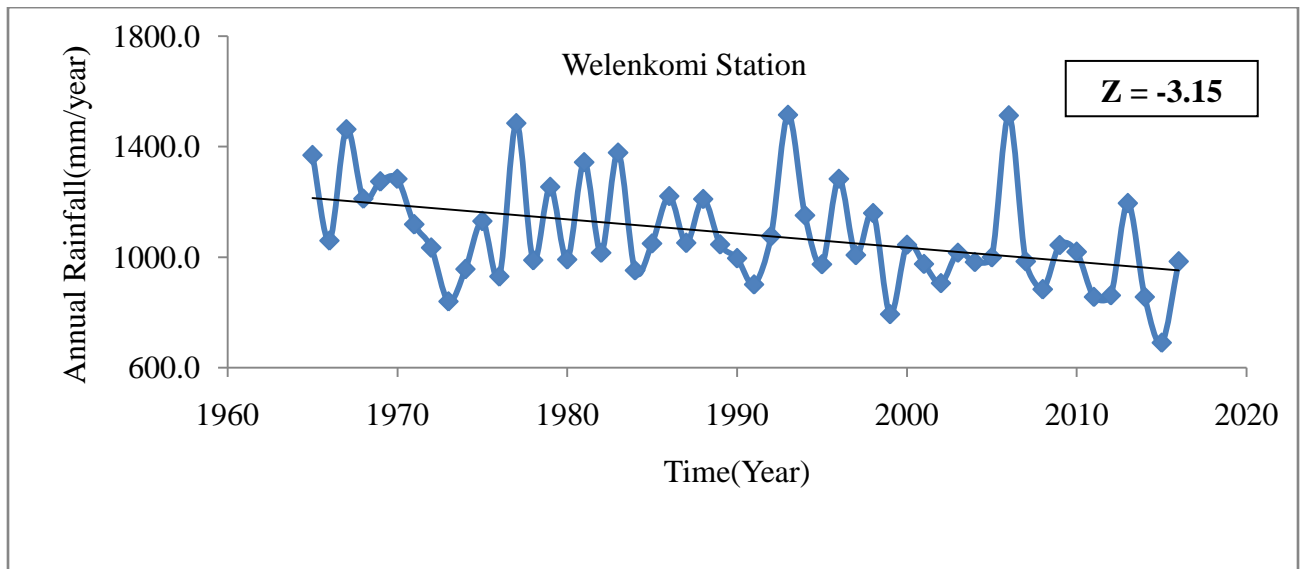
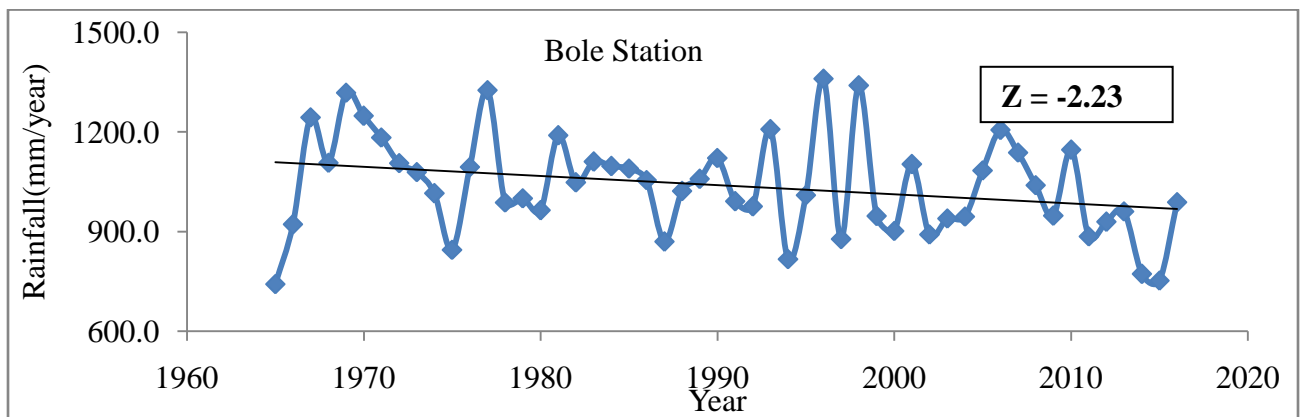
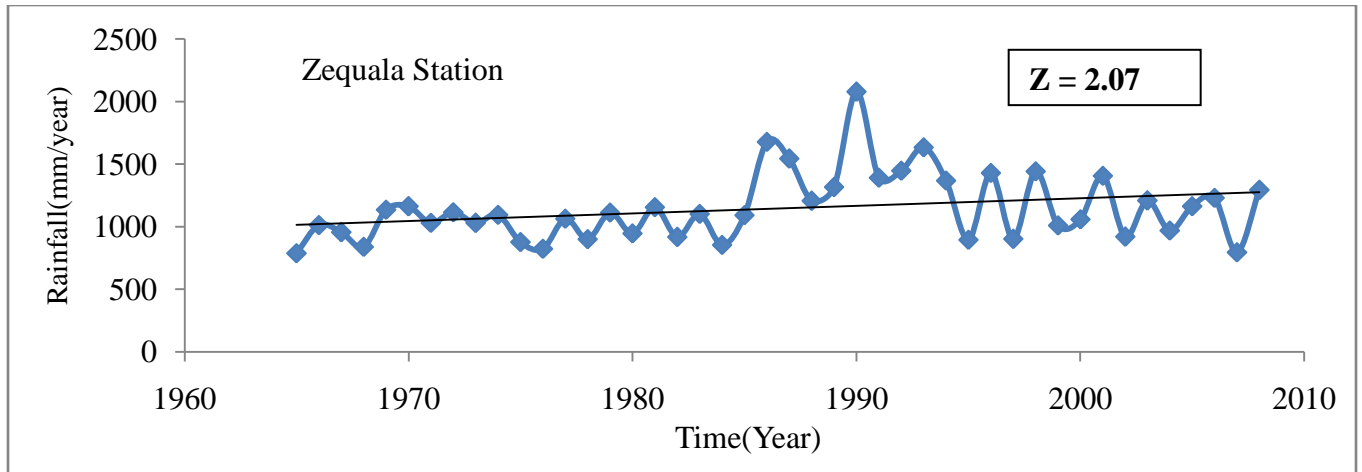


Figure 5-12: Test Statistics Z and Magnitude Q for individual stations of annual rainfall
Trend Magnitude

On evaluating, across the considerable number of stations, the rate of rainfall change over time (mm/year) at Zequala station was found to have undergone increasing rainfall in annual. The greatest decline was found for the Welenkomi station (-6.03mm/year), while the greatest increase occurred in the Koka Dam (7.67 mm/year).

Maximum decreasing change in annual rainfall is 23.2% at Welenkomi station while maximum increasing change in annual rainfall is 34.9 % at Koka Dam station.



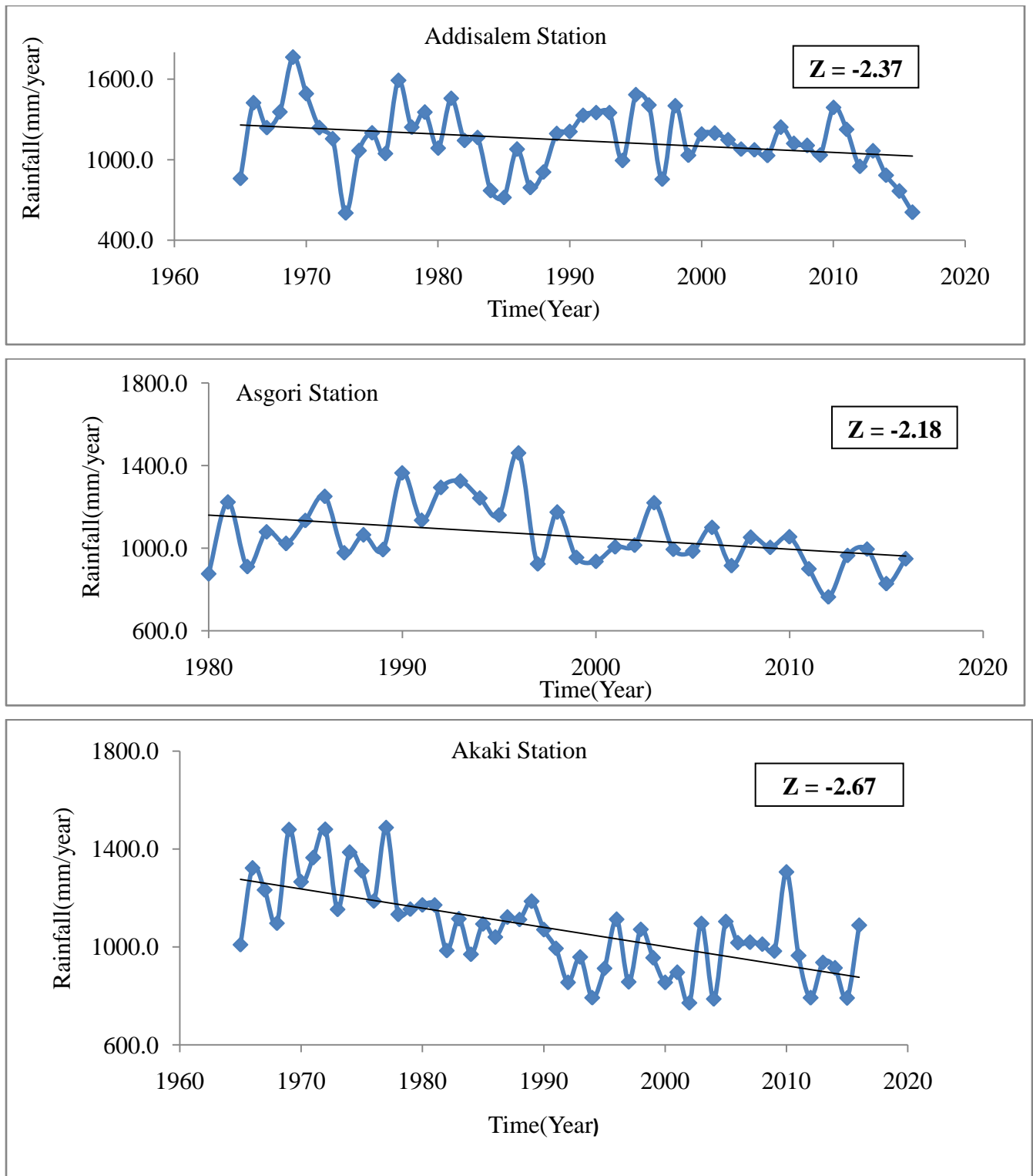


Figure 5-13 : Variations of annual rainfall time series in stations with significant trends during observation period.

5.4 Spatial Distribution of Seasonal and Annual Rainfall Trends

Figure 5-14 demonstrates the spatial distribution of the seasonal and annual rainfall in the Upper Awash basin. In autumn, the upper awash basin is dominated by decreasing rainfall. Although a significant decreasing and increasing rainfall trend occurred in the south western; western and north eastern part of the upper awash basin, the remainder of the upper awash basin is dominated by increasing rainfall trend (Figure 5-14a).

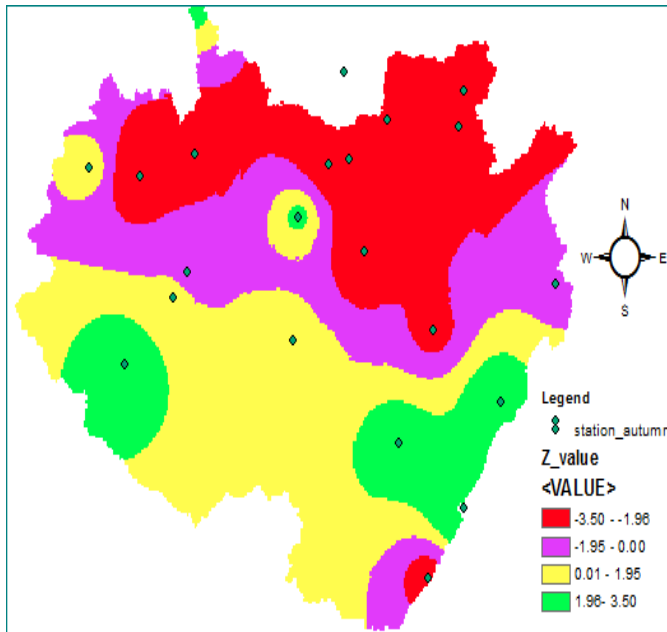
The rainfall in summer shows a dominance increasing and decreasing trend at most part of the upper awash basin (Figure 5-14b). In general, some parts of the southwestern, central and south eastern of the upper awash basin show a significantly decreasing trend and the eastern showed significant increasing rainfall trend. No rainfall trend was found in small part of the western upper basin.

Figure 5-14c indicates that most parts of the upper awash basin are dominated by increasing rainfall trend in spring. Statistically significant decreasing trend were found at some parts of south western, western and central. Statistically significant increasing trend were also found at some parts of eastern and uneven distribution is present at different point.

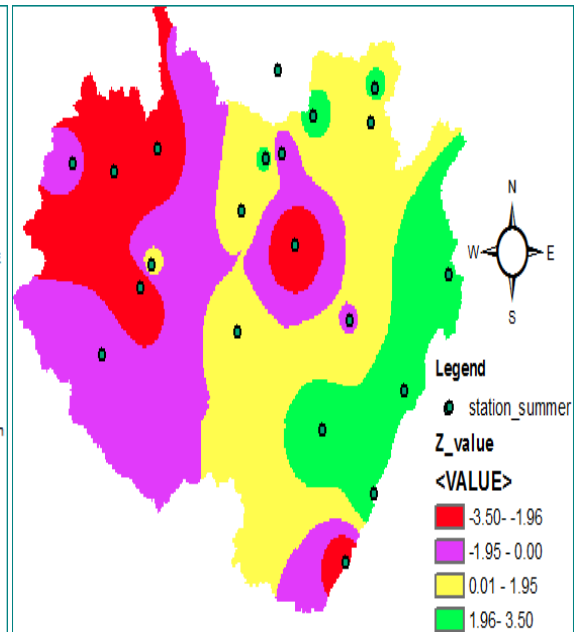
Most parts of the upper awash basin are dominated by decreasing rainfall trend in winter except the western part which was dominated only by decreasing trend. Increasing and significant decreasing trends were simultaneously found in most parts of the upper basin (Figure 5-14d). A significance increasing trend was found at some part of the upper basin in winter.

For the annual rainfall trend (Figure 5-14e), the spatial distribution pattern of annual rainfall trend reflects a combined effect of the seasonal rainfall. The upper awash basin is dominated by decreasing rainfall and followed by increasing rainfall in most area of the basin, and small part indicate significant increasing trend(one station). Parts of the western and central stations show a significant decreasing rainfall trend.

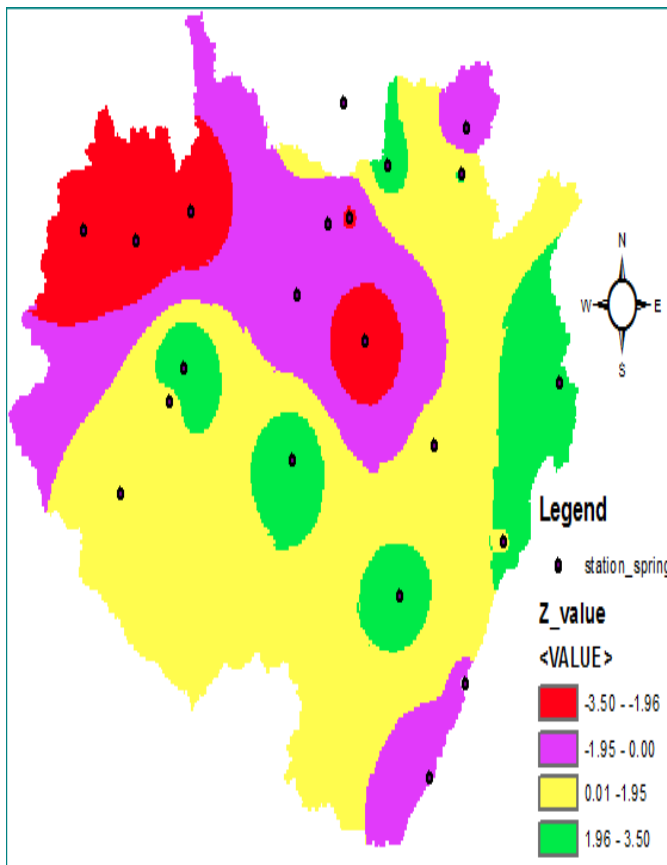
a. autumn(MAM)



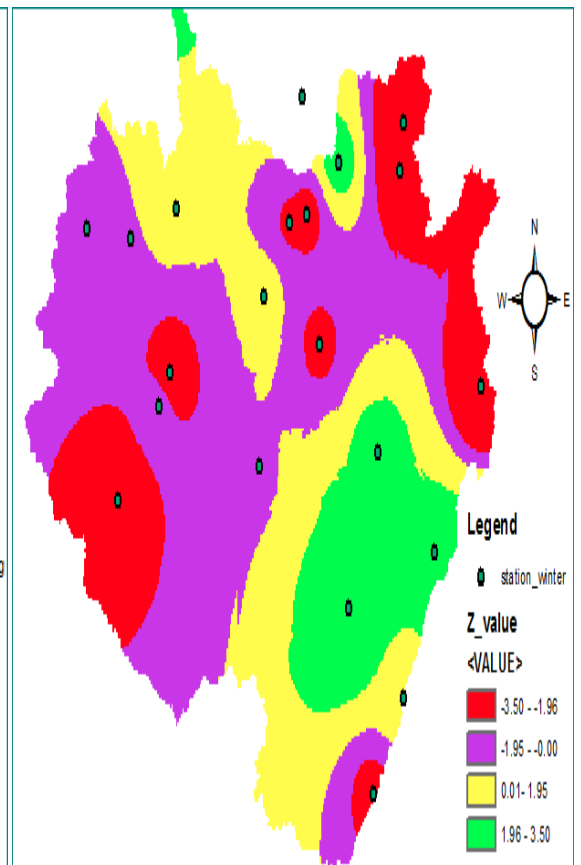
b. summer (JJA)



c. spring(SON)



d. winter(DJF)



e. annual

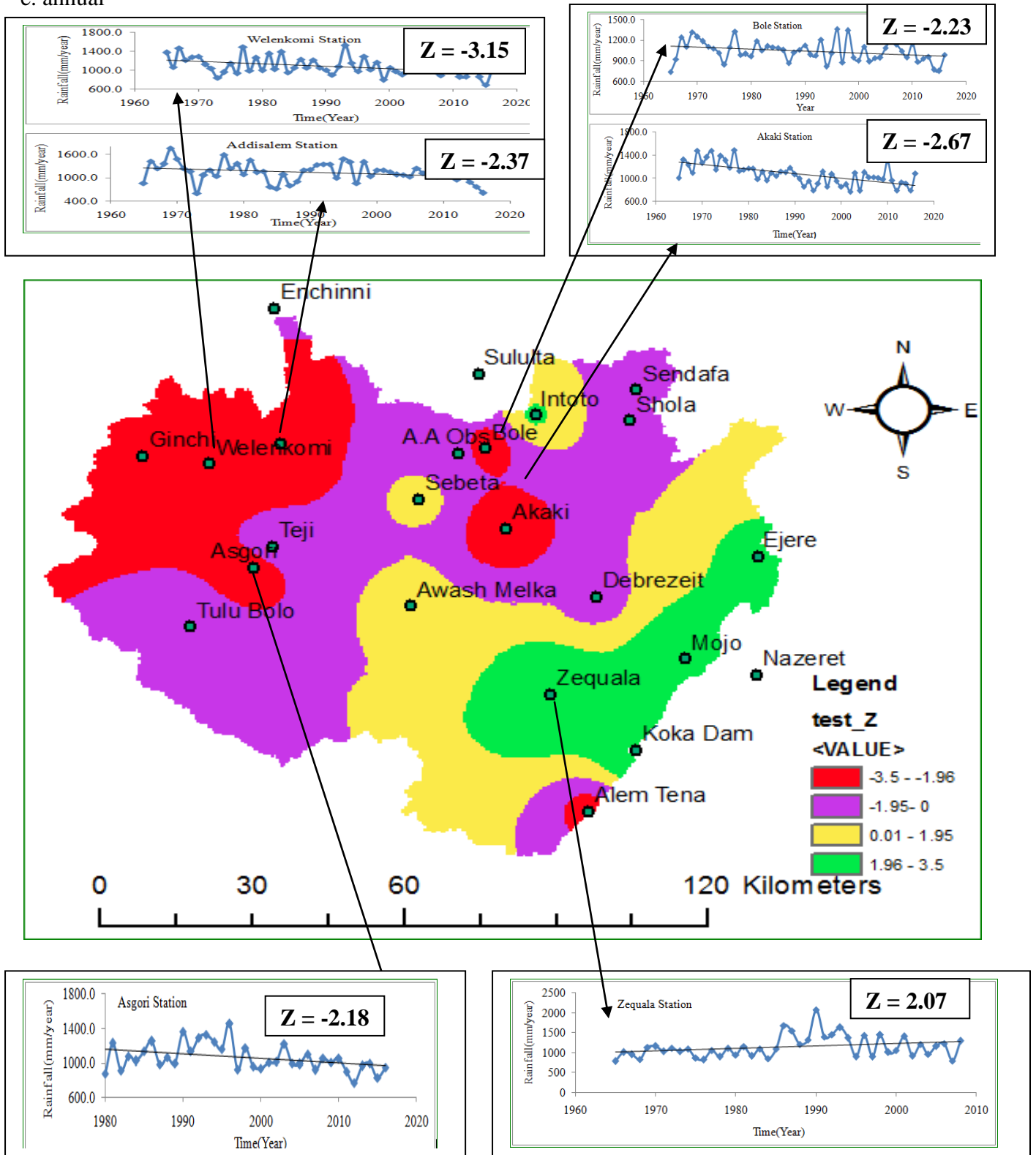


Figure 5-14: Spatial distribution of rainfall trend test statistics (Z)

5.5 Spatial Rainfall Distribution

The spatial distribution of mean monthly, seasonal and annual rainfall distribution is studied with the help of Spatial Interpolation which is the procedure of estimating the values of rainfall at unsampled sites within an area covered by existing observations.

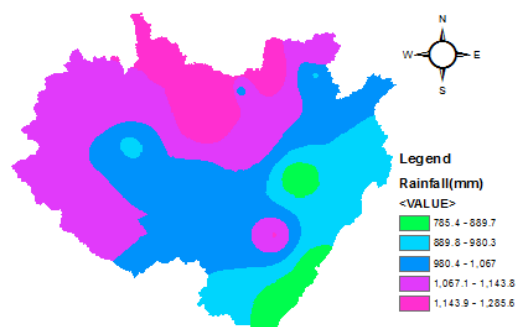
Four different interpolation methods (IDW, Kriging, Spline, and Trend) were tested in this study to estimate the rainfall at ungauged surfaces. These methods were chosen as they are representative of available interpolation.

5.5.1 Annual Rainfall Distribution

Spatial distribution of the mean annual rainfall is shown in the (figure5-15a), which shows the decreasing amount of rainfall is found in the eastern and southwestern part of the upper basin as also depicted in the trend analysis results. Middle part of the upper basin gets maximum rainfall and western part of the upper basin gets moderate rainfall which varies from 1082mm to 1241mm.

The spatial distribution of annual rainfall is shown in figure5-15: with different colours. The annual rainfall distribution maps show the different distribution of rainfall on different meteorological stations. The rainfall distribution map of the Upper Awash Basin showed that annual rainfall value is within the range 785.4mm to 1285.6mm while most parts of sub-basin obtained the rainfall range of 1067.1mm to 1143.8mm. The variability of annual rainfall is high. Addis Ababa Obs. station receives the maximum mean annual rainfall; whereas Alem Tena receives the minimum mean annual rainfall.

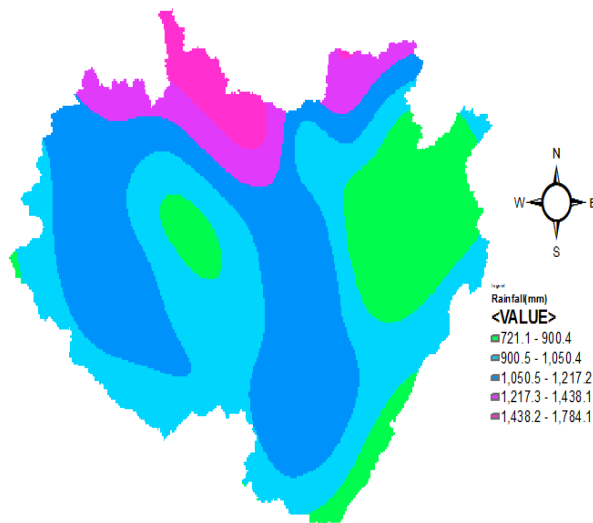
a). IDW Method



b). Co-Kriging Method



c) Spline



d) Trend

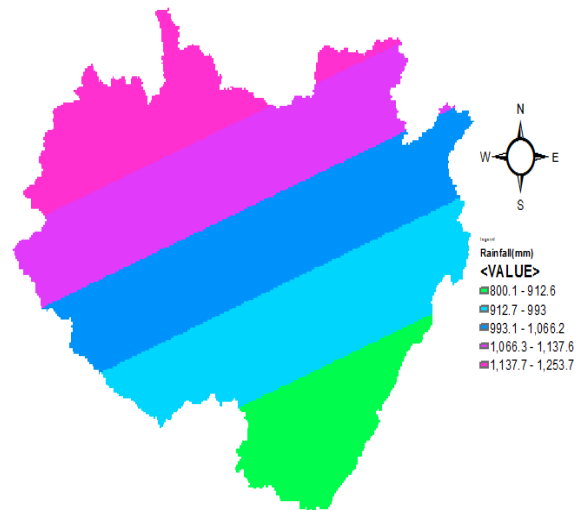


Figure 5-15: Annual rainfall distribution of the study area extracted by mask tools in GIS (a-d)

Comparing the rainfall maps (IDW, Kriging, Spline, Trend) in Figure 5-16, it is clear that all four maps display a definite rainfall pattern over the study area: rainfall decreases progressively from the northwestern to the southeastern. Such trends are clearly associated with the elevation of the study area, that reflects orographic effects. One can observe a rather uneven spatial distribution of rainfall values with significant differences in magnitude.

The spatial distribution of the Kriging and Trend rainfall estimates were represented by a continuous and smooth surface, which though, does not accurately represent local rainfall. In contrast, the map produced by the IDW and Spline methods is more informative, represented by a surface with reduced smoothness (compared to the maps produced by Kriging and Trend) and reflecting accurately the local variations of rainfall throughout the Upper Basin.

5.5.2 Seasonal Rainfall Distribution

The upper basin experiences four distinct seasons namely, winter (January, February and December), autumn (March-May), summer (June-August) and spring (September, October and November). Mean rainfall in winter season varies from 34.9 mm in shola station to a maximum of 82.9mm in Addis Ababa obs. station. The average winter rainfall of the upper awash basin is 54.2mm with standard deviation of 14.4mm. Winter rainfall contributes only 5.2% to the annual rainfall. The spatial distribution of the winter rainfall shows that the rainfall of the eastern part of

the upper basin is less than average rainfall value while western, central and south western part of the upper basin receives higher amount of rainfall than the average. In spring season, rainfall varies from 121mm in Debrezeit to 234.8mm in Addis Ababa Obs. The average rainfall in spring season is 159.1mm with standard deviation of 29.6mm which contribute 15.3% to the annual rainfall. During this season, eastern and south western part of the upper basin receives rainfall lower than the mean value except at Zequala station while all western and central part of the upper basin gets higher amount of rainfall which is greater than average value. North part receives rainfall higher than the mean while northeastern part receives lower than the mean. The upper basin receives maximum rainfall during summer season which contribute 59.9% to the annual rainfall. The rainfall varies from 435mm in AlemTena to 785.1 mm at Sululta. The spatial distribution of the summer rainfall shows that middle and western part of the upper basin gets higher rainfall than the average value except at Bole and Ginchi stations whereas eastern receives lower rainfall than the average value except at Zequala. During autumn season, the average rainfall of the basin is 203.3mm with standard deviation of 32.6mm which contribute 19.6% to the annual rainfall of the upper basin. In this period western and northern part of the upper basin gets maximum amount of rainfall than the average whereas eastern part receive lower than average. Southwestern receive higher/lower rainfall than the average value. The spatial distribution of seasonal (autumn, summer, spring and winter) rainfall is shown in Figure.5-16: with different colours. The seasonal rainfall distribution maps show the different distribution of rainfall on different meteorological stations by four interpolation methods.

Abundant rainfall was observed in most parts of the upper basin with the maximum value (>580 mm) occurring during the summer months (July to August), whereas the opposite is true during the winter months (December-February). Variation in the temporal rainfall magnitude is also clearly visible, with much higher rainfall levels during autumn and summer and much lower rainfall levels during spring and winter.

A). IDW Method

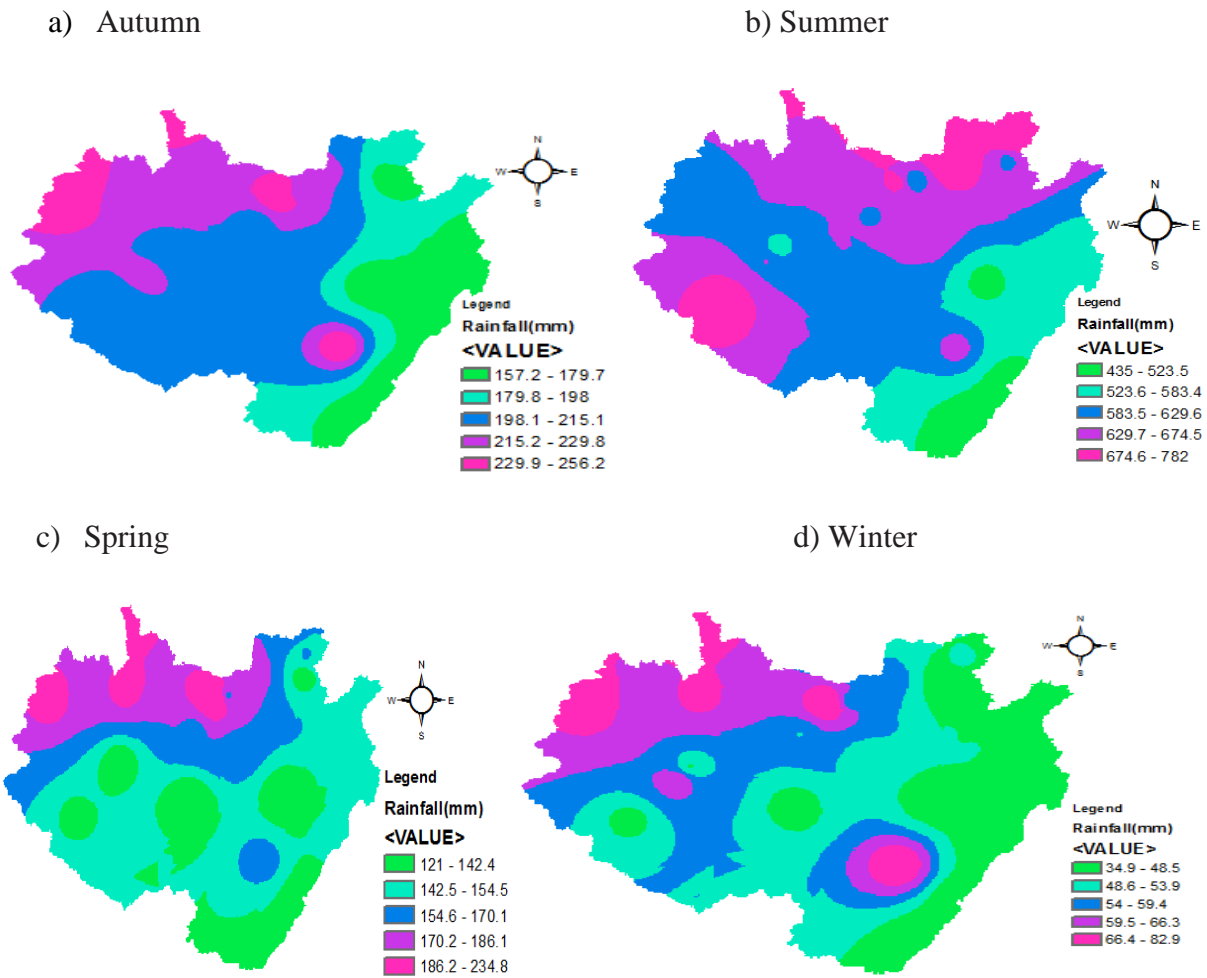
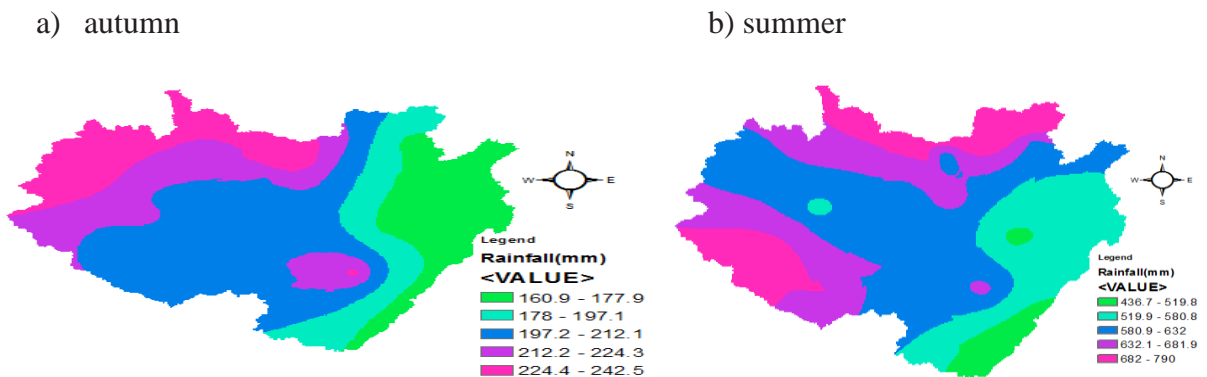


Figure 5-16: Seasonal rainfall distribution of the study area by IDW interpolation method extracted by mask tools in GIS (a-d)

B) Kriging Method



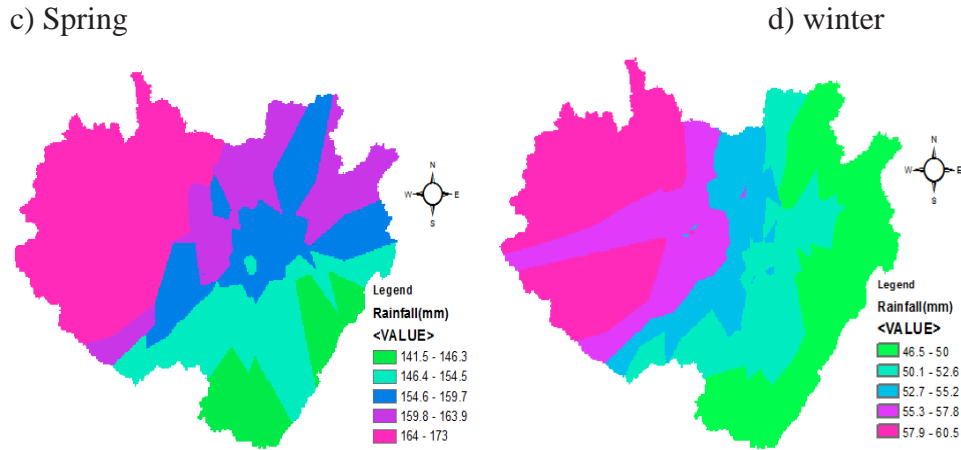


Figure 5-17 Figure: Seasonal rainfall distribution of the study area by kriging interpolation method extracted by mask tools in GIS (a-d)

C) Spline Method

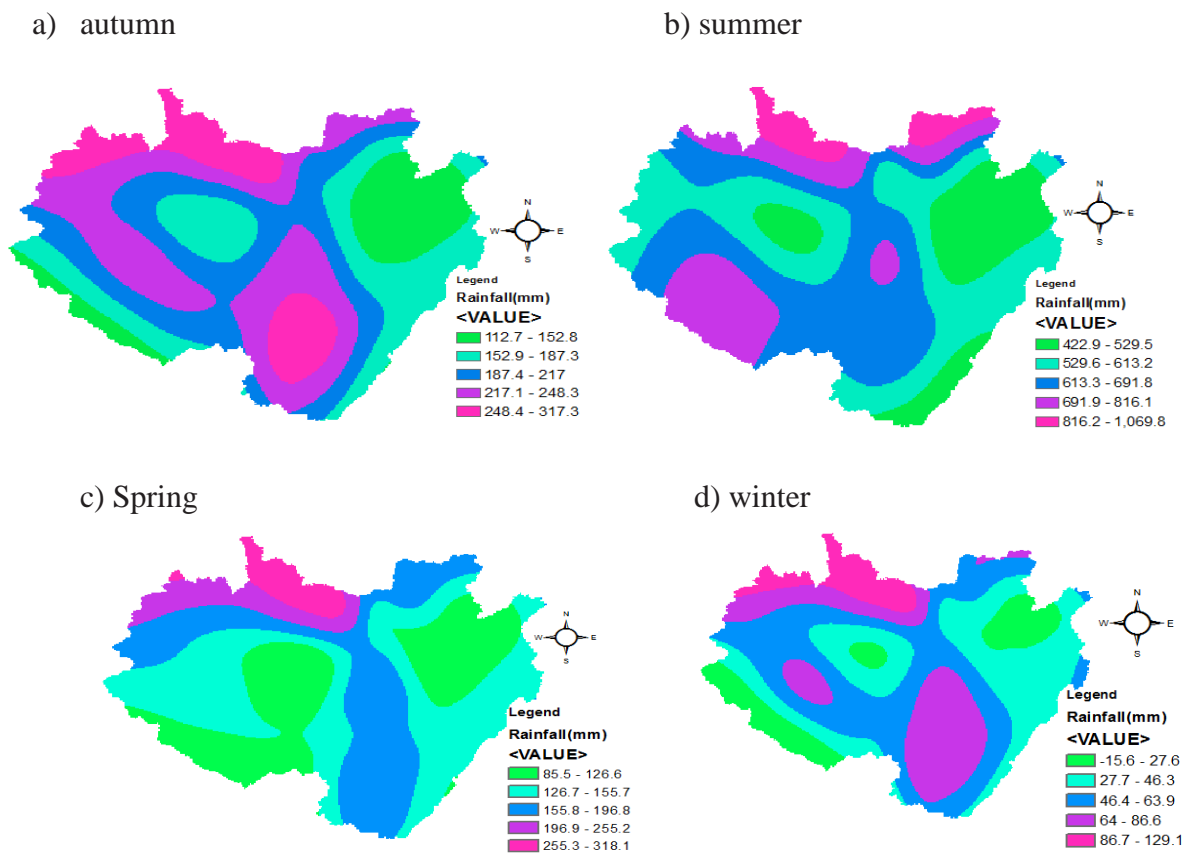
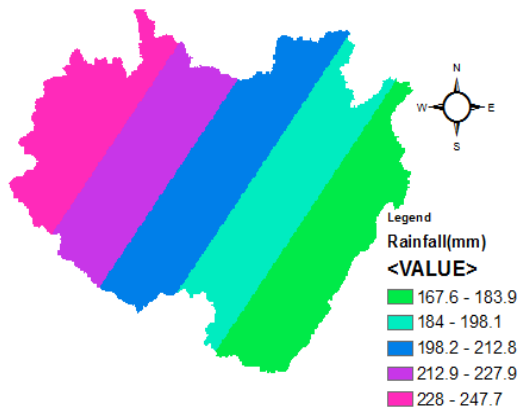


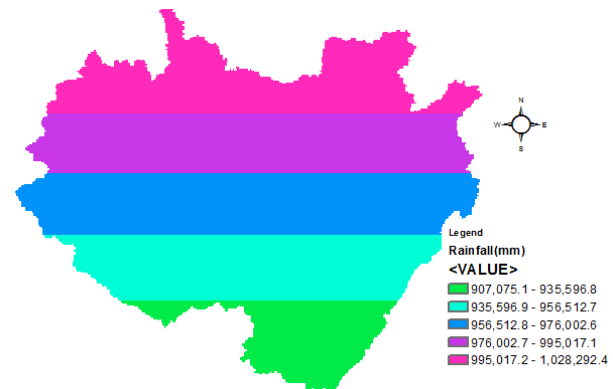
Figure 5-18: Seasonal rainfall distribution of the study area by spline interpolation method extracted by mask tools in GIS (a-d).

D) Trend Method

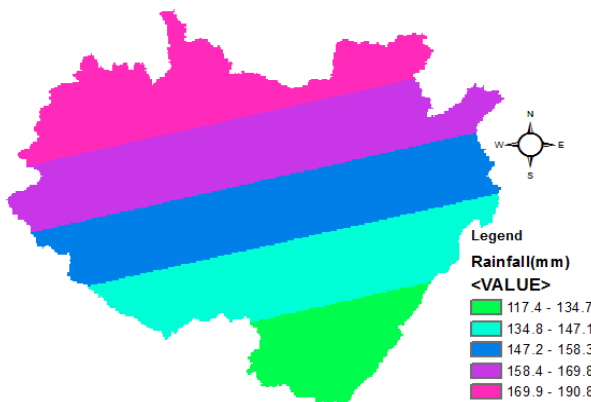
a) autumn



b) summer



c) Spring



d) winter

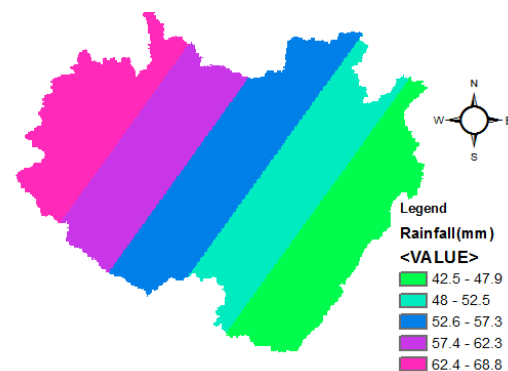


Figure 5-19: Seasonal rainfall distribution of the study area by trend interpolation method extracted by mask tools in GIS (a-d).

5.5.3 Monthly Rainfall Distribution

Monthly distribution shows the results obtained by the four methods of rainfall mapping considered in this thesis (IDW, Kriging, Spline and Trend). What the four methods share is that they all provide valuable space-time visualizations of the considerable spatial and temporal variation of rainfall throughout the study area. The change in the spatial rainfall pattern from month to month is clearly depicted in all maps. The spatial trend in the rainfall distribution decreases from the northwest to the southeast as showed with different colors. The monthly rainfall distribution maps show the different distribution of rainfall on different meteorological

stations. From monthly rainfall distribution map, it can be said that western area mainly gets maximum rainfall during April where as North Western gets during January, December and November and the eastern part of the upper basin gets maximum rainfall during May and June. The central area of the upper basin gets maximum rainfall during September, October, May, July and August while southwestern part of the study area receive maximum rainfall during june. Due to the heavy rainfall during July and August, the Upper Basin experiences flood.

5.6 Error Statistics of Interpolation Methods Assessment Results

In this study, mean absolute error (MAE), mean relative error (MRE), root mean squared error (RMSE), mean absolute relative error (MARE), mean biased error (MBE) and mean relative error were used to assess the performances of the four interpolation methods. MRE reflects the relative accuracy of the interpolation, and the MAE and RMSE are indicators of the magnitude of extreme errors. Lower MAE, MRE, and RMSE values indicate greater central tendencies and generally smaller extreme errors.

Table 5.8 : Interpolation type evaluation result.

Time	Interpolation Methods	MAE	MSE	RMSE	MARE	MBE	MRE
annual	IDW	0.104	0.021	0.146	0.052	0.009	0.000
	Kriging	42.606	2877.193	53.639	21.303	-0.639	0.041
	Spline	0.069	0.101	0.105	0.035	0.006	0.000
	Trend	76.396	10557.133	102.748	38.198	1.749	0.073
Autumn	IDW	0.019	0.001	0.026	0.010	0.001	0.000
	Kriging	9.292	140.482	11.852	4.646	-0.775	0.044
	Spline	0.541	0.472	0.687	0.271	0.010	0.003
	Trend	18.907	669.735	25.879	9.453	-1.439	0.090
Summer	IDW	0.065	0.008	0.091	0.033	-0.002	0.000
	Kriging	9.382	132.290	11.502	4.691	-0.221	0.015
	Spline	1.039	1.684	1.298	0.519	-0.063	0.002
	Trend	61.601	5105.166	71.450	30.801	-1.086	0.098
Spring	IDW	0.017	0.001	0.028	0.009	0.005	0.000

	Kriging	14.202	324.509	18.014	7.101	-0.292	0.088
	Spline	0.551	0.736	0.858	0.275	0.028	0.003
	Trend	20.798	653.799	25.569	10.399	0.406	0.129
Winter	IDW	0.012	0.000	0.017	0.006	0.002	0.000
	Kriging	10.660	178.096	13.345	5.330	-0.614	0.187
	Spline	0.338	0.236	0.486	0.169	0.027	0.006
	Trend	9.320	154.006	12.410	4.660	-0.255	0.164

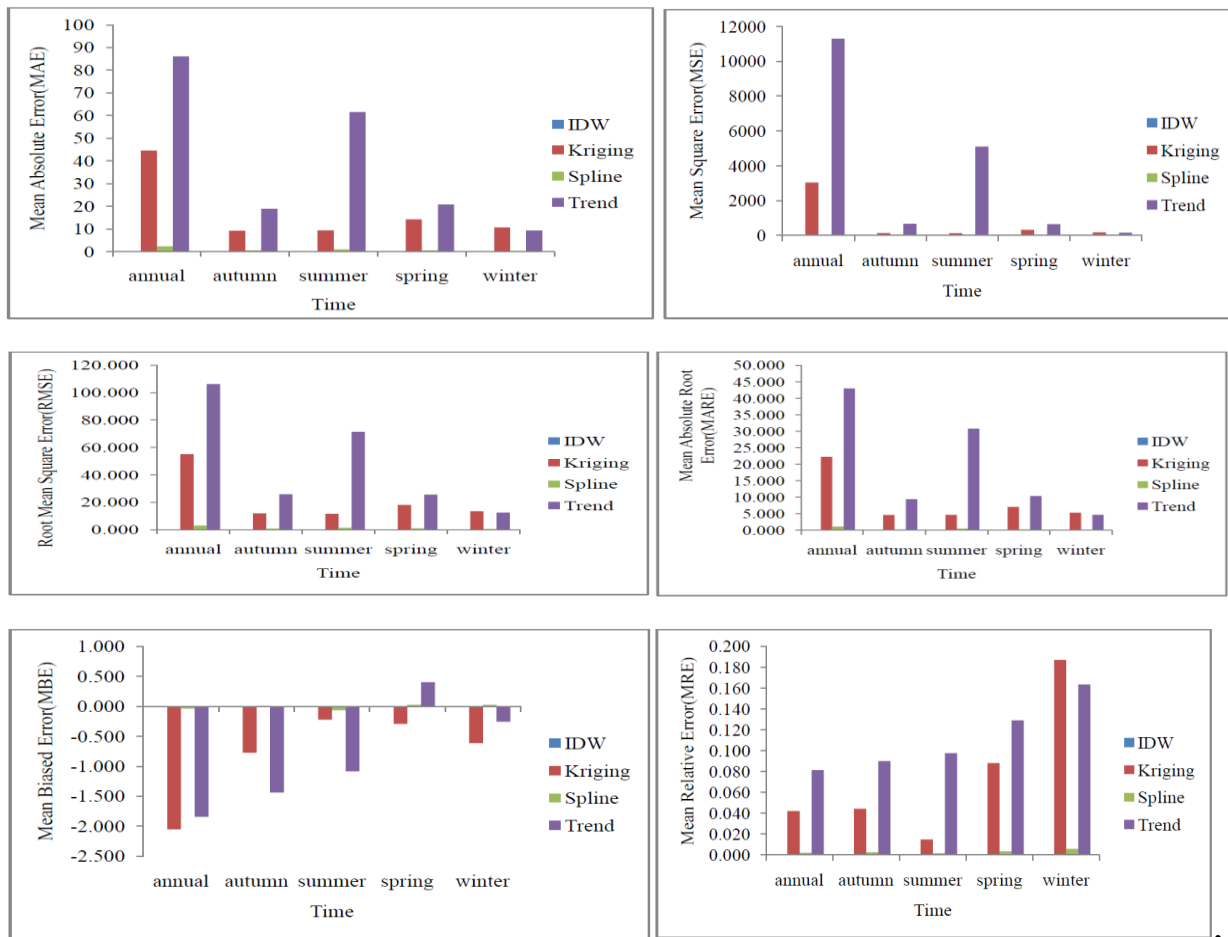


Figure 5-20: Error assessment results of observed values in comparison with estimated values on different time scale.

From the figure 5-21, the results of observed versus estimated annual rainfall generally showed the coefficient of determination (R^2) values of 99.9%, 86.0%, 99.8% and 37.8% for IDW, Kriging, Spline and Trend methods respectively. From the results, IDW and Spline methods

indicated high R^2 values of 99.9% and 99.8%. Thus those two methods are the optimal methods for interpolating rainfall in the study area.

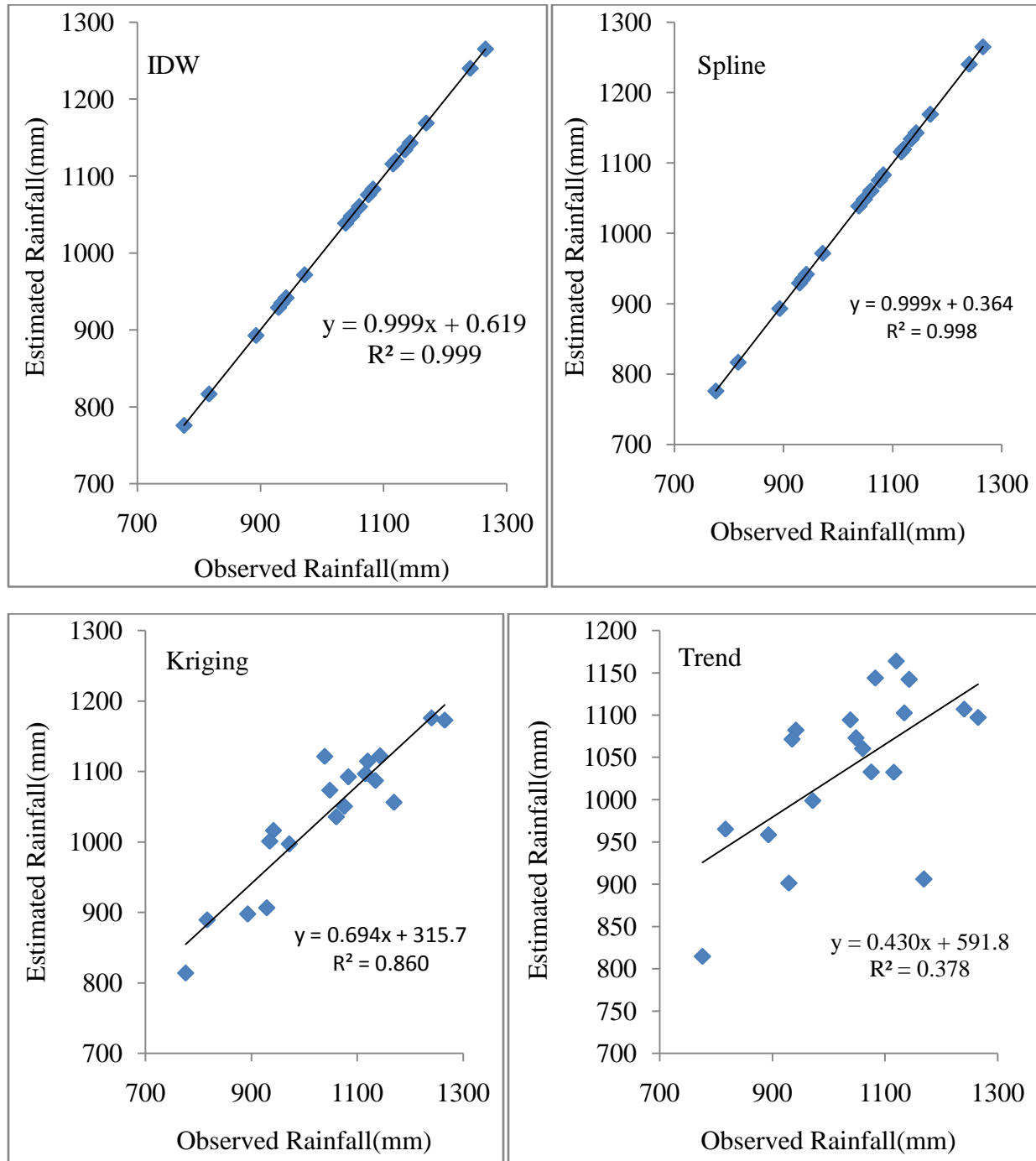


Figure 5-21: Comparing observed annual rainfall values with estimated rainfall value by (IDW, Kriging, Spline and Trend) methods.

5.7 Spatio-Temporal variability of the Rainfall over Upper Awash Basin

5.7.1 Annual Variability.

The rainfall variability is expressed as the coefficient of variation [5; 54]. In order to know the spatial variability of annual rainfall in Upper Awash Basin, annual Coefficient of variation (CV) has been calculated using mean annual rainfall values. It is observed that annual coefficient of variation is less than 0.3 for most parts which indicates less variability except at Koka Dam and Sebeta stations including their surrounding having 0.52 and 0.66 respectively which have significant/higher variability. Most of the stations have 0.2 coefficient of variation which is relatively low variability. The average coefficient of variation for the study area is 0.25. The central stations of Addis Ababa have relatively an average low variability of 0.19; this fact is confirmed by [82] who demonstrated the same value.

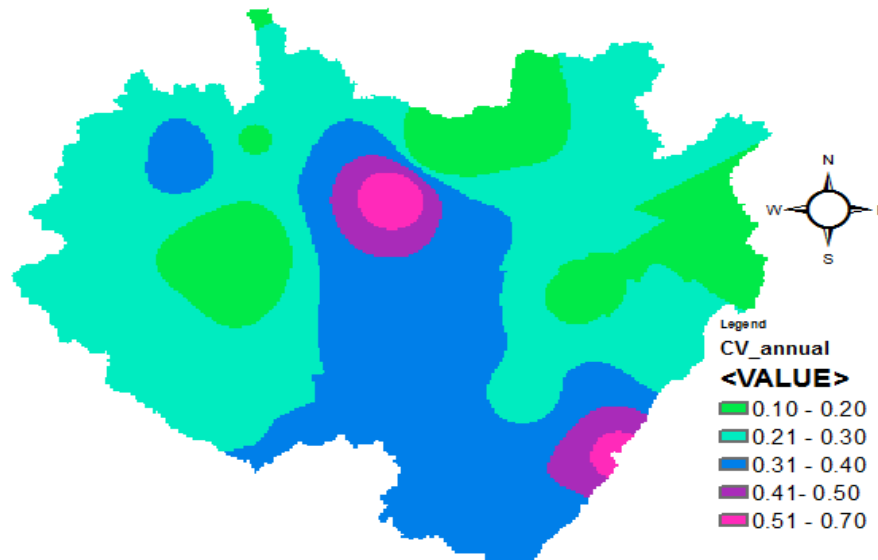


Figure 5-22: Spatial Distribution map for annual Coefficient variation masked by GIS

5.7.2 Seasonal Variability

The seasonality of rainfall in Upper Awash Basin is very strong. Due to seasonality, an inter-annual variability of rainfall events is very large. Considering summer rainfall variability, which is directly affecting agricultural production over upper awash basin, all stations exhibited a coefficient of variation (CV) from 0.1 to 0.3 which indicates very less variability except at Koka Dam station which showed a coefficient of variation of 0.5 i.e. higher variability of the rainfall. On the contrary spring season; south western, north eastern, eastern and western part of the upper

basin has the higher variability of the rainfall as the coefficient of variation varies from 30% to 70% has significant variability. In the central part, some of the area exhibited a coefficient of variation 0.3 which indicates less variability while other area exhibited a coefficient of variation from 0.4 to 0.5 which indicates moderate variability. In general, a coefficient of variation from 0.3 to 0.5, this indicates the consistent rainfall during this period in the central part of upper basin. During winter season, most part of the upper basin exhibited a coefficient of variation from 0.5 to 1.2 which indicates extreme variability of rainfall during this period. In autumn season eastern part of the upper basin have the higher variability of the rainfall as the CV varies from 0.6 to 0.7 whereas central and western consists CV of 0.3 to 0.5 showed variability. North and northeastern also has a coefficient of variation of 0.4 and 0.5. Finally, the coefficient of variation of southwestern part of the study area consists from the ranges 0.3 to 0.4 have significant variability. In general, the seasonal variability of rainfall during summer is low whereas for autumn and spring, there is a significant variability. Winter season has been extremely high variability.

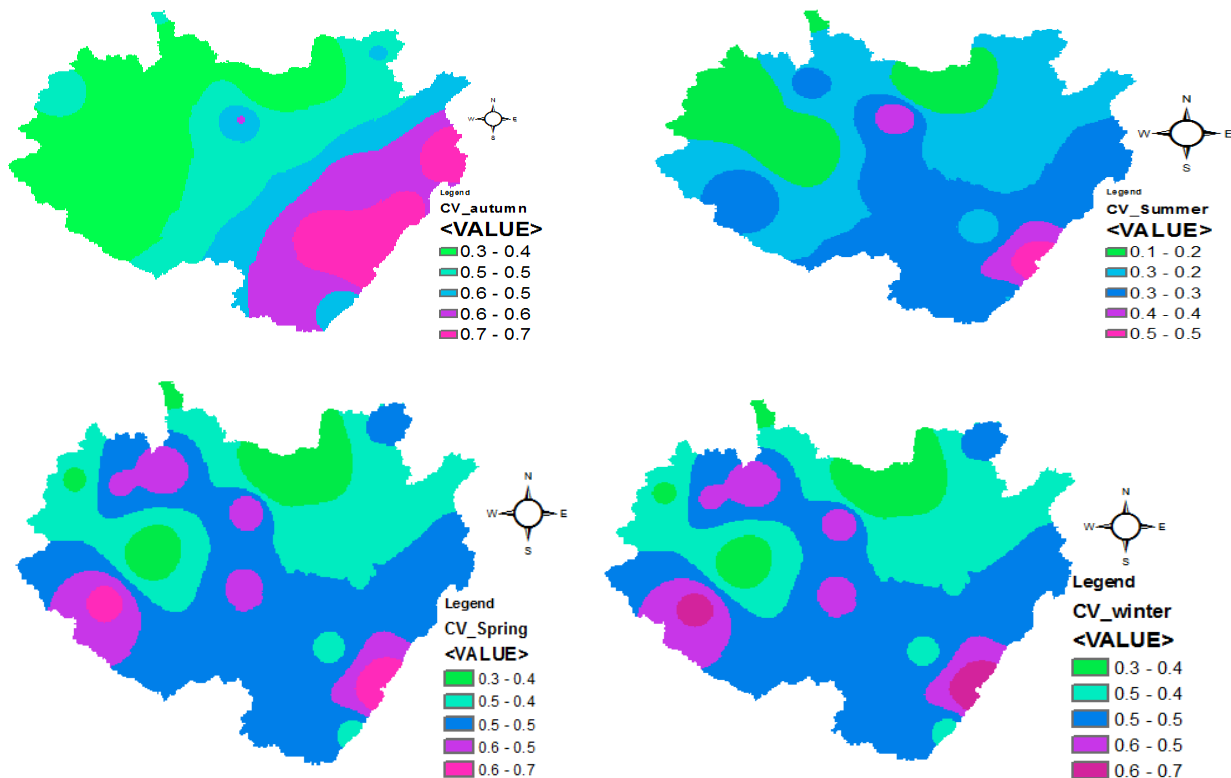
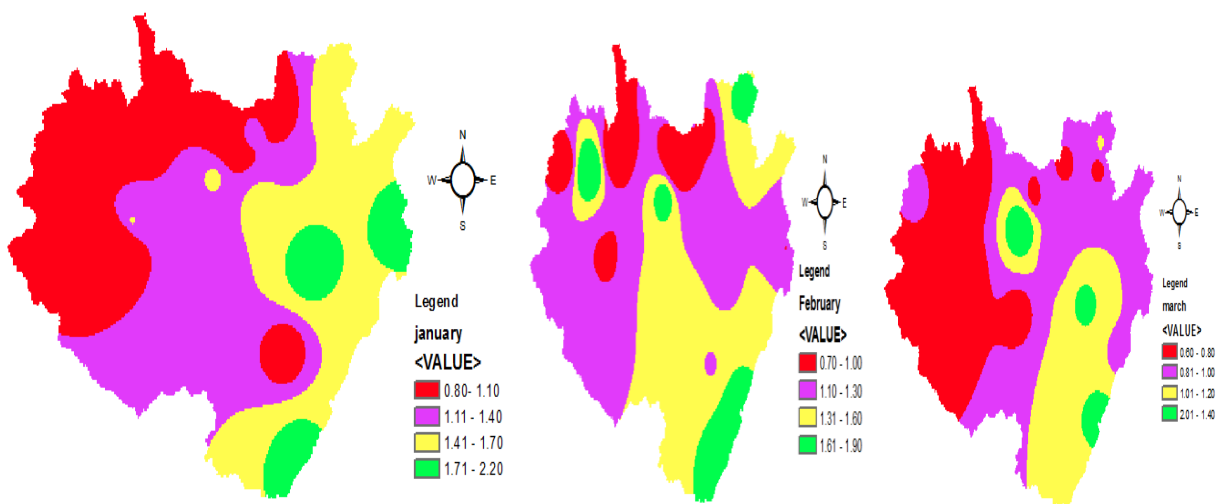


Figure 5-23: Spatial Distribution map for seasonal rainfall Coefficient of variation masked by GIS.

5.7.3 Monthly Variability

Using the entire time series, monthly rainfall variability (CV) for the 23 selected station of Upper Awash Basin were determined using an inverse distance weighted (IDW) technique applied in Arc-Map 10.2.2 (Figure 5-25).

To know the spatial variability of the monthly rainfall in Upper Awash Basin, Coefficient of variation (CV) has been calculated using mean monthly rainfall values. From the spatial variability results southwestern stations have lower coefficient of variation ranges 0.1 to 0.3 from June to September months except at Sebeta station which has a coefficient of variation of 0.7 to 0.8 on the same months whereas the for the rest of the months, its values are from 0.4 to 2.5 indicating that it is moderate to extremely variable. In most part of the study area, the coefficient of variation of the months October, November, December, January, February and March were from the range 0.6 to 3.6 indicating that it is extreme variability of monthly rainfall. The coefficient of variation of western part station from June to September rainfall is 0.1 to 0.4 showing that it is low to moderate variable except at Welenkomi station which is 0.6 on September month. From the result of eastern part of month July to September, it was varied from 0.2 to 0.5 (low to high) where as 0.5 to 0.8 (high to extreme high on June rainfall. In the central part, coefficient of variation is from 0.3 to 0.4 on June to September except at shola, Akaki and Bole (CV of 0.6, 0.5 and 0.5) for June month while Shola and Akaki station of 0.5 on September month. At Enchinni and Ejere stations, the coefficient of variation is 0.2 to 0.3 indicating that it is less variability of rainfall over the whole month.



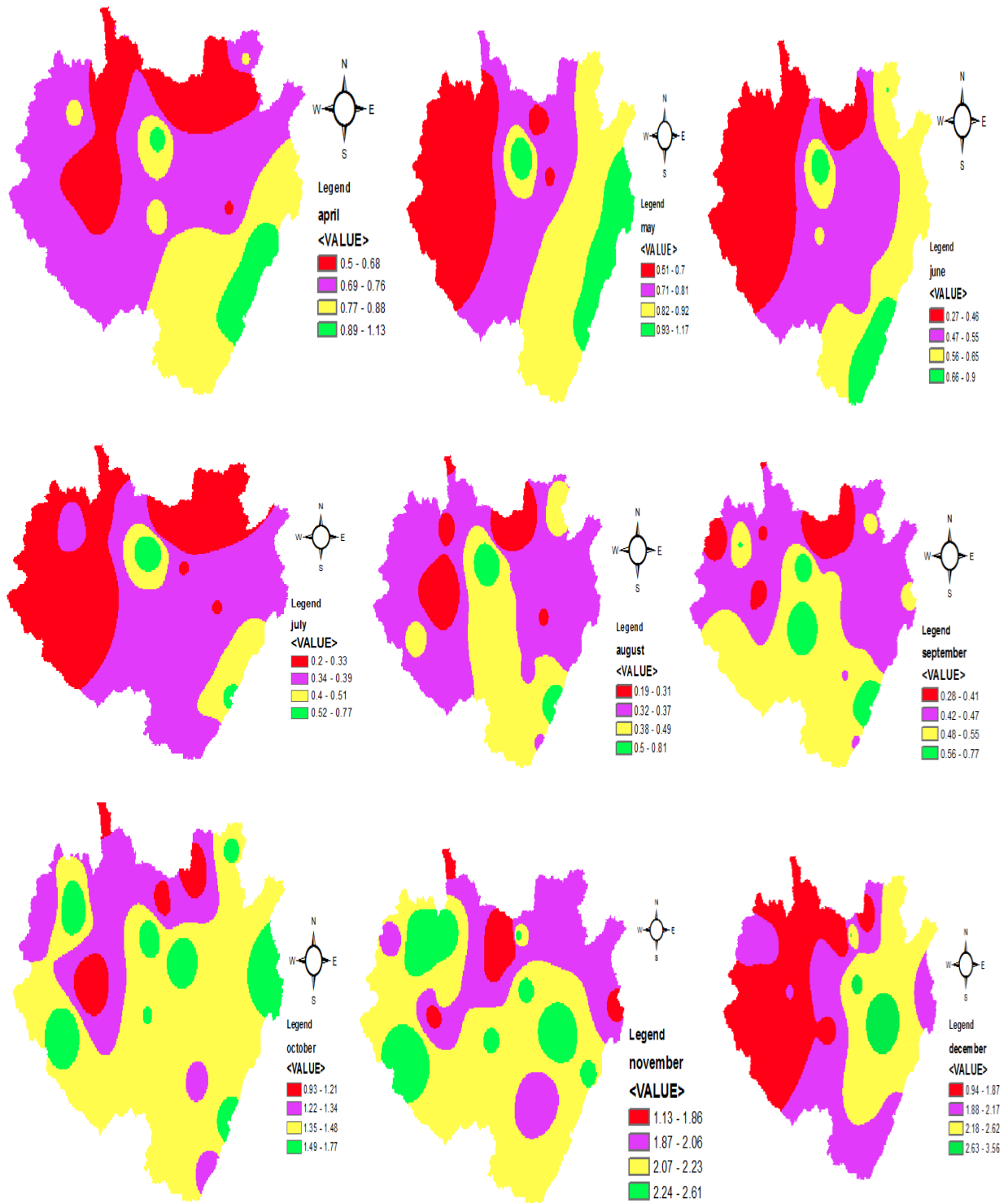


Figure 5-24: Spatial Distribution map for monthly rainfall Coefficient of variation masked by GIS.

CHAPTER SIX

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The rainfall characteristics especially variability and trend are necessary for the proper design of hydro related schemes such as clean water supply, reservoir, storm water channels, urban drainage, bridge and water resource planning in rapidly growing area like upper awash basin.

The study is based on available rainfall data recorded at 23 meteorological stations during the period (1965 ~ 2016). Spatial and temporal variation of rainfall has been evaluated on mean monthly, seasonal and annual time scale. The results showed that from high to low variability has been found at different parts of the study area.

Trend analysis has been tested by Excel template MAKESENS (Mann-Kendall test and Sen's slope estimates) for trend significance and magnitude. Mixed trend result dominated by non-significant trend was observed in the area. Mostly, statistically non-significant decreasing trend followed by increasing were discovered. Some statistically significant decreasing trend followed by increasing was revealed. Trend magnitude value exhibited decline rate (70%) of rainfall (mm/year) where as rising rate (30%) of rainfall (mm/year) in annual time scale at the study area. On evaluating, across the considerable number of stations, the greatest decline rainfall magnitude was found for the Alemtena station (-6.03mm/year), while the greatest increase occurred at Koka Dam (7.67 mm/year) in annual. On Seasonal scale, significant increasing trend were observed at Koka Dam station in autumn where as significant decreasing trend were observed at Akaki, Alem Tena, Bole, Sendafa and Tulubolo in winter. The same is true for spring at Welenkomi and Akaki. Rainfall trend in the season of summer indicated that statistically significant decreasing and increasing trends at stations (Asgori, Welenkomi, and Sululta) and (Mojo and Ejere) respectively. The greatest decline rainfall magnitude was found at Akaki station (-5.12mm/year) in summer, while the greatest rise occurred at Koka Dam (12.065 mm/year) in autumn.

The recorded data were interpolated using four GIS-based interpolation methods for spatial distribution. Cross-validation was used to compare various performances of interpolation methods. Investigative parameters indicated that IDW and Spline had the smallest error determination and thus they are considered the optimal methods for interpolating rainfall in this

area. For this specified study, IDW was selected as the best optimal interpolation technique. Spatial distribution of the mean annual rainfall shows the decreasing amount of rainfall is found in the eastern and southwestern part of the upper basin. Rainfall decreases progressively from the northwestern to the southeastern. Middle part gets maximum rainfall and western part of the upper basin gets moderate rainfall which indicates the rainfall distribution is affected by elevation that is rainfall increases with elevation. This phenomenon, commonly called the orographic effect.

Variation in the temporal rainfall pattern is also clearly visible, with much higher rainfall levels during autumn and summer and much lower rainfall levels during spring and winter. From trend distribution map, the western part of the study area has been statistically significant decreasing trend. The spatial distribution of some annual rainfall trend does not reflect a combined effect of the trend obtained by Mann-kendall trend test. The rainfall variability is expressed as the coefficient of variation. This variability distribution has been mapped on GIS and showed that most of the study area has low variability on annual scale. Seasonal variability distribution showed rough surface distribution at most parts of the study area.

The trend in rainfall observed for each station could imply that the changes are more pronounced for certain locations and less for others. The cause of these changes requires further study to link the observed trends with climate variability. Thus, the change in trends of rainfall becomes evidence across the study area to reach on conclusion.

Overall, the maps of rainfall presented in this study can provide invaluable extensive information to water management policy (policy makers) and decision-makers, as well as for hydrologic analyses and water resource planning and management (water resources managers) in upper basin wide and basin-scale watersheds, because spatial distributions of annual, seasonal, and monthly values of rainfall is important driving forces in various aspects of the hydrological cycle.

6.2 Recommendation

Upper Awash Basin has been selected for this study due to having long term data series and densely meteorological data. Even if densely meteorological stations are found in the study area, discontinuity of recording data has been high in most stations. Therefore, it is highly recommended that the data recording and management be improved, to facilitate further water resource management study and development, based on reliable information. Modern and reliable rainfall observation facilities with reasonable spatial distribution need to be established, to enhance resource management research in the country.

In the light of decreasing temporal rainfall during the study period of the Upper Awash Basin, water resource management measures and supporting policies should be thoroughly designed and strictly implemented. This would enable to undertake the challenges of rainfall deficit, and meet the ever increasing demand of progressively growing population for water for survival and any development activities.

In addition, this study was limited with rainfall trend analysis by Mann-Kendall and Sen's Slope Estimator only using long term data series of rainfall. Parameters such as temperature and stream flow regime need to be analyzed in term of climatic effect in order to be better understood. These factors are therefore expected to be the focus of future work.

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8 APPENDICES

Appendix A: Station Wise descriptive statistics results of annual rainfall data

		Statistic	Std. Error			Statistic	Std. Error
Akaki	Mean	1075.6615	25.56298	Ginchi	Mean	1119.7577	28.16937
	95% Confidence Interval for Mean	Lower Bound	1024.3417		95% Confidence Interval for Mean	Lower Bound	1063.2053
		Upper Bound	1126.9814			Upper Bound	1176.3101
	5% Trimmed Mean	1069.3577	5% Trimmed Mean		1118.9457		
	Median	1080.3000	Median		1134.4000		
	Variance	33980.229	Variance		41262.705		
	Std. Deviation	184.33727	Std. Deviation		203.13223		
	Minimum	771.30	Minimum		710.90		
	Maximum	1487.30	Maximum		1589.60		
	Range	716.00	Range		878.70		
	Interquartile Range	215.43	Interquartile Range		242.08		
	Skewness	0.435	0.330		Skewness	0.173	0.330
	Kurtosis	-0.199	0.650		Kurtosis	-0.214	0.650
Addisalem	Mean	1142.9865	33.97013	Mojo	Mean	929.2769	29.06335
	95% Confidence Interval for Mean	Lower Bound	1074.7886		95% Confidence Interval for Mean	Lower Bound	870.9298
		Upper Bound	1211.1844			Upper Bound	987.6240
	5% Trimmed Mean	1144.1735	5% Trimmed Mean		921.4077		
	Median	1151.5000	Median		876.8500		
	Variance	60006.442	Variance		43923.258		
	Std. Deviation	244.96212	Std. Deviation		209.57876		
	Minimum	601.80	Minimum		534.00		
	Maximum	1763.50	Maximum		1470.20		
	Range	1161.70	Range		936.20		
	Interquartile Range	313.95	Interquartile Range		278.98		
	Skewness	-0.101	0.330		Skewness	0.622	0.330
	Kurtosis	0.095	0.650		Kurtosis	0.527	0.650
AAObs	Mean	1265.3808	20.43556	Nazeret	Mean	866.2365	23.50125
	95% Confidence Interval for Mean	Lower Bound	1224.3547		95% Confidence Interval for Mean	Lower Bound	819.0558
		Upper Bound	1306.4069			Upper Bound	913.4173
	5% Trimmed Mean	1263.9321	5% Trimmed Mean		867.3735		
	Median	1252.9000	Median		859.1000		
	Variance	21715.824	Variance		28720.057		
	Std. Deviation	147.36290	Std. Deviation		169.46993		

	Minimum		985.20			Minimum		436.00	
	Maximum		1567.40			Maximum		1209.80	
	Range		582.20			Range		773.80	
	Interquartile Range		161.93			Interquartile Range		235.33	
	Skewness		0.092	0.330		Skewness		-0.063	0.330
	Kurtosis		-0.370	0.650		Kurtosis		-0.211	0.650
Bole	Mean		1038.3942	20.68833		Sebeta	Mean	1048.1308	43.61930
	95% Confidence Interval for Mean	Lower Bound	996.8607				95% Confidence Interval for Mean	Lower Bound	960.5614
		Upper Bound	1079.9278					Upper Bound	1135.7002
	5% Trimmed Mean		1037.2389				5% Trimmed Mean	1045.1786	
	Median		1030.8000				Median	975.7000	
	Variance		22256.370				Variance	98937.454	
	Std. Deviation		149.18569				Std. Deviation	314.54325	
	Minimum		741.80				Minimum	400.40	
	Maximum		1360.50				Maximum	1698.30	
	Range		618.70				Range	1297.90	
	Interquartile Range		178.28				Interquartile Range	342.50	
	Skewness		0.201	0.330			Skewness	0.461	0.330
	Kurtosis		-0.268	0.650			Kurtosis	-0.118	0.650
Sendafa	Mean		1134.1423	29.17645		Debrezeit	Mean	819.3318	22.44089
	95% Confidence Interval for Mean	Lower Bound	1075.5681				95% Confidence Interval for Mean	Lower Bound	774.0755
		Upper Bound	1192.7165					Upper Bound	864.5882
	5% Trimmed Mean		1130.0175				5% Trimmed Mean	821.2864	
	Median		1125.1000				Median	855.9000	
	Variance		44265.790				Variance	22158.107	
	Std. Deviation		210.39437				Std. Deviation	148.85600	
	Minimum		635.10				Minimum	485.20	
	Maximum		1590.00				Maximum	1144.10	
	Range		954.90				Range	658.90	
	Interquartile Range		259.23				Interquartile Range	196.60	
	Skewness		0.305	0.330			Skewness	-0.382	0.357
	Kurtosis		0.000	0.650			Kurtosis	-0.347	0.702
Shola	Mean		941.7231	20.45645		Zequala	Mean	1140.5386	38.31647
	95% Confidence Interval for Mean	Lower Bound	900.6550				95% Confidence Interval for Mean	Lower Bound	1063.2661
		Upper Bound	982.7911					Upper Bound	1217.8112
	5% Trimmed Mean		935.0944				5% Trimmed Mean	1125.5409	
	Median		935.6500				Median	1098.9500	

	Variance		21760.242			Variance		64598.686		
	Std. Deviation		147.51353			Std. Deviation		254.16272		
	Minimum		647.20			Minimum		787.50		
	Maximum		1348.30			Maximum		1860.00		
	Range		701.10			Range		1072.50		
	Interquartile Range		215.50			Interquartile Range		383.85		
	Skewness		0.578	0.330		Skewness		0.851	0.357	
	Kurtosis		0.434	0.650		Kurtosis		0.326	0.702	
Tulubolo	Mean		1115.7577	33.29011		Ejere	Mean		892.9000	26.56569
	95% Confidence Interval for Mean	Lower Bound	1048.9250				95% Confidence Interval for Mean	Lower Bound	839.2087	
		Upper Bound	1182.5904					Upper Bound	946.5913	
	5% Trimmed Mean		1108.8944				5% Trimmed Mean		890.6099	
	Median		1076.9000				Median		917.2000	
	Variance		57628.044				Variance		28935.162	
	Std. Deviation		240.05842				Std. Deviation		170.10339	
	Minimum		640.30				Minimum		474.00	
	Maximum		1641.20				Maximum		1276.10	
	Range		1000.90				Range		802.10	
	Interquartile Range		289.10				Interquartile Range		245.65	
	Skewness		0.567	0.330			Skewness		0.161	0.369
	Kurtosis		-0.161	0.650			Kurtosis		0.061	0.724
Welenkomi	Mean		1082.9000	26.50476		Enchinni	Mean		1240.9341	28.56135
	95% Confidence Interval for Mean	Lower Bound	1029.6895				95% Confidence Interval for Mean	Lower Bound	1183.2095	
		Upper Bound	1136.1105					Upper Bound	1298.6588	
	5% Trimmed Mean		1077.0462				5% Trimmed Mean		1241.9474	
	Median		1038.5500				Median		1201.5000	
	Variance		36530.115				Variance		33445.783	
	Std. Deviation		191.12853				Std. Deviation		182.88188	
	Minimum		689.80				Minimum		834.20	
	Maximum		1515.00				Maximum		1574.70	
	Range		825.20				Range		740.50	
	Interquartile Range		236.75				Interquartile Range		274.15	
	Skewness		0.620	0.330			Skewness		0.128	0.369
	Kurtosis		-0.059	0.650			Kurtosis		-0.596	0.724
Asgori	Mean		1060.4378	25.72636		Koka Dam	Mean		788.1054	58.15817
	95% Confidence Interval for Mean	Lower Bound	1008.2624				95% Confidence Interval for Mean	Lower Bound	670.1552	
		Upper Bound	1112.6133					Upper Bound	906.0556	

	5% Trimmed Mean	1055.5212			5% Trimmed Mean	780.2611	
	Median	1013.8000			Median	778.7000	
	Variance	24488.281			Variance	125147.776	
	Std. Deviation	156.48732			Std. Deviation	353.76232	
	Minimum	763.90			Minimum	151.00	
	Maximum	1460.50			Maximum	1559.70	
	Range	696.60			Range	1408.70	
	Interquartile Range	215.15			Interquartile Range	447.45	
	Skewness	0.624	0.388		Skewness	0.460	0.388
	Kurtosis	0.046	0.759		Kurtosis	0.034	0.759
Teji	Mean	934.7108	20.66540		Mean	775.9133	28.40461
	95% Confidence Interval for Mean	Lower Bound	892.7994		95% Confidence Interval for Mean	Lower Bound	717.8194
		Upper Bound	976.6222			Upper Bound	834.0073
	5% Trimmed Mean	934.3290			5% Trimmed Mean	777.7926	
	Median	930.3000			Median	806.0500	
	Variance	15801.174			Variance	24204.656	
	Std. Deviation	125.70272			Std. Deviation	155.57846	
	Minimum	686.80			Minimum	441.40	
	Maximum	1200.20			Maximum	1111.80	
	Range	513.40			Range	670.40	
	Interquartile Range	150.35			Interquartile Range	191.13	
	Skewness	0.294	0.388		Skewness	-0.420	0.427
	Kurtosis	-0.223	0.759		Kurtosis	0.075	0.833
Sululta	Mean	1204.6162	41.13487		Mean	971.6333	40.68783
	95% Confidence Interval for Mean	Lower Bound	1121.1908		95% Confidence Interval for Mean	Lower Bound	888.4174
		Upper Bound	1288.0416			Upper Bound	1054.8493
	5% Trimmed Mean	1197.3821			5% Trimmed Mean	964.2815	
	Median	1181.3000			Median	886.2500	
	Variance	62606.855			Variance	49664.991	
	Std. Deviation	250.21362			Std. Deviation	222.85644	
	Minimum	777.80			Minimum	623.10	
	Maximum	1756.50			Maximum	1440.70	
	Range	978.70			Range	817.60	
	Interquartile Range	375.80			Interquartile Range	341.65	
	Skewness	0.349	0.388		Skewness	0.736	0.427
	Kurtosis	-0.294	0.759		Kurtosis	-0.411	0.833
					Awashmelka		

Appendix B: Station Wise Extreme Value results of annual rainfall data

Extreme Values								
		Case Year	Rainfall Value			Case Year	Rainfall Value	
Akaki	Highest	1	1987	1487.30	Ginchi	1	2006	1589.60
		2	1972	1480.40		2	1989	1486.40
		3	1969	1479.60		3	1993	1463.00
		4	1974	1386.30		4	1983	1447.10
		5	1971	1364.10		5	1986	1444.90
	Lowest	1	2002	771.30		1	1973	710.90
		2	2004	787.10		2	2016	720.30
		3	2015	791.00		3	1984	792.90
		4	2012	792.00		4	2011	803.60
		5	1994	792.10		5	2012	822.40
Addisalem	Highest	1	1969	1763.50	Mojo	1	2005	1470.20
		2	1977	1591.00		2	2008	1460.40
		3	1970	1491.00		3	2016	1380.90
		4	1995	1484.70		4	2012	1318.20
		5	1981	1457.30		5	1999	1185.70
	Lowest	1	1973	601.80		1	1980	534.00
		2	2016	606.40		2	2002	564.30
		3	1985	717.80		3	1986	571.80
		4	2015	764.70		4	1995	638.70
		5	1984	768.50		5	2011	676.40
AAObs	Highest	1	1993	1567.40	Nazeret	1	2012	1209.80
		2	1996	1560.70		2	1985	1185.60
		3	1977	1540.80		3	1977	1144.00
		4	2001	1538.60		4	2003	1126.70
		5	1970	1470.90		5	2007	1107.20
	Lowest	1	1975	985.20		1	1980	436.00
		2	1999	1002.80		2	1965	580.20
		3	1972	1012.00		3	2009	588.70
		4	1965	1042.20		4	2002	615.20
		5	1997	1052.40		5	1978	647.80
Bole	Highest	1	1996	1360.50	Sebeta	1	1988	1698.30
		2	1998	1339.80		2	1987	1683.20
		3	1977	1326.00		3	1986	1679.40
		4	1969	1318.00		4	1993	1631.10
		5	1970	1248.20		5	1996	1630.20
	Lowest	1	1965	741.80		1	1984	400.40
		2	2015	752.70		2	1971	495.00

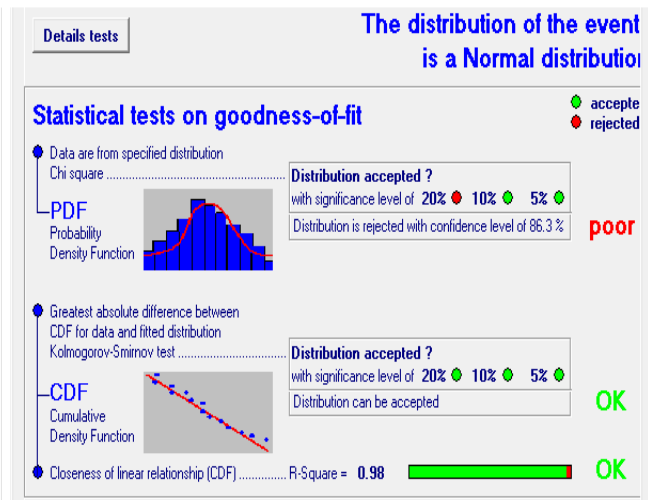
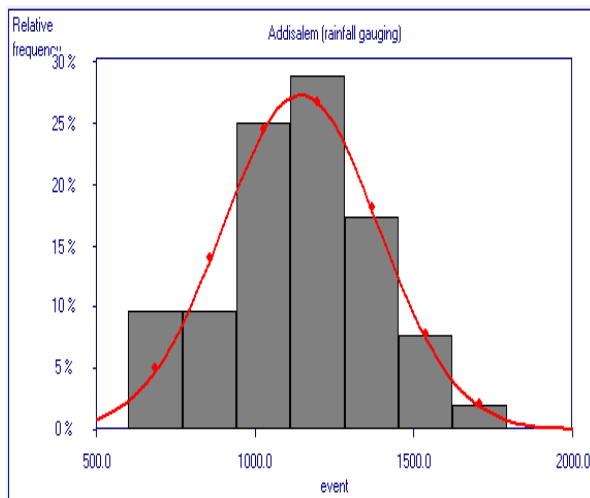
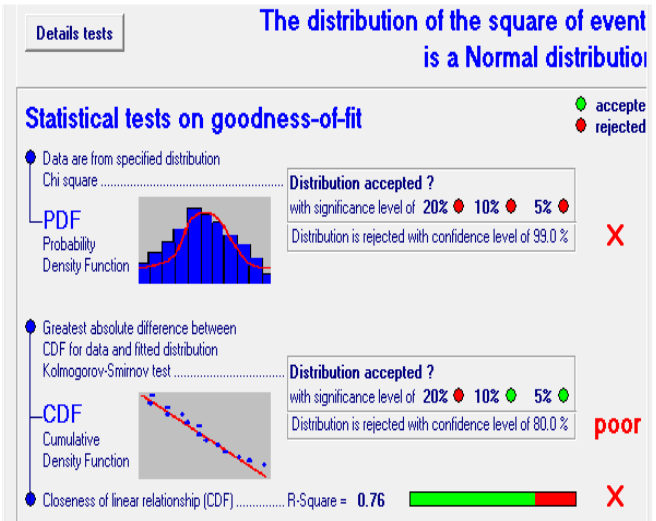
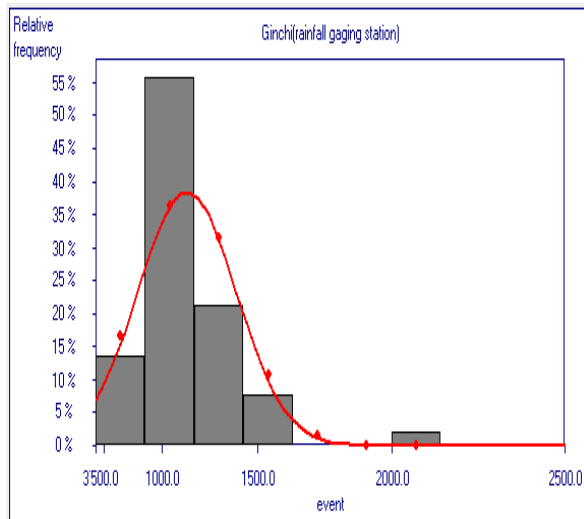
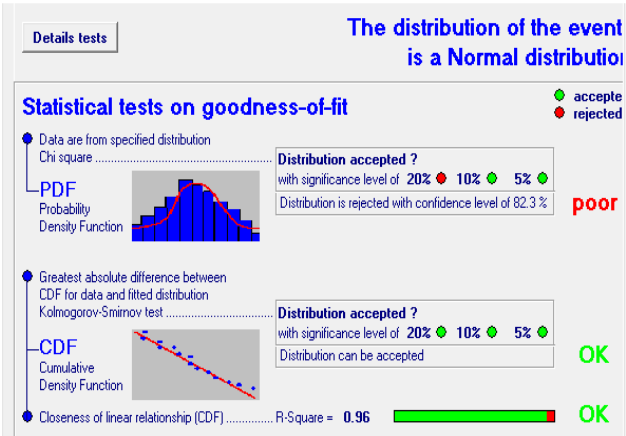
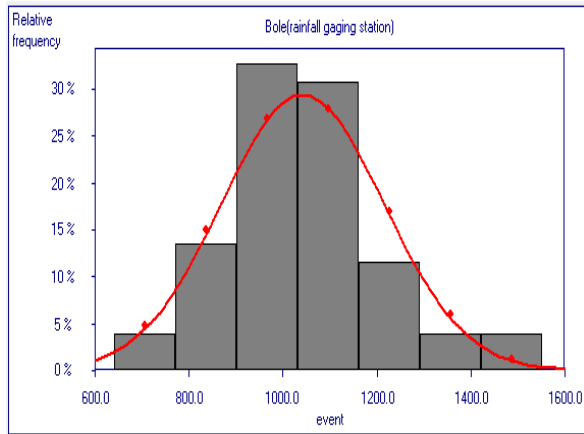
		3	2014	772.20			3	1972	506.50
		4	1994	816.80			4	1979	586.00
		5	1974	844.70			5	1965	734.10
Sendafa	Highest	1	1971	1590.00	Debrezeit	Highest	1	1977	1144.10
		2	1993	1589.40			2	2003	1033.50
		3	1977	1585.80			3	1974	1019.50
		4	1970	1491.90			4	2006	999.20
		5	1990	1483.90			5	1970	979.20
	Lowest	1	1991	635.10		Lowest	1	1995	470.20
		2	1973	811.00			2	1994	485.20
		3	1994	856.00			3	1992	552.80
		4	2004	877.80			4	1997	585.90
		5	1987	889.70			5	1993	602.90
Shola	Highest	1	1985	1348.30	Zequala	Highest	1	1990	1860.00
		2	1986	1326.00			2	1986	1677.90
		3	1977	1203.30			3	1993	1634.10
		4	1981	1133.40			4	1987	1543.60
		5	1996	1113.70			5	1992	1447.70
	Lowest	1	1965	647.20		Lowest	1	1965	787.50
		2	1988	723.90			2	2007	795.20
		3	1990	733.00			3	1976	824.30
		4	1984	735.00			4	1968	838.40
		5	2002	770.50			5	1984	853.80
Tulubolo	Highest	1	1993	1641.20	Ejere	Highest	1	1977	1276.10
		2	1992	1637.90			2	2016	1225.30
		3	2013	1633.60			3	1976	1206.40
		4	1977	1559.60			4	2003	1169.10
		5	1982	1548.00			5	1982	1068.60
	Lowest	1	1995	640.30		Lowest	1	1979	474.00
		2	1974	760.50			2	1994	675.30
		3	1991	771.80			3	1986	687.50
		4	2015	808.00			4	2014	688.30
		5	2001	819.60			5	1988	692.10
Welenkomi	Highest	1	1993	1515.00	Enchinni	Highest	1	1976	1574.70
		2	2006	1512.00			2	1977	1564.70
		3	1977	1485.20			3	2007	1543.50
		4	1967	1463.00			4	2006	1503.40
		5	1983	1378.10			5	1996	1497.10
	Lowest	1	2015	689.80		Lowest	1	1984	834.20
		2	1999	793.30			2	1985	951.30
		3	1973	839.70			3	2012	967.30
		4	2011	855.40			4	2015	1018.20
		5	2014	855.60			5	1999	1024.30

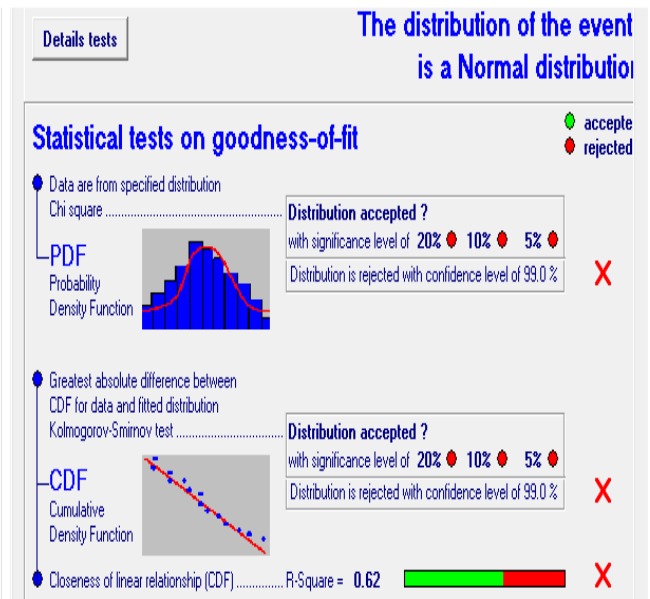
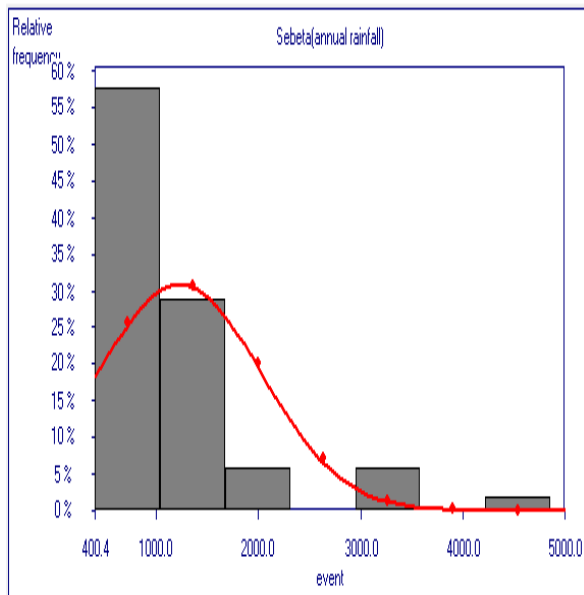
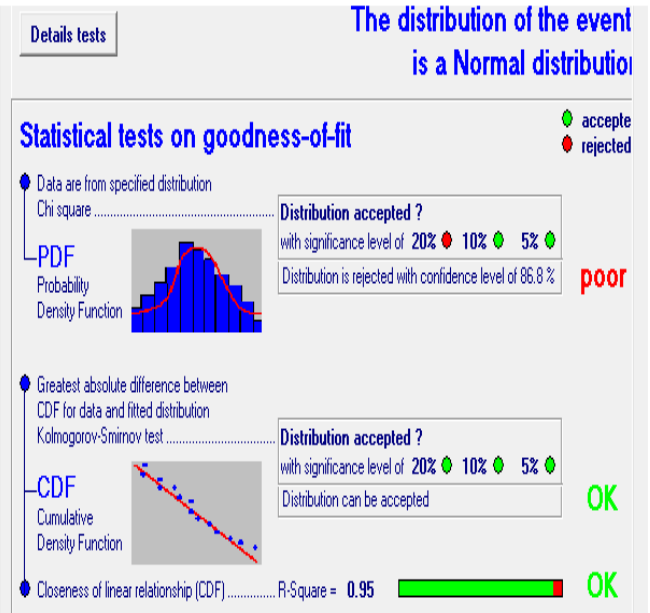
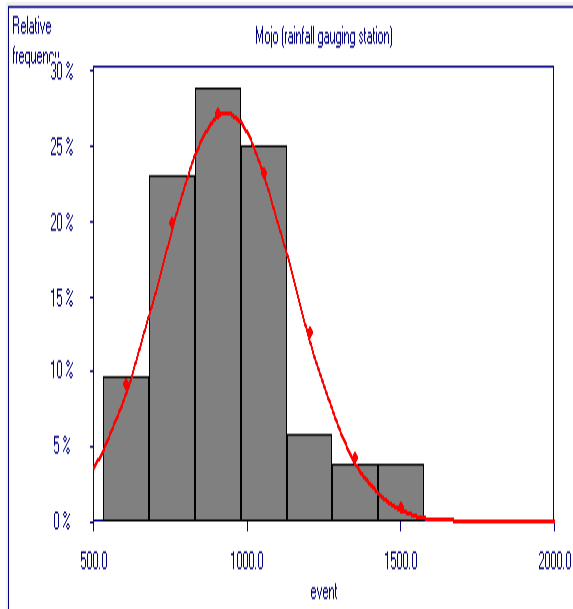
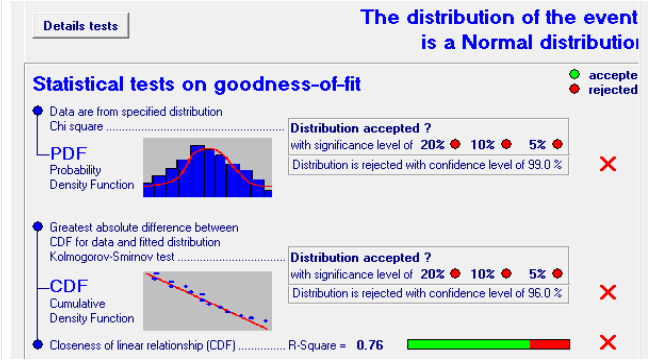
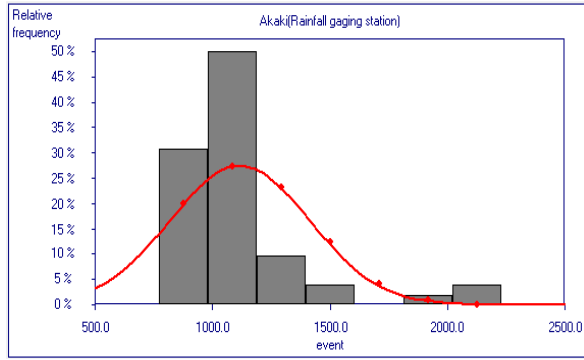
Asgori	Highest	1	1996	1460.50	Intoto	Highest	1	24	1601.00
		2	1990	1364.00			2	10	1595.00
		3	1993	1324.40			3	12	1467.30
		4	1992	1292.90			4	4	1422.20
		5	1986	1250.70			5	3	1406.50
	Lowest	1	2012	763.90	Lowest	1	1	945.30	
		2	2015	827.70		2	13	958.20	
		3	1980	875.20		3	11	997.60	
		4	2011	899.90		4	2	1026.60	
		5	1982	910.30		5	16	1099.70	
Teji	Highest	1	2010	1200.20	Alemtena	Highest	1	1992	1111.80
		2	2006	1170.20			2	2008	972.10
		3	1988	1152.80			3	1993	952.10
		4	1998	1135.70			4	2003	936.10
		5	2005	1112.60			5	1990	906.90
	Lowest	1	2009	686.80	Lowest	1	2013	441.40	
		2	2012	693.50		2	2011	475.50	
		3	1995	786.80		3	2012	509.50	
		4	1997	794.70		4	2015	546.00	
		5	2002	811.10		5	2002	589.00	
Sululta	Highest	1	1990	1756.50	Awashmelka	Highest	1	2013	1440.70
		2	2010	1732.30			2	1993	1435.00
		3	2012	1637.60			3	2010	1319.00
		4	1991	1613.60			4	2011	1307.30
		5	2000	1422.70			5	1991	1246.90
	Lowest	1	1992	777.80	Lowest	1	2009	623.10	
		2	2015	813.20		2	1997	664.20	
		3	1993	855.80		3	2004	714.10	
		4	2005	881.10		4	2002	771.30	
		5	1987	889.70		5	1989	788.10	
Koka Dam	Highest	1	1992	1559.70					
		2	1993	1556.00					
		3	2001	1525.00					
		4	1998	1214.70					
		5	1990	1214.00					
	Lowest	1	1984	151.00					
		2	1986	169.30					
		3	1987	307.40					
		4	1985	376.60					
		5	1983	394.30					

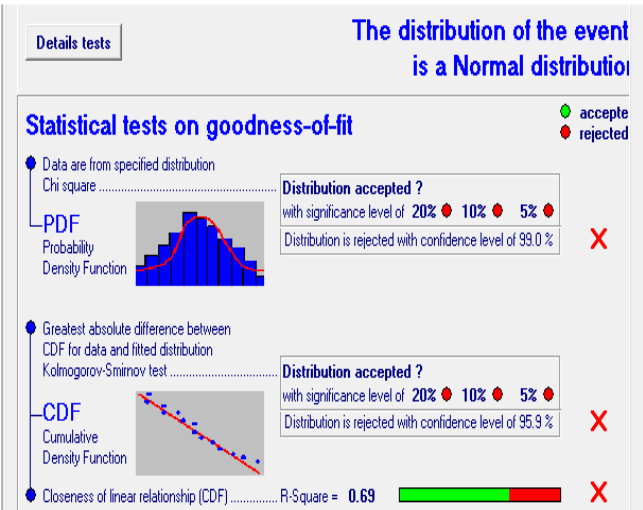
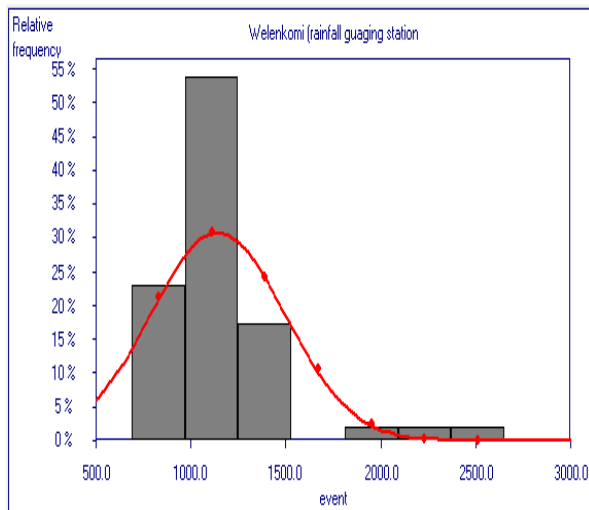
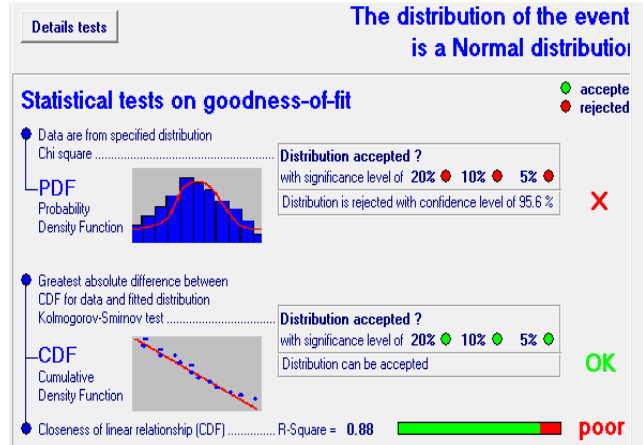
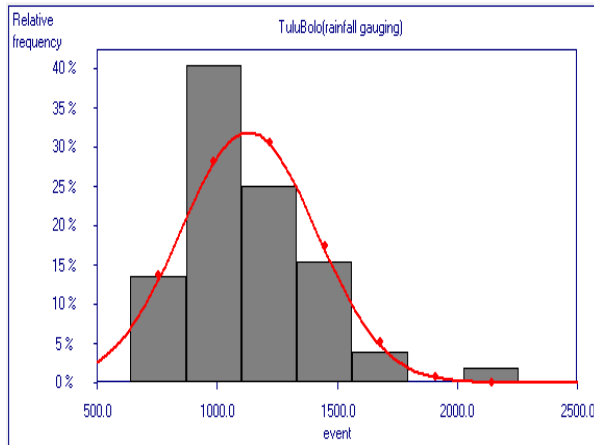
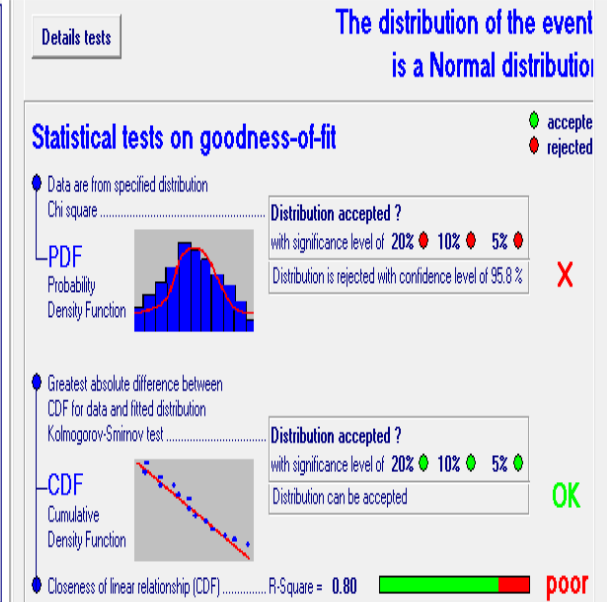
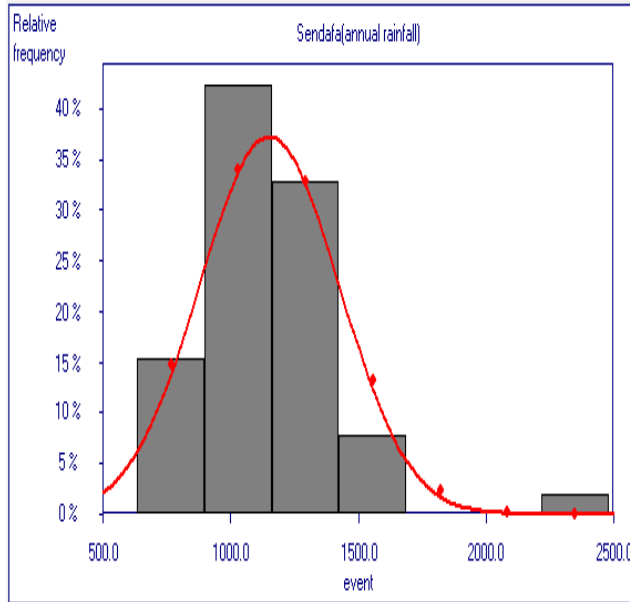
Appendix C: Station Wise Percentiles based on Weighted Average results of annual rainfall data

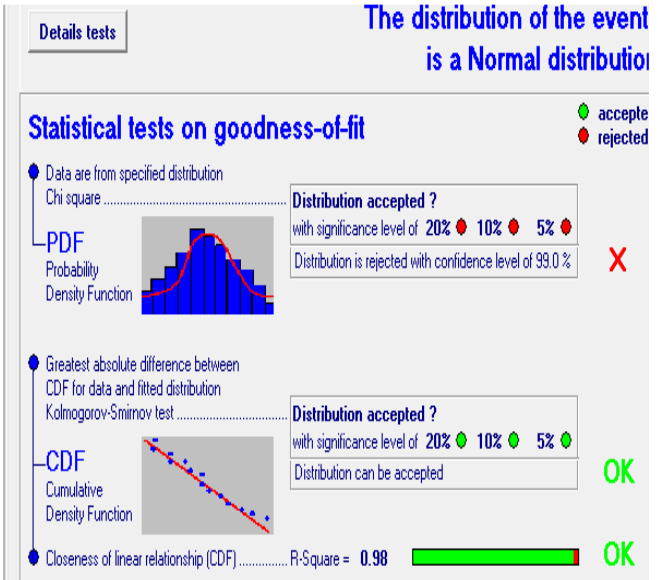
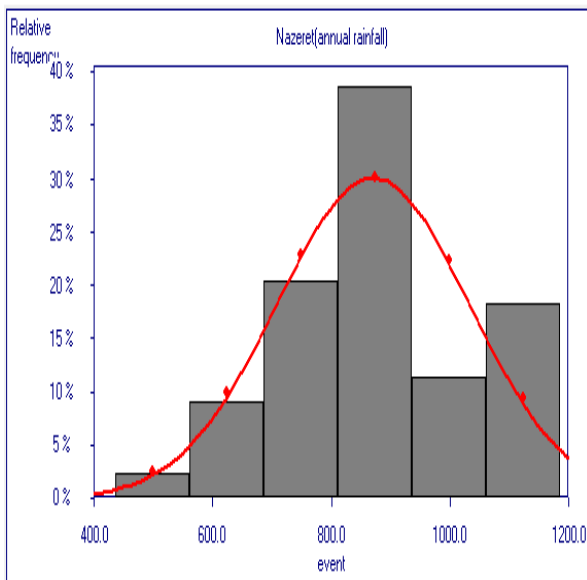
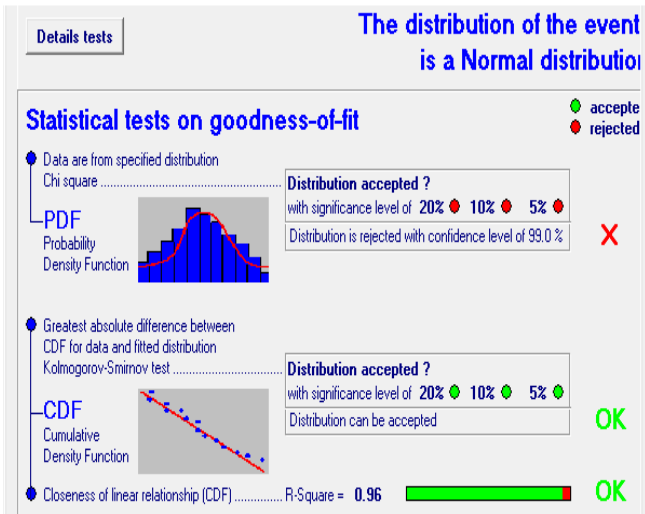
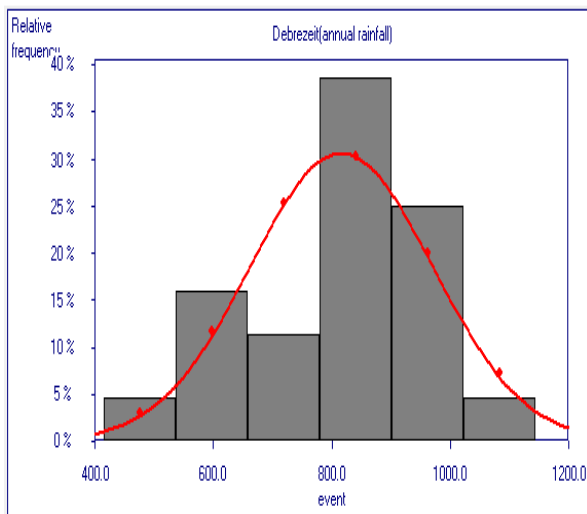
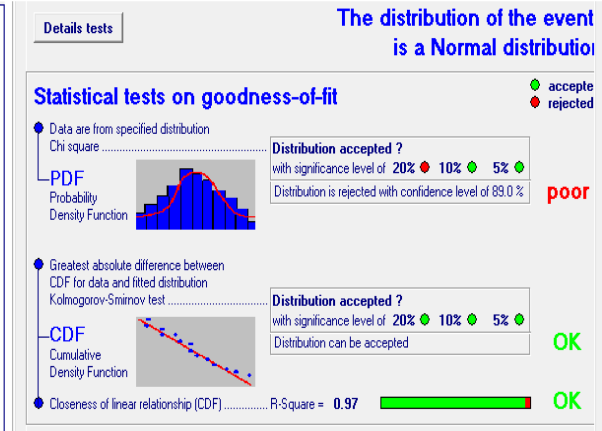
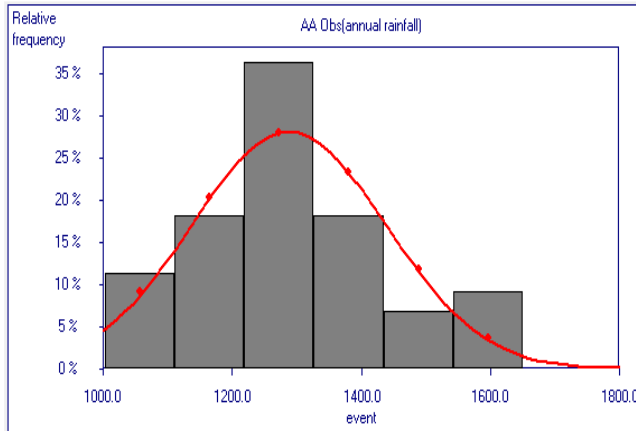
Method	Station	Percentiles						
		5	10	25	50	75	90	95
Weighted Average(Definition 1)	Akaki	789.6350	810.7600	956.0250	1080.3000	1171.4500	1351.4100	1479.8800
	Addisalem	678.8100	775.4000	1030.8000	1151.5000	1344.7500	1446.9200	1526.0000
	AAObs	1008.7800	1053.9000	1206.2750	1252.9000	1368.2000	1465.8900	1547.7650
	Bole	765.3750	852.1100	940.6000	1030.8000	1118.8750	1246.9700	1330.8300
	Ginchi	767.4900	830.4700	992.1500	1134.4000	1234.2250	1440.2800	1471.1900
	Mojo	569.1750	686.5700	779.9250	876.8500	1058.9000	1184.4100	1408.7250
	Nazeret	585.7250	625.3500	738.7000	859.1000	974.0250	1106.7500	1158.5600
	Sebeta	502.4750	734.8800	857.6250	975.7000	1200.1250	1595.2500	1680.7300
	Sendafa	840.2500	889.9100	970.8500	1125.1000	1230.0750	1460.2300	1587.0600
	Shola	729.8150	772.7800	828.3250	935.6500	1043.8250	1109.8000	1246.2450
	Tulubolo	767.8450	821.3100	945.6750	1076.9000	1234.7750	1518.0600	1635.1050
	Welenkomi	823.4600	857.4000	974.3250	1038.5500	1211.0750	1375.1600	1494.5800
	Debrezeit	551.0000	594.4000	720.0000	855.9000	916.6000	989.2000	1030.0000
	Zequala	802.4750	846.1000	926.5750	1098.9500	1310.4250	1495.6500	1666.9500
	Ejere	676.5200	689.0600	758.2500	917.2000	1003.9000	1149.0000	1223.4100
	Enchinni	952.9000	1019.4200	1115.2000	1201.5000	1389.3500	1502.1400	1562.5800
	Asgori	821.3200	894.9600	951.5000	1013.8000	1166.6500	1299.2000	1373.6500
	Teji	692.8300	793.1200	844.3500	930.3000	994.7000	1139.1200	1173.2000
	Sululta	809.6600	876.0400	988.8000	1181.3000	1364.6000	1618.4000	1734.7200
	Koka Dam	167.4700	362.7600	552.1000	778.7000	999.5500	1276.7600	1556.3700
Intoto	948.5250	977.9000	1165.6250	1213.3500	1357.3500	1531.1500	1599.5000	
Alemtena	460.1550	513.1500	692.4000	806.0500	883.5250	950.5000	1034.9650	
Awashmelka	645.7050	719.8200	843.6250	886.2500	1185.2750	1317.8300	1437.5650	

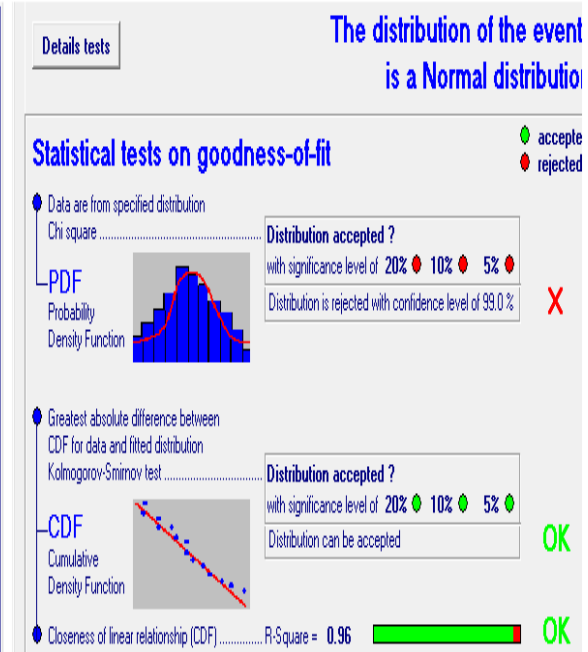
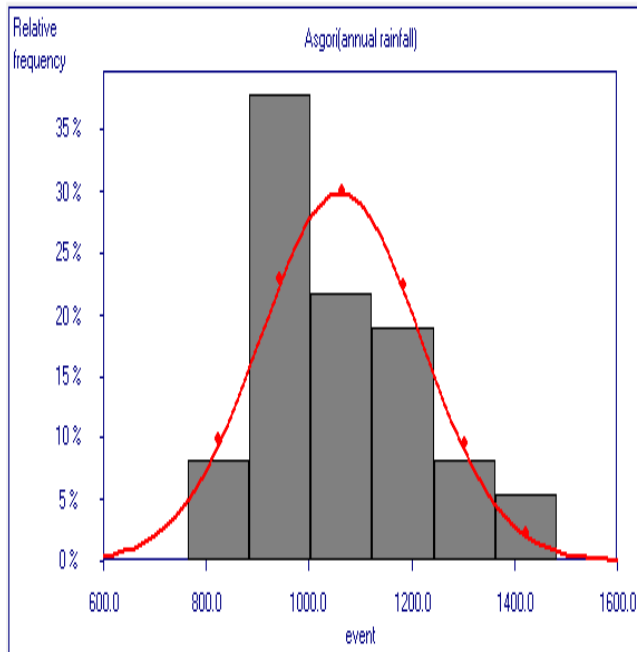
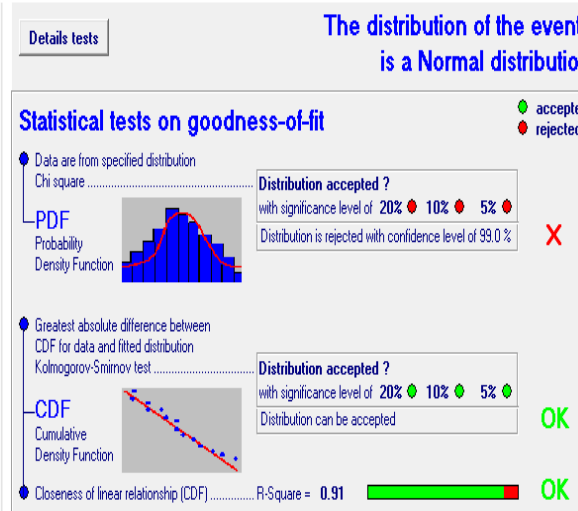
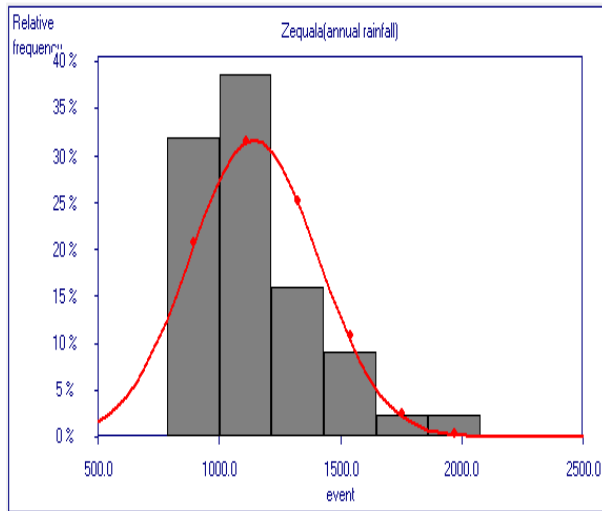
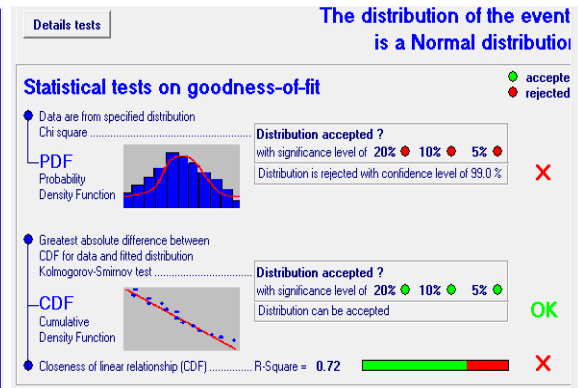
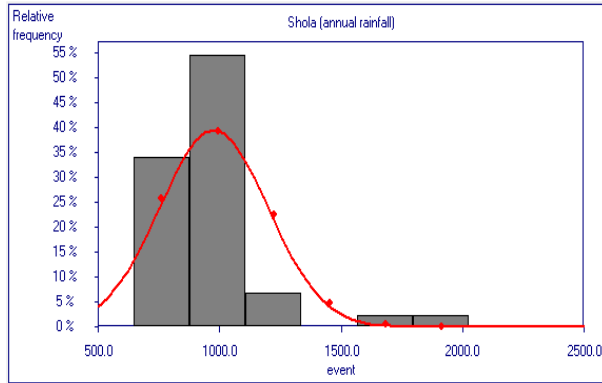
Appendix D: Station wise normality test results of figures annual rainfall data
Bole

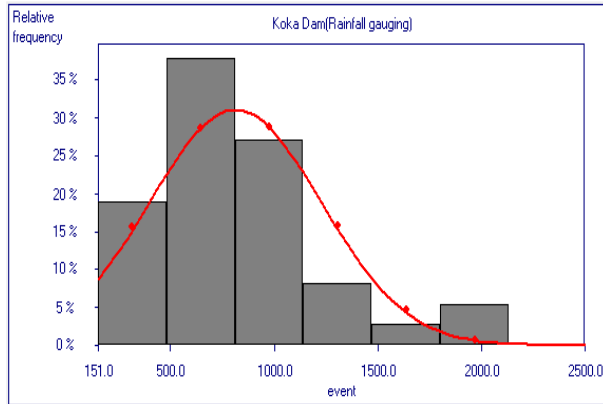










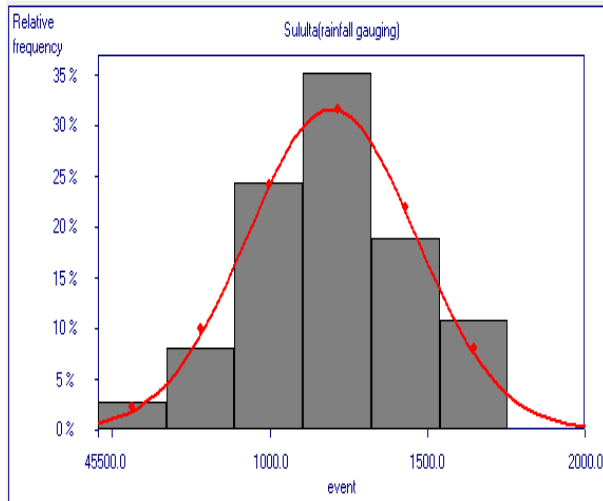


The distribution of the event is a Normal distribution

Details tests

Statistical tests on goodness-of-fit

- Data are from specified distribution
- Chi square **Distribution accepted ?** with significance level of 20% 10% 5% **✗**
Distribution is rejected with confidence level of 98.3 %
- PDF Probability Density Function
- Greatest absolute difference between CDF for data and fitted distribution Kolmogorov-Smirnov test **Distribution accepted ?** with significance level of 20% 10% 5% **OK**
Distribution can be accepted
- CDF Cumulative Density Function
- Closeness of linear relationship (CDF) R-Square = 0.90 **OK**

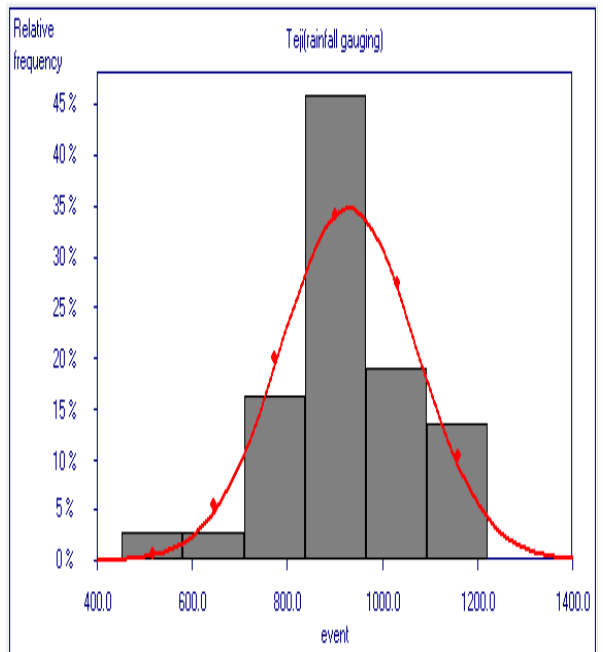


The distribution of the event is a Normal distribution

Details tests

Statistical tests on goodness-of-fit

- Data are from specified distribution
- Chi square **Distribution accepted ?** with significance level of 20% 10% 5% **OK**
Distribution can be accepted
- PDF Probability Density Function
- Greatest absolute difference between CDF for data and fitted distribution Kolmogorov-Smirnov test **Distribution accepted ?** with significance level of 20% 10% 5% **OK**
Distribution can be accepted
- CDF Cumulative Density Function
- Closeness of linear relationship (CDF) R-Square = 0.97 **OK**

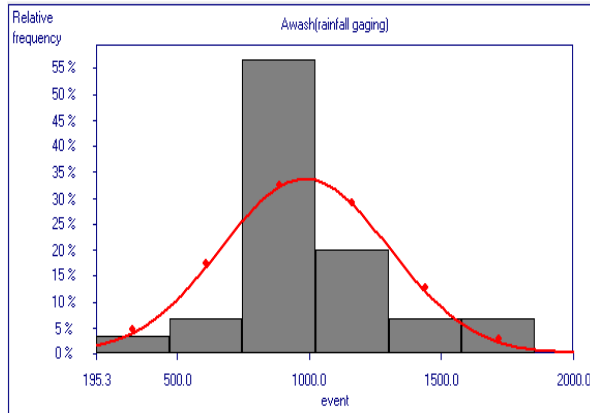


The distribution of the event is a Normal distribution

Details tests

Statistical tests on goodness-of-fit

- Data are from specified distribution
- Chi square **Distribution accepted ?** with significance level of 20% 10% 5% **✗**
Distribution is rejected with confidence level of 98.0 %
- PDF Probability Density Function
- Greatest absolute difference between CDF for data and fitted distribution Kolmogorov-Smirnov test **Distribution accepted ?** with significance level of 20% 10% 5% **OK**
Distribution can be accepted
- CDF Cumulative Density Function
- Closeness of linear relationship (CDF) R-Square = 0.93 **OK**

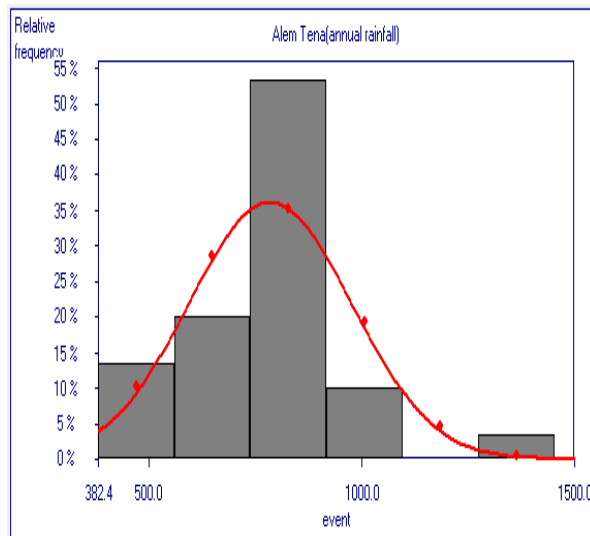


The distribution of the event is a Normal distribution

Details tests

Statistical tests on goodness-of-fit

- Data are from specified distribution
- Chi square **Distribution accepted ?** with significance level of 20% 10% 5% **X**
- PDF Probability Density Function
- Greatest absolute difference between CDF for data and fitted distribution Kolmogorov-Smirnov test **Distribution accepted ?** with significance level of 20% 10% 5% **OK**
- CDF Cumulative Density Function
- Closeness of linear relationship (CDF) R-Square = 0.84 **poor**

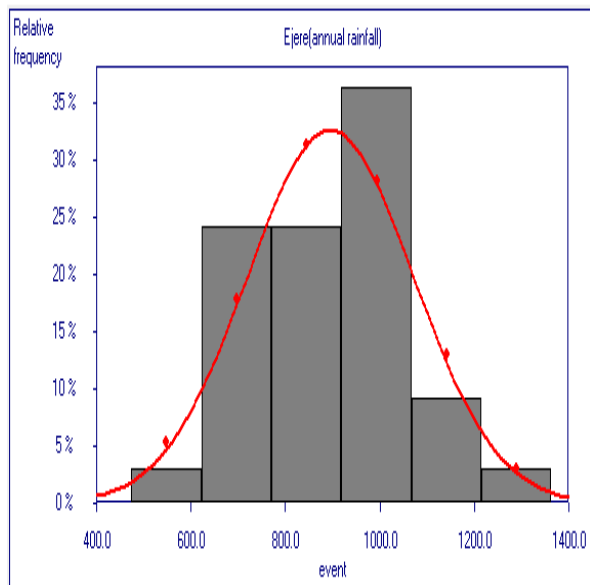


The distribution of the event is a Normal distribution

Details tests

Statistical tests on goodness-of-fit

- Data are from specified distribution
- Chi square **Distribution accepted ?** with significance level of 20% 10% 5% **X**
- PDF Probability Density Function
- Greatest absolute difference between CDF for data and fitted distribution Kolmogorov-Smirnov test **Distribution accepted ?** with significance level of 20% 10% 5% **OK**
- CDF Cumulative Density Function
- Closeness of linear relationship (CDF) R-Square = 0.87 **poor**



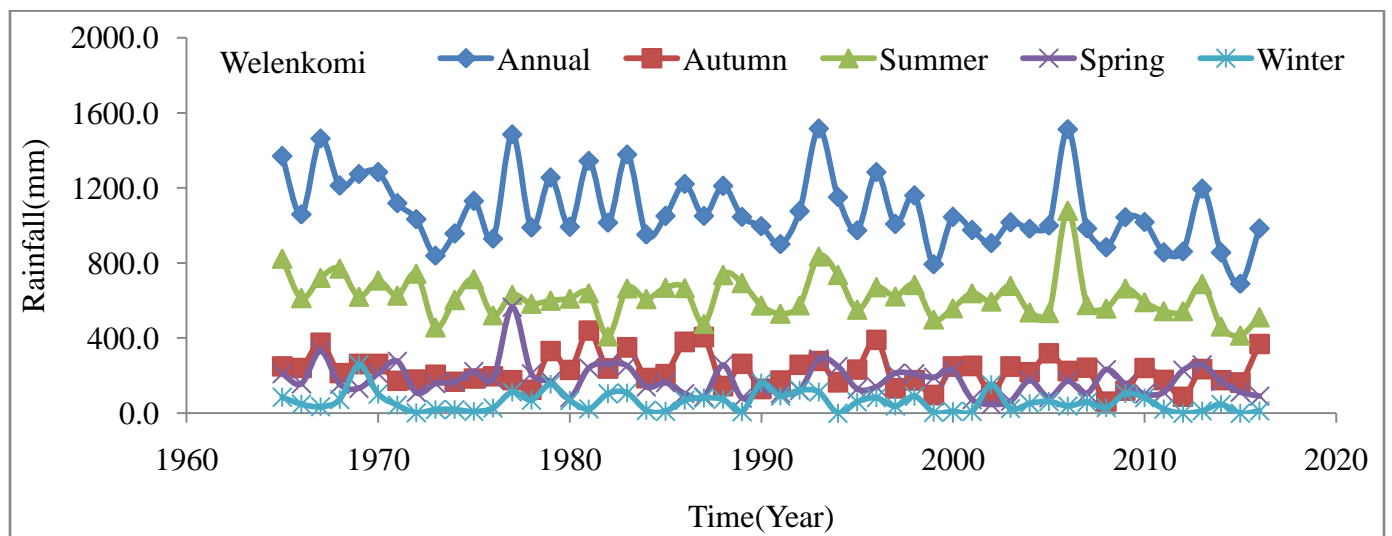
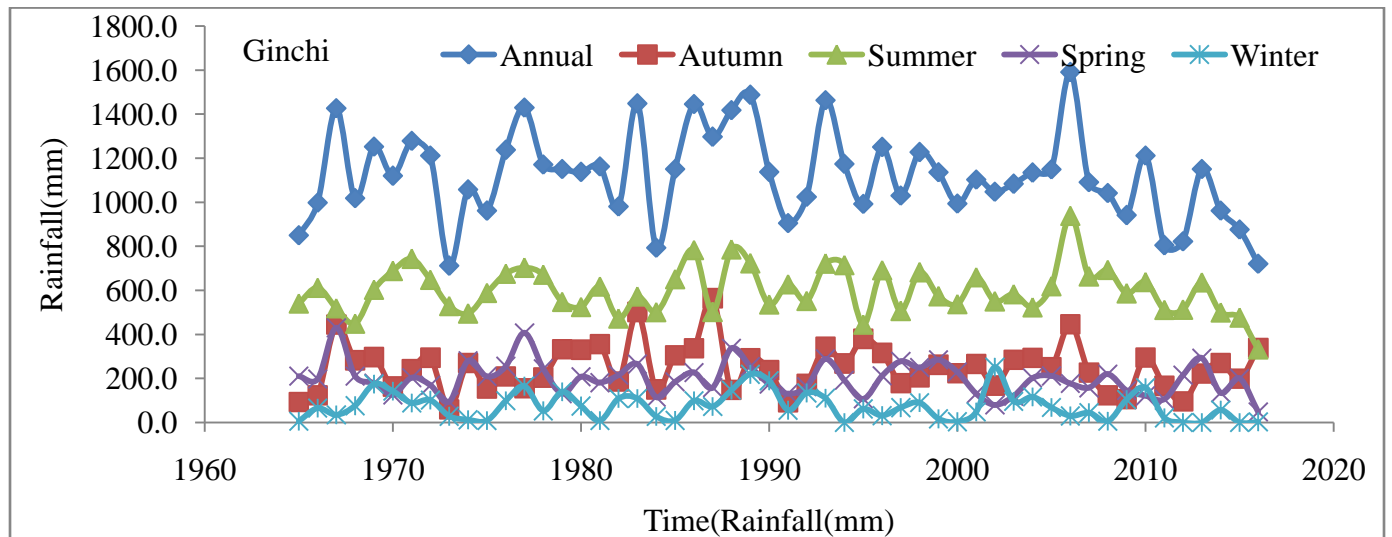
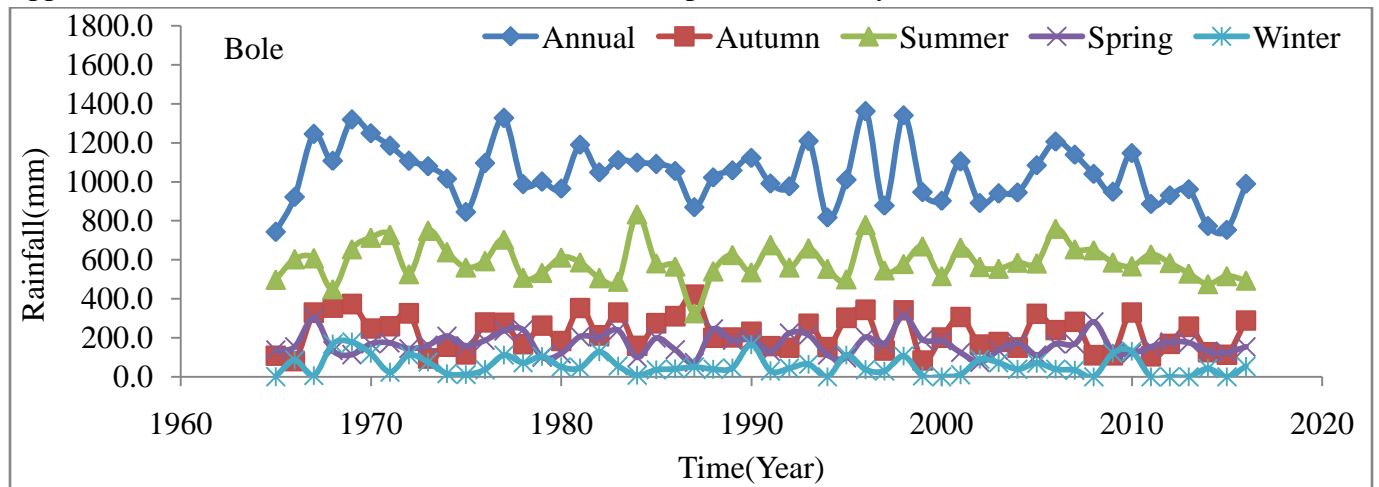
The distribution of the event is a Normal distribution

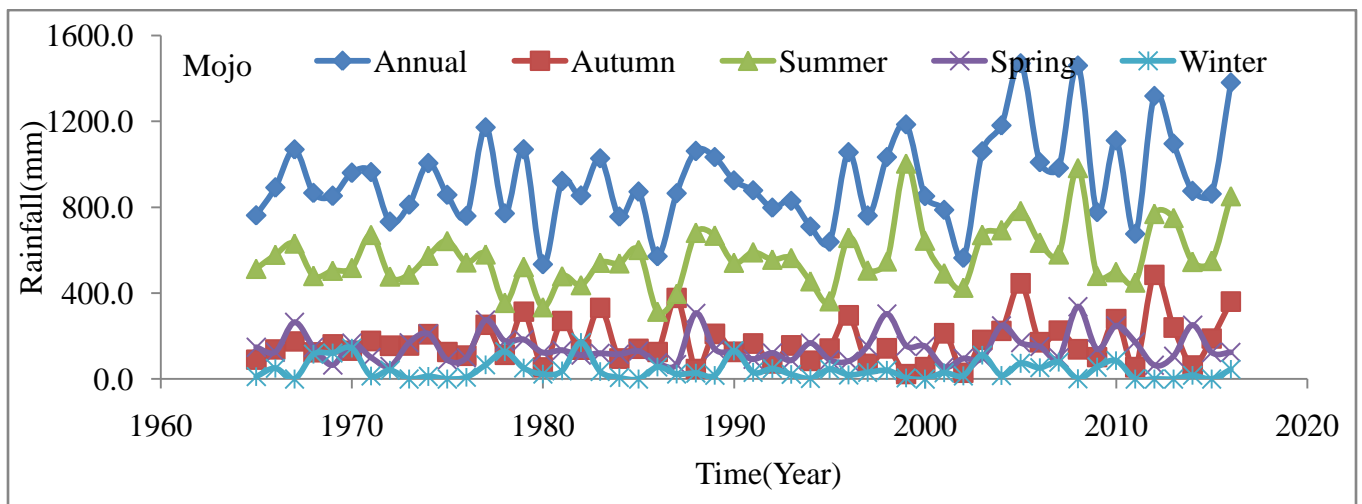
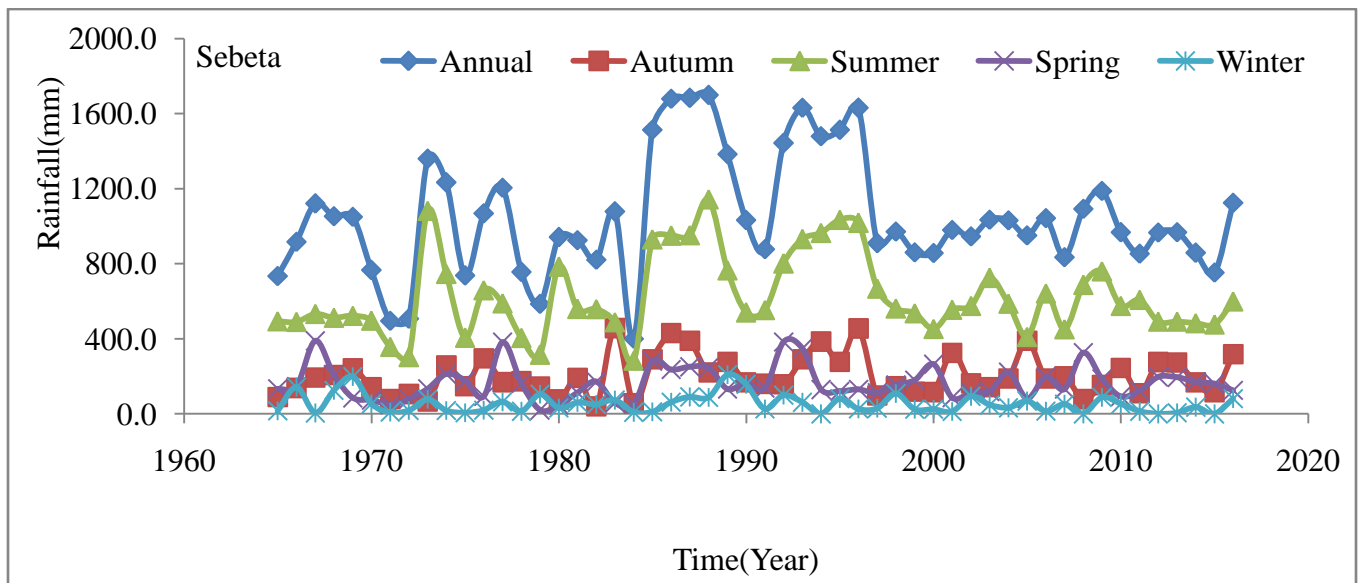
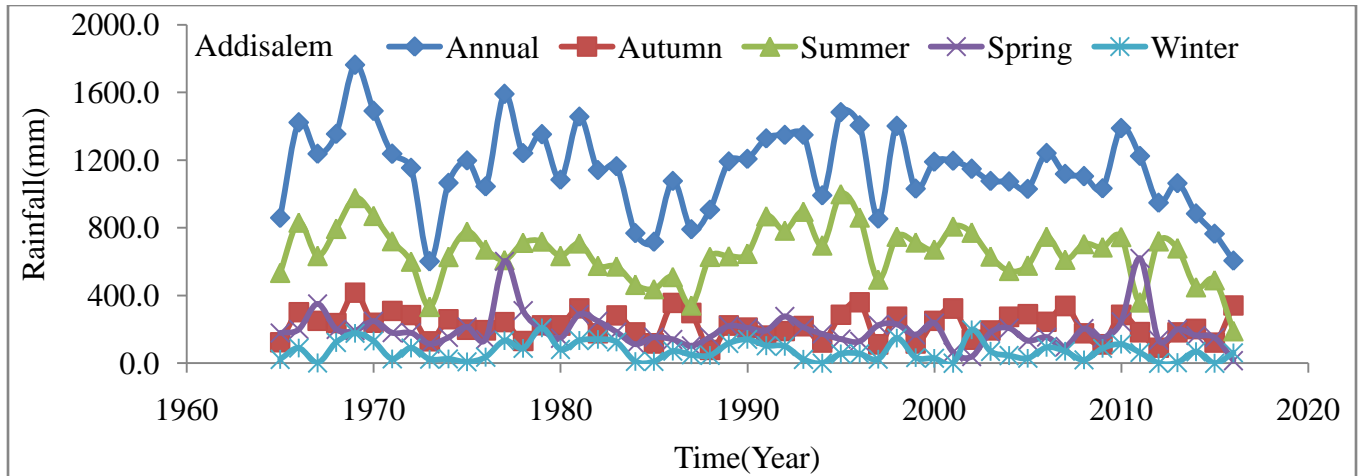
Details tests

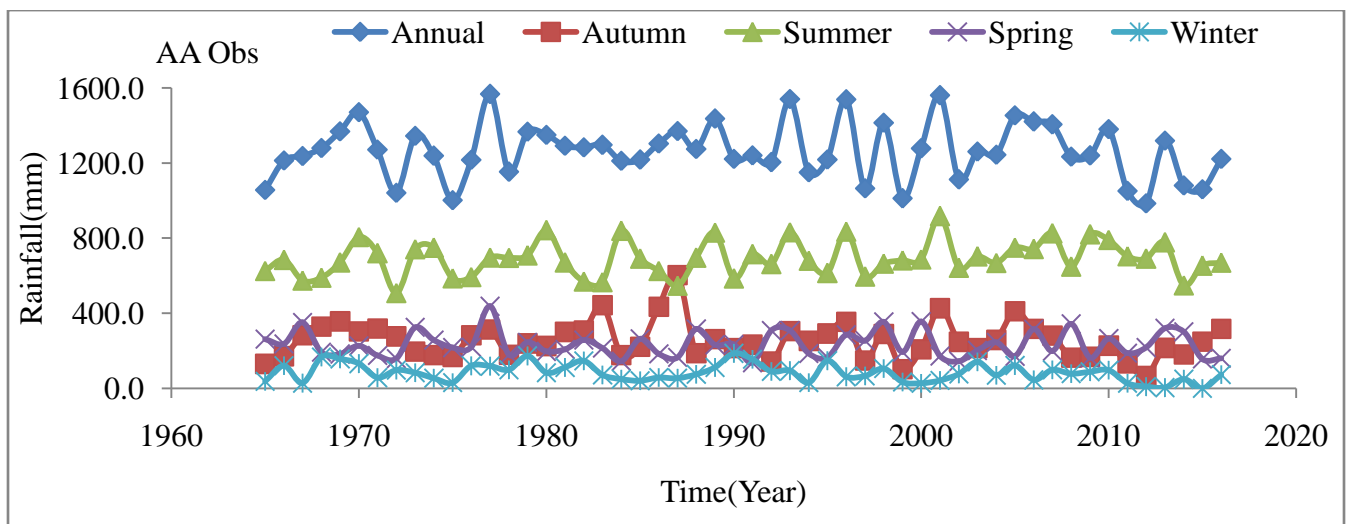
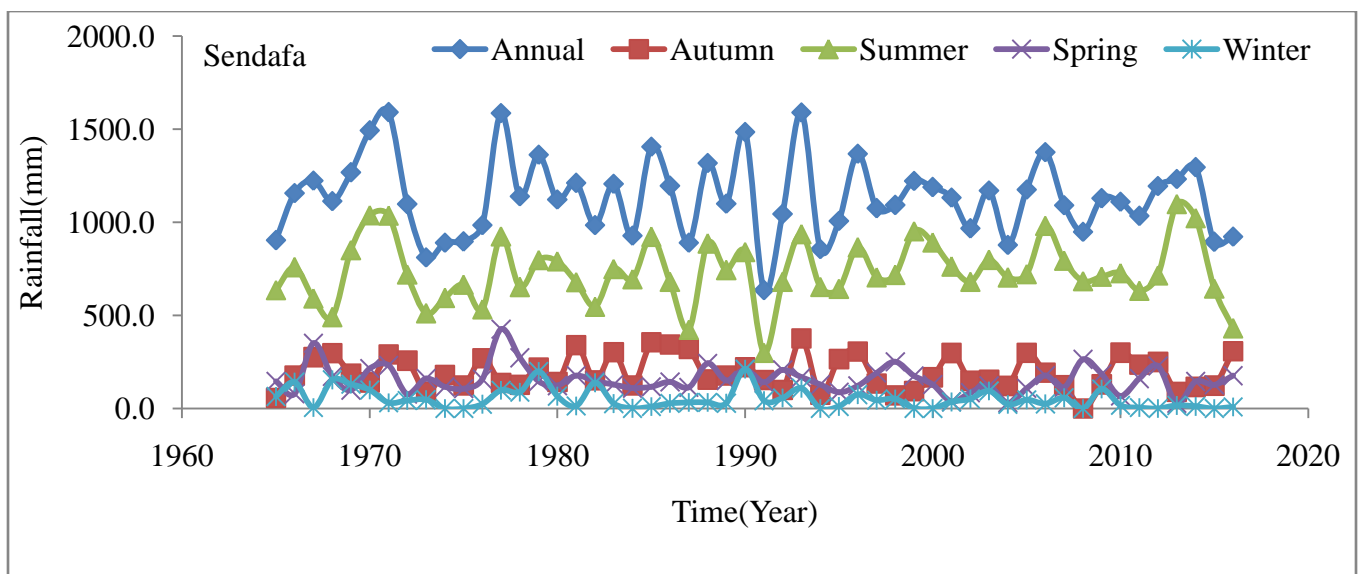
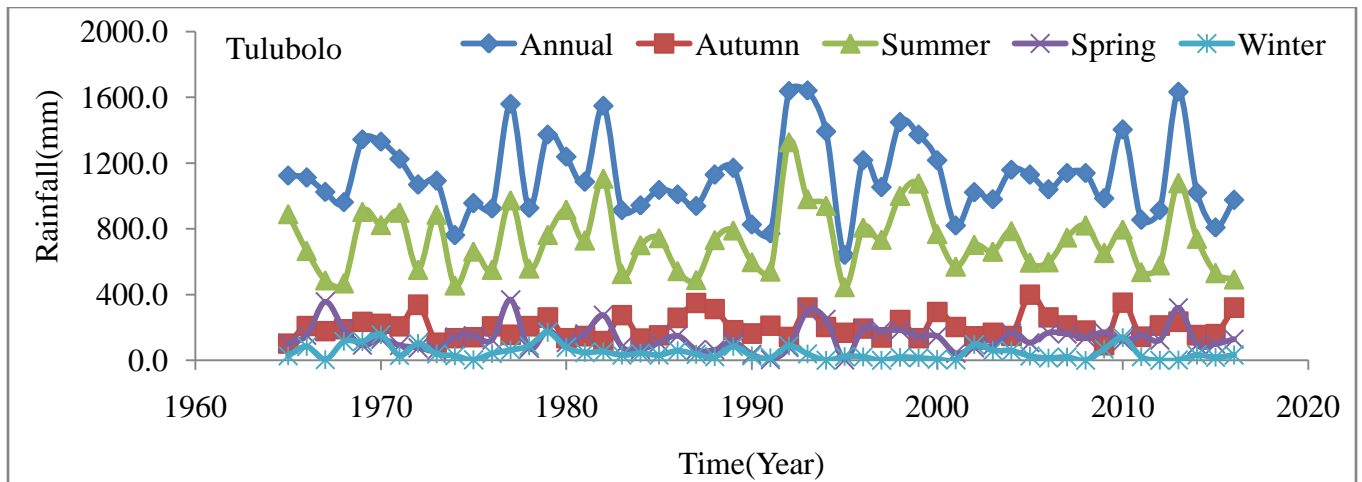
Statistical tests on goodness-of-fit

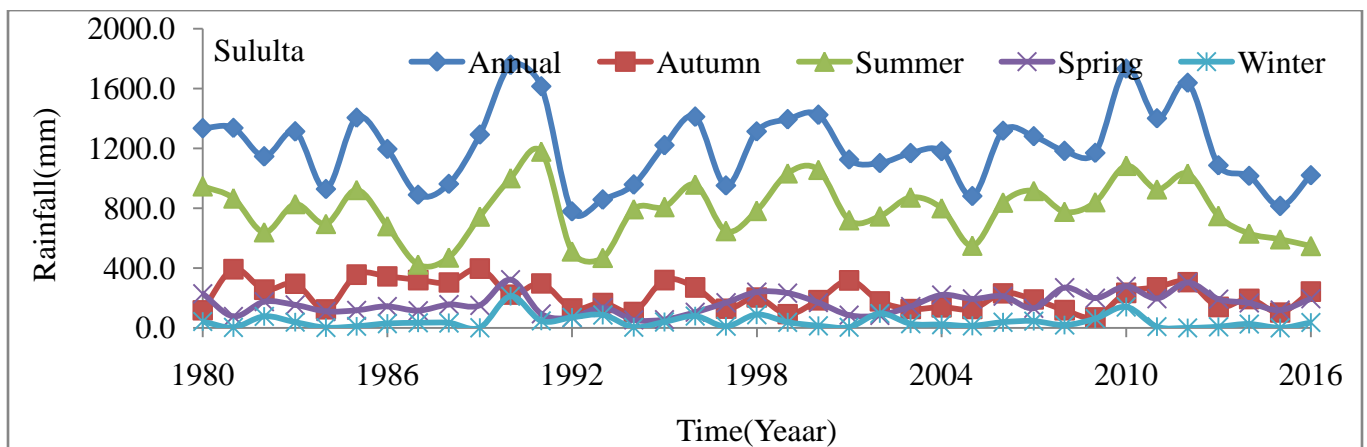
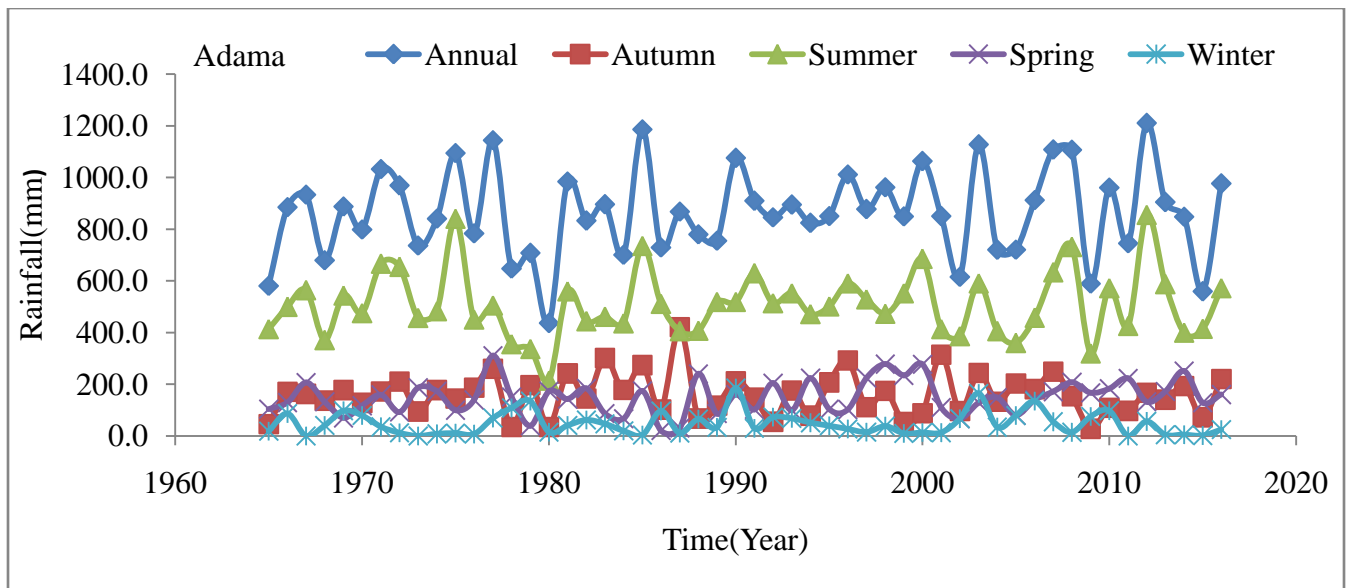
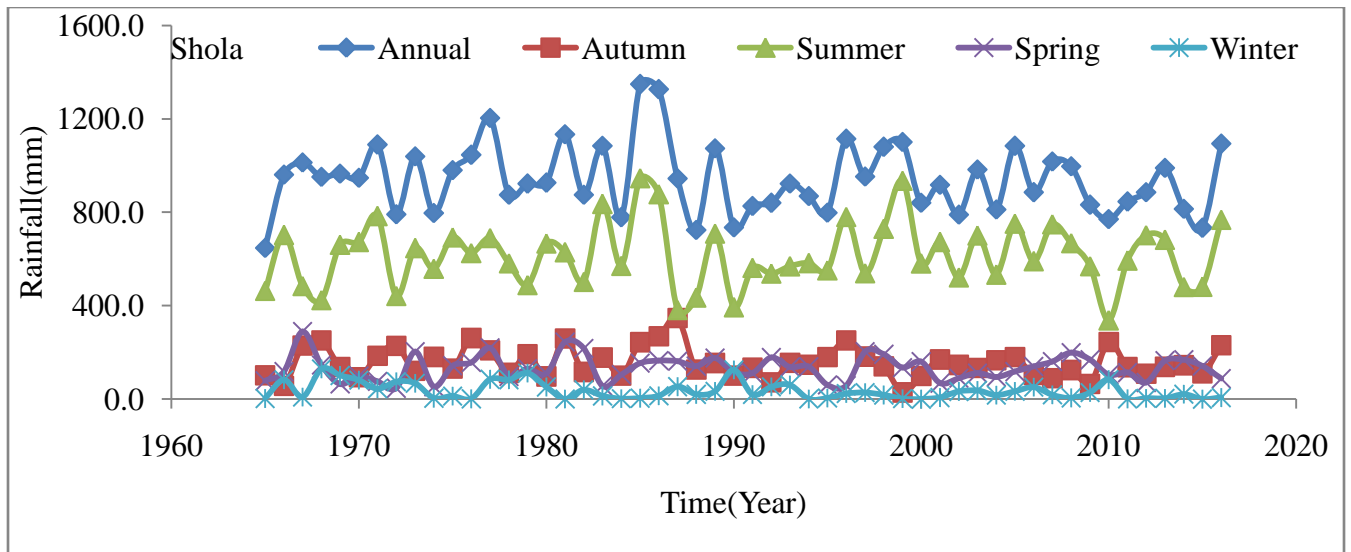
- Data are from specified distribution
- Chi square **Distribution accepted ?** with significance level of 20% 10% 5% **X**
- PDF Probability Density Function
- Greatest absolute difference between CDF for data and fitted distribution Kolmogorov-Smirnov test **Distribution accepted ?** with significance level of 20% 10% 5% **OK**
- CDF Cumulative Density Function
- Closeness of linear relationship (CDF) R-Square = 0.89 **poor**

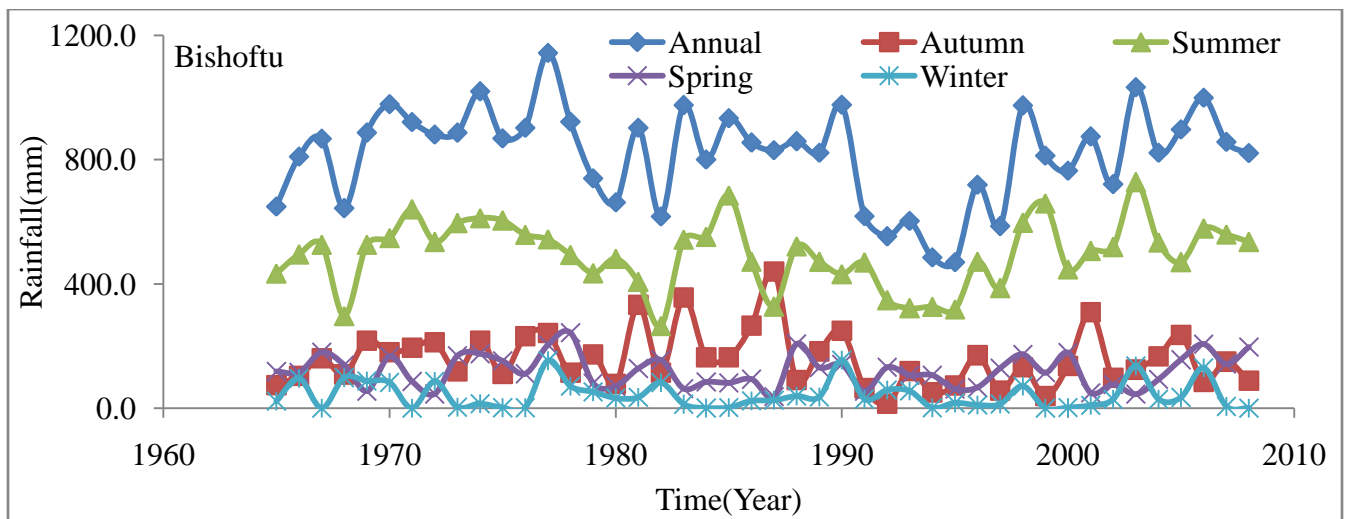
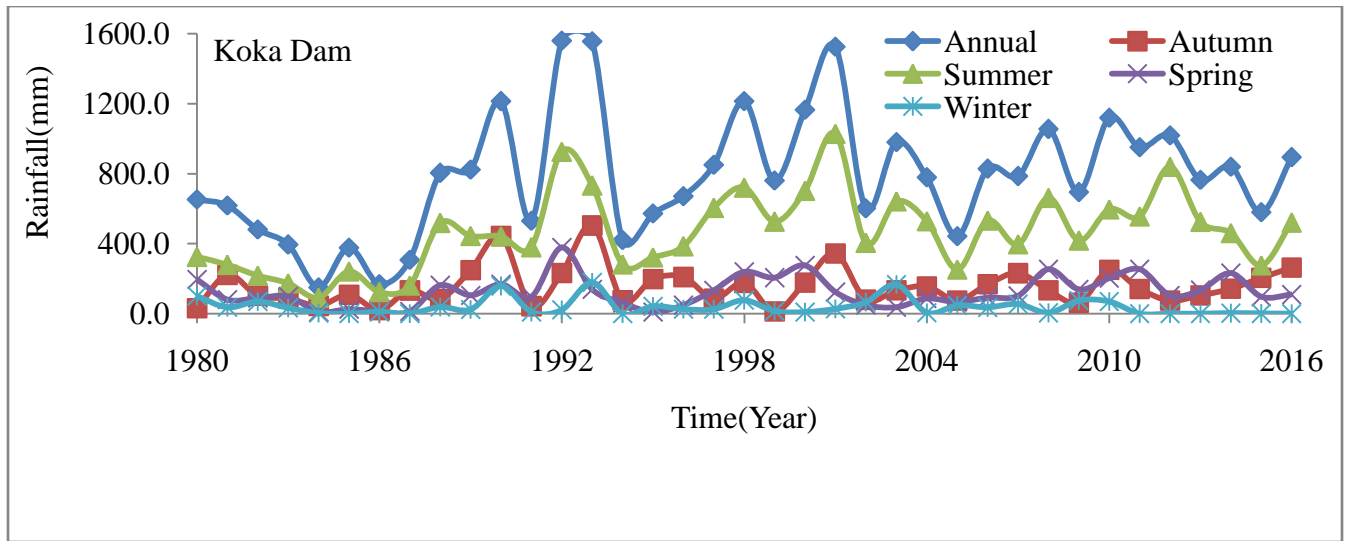
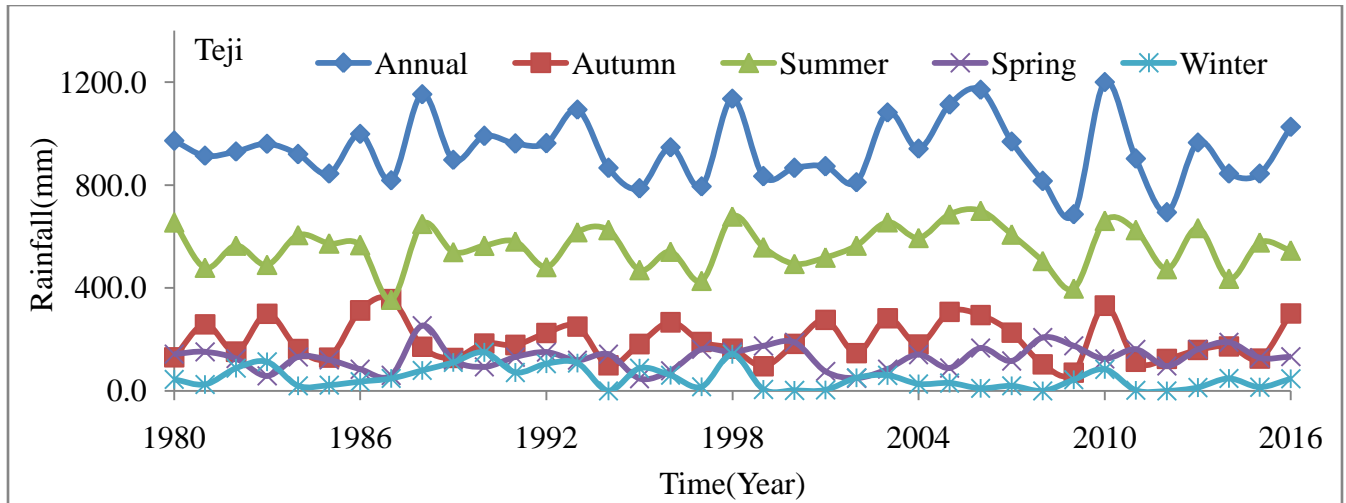
Appendix E: Station Wise Annual and Seasonal Temporal variability of rainfall

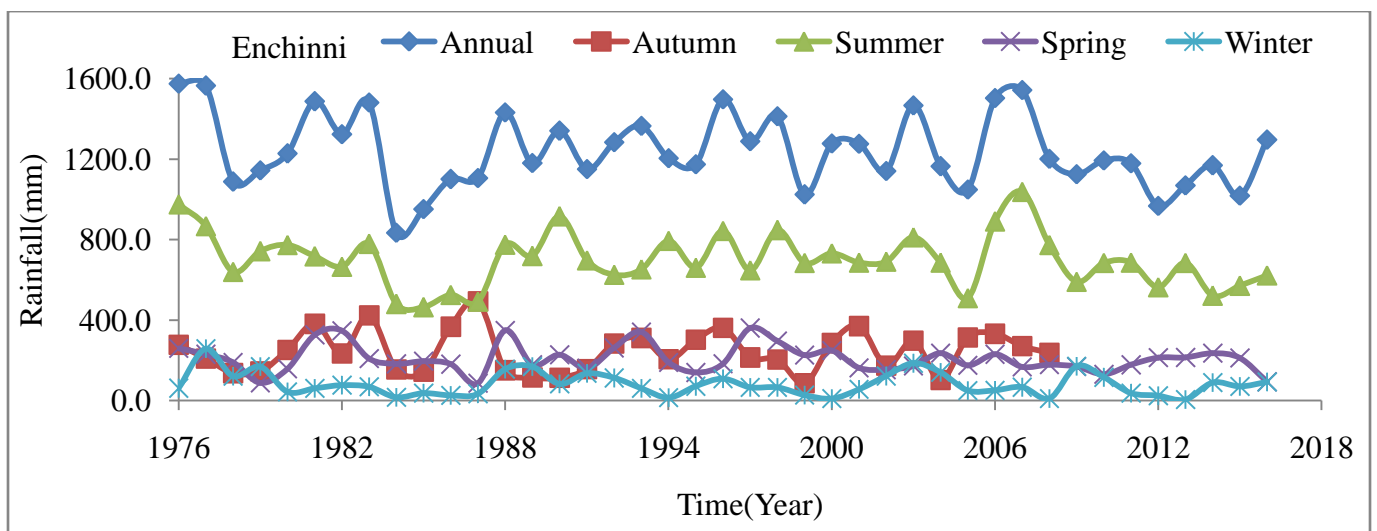
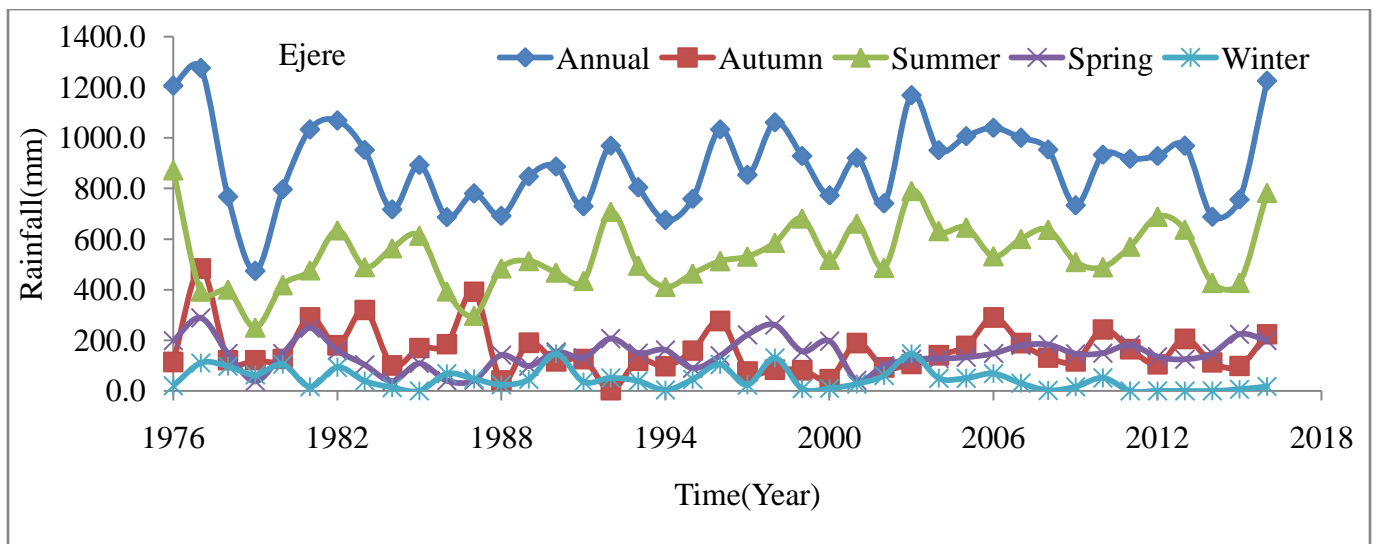
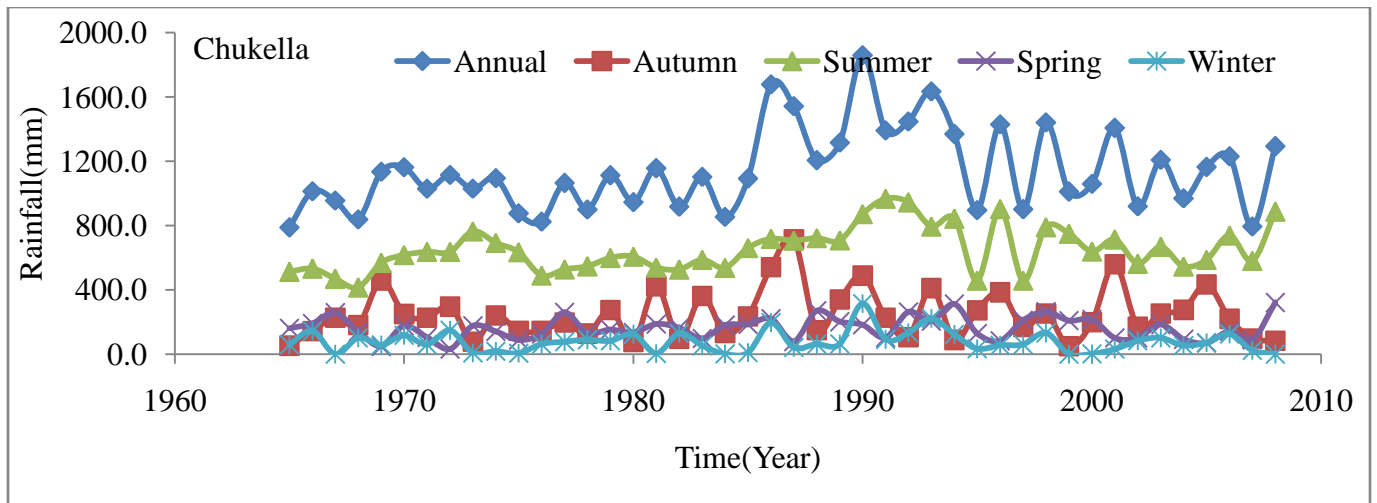








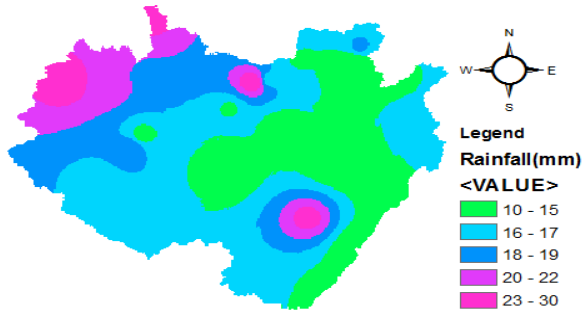




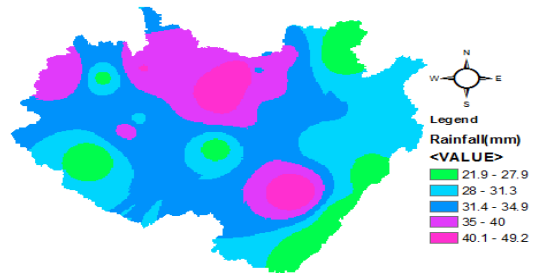
Appendices F: Monthly rainfall distribution on meteorological stations

a) IDW Methods

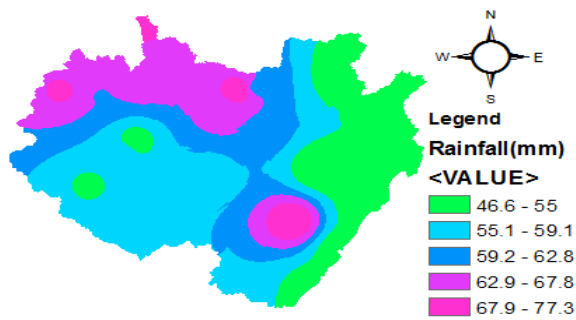
January



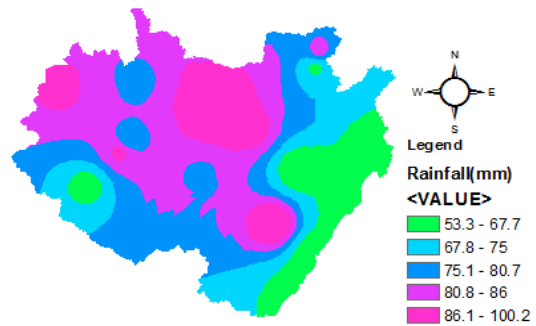
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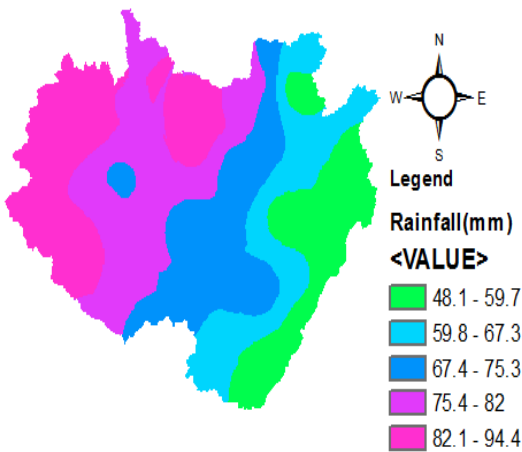
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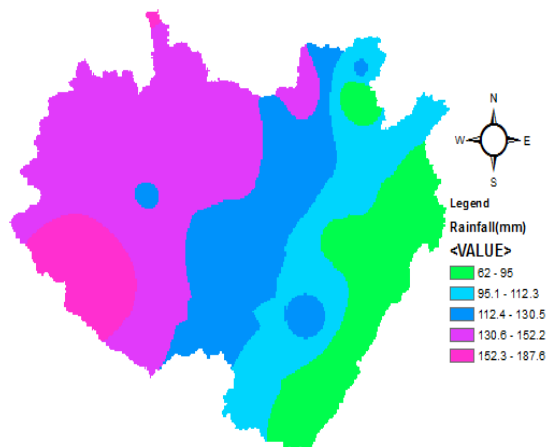
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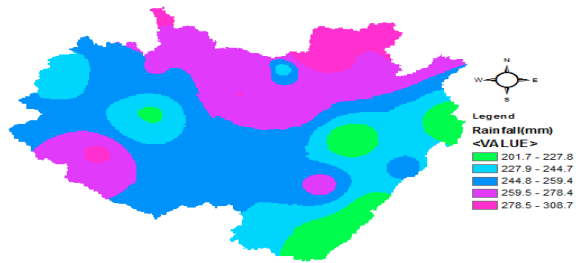
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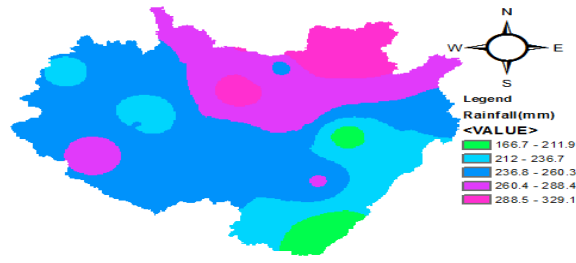
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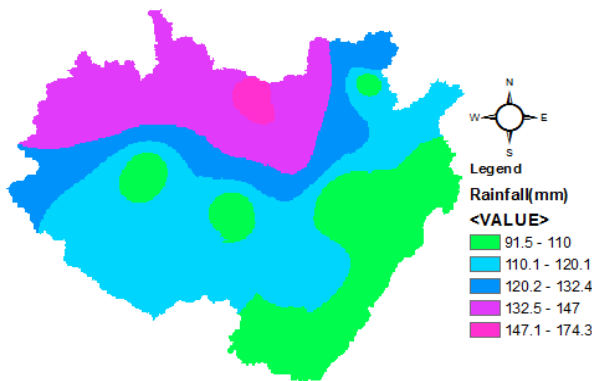
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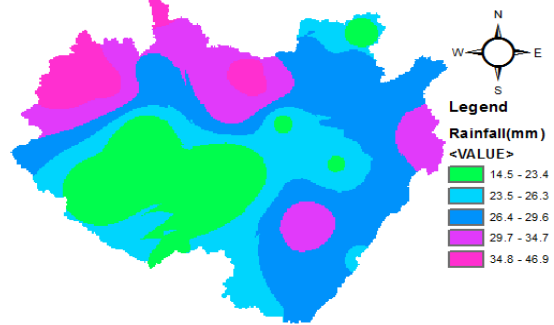
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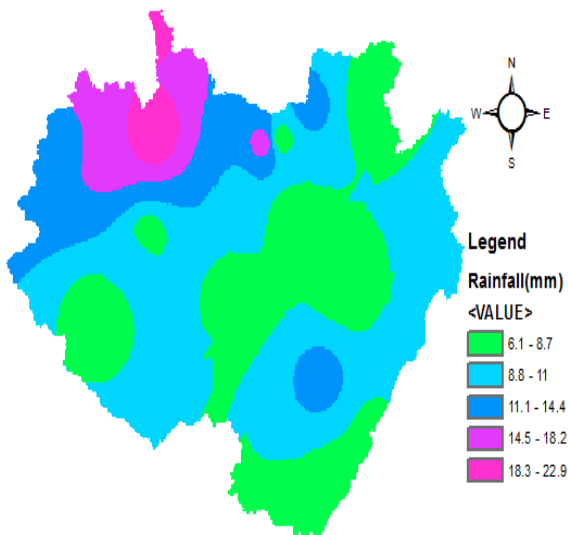
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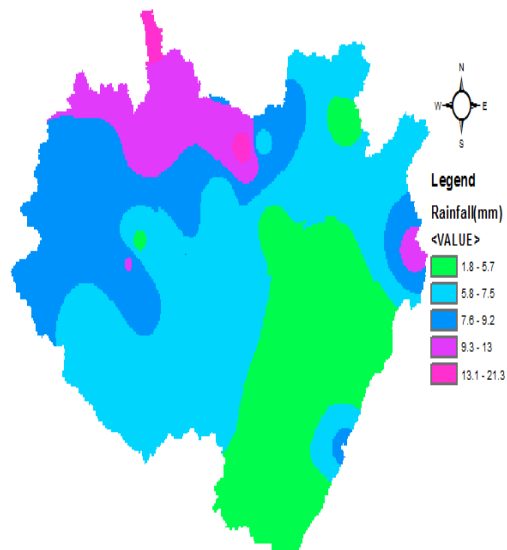
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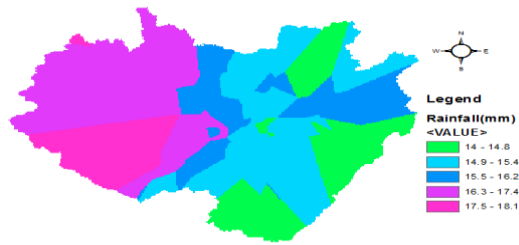
November



December



b) Kriging Methods
January



February



March



April



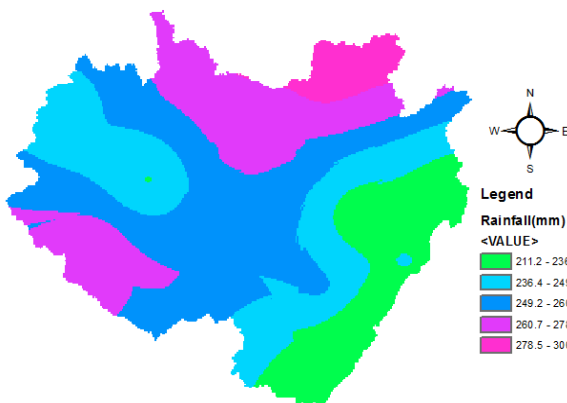
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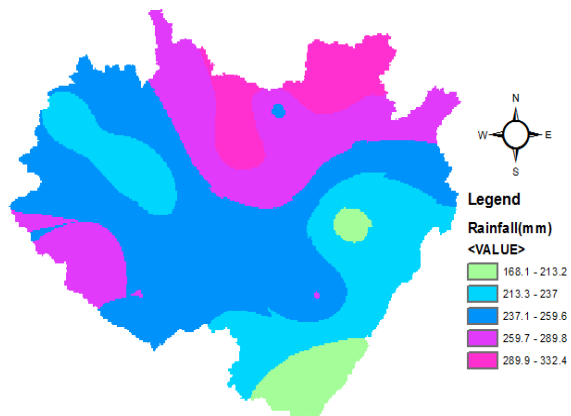
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July



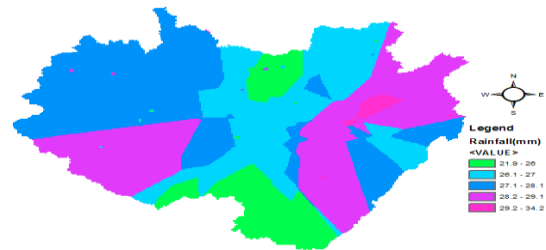
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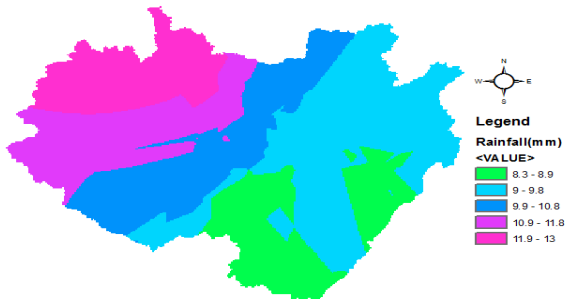
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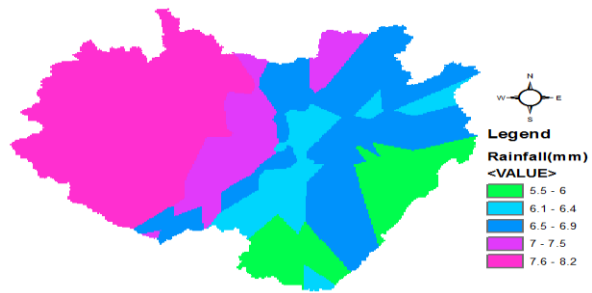
October



November



December



c) Spline Methods

January



February



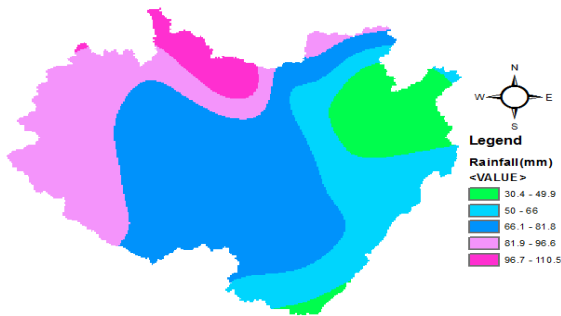
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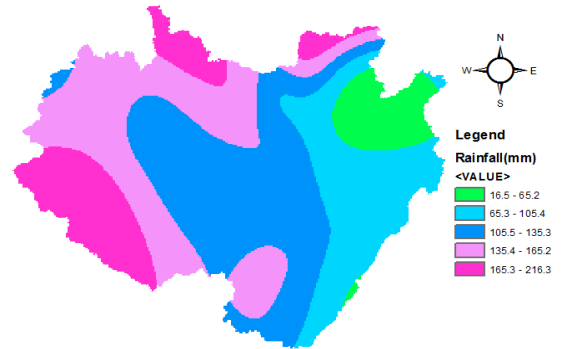
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May



June



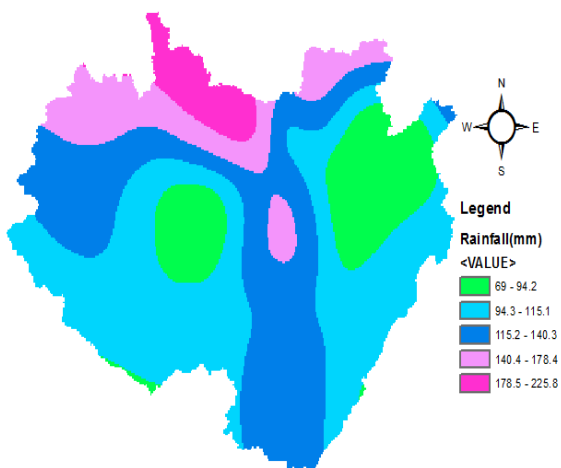
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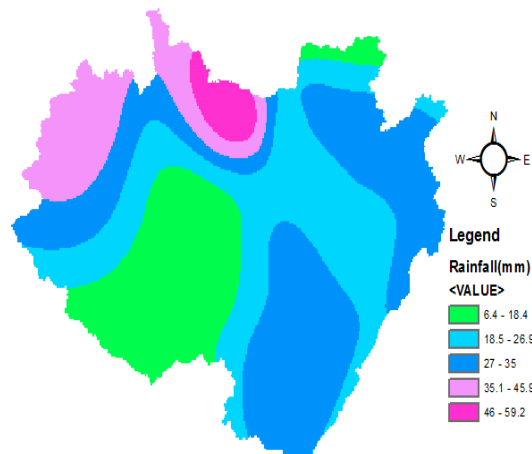
August



September



October



November



December



d) Trend Method
January



February



March



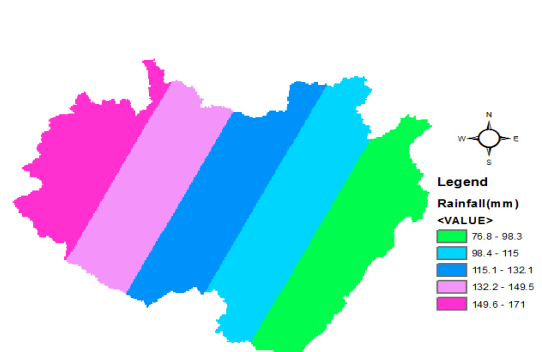
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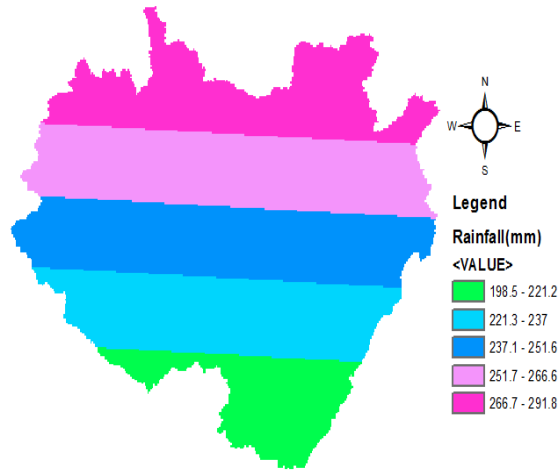
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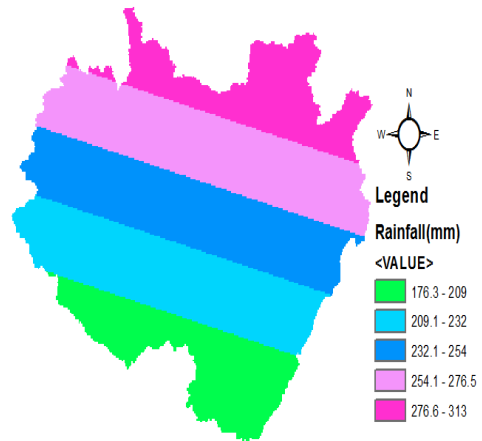
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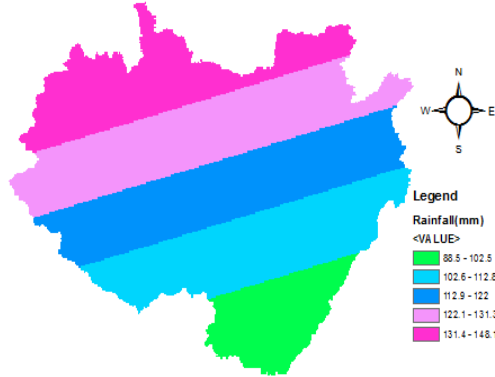
July



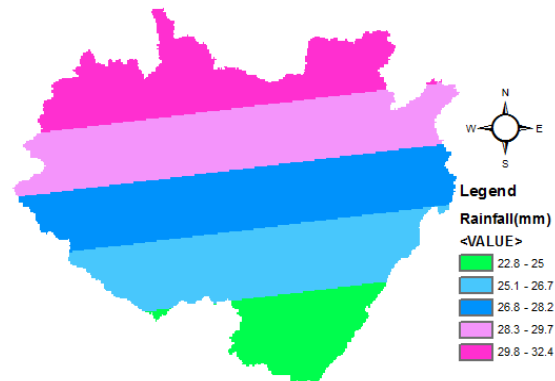
August



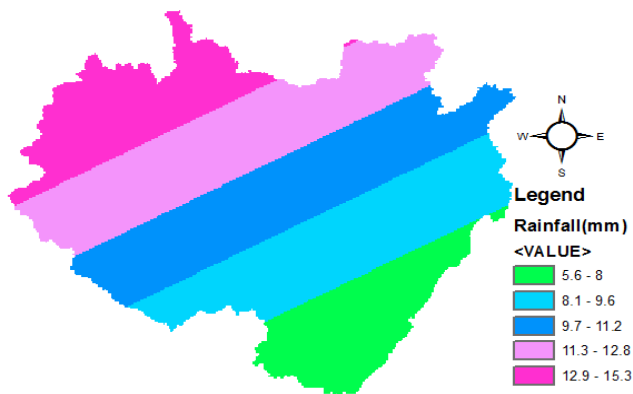
September



October



November



December

