ANALYSIS OF RAINFALL TREND OVER LONG PERIOD IN UPPER BETWA BASIN, MADHYA PRADESH

काशी हिन्दू विश्वविद्यालय

BANARAS HINDU UNIVERSITY

THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Agricultural Engineering

(SOIL & WATER CONSERVATION ENGINEERING)

Submitted by

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CERTIFICATE

To,
The Registrar (Academic)
Banaras Hindu University,
Varanasi–221005,
U.P., India

Through: The Head, Department of Farm Engineering, I. Ag. Sc., BHU, Varanasi

Dear Sir,

We have great pleasure in forwarding the thesis entitled "**Analysis of rainfall trend over long period in Upper Betwa Basin, Madhya Pradesh**" submitted by **Mr. Kuldeepak Pal, ID. No. 16SWE11, Enrolment No. 390179** in partial fulfillment of the requirements for the award of the degree of **Master of Technology in Agricultural Engineering (Soil and Water Conservation Engineering)**, Department of Farm Engineering, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

This is to certify that the work has been carried out solely by **Mr. Kuldeepak Pal** under my supervision and guidance and his findings and data presented herein are genuine and original to the best of my knowledge and belief and no part of the work has been submitted for any other degree or distinction.

Thanking you, Yours faithfully

FORWARDED BY

Dr. Anupam Kumar Nema
Professor
(Supervisor)

HEAD

Er. Rahul Kumar Jaiswal
Scientist-D
(Co-supervisor)

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CERTIFICATE

We, the undersigned members of the advisory committee of **Mr. Kuldeepak Pal**, **Id. No.: 16SWE11**, a candidate for the degree of **Master of Technology in Agricultural Engineering (Soil and Water Conservation Engineering)**, agree that the thesis entitled "Analysis of rainfall trend over long period in Upper Betwa Basin, Madhya Pradesh" may be submitted in partial fulfillment of the requirements for the degree.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

CWC	Central Water Commission
WRD	Water Resource Department
G.I.S.	Geographical Information System
BMC	Billion Meters Cubic
e.g.	For example
i.e.	That is
No.	Number
Sl.	Serial
Viz.	Namely
et al.	et alii (and others)
etc.	Etcetera
Fig.	Figure
E	East
N	North
IPCC	Intergovernmental Panel on Climate Change
Min	Mininum
Ma	Maximum
^{0}C	Degree centigrade
%	Percentage
‘	Minute
“	Second
∑	Summation
б or SD	Standard deviation
CV	Coefficient of Variance
Jun	June
Jul	July
Aug	August
Sept	September
Oct	October
mm	Millimeter
cm	Centimeter

Chapter I

INTRODUCTION

1.1 Background

Climate is one of the key components of our earth system. There are many variables such as precipitation, temperature, atmospheric pressure, humidity. Different studies over world on trend of climate and hydro-meteorological sciences point towards that fluctuations in various parameters like rainfall, temperature leading to alternate cycles of flood and drought conditions.

Indian climate is dominated by southwest monsoon. About 80% of the rainfall in India occurs during the four monsoon months (June-September) with large spatial and temporal variations over the country. For sustainable development of agriculture in India, there is a need for the identification and quantification of climate change. Soil erosion and flooding will happen due to the melting of glacier triggered by global warming as a result of climate change. Water resources have become a prime concern for any development and planning including food production sector, flood control and effective water resources management. In India one of the biggest problems faced by water resources management is the unequally distributed water supply throughout the country. Due to this agriculture sector seems to be the biggest sufferer where rainfall has not been occurring when expected, has been occurring when not expected and is being often accompanied by high winds and hails and thus causing huge losses to crops and devastating farmers who entirely depend on their crops.

Trend analysis of precipitation simply means to have an idea about how rainfall is varying temporally and spatially over a long period of time. Trend is present when a time series exhibits steady upward growth or a downward decline, at least over successive time periods. Trend may be loosely defined as "long-term change in mean level", but there is no fully satisfactory mathematical definition. But trend analysis helps in finding 'forecasting'. The rainfall trend is very crucial for the economic development and hydrological planning for the country. Trend analysis of rainfall in different spatial scales will be lead to a better understanding of the problems associated with floods, droughts, and the availability of water for various uses with respect to future climate scenarios. Analysis of rainfall trends is important in studying the impacts of climate change for water resources planning and management. Knowledge of trends and variations of current and historical hydro climatological variables is relevant to the future development and sustainable management of water resources of a given region especially within the perspective of global warming, water and energy cycles and the increasing demand for water due to population and economic. The study of precipitation trends is crucially important for a country like India whose food security and economy are dependent on the timely availability of water. Allocation and management of water for irrigation purposes, in the present situation of climate change, is very important. With the growing stress on water due to climate changes, analysis on a broad as well as regional scale is required as India has vast climatic zones and variations.

1.2 Need of Study

Increasing population and urbanization are causing undesirable impacts on the environment. Further, with increasing in urbanization additional pervious areas are becoming impervious, leading to decreases in vegetation cover. Rapid economic development and population growth in various parts of the world such as India have caused concerns regarding the quantity of natural resources and in particular water resources. Based on experimentation at New Delhi, India (Aggarwal, 2007) has reported that a 1^0 C rise in temperature throughout the growing period will reduce wheat production by 5 million tonnes. Associated with global warming, there is strong indication that rainfall changes are taking place on both the global and regional scales. The global average precipitation is projected to increase but both increases and decreases are expected at the regional and continental scales (Dore, 2005). 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 also influence the frequency of droughts and floods. Further, temporal change in precipitation distribution will affect cropping patterns and productivity. According to the

Intergovernmental Panel on Climate Change (IPCC, 2007), future climate change is likely to cause an increase in the number and severity of glacier melt related floods, slope destabilization and a decrease in river flows as glaciers recede (IPCC, 2007). Lal (2001) discussed the implications of climate change on Indian water resources. Gosian *et.al.* (2006) have quantified the impact of climate change on the water resources of Indian River system. Kalra *et.al.* (2008) found that the yield of wheat, mustered, barely and chickpea show signs of stagnation or decrease following a rise in temperature in four northern states of India.

Rainfall being an essential part of the hydrologic cycle and changes in its pattern would directly influence the water resources of the concerned region and if the changes occurs in its pattern, then t would alter pattern of stream flows and demands (particularly agricultural), spatial and temporal distribution of runoff, soil moisture and groundwater reserves. This will call for a review of our reservoir operation and water resource management policies. Water resources has become a primary concern for any development and planning including food production, flood control and effective water resources management. Impact of climate change in future is quite severe as given by (Intergovernmental Panel on Climate Change) IPCC reports which signify that there will be reduction in the freshwater availability because of climate change. This has also been revealed that by the middle of 21st century, decrease in annual average runoff and availability of water will project up to 10-30 % (IPCC, 2007). Study of different time series data have proved that trend is either decreasing or increasing, both in case of temperature and rainfall. Human interference is also leading to climate change with changing land use from the impact of agricultural and irrigation practices (Kalnay and Cai, 2003). Central Water Commission (CWC, 2005) reported that annual average precipitation received by India about 4000 billion cubic meters (BMC). Out of that, utilized surface water and groundwater resources are approximated to b only 690 and 432 BCM respectively. Again, in the report of central water commission (CWC, 2008), the annual average precipitation has been approximated to be 3882.07 BMC utilizable total surface water and total replenishable ground water is estimated to be about 690 BMC and 433 BMC correspondingly. Therefore, it is evident from the report that there is reduction in the annual average rainfall over the country indicating decreasing trend in the precipitation. Thus, difficulty in availability of water will be rising day by day due to large variation and irregularity of rainfall in most areas. Major parts of India are facing decrease in precipitation during the monsoon time. A decreasing trend has been observed in north-east India, central north-east India and west-central India (Kumar *et.al.* 2010).

Upper Betwa basin is situated in central part of India and majority of its population is dependent on agriculture for their livelihood. But due to lack of proper infrastructure farmers are dependent on rainfall for irrigation. And without studying the trends, adoption of farming system to an area might be unsuccessful with the future climatic conditions. Meteorological data sets are used in evaluation of potential aspects of crop production. Investigation of regional and global climatic changes and variabilities and their impacts on the society have received considerable attention in recent years.

In the above context, the present study aims to investigate, rain gauge station wise rainfall trends of Upper Betwa basin. And its effect on climate change which will facilitate the sustainable utilization of water resources in this watershed area. Therefore, in this study an attempt has been made to find the long-term variability of rainfall both temporally and spatially over 11 stations of Upper Betwa basin for effective water resources management, disaster preparedness and to develop flood control measures. In this current study, the analysis of extreme rainfall events is also carried out. The rainfall trend analysis in 11 rain gauge stations of basin will help the water resources planners to understand the recent scenario of climate change in this area.

1.3 Objectives of the study

(i) To study the annual and monthly rainfall trend from 1970 to 2014.

(ii) To study spatial variability of rainfall using Kriging Interpolation Techniques.

Chapter II

REVIEW OF LITERATURE

The many previous studies have been conducted on the topics of trend analysis of climatic parameters i.e. temperature, relative humidity, sunshine hours, wind velocity, rainfall, pan evaporation and computed reference evapotranspiration, by various statistical methods. Different statistical method used to identify the impact of climate change on rainfall and some of them literature was referred and reviewed.

Panse and Sukhatme (1954) They have given the methodology for testing the significance of test statistic at different probability levels and testing the significance of the results obtained from experiments or observational programmes in agricultural research.

Parthasarathy and Dhar (1974) studied the secular variations of regional rainfall over India for the period 1901-1960. They have shown that the yearly rainfall data for western part in Indian Peninsula o central parts of the country follow a positive trend. The yearly rainfall data for some sub-divisions, namely Punjab, Himachal Pradesh and Assam follow and increasing trend. However, south Assam is the only sub-division where rainfall data show a negative trend.

Roy *et. al.* (1987) studied the trends of regional variations and periodicities of annual rainfall in Bangladesh for 32 years between 1947 to 1979 at 30 meteorological stations and they have shown the yearly rainfall amounts for most of the stations follow a normal distribution. Annual rainfall data for Rajshahi, Ishwardi, Pabna and Khulna stations have shown positives trends while for Comilla stations a negative trend has been found.

Mirza *et. al.* (1998) Analysed the trends and persistence in precipitation in the Ganges, Brahmaputra and Meghna river basins. Time series of annual precipitation of the 16 meteorological subdivisions covering the three river basins were examined for trends using the Mann-Kendall rank statistic, Student's t-test and regression analysis, and first order autocorrelation analysis was used for persistence. The results indicated that precipitation was by-and-large stable in Ganges basin while sub-division of both Brahmaputra and Meghna basin had either increasing or decreasing trend. It was also concluded that persistence was not present in precipitation series of Ganga basin but existed in 2 common sub-division in Brahmaputra and Meghna basin.

Kahya and Kalayc (2004) In this study, trends computed for the 31-year period of monthly stream flows obtained from 26 basins over Turkey. Four non-parametric trend tests (the Sen's T, the Spearman's Rho, the Mann-Kendall, and the Seasonal Kendall which are known as appropriate tools in detecting linear trends of a hydrological time series) are adapted in this study. Moreover, the Van Belle and Hughes' basin wide trend test is included in the analysis for the same purpose. The procedure developed by Van Belle and Hughes is tested by homogeneity of trends in monthly stream flows. As a result, basins located in western Turkey, in general, exhibit downward trend, significant at the 0.05 or lower level, whereas basins located in eastern Turkey show no trend. In most cases, the first four tests provide the same conclusion about trend existence. Use of the Seasonal Kendall, which involves a single overall statistic rather than one statistic for each season, is justified by the homogeneity of trend test. Moreover, some basins located in southern Turkey exhibit a global trend, implying the homogeneity of trends in seasons and stations together, based on the Van Belle and Hughes' basin wide trend test.

Partal *et. al*. (2006) Aims of this study is to determine trends in the long-term annual mean and monthly total precipitation series using nonparametric methods (i.e. the Mann–Kendall and Sen's T tests). The data network used in this study, which is assumed to reflect regional hydroclimatic conditions, consists of 96 precipitation stations across Turkey. Monthly totals and annual means of the monthly totals are formed for each individual station, spanning from 1929 to 1993. In this case, a total of 13 precipitation variables at each station are subjected to trend detection analysis. The application of a trend detection framework resulted in the identification of some significant trends, especially in January, February, and September precipitations and in the annual means. A noticeable decrease in the annual mean precipitation was observed mostly in western and southern Turkey, as well as along the coasts of the Black Sea. Regional average series also displayed trends similar to those for individual stations.

Guhathakurta and Rajeevan (2008) Linear trend analysis was carried out to examine the long-term trends in rainfall over different subdivisions and monthly contribution of each of the monsoon months to annual rainfall. New monthly, seasonal and annual rainfall time series of 36 meteorological subdivisions of India were constructed using the monthly rainfall data for the period 1901–2003 of fixed network of 1476 rain gauge stations. In the new network, on an average, there is one rain gauge station for every 3402 Sq km area. The new rainfall series is temporally as well as spatially homogenous. During the south-west monsoon season, three subdivisions viz. Jharkhand, Chattisgarh, Kerala showed significant decreasing trend and eight subdivisions viz. Gangetic WB, West UP, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra subdivision, Rayalseema, Coastal AP and North Interior Karnataka showed significant increasing trends. It has been found that the contribution of June, July and September rainfall to annual rainfall is decreasing for few subdivisions while contribution of August rainfall is increasing in few other subdivisions. EOF analysis is also done to know the spatial distribution of rainfall. The all India Monthly, seasonal and annual rainfall series constructed based on the 1476 stations are also reported.

Longobardi *et. al.* (2010) The aim of the present study is to analyse rainfall time series over a wide time interval and a wide area, detecting potential trends and assessing their significance. For this purpose, 211 gauged stations, mainly located within the Campania region, southern Italy, have been analysed for the period 1918–1999. An accurate database has been set up through a data quality and time series homogeneity process. Statistical analysis of the database highlight that (1) the trend appears predominantly negative, both at the annual and seasonal scale, except for the summer period when it appears to be positive; (2) over the whole reference period, positive and negative trends are significant respectively for 9 and 27% of total stations and (3) over the last 30 years, a negative trend is instead significant for 97% of the total stations.

Kumar *et. al.* (2010) Studied monthly, seasonal and annual trends of rainfall of 135 years (1871–2005) for 30 sub-divisions (sub-regions) in India. Half of the sub-divisions showed an increasing trend in annual rainfall, but for only three (Haryana, Punjab and Coastal Karnataka) was statistically significant. Similarly, only one sub-division (Chhattisgarh) indicated a significant decreasing trend out of the 15 sub-divisions. In India, the monsoon months of June to September account for more than 80% of the annual rainfall. During June and July, the number of sub-divisions showing increasing rainfall is almost equal to those showing decreasing rainfall. In August, the number of sub-divisions showing an increasing trend exceeds those showing a decreasing trend, whereas in September, the situation is the opposite. The majority of sub-divisions showed very little change in rainfall in non-monsoon months. The five main regions of India showed no significant trend in annual, seasonal and monthly rainfall in most of the months. For the whole of India, no significant trend was detected for annual, seasonal, or monthly rainfall.

Shahid (2010) studied Spatial patterns of annual and seasonal rainfall trends of Bangladesh over the time period 1958–2007 by using rainfall data recorded at 17 stations distributed over the country. Mann–Kendall trend test and the Sen's slope method are used to detect the significance and the magnitude of rainfall change, respectively. Historical dry and wet months are identified by using standardised precipitation index method and their trends are analysed to assess the possible change in wet and dry events in Bangladesh. The result shows a significant increase in the average annual and pre-monsoon rainfall of Bangladesh. The number of wet months is found to increase and the dry months to decrease in most parts of the country. Seasonal analysis of wet and dry months shows a significant decrease of dry months in monsoon and pre-monsoon.

Karmeshu *et. al.* (2012) This study focuses on detecting trends in annual temperature and precipitation for the nine states in the North-eastern United States. For this study, the widely used modified Mann-Kendall test was run at 5% significance level on time series data for each of the nine states for the time period 1900 to 2011. For temperature, linear trend line plotting indicates increasing trend in temperature for all nine north-eastern states in the range of 0.00006 to 0.02 °F/yr, except for Pennsylvania and Maine that do not indicate statistically significant trends. For precipitation, the linear trend line indicates a decreasing trend for Maine, while the other eight states have an increasing trend that ranges from 0.03 to 0.13 mm/yr.

Santos *et. al.* (2013) studied spatial and temporal variability of selected extreme precipitation indices in Northern Portugal. Data were collected in the period of 1950–2000 from 39 meteorological and gauge stations. Tests of homogeneity (e.g., Pettit, SNHT, Buishand and Von Neumann tests) were performed in order to identify and select the useful series to time variability analysis. Four extreme precipitation indices were investigated: total precipitation in wet days, with daily precipitation ≥1 mm (PRCPTOT); number of days with precipitation amount ≥ 30 mm (R30mm); the maximum 5-day precipitation amount (R×5day); and total precipitation amount ≥ 95th percentile (R95p). The Mann–Kendall non-parametric test was applied to detect annual and seasonal trends in this study. The results showed a decrease in extreme precipitation indices during annual scale, spring, winter and summer but showed a slight increase during autumn. Out of all of the indices examined, only three rain-gauges showed significant trends on annual scale. On a seasonal timescale, extreme precipitation indices tended to decrease in winter, spring and summer in more than 80% of the precipitation series. In autumn in which the four indices studied showed that more than 70% of the series had a positive trend. However, only 15% of the series showed a significant trend in winter, 46% in spring, only 2% in summer and 4% in autumn.

Duhan and Pandey (2013) made an investigation to study the spatial and temporal variability of precipitation at 45 districts of the Madhya Pradesh (MP), India over the period of 102 years (1901–2002) on annual and seasonal basis. They used Mann–Kendall test and Sen's slope estimator test to detect monotonic trend direction and magnitude of change over time on annual and seasonal basis. They applied cumulative deviations and Pettit-Mann–Whitney test to detect possible change points and discussed change in percentage in terms of percentage change over mean. They interpolated linear regression value of each station using ArcGIS

9.3 on seasonal and annual basis to explore the spatial distribution of trends. Their result showed that mean annual precipitation varied from 694 mm (at Westnimar) to 1416 mm (at Mandla). Maximum decrease in annual precipitation was found at Balaghat (−11.99%) and minimum at Shahdol (−8.52%) district. The most probable year of change was 1978 in annual precipitation. Change in percentage in mean of 1901–1978 over the mean of 1979–2002 showed the decrease in precipitation in almost all the stations. Again, the decrease in annual precipitation was −2.59% over the entire Madhya Pradesh in 102 years. West MP showed more increase in annual precipitation than East MP during the period of 1901–1978. However, the East MP showed more decrease than west MP during the period of 1979–2002.

Kharol *et. al.* (2013) analyzed the precipitation trends over six Indian cities during the summer monsoon (June–September) covering the period 1951–2007 and also attempted to investigate possible urban forcing and dynamics by examining the variation in precipitation in the upwind and downwind directions. The analysis showed negative trends in the total number of rainy days over Hyderabad (−10.4%), Kanpur (−7.1%), Jaipur (−10.5%), and Nagpur (−4.8%) and positive trends over Delhi (7.4%) and Bangalore (22.9%). On the other hand, decreases of −21.3%, −5.9%, −14.2%, and −14.6% in seasonal rainfall are found over Delhi, Hyderabad, Jaipur, and Kanpur, respectively, whereas Bangalore and Nagpur show 65.8% and 13.5% increase. The lesser rainfall and rainy days, along with the mostly declining trend, in the downwind directions of the cities may imply an urban influence in precipitation associated with the increased anthropogenic emissions due to expansion of the urban areas and the increase of population. However, the large spatiotemporal variability of precipitation and the lack of statistical significance in the vast majority of the trends do not allow the extraction of safe conclusion concerning the aerosol-precipitation interactions around Indian cities.

Murumkar and Arya (2013) analysed Seasonal and annual rainfall data of the stations: Akluj, Baramati, Bhor and Malsiras stations located in Nira catchment which is a sub basin of the Bhima watershed located in the state of Maharashtra in India for studying trend and periodicity using 104 years (1904-2013) rainfall data. They estimated autocorrelation coefficient of rainfall series for lag 1 checked its significance by the student's t-test at 10% significance level. Rainfall trend detection was carried out for seasonal and annual series They used Mann Kendall (MK) for non-autocorrelated rainfall series while the Modified Mann Kendall (MMK) tests for autocorrelated rainfall series at 10% significance level. Trend line and its significance were also checked using t-test statistics. Magnitude of trend slope was computed by Theil and Sen's median slope estimator. They analysis showed rising trend at all the stations. However, it was statistically significant at Akluj and Bhor stations at 10% significance level. Bhor station showed the maximum increase in percentage change i.e. 0.28% in annual rainfall. Monsoon and post-monsoon seasonal rainfall showed a rising trend while the summer and winter seasonal rainfall showed a falling trend.

Narayan *et. al.* (2013) explored the rainfall behaviour in the premonsoon (March, April and May) season over a period 1949–2009 for the western part of India. They conducted the study by using long series station-wise data for western part of India, which is semi-arid and has extremely low-pressure conditions and intense dust storms during this season. They analysed Monthly Rainfall data for March, April, May (MAM) for six stations (Abu (Ab),Ahemdabad (Ah), Ajmer (Aj), Amritsar (Am), Bikaner (Bk), Jodhpur (Jd)) for a period of 60 years. Consistency checks and data gaps were filled according to standard procedures and performed trend analysis on rainfall data using a pre-whitened Mann Kendall Test, autocorrelation removal was done in the required dataset at the chosen level of significance ($\alpha = 10\%$). The magnitude and practical significance of trend was estimated using the Theil and Sen's median slope estimator, and by assessing the percentage change over the mean for the period concerned.

Jain *et. al.* (2013) In this study monthly, seasonal, and annual rainfall and temperature trends were examined on the subdivision and regional scale for the Northeast region (NER). Trend analysis of rainfall data series for 1871–2008 did not show any clear trend for the region as a whole, although there are seasonal trends for some seasons and for some hydro-meteorological subdivisions. Similar analysis for temperature data showed that all the four temperature variables (maximum, minimum, and mean temperatures and temperature range) had rising trend. Notably for the post-monsoon season, the Sen's estimator of slope (°C/year) was 0.019, 0.011, and 0.015 for the maximum, minimum, and mean temperature, respectively.

Gocic *et. al.* (2013) Analysed Precipitation and Standardised Precipitation Index (SPI) trends by using linear regression, Mann–Kendall and Spearman's Rho tests at the 5% significance level. For this purpose, meteorological data from 12 synoptic stations in Serbia over the period 1980–2010 were used. Two main drought periods were detected (1987–1994 and 2000–2003), while the extremely dry year was recorded in 2000 at all stations. The monthly analysis of precipitation series suggests that all stations had a decreasing trend in February and September, while both increasing and decreasing trends were found in other months. On the seasonal scale, there were the increasing trends in autumn and winter precipitation series, while on the annual scale the most of the stations had no significant trends. Besides, the decreasing trend was found at the Belgrade and Kragujevac stations, while the other stations had the increasing trend for the SPI-12 series.

Jena *et. al.* (2014) analysed the trends of peak discharge at the mouth of the delta at Naraj gauging site (the flow which is responsible for floods in the delta of Mahanadi basin) and peak releases from Hirakud dam in Mahanadi basin. Subsequently, they also carried out grid-based analysis of extreme rainfall for the entire Mahanadi basin to analyse the spatially varied extreme rainfall trend sand also, a region based (upper and middle regions of Mahanadi basin) analysis of extreme rainfall is carried out using daily mean areal rainfall. The trends of extreme rainfalls are analysed in relation to the trends of peak floods. They used Mann–Kendall test and Sen's slope test to detect trends. The entire analysis pertains to post-Hirakud dam construction period. Their analysis revealed that the recent incidences of high floods in Mahanadi basin is due to an increase in extreme rainfall in the middle reaches of the basin.

Pranuthi *et. al.* (2014) analyzed long term trends of monthly, seasonal and annual rainfall of Haridwar, Dehradun, Udham Singh Nagar, Almora and Nainital of the state Uttarakhand. They determined the trend of rainfall on saptio-temporal basis in the selected district of Uttarakhand state which is most prone to high rainfall variability using Mann Kendall (MK) Test and Spearman's Rho (SR) Test trend test. They observed magnitude of slope by using Thiel-Sen method method and detected change in trend by using Worsely likelihood technique and CUSUM method. Change-point analysis was done to detect abrupt climate variation. The result of MK test revealed that there was significant increase in rainfall only for Haridwar district which has more urbanizing area compared to other districts. The monthly trend tests showed that July rainfall was increasing whereas the December rainfall was decreasing which could be due to the seasonal shift. The start of change in the rainfall trend for the five districts were observed with distinct difference from 2009 onwards.

Taxak *et. al.* (2014) analysed Gridded rainfall data of 0.5°×0.5° resolution to study long term spatial and temporal trends on annual and seasonal scales in Wainganga river basin located in Central India during 1901–2012. They first tested the presence of autocorrelation and applied Mann–Kendall (Modified Mann–Kendall) test to non-auto correlated (auto correlated) series to detect the trends in rainfall data. For finding the magnitude of change over a time period, Theil and Sen′s slope estimator test was used. For detecting the most probable change year, Pettitt–Mann–Whitney test was applied. They also divided Rainfall series into two partial duration series for finding changes in trends before and after the change year and used Arc GIS to explore spatial patterns of the trends over the entire basin. Though most of the grid points showed a decreasing trend in annual rainfall, only seven grids has a significant decreasing trend during 1901–2012. On the basis of seasonal trend analysis, non-significant increasing trend is observed only in post monsoon season while seven grid points show significant decreasing trend in monsoon rainfall and non-significant in premonsoon and winter rainfall over the last 112 years. During the study period, overall 8.45% decrease in annual rainfall is estimated. The most probable year of change was found to be 1948 in annual and monsoonal rainfall. There is an increasing rainfall trend in the basin during the period 1901–1948, which is reversed during the period 1949–2012 resulting in decreasing rainfall trend in the basin. Homogeneous trends in annual and seasonal rainfall over a grid points is exhibited in the basin by van Belle and Hughes ′ homogeneity trend test.

Hasan (2014) The aim of this study is to find out annual and seasonal rainfall trends in the South-East part of coastal Bangladesh over the period between 1980 and 2011. Non-parametric- Mann-Kendall and Sen's test estimate is applied for detecting and estimating rainfall trends respectively. In South-East Bangladesh, annual rainfall trends is increasing although this trend is not statistically significant. Seasonal analysis reveals least amount of rainfall occurs in winter and it is getting drier. However, trends analysis indicates the other three seasons, e.g. Pre-Monsoon, Rainy Monsoon and Post Monsoon, are becoming wetter. It is important to note that among all the seasons rainfall in Pre-Monsoon is increasing significantly (significant at *p= 0.05 level*) and the rate of increase is 8.5 mm/year.

Ahmad *et. al.* (2015) in this study precipitation variability is investigated across 15 stations in the Swat River basin, Pakistan, over a 51-year study period (1961–2011). Nonparametric Mann-Kendall (MK) and Spearman's rho (SR) statistical tests were used to detect trends in monthly, seasonal, and annual precipitation, and the trend-free pre-whitening approach was applied to eliminate serial correlation in the precipitation time series. The results highlighted a mix of positive (increasing) and negative (decreasing) trends in monthly, seasonal, and annual precipitation. One station in particular, the Saidu Sharif station, showed the maximum number of significant monthly precipitation events, followed by Abazai, Khairabad, and Malakand. On the seasonal time scale, precipitation trends changed from the summer to the autumn season.The Saidu Sharif station revealed the highest positive trend (7.48 mm/year) in annual precipitation. In the entire Swat River basin, statistically insignificant trends were found in the sub basins for the annual precipitation series; however, the Lower Swat sub basin showed the maximum quantitative increase in the precipitation at a rate of 2.18mm/year. The performance of the MK and SR tests was consistent at the verified significance level.

Adarsh and Reddy (2015) Studied, long-term trends of rainfall in four subdivisions of southern India namely Kerala, Tamil Nadu, North Interior (NI) Karnataka and Telangana regions are analysed using linear regression, nonparametric Mann–Kendall (MK) test and Sen's slope estimator methods. Trend analysis of annual rainfall time series shows an increasing trend in three subdivisions – Tamil Nadu, NI Karnataka and Telangana, and a decreasing trend in Kerala subdivision. Further the sequential change in trend of annual and seasonal rainfalls in the four subdivisions is conducted using sequential MK (SQMK) method. The SQMK analysis shows an early divergence of progressive and retrograde modes of post-monsoon rainfall of Kerala and winter rainfall of Telangana subdivisions. Further it is observed that among different seasonal rainfalls, the post-monsoon rainfall of Kerala subdivision shows a statistically significant increase in the recent past. Then the trend analysis based on discrete wavelet transform (DWT) in conjunction with SQMK method is performed on the post-monsoon rainfall time series of Kerala.

Sahu and Khare (2015) made an attempt to observe the spatial and temporal rainfall variability and trend over a period of 110 years (1901-2010) at regional scale for the state of Odisha. For examining the monotonic trend direction and magnitude of change over time, the statistical trend analysis techniques namely Mann-Kendall test and Sen's slope estimator test were used. To determine the possible change points in the rainfall time series, Standard Normal Homogeneity test (SNHT) and Mann-Whitney-Pettitt (MWP) test were conducted. Inverse Distance Weighted (IDW) interpolation technique was applied in ArcGIS background for detection of spatial variation of rainfall on annual and seasonal basis in different districts of the state. Their results of the analysis indicated that the annual rainfall was decreasing in northern region and extreme west region of Odisha with a maximum decrease (-1.425 mm/year) at Nuapada district, while highest decrease in monsoon rainfall (-1.25 mm/year) was found at district Sundargarh. In district Jagatsinghpur highest increase in rainfall was noticed in annual and monsoon season with maximum values 2.205 mm/year and 1.327 mm/year respectively, where significant change in annual rainfall was observed in the year 1961. Variation in rainfall was observed at different spatial scales of districts.

Kakade *et. al.* (2016) The coherent regions for various fields such as sea level pressure, temperature, geopotential height and zonal wind anomalies at the surface, 850, 500 and 200 hPa levels in pre-monsoon months (January through May) and seasons (winter, spring) have been identified by applying the shared nearest neighbour algorithm. The fields over the corresponding cluster regions could be possible predictors for Indian summer monsoon rainfall as well as the rainfall over various homogeneous regions of India. The time series have been constructed by averaging the parameters over the respective clusters. The relationship between these time series and the summer monsoon rainfall over India and its well-defined homogeneous regions over India, (northwest India, central northeast India, northeast India, west central India and peninsular India), has been examined during the positive and negative phases of effective strength index tendency using the simple technique of multiple regression. Along with the linear relationship, the non-linear relationships between the cluster parameters and the seasonal rainfall have also been considered. Independent cluster parameters have been selected by cross-validation procedure and the performance of each predictive model is tested. The extreme yearly rainfall departures over India are qualitatively well predicted by the model. Also, the unprecedented droughts over India in 2002 and 2009, where all earlier models have failed to forecast, are well predicted by the present model. The performances of models for summer monsoon rainfall prediction over homogeneous regions of India are convincing.

Machiwal *et. al.* (2017) The aim of this study was identification of abrupt change points (CPs) and detection of gradual trends in 34-year (1980–2013) annual rainfall at nine stations of an Indian arid region. The CPs were determined by five tests and their significance was examined by two tests. Furthermore, trends were tested by three tests and their magnitudes were quantified by two tests. The identified CPs were similar for standard normal homogeneity test and cumulative deviations test at most stations. In contrast, Pettitt and Bayesian tests detected CP in years 2002 and 2005 at six and three stations, respectively, and their significance was verified. Results of sequential M-K test did not match with other tests' results. The mean annual rainfall after CP (350–627 mm) increased by 14–80% of the amount before CP (306–444 mm) with 7–42% reduction in coefficient of variation. The box–whisker plots supported these findings. Results of trend tests indicated statistically significant trends at Anjar, Bhachau, Mandvi and Rapar. Trend magnitudes by linear regression prior to CP (－6.2 to 7.1mmyear－1) showed an overall increase after CP (4.7–40.8mmyear－1) with negative trend at one station. Sen's slope test, showing good harmony with linear regression, revealed that trend magnitudes after CP were 2–10 times higher than that for 34-year period at six stations. Results of M–K test applied for sequential periods emphasized that rainfall trends are becoming stronger over time. This finding suggests that significance level of increasing rainfall trends may further increase in future

Wua and Qiana (2017) This study investigates the trends in annual and seasonal rainfall at 14 rainfall stations in Shaanxi Province, China, using an innovative trend analysis (ITA), Mann–Kendall test and linear regression analysis. Moreover, using ITA, annual rainfall is analysed for different rainfall intensities, and seasonal rainfall is analysed for extreme values. The results show non-uniform trends in rainfall intensities on a regional and seasonal scale. Annual rainfall shows a significant decreasing trend in the Wei River Basin and north of the Loess Plateau. Overall, the trend is reinforced with the increase of rainfall intensity. A few stations show significant trends in seasonal rainfall. Spring rainfall is the major contributor to the decline in annual rainfall. Heavy rainfall (more than 90th percentile) in summer exhibits a marked downward trend mainly in the basin, which makes it possible for flooding to abate along the Wei River. Light rainfall (less than 10th percentile) shows a prevailing increasing trend in summer, but a decreasing trend in other seasons. From north to south, the seasonal trends become clearer and stronger. In terms of management, more attention should be paid to autumn droughts in the-Wei River Basin. A quantitative measurement of a trend for ITA is proposed. Comparison of the three methods endorses the ITA method. Moreover, the ITA shows many advantages, such as graphical results and for observing sub-trends. It is hoped that this study can provide.

Frazier *et. al*. 2017 Utilized a high-resolution gridded data set of monthly and annual rainfall for Hawai‘i from January 1920 to December 2012,seasonal and annual trends were calculated for every 250-m pixel across the state and mapped to produce spatially continuous trend maps. To assess the stability of these trends, a running trend analysis was performed on 34 selected stations. From 1920 to 2012, over 90% of the state experienced drying trends, and especially western part of the island, experienced the largest significant long term declines in annual and dry season rainfall. The running trend analysis highlighted the multi-decadal variability present in these trends, and revealed that the only region in the state with persistent annual and dry season trends through the study period is the western part of Hawai‘i Island. These results support previous studies that indicate drying across the state over recent decades, and reveal the timing of upward and downward trends as well as important spatial details for natural resource management in Hawai‘i.

Chapter III

MATERIAL AND METHODS

3.1 General

This chapter is split up into three division viz., study area, data acquisition and methods used for data processing. The first section provides description of the details of the study area (tributary of the Yamuna river), it includes location and its surrounding are given here along with the brief description of climate. Second section deals with the descriptions of dataset used in the study. Furthermore, third section about software used and describe the methodologies for trend analysis.

3.2 Study Area

Upper Betwa basin is one of the most important perennial rivers in Central India which flows from south to north and eventually joins Yamuna. Nion, an important right bank perennial tributary of Betwa river, covers an area of about 1100 km^2 and flows from southeast to the northwest.

The drainage pattern of the basin is dendritic in nature. The southern and eastern margins of the basin are surrounded by Vindhyan Sandstone and Deccan maps hillocks with elevation ranging from 400-600 m. The central and western parts are generally flat with sporadic occurrence of hills covered with deep vegetation of deciduous trees and 85% of the area comes under rainfed cultivation. It covers an area of 12,137 km^2 and lies between 23° 0' 0" N to 24° 14' 34.8" N latitude and 77° 5' 56.4" E and 78° 32' 31.2" E longitude (Fig.3.2).

The study area is coming in humid sub-tropical and tropical with three distinct type of climates: Summer, Monsoon and Winter. The average rainfall and potential evapotranspiration values are around 1230 mm and 1624 mm respectively. Location map of Upper Betwa basin is shown in Fig. 3.1.

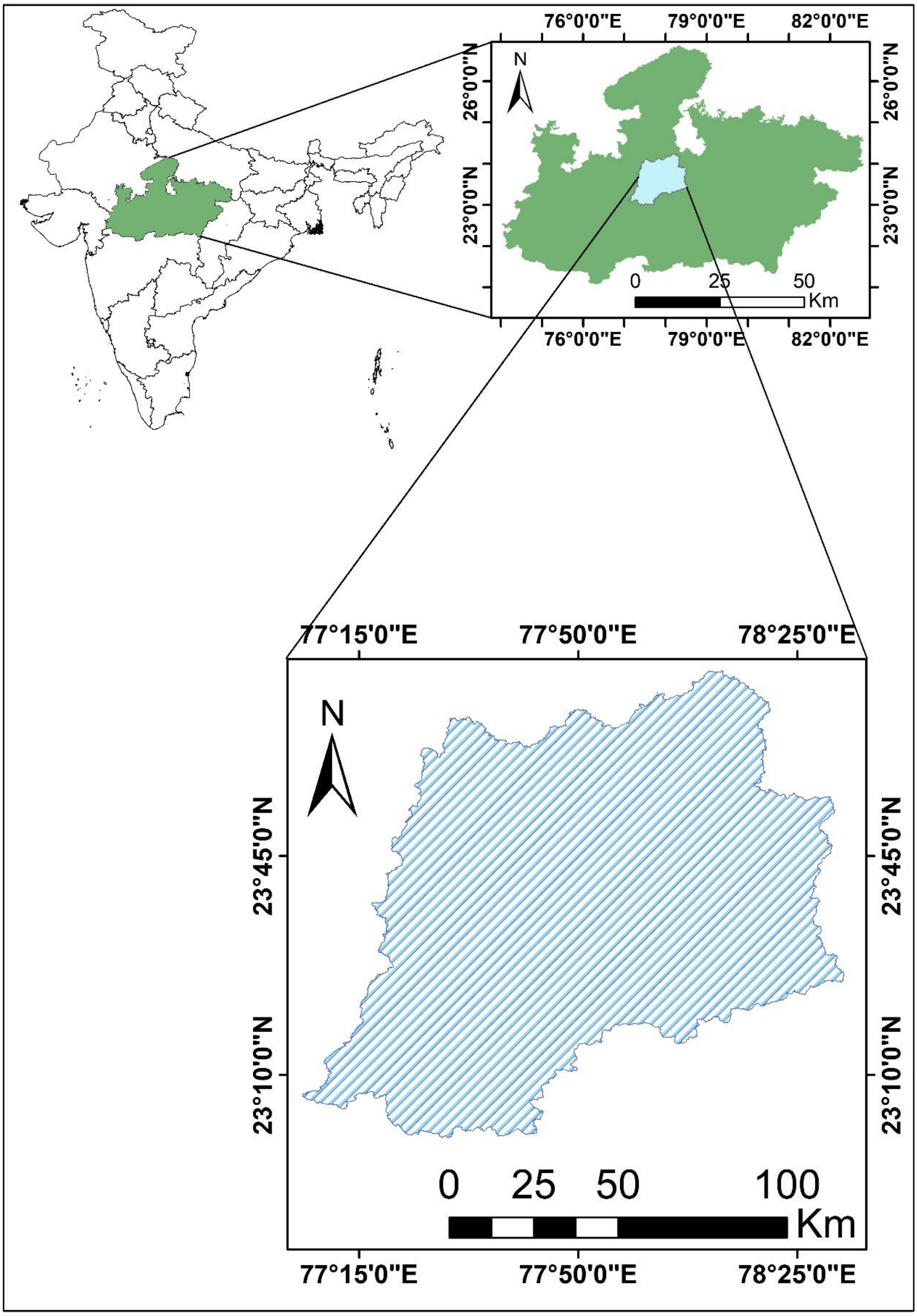


Fig. 3.1: Location map of Upper Betwa basin.

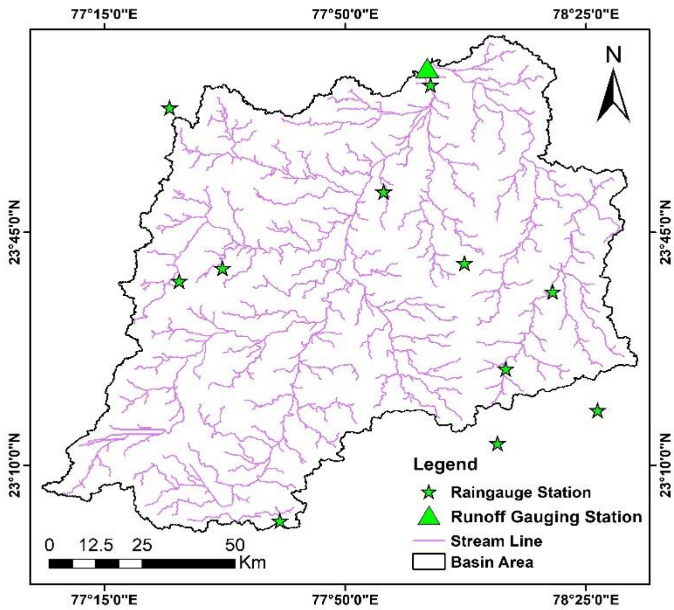


Fig. 3.2: Drainage Network map of study area.

3.3 Data Collection

Monthly and annualy rainfall data of Bairagarh, Berasia, Bareli, Begumganj, Ghairatgan, Goharganj, Raisen, Silwani, Udaipura, Basoda, Gyaraspur, Kurwai, and Lateri stations of Upper Betwa basin was collected from Water Resources Department, Madhya Pradesh. The geographical locations of rain gauge stations and duration of rainfall data collected is presented in Table 3.1.

Table no. 3.1; Geographical location and availability of data for study stations.

Rain Gauge Stations	Latitude, (N)	Longitude, (E)	Period (year)		Missing data
			From	To	
Bairagarh	23.66	77.54	1970	2014	_
Berasia	23.63	77.43	1970	2014	_
Bareli	23.01	78.23	1977	2014	1979, 1980, 1990, 1997
Begumganj	23.60	78.34	1970	2014	1980

Ghairatganj	23.41	78.22	1970	2014	1980
Goharganj	23.03	77.68	1970	2014	1970, 1972-73, 1979-80, 1997
Raisen	23.22	78.20	1970	2014	1980
Silwani	23.30	78.44	1970	2014	1975, 1978,1980
Udaipura	23.08	78.51	1970	2014	1971,1980
Basoda	23.85	77.93	1970	2014	_
Gyaraspur	23.67	78.12	1986	2014	_
Kurwai	24.12	78.04	1970	2014	_
Lateri	24.06	77.41	1970	2014	_

3.4 About XLSTAT

XLSTAT is the leading data analysis and statistical solution for Microsoft Excel. The XLSTAT statistical analysis add-in offers a wide variety of functions to enhance the analytical capabilities of Excel, making it the ideal tool for data analysis and statistics requirements. Over the years XLSTAT has become a focal point in statistics and multivariate analysis. XLSTAT is a must for all analysts, teachers, consultants, students and statistics experts who need a powerful and efficient program for analysing data.

Software used for performing the statistical Mann-Kendall test is Addinsoft's XLSTAT 2018.

3.5 Homogeneity analysis

In conclusion, the methodology used to assess the quality of the series was completed with the application of relative homogeneity tests using reference series, as recommended by Aguilar et al. (2003).

The final classification of series quality was assigned as follows: "useful" — if a series is judged as homogeneous by all the tests; "potentially useful"- when the series is classified as inhomogeneous by only one test and as homogeneous by the remaining tests; a series is "rejected" - if more than two tests detected inhomogeneity.

3.5.1 Pettitt's test

The Pettitt's test is a non-parametric test, meaning that its application requires no assumption about the distribution of data. This test provides assessment of the null hypothesis (H_0) implying that the data are homogeneous throughout the period of observation, *i.e.* that the data have been obtained from a single or several distributions with the same location parameter (average values). The alternative hypothesis (H_1) implies presence of a non-accidental component among data causing a shift of the location parameter at a particular moment. Aside from providing for a data homogeneity check, the Pettitt's test also determines, if the alternative hypothesis happens to be accepted, the change-point when a shift of the location parameter occurred.

The test statistics (K_T) used in this test is:

$$K_T = \max_{1 \le t \le T} \left| U_{t,T} \right|$$

Where,

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=i+1}^{T} D_{ij}$$

$$D_{ij} = \operatorname{sgn}(X_i - X_j)$$

$$\operatorname{sgn}(r) = \begin{cases} -1, & r < 0 \\ 0 & r = 0 \\ 1 & r > 0 \end{cases}$$

3.5.2 Standard Normal Homogeneity Test (SNHT)

The SNHT homogeneity test is a statistical test which also checks if the data originate from the same population with the same distribution or indicate presence of a significant difference in the location parameter between the data before and after a specific change-point *t*c bringing an increase or decrease of the value of the observed feature. The null hypothesis in this test H_0 implies that the data are homogeneous, *i. e.* that they originate from the same population, while the alternative hypothesis H_1 implies presence of a significant difference in the location parameter in the period before and after the moment *t*c. The SNHT test determines the moment of change of the location parameter *t*c.

The test statistics used in this test runs as follows:

$$T_0 = \max_{l \leq t < T} \left| t_c \overline{X_1}^2 + (T - t_c) \overline{X_2}^2 \right|$$

where X_1 and X_2 are the average values of the observed feature before and after *t*c:

$$\overline{X_1} = \frac{1}{t_c} \sum_{i=1}^{t_c} X_i$$

And

$$\overline{X_2} = \frac{1}{T - t_c} \sum_{i=t_c+1}^{T} X_i$$

3.5.3 Buishand`s Test

The Buishand`s test is also a non-parametric test checking presence of a change-point in the given data marking a change of the location parameter (average values) distribution. The null hypothesis H_0 implies data homogeneity in terms of the location parameter, *i. e.* absence of a change regarding the said parameter over time. The alternative hypothesis H_1 implies presence of a change-point involving an increase or decrease of the average value of the observed feature. There are two variants of this test. The Buishand`s test with a quotient range *R* does not reveal the moment when the location parameter occurs.

Follows the test statistics used:

$$Q = \max_{j \leq t < T} \left| S_t^{**} \right|$$

And

$$R = \max_{1 \le t < T}(S_t^{**}) - \min_{1 \le t < T}(S_t^{**})$$

$$S_t^{**} = \frac{S_t^*}{\overline{S_n}}$$

is the ratio of the value *St** and the sample standard deviation:

$$S_t^* = \sum_{i=1}^{t}(X_i - \overline{X_T}),\ t = 1, 2, \ldots, T$$

is the difference of the value in the moment t from the sample mean, $S_0^* = 0$;

$$\overline{X_T} = \frac{1}{T}\sum_{i=1}^{T} X_i$$

and

$$\overline{S_T} = \sqrt{\frac{1}{T}\sum_{i=1}^{T}(X_i - \overline{X_T})^2}$$

represent the sample mean ($\overline{X_T}$) and the sample standard deviation ($\overline{S_T}$).

3.6 Trend analysis

A trend is a significant change over time exhibited by a random variable, detectable by statistical parametric and non-parametric procedures. Onoz and Bayazit (2003) showed that the parametric *t* -test has less power than the non-parametric Mann–Kendall test when the probability distribution is skewed, but that, in practical applications, they can be used interchangeably, with identical results in most cases. With the aim of trend detection, non-parametric statistical procedures are applied to the precipitation time series. The precipitation time series are aggregated in the annual time series and also in months (Jun to October) to further observe potential changes at the seasonal scale.

3.6.1 Mann-Kendall Test

Mann (1945) presented a non-parametric test for randomness against time, which constitutes a particular application of Kendall's test for correlation commonly known as the 'Mann–Kendall' or the 'Kendall *t* test' (Kendall,1962).

Mann-Kendall Test is a statistical test widely used for the analysis of trend in climatology 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. Secondly, the test has low sensitivity to abrupt breaks due to inhomogeneous time series.

According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is trend.

Mann-Kendall test is a non-parametric test for identifying trends in time series data. This test assumes that there exists only one data value for a time period. When multiple data points exist for a single time period, the median value will be used. The initial value of the Mann-Kendall statistics S is assumed to be 0. If a data value from a later time period is higher than a data value from an earlier time period, S is increased by 1. On the other hand, if the data value from the later time period is lower than a data valued sampled earlier, is decreased by 1. The net result of increments and decrements yields the final value of S. This method is more suitable for non-normally distributed and censored data, and is less influenced by the presence of outliers in the data (Mann,1945; Kendall, 1975)

Let, $x_1, x_2, x_3, \ldots\ldots, x_n$ represent n data points, then the Mann-Kendall test statistics S is given by;

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

Where, n is the number of observations and x_j is the jth observation and sgn (θ) is the sign function which can be defined as follows:

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

Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistics are given by (Kendall,1975)

$$E[S] = 0$$

$$\operatorname{Var}(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k(t_k - 1)(2t_k + 5)}{18}$$

Where, m is the number of groups of tied ranks, each with tied observations.

The Z-statistics can be computed as follows:

$$Z = \begin{cases} \frac{S-1}{\sigma} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sigma} & if \quad S < 0 \end{cases}$$

Here, if the computed value of $|Z| > Z\alpha/2$, then the null hypothesis of no trend is rejected at α level of significance in a two-sided test (i.e. the trend is significant). In this study, the null hypothesis was tested at 5% significance level. A positive value of *Z* indicates an increasing trend and a negative value of *Z* indicates a decreasing trend.

3.6.2 Magnitude of trend

Sen's method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series (Lettenmaier *et al.*, 1994; Yue and Hashino, 2003; Partal and Kahya, 2006). In this method, the slopes (*Ti)* of all data pairs are first calculated by;

$$T_i = \frac{x_j - x_k}{j - k} \quad \text{for} i = 1, 2, \ldots, N,$$

where *xj* and *xk* are data values at time *j* and *k* (*j* > *k*), respectively. The median of these *N* values of *Ti* is Sen's estimator of slope, which is calculated as follows:

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases}$$

A positive value of *β* indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

3.6.3 Spearman`s rho Test

Spearman's rho test is another rank-based nonparametric method used for trend analysis and was applied as a comparison with the Mann- Kendall test. In this test, which assumes that time series data are independent and identically distributed, the null hypothesis (H_0) again indicates no trend over time; the alternate hypothesis (H_1) is that a trend exists and that data increase or decrease with *i*.

The SR test statistics R_{sp} and standardized statistics Z_{sp} are defined as follows:

$$R_{sp} = 1 - \frac{6\sum_{i=1}^{n}(D_i - i)^2}{n(n^2 - 1)},$$

$$Z_{sp} = R_{sp}\sqrt{\frac{n-2}{1 - R_{sp}^2}}.$$

In these equations, D_i is the rank of i^{th} observation, I is the chronological order number, n is the total length of the time series data, and Z_{sp} is Student's -distribution with (n-2) degree of freedom. The positive values of Z_{sp} represent an increasing trend across the hydrologic time series; negative values represent the decreasing trends.

The critical value of t at a 0.05 significance level of Student's t-distribution table is defined as $t_{(n-2,1-\alpha/2)}$. If $|Z_{sp}| > t_{(n-2,1-\alpha/2)}$, H_0 is rejected and a significant trend exists in the hydrologic time series.

3.7 Spatial Analysis of Rainfall Series using Kriging Interpolation Techniques.

Spatial Interpolation is the process of using points with known values to estimate values at other points. Through Spatial Interpolation, we can estimate the precipitation value at a location with no recorded data by using known precipitation readings at nearby weather stations. In the present study, the spatial distribution of trends on annual and seasonal basis, were determined using the Kriging interpolation techniques using ArcGIS.

Kriging is a geostatistical method for spatial interpolation. Kriging differs from the interpolation methods like IDW, spline etc. Kriging can assess the quality of prediction with estimated prediction errors.

Kriging uses the semi variance to measure the spatially correlated components, a component that is also called spatial dependence. Kriging measures distances between all possible pairs of sample and uses this information to model the spatial autocorrelation for the particular surface that is interpolating. In other words, Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. It fits a function to a specified number of data points or all data points within a specified radius to determine output value for each location. Kriging is most appropriate when a spatially correlated distance or directional bias in the data is known. The kriging operation is of two types; Ordinary and Universal. Ordinary Kriging is the most general and widely used of the kriging methods and is the default. It assumes the constant mean is unknown. Universal Kriging assumes that there is a strong trend in data throughout the region. Rainfall exhibits a more complex spatial structure than even temperature, as the gradients of precipitation can be very large, and dramatically different at different locations in the study area, especially when summertime thunderstorms are the producers of precipitation. Also, because precipitation data is only collected at points, a simple interpolation method might completely misrepresent the precipitation that fell between the observing stations. It was found, however, that ordinary kriging can handle the unique situations inherent in a precipitation field and in fact, produces the best results for interpolating precipitation (Earls et al., 2007).

Chapter IV

RESULTS AND DISCUSSION

In the present study, assessment of climate change (i.e., trends, shifts and variability) for the all rain gauge stations was carried out at annual and monthly time series through the M-K trend test and Spearman`s rho test are non-parametric statistical tests. Sen's slope estimator and percentage change were also estimated.

4.1 Preliminary Analysis

4.1.1 Annual rainfall variability

The annual rainfall of selected stations is presented in Table 4.1, which shows that highest annual mean rainfall among the selected stations was observed at Gyaraspur station (1262.51 mm) of basin. Whereas the lowest annual mean rainfall among the selected station was observed at Berasia station (912.32 mm). Highest standard deviation was observed at Gyaraspur station with 29.85% coefficient of variation however the minimum deviation was observed at Goharganj with 23.56% coefficient of variation.

Table 4.1: Annual rainfall variation at selected study stations.

Stations	Mean	Min	Max	SD	CV (%)
Bairagarh	1101.75	554.50	1829.30	307.24	27.89
Berasia	912.316	355.90	1494.10	277.34	30.40
Begumganj	1158.69	585.90	2483.30	338.99	29.26
Ghairatganj	1136.74	540.00	2036.20	335.01	29.47
Goharganj	1081.75	560.50	1776.80	254.82	23.56
Raisen	1110.06	612.10	1770.00	304.74	27.45
Silwani	1085	172.30	1807.40	334.71	30.85
Basoda	1035.67	422.00	2031.00	295.36	28.52
Gyaraspur	1262.51	510.00	2310.00	376.86	29.85
Kurwai	1003.61	340.00	1992.10	292.79	29.17
Lateri	971.491	355.80	1723.80	293.90	30.25

4.1.2 Monthly rainfall variability

Monthly mean rainfall contribution to study stations for available data period were calculated and presented in Table 4.2. July month contributes highest amount of rainfall followed by Jun, July, August, September and October at all study stations except Begumganj station.

Table 4.2: Monthly rainfall contribution to the total annual rainfall.

Stations	**Mean**	**Jun (%)**	**Jul (%)**	**Aug (%)**	**Sep (%)**	**Oct (%)**
Bairagarh	1101.75	13	34	36	14	3
Berasia	912.316	14	33	34	15	4
Begumganj	1158.69	14	30	37	17	2
Ghairatganj	1136.74	11	33	36	17	3
Goharganj	1081.75	13	34	35	16	2
Raisen	1110.06	12	33	38	15	3
Silwani	1085	12	34	34	18	2
Basoda	1035.67	14	33	36	15	3
Gyaraspur	1262.51	14	35	31	17	2
Kurwai	1003.61	15	32	36	14	3
Lateri	971.491	12	32	37	16	2

4.1.2.1 Variation of rainfall in the month of June

The mean rainfall in June month is shown in Table 4.3 for the stations of selected watershed. The highest mean rainfall for June month was observed at Gyaraspur station (180.59 mm) and lowest at Lateri station (120.84 mm). Maximum standard deviation was shown at Begumganj (153.23 mm) and lowest at Raisen (95.98 mm) with a coefficient of variation 93.16% and 73.16%, respectively. The result also shows that, at Raisen observed rainfall was most consistent as compared to all other station and highest variation observed at Lateri station. All stations receive more than 110 mm rainfall in June month.

Table 4.3: Rainfall variation at selected stations in the month of June.

Stations	Mean	Min	Max	SD	CV (%)
Bairagarh	140.38	0.00	459.50	105.79	75.36
Berasia	130.63	5.00	540.90	106.20	81.30
Begumganj	164.47	0.00	691.40	153.23	93.16
Ghairatganj	123.85	0.00	477.10	123.21	99.48
Goharganj	139.34	0.00	371.60	97.43	69.93
Raisen	131.19	0.00	427.20	95.98	73.16
Silwani	130.51	0.00	521.80	127.72	97.86
Basoda	145.98	9.20	567.20	121.43	83.18
Gyaraspur	180.59	0.00	471.00	133.75	74.06
Kurwai	148.88	10.00	587.90	123.12	82.70
Lateri	120.84	5.00	660.00	121.88	100.86

4.1.2.2 Variation of rainfall in the month of July

July month receives highest amount of rainfall in the monsoon season in this region (Table 4.4). Mean monthly rainfall in July was maximum at Gyaraspur (447.17 mm) followed by Bairagarh (374.84 mm) and Ghairatganj (370.83 mm) whereas lowest rainfall was observed at Berasia (302.58 mm). Maximum monthly rainfall in July was observed at Bairagarh (1041.80 mm) in the year 1986 and lowest at Silwani, Ghairatganj and Raisen station (0.00 mm) in the year1976, 2002 and 2006 respectively. Maximum regional rainfall deviation in July month was observed at Gyaraspur (203.57 mm) and minimum rainfall deviation at Lateri (149.2 mm) with coefficient of variation 45.53% and 48.29%, respectively. All stations received more than 300 mm rainfall in July month. Coefficient of variation in monthly rainfall was observed highest at Kurwai station which is northern most station of the basin.

Table 4.4: Rainfall variation at selected stations in the month of July.

Stations	Mean	Min	Max	SD	CV (%)
Bairagarh	374.84	35.80	1041.80	187.46	50.01
Berasia	302.58	34.20	765.00	168.15	55.57
Begumganj	349.84	77.40	855.00	151.73	43.37
Ghairatganj	370.83	0.00	812.00	177.49	47.86
Goharganj	363.31	89.30	790.00	175.07	48.13
Raisen	361.56	0.00	871.00	180.86	50.02
Silwani	367.97	0.00	844.50	172.96	47.01
Basoda	336.91	33.00	964.40	177.96	52.82
Gyaraspur	447.17	131.00	899.00	203.57	45.53
Kurwai	325.97	73.00	991.60	200.57	61.52
Lateri	308.60	75.40	663.00	149.02	48.29

4.1.2.3 Variation of rainfall in the month of August

In the month of August ample amount of rainfall was received all over the Upper Betwa basin. All selected stations received more than 350 mm average rainfall, except Berasia station. Table 4.5 shows that mean monthly rainfall in august was maximum at Begumganj (425.62 mm) and lowest at Berasia station (310.98 mm). Bairagarh station exhibited maximum deviation as compared to all other stations and minimum deviation at Basoda station with coefficient of variation 50.42% and 37.43%, respectively. Basoda station received more uniform rainfall in august month as compared to remaining station and Berasia station adduces maximum variation in among the study stations.

Table 4.5: Rainfall variation at selected stations in the month of August.

Stations	Mean	Min	Max	SD	CV (%)
Bairagarh	400.63	0.00	1011.60	202.00	50.42
Berasia	310.98	76.20	693.30	147.17	47.32
Begumganj	425.62	105.60	905.30	184.44	43.33
Ghairatganj	409.74	145.00	784.00	180.29	44.00
Goharganj	380.07	76.80	846.70	159.92	42.08
Raisen	418.18	138.40	858.90	165.08	39.48
Silwani	367.42	121.80	801.80	168.15	45.77
Basoda	373.11	140.40	644.00	139.67	37.43
Gyaraspur	391.57	151.00	774.00	160.46	40.98
Kurwai	358.70	94.00	828.00	163.43	45.56

Lateri	363.67	78.00	848.00	178.47	49.07

4.1.2.4 Variation of rainfall in the month of September

Monsoon rainfall decline in September month and received less rainfall as compared to June, July and August months at all stations. The maximum rainfall observed at Gyaraspur station (215.60 mm) in September and lowest rainfall at Berasia station (135.04 mm). All stations received more than 150 mm rainfall except Kurwai (141.30 mm) and Berasia station (135.04 mm). Variation of rainfall from its mean was highest at Gyaraspur with 94.40% and minimum at both Kurwai and Berasia with nearly 72% coefficient of variation in the month of September

Table 4.6: Rainfall variation at selected stations in month of September.

Stations	Mean	Min	Max	SD	CV (%)
Bairagarh	157.84	0.00	494.20	125.34	79.41
Berasia	135.04	0.00	357.70	97.76	72.39
Begumganj	192.04	23.70	778.90	159.90	83.26
Ghairatganj	194.78	1.00	802.20	167.54	86.02
Goharganj	174.76	12.90	587.80	115.77	66.25
Raisen	169.80	8.60	693.00	147.58	86.91
Silwani	197.39	0.00	689.30	162.81	82.48
Basoda	150.31	0.00	456.00	113.52	75.52
Gyaraspur	215.60	0.00	888.00	203.53	94.40
Kurwai	141.30	23.00	402.40	101.64	71.93
Lateri	155.32	10.00	564.00	123.06	79.23

4.1.2.5 Variation of rainfall in the month of October

October month is the recession stage of monsoon rainfall and received lowest rainfall as compared to all monsoon season months. Mean rainfall in October month received maximum at Ghairatganj (37.55 mm) and minimum at Silwani (21.71 mm) and many times for a considered study period October month did not receive rainfall at every station. Table 4.7 reveals that highest deviation was observed at Ghairatganj (62.88 mm) and lowest at Goharganj (36.01 mm) with coefficient of variation 167.47% and 148.40% respectively. All stations except Berasia and Ghairatganj received less than 30 mm rainfall in October month. In October month, most of the stations did not receives rainfall for considered time period. Standard deviation of rainfall at selected stations was increases as rainfall increased.

Table 4.7: Rainfall variation at selected stations in the month of October.

Stations	Mean	Min	Max	SD	CV (%)
Bairagarh	28.07	0.00	149.50	38.54	137.30
Berasia	33.09	0.00	298.30	56.88	171.91
Begumganj	26.72	0.00	219.00	44.63	167.05
Ghairatganj	37.55	0.00	311.00	62.88	167.47
Goharganj	24.27	0.00	176.60.	36.01	148.40
Raisen	29.33	0.00	211.20	49.01	167.10
Silwani	21.71	0.00	164.00	38.44	177.00
Basoda	29.35	0.00	203.00	45.03	153.41
Gyaraspur	27.59	0.00	209.00	49.38	179.00
Kurwai	28.76	0.00	337.00	58.72	204.16
Lateri	23.07	0.00	346.00	55.30	239.74

4.2 Homogeneity analyis (Change Point Detection)

In change point test, the presence of high and low values was examined by determining number of change points in the time series. Change point occurs for all values except first and last in time series. The results of three CP tests (i.e. Standard Normal Homogeneity Test (SNHT), Pettitt`s test and Buishand`s Test) are used to identify, years of the showed CPs in annual and monthly rainfall series of eleven stations, are presented in Table 4.8 to Table 4.13.

4.2.1 Annual rainfall Change point test

The results of change point test of annual rainfall are presented in Table 4.13 which revealed that there are no one abrupt change points showed at anyone stations.

Table 4.8: Results of Homogeneity test on annual rainfall series on different Stations.

Stations	Pettitt's test		SNHT		Buishand`s test		Homo-geneity
	p	Result	p	Result	p	Result	
Bairagarh	0.44	N.C.P.	0.27	N.C.P.	0.23	N.C.P.	Y
Berasia	0.17	N.C.P.	0.03	C.P.	0.16	N.C.P.	Y
Begumganj	0.52	N.C.P.	0.35	N.C.P.	0.22	N.C.P.	Y
Ghairatganj	0.19	N.C.P.	0.63	N.C.P.	0.90	N.C.P.	Y
Goharganj	0.32	N.C.P.	0.76	N.C.P.	0.93	N.C.P.	Y
Raisen	0.18	N.C.P.	0.11	N.C.P.	0.07	N.C.P.	Y
Silwani	0.08	N.C.P.	0.79	N.C.P.	0.96	N.C.P.	Y
Basoda	0.10	N.C.P.	0.48	N.C.P.	0.84	N.C.P.	Y
Gyaraspur	0.77	N.C.P.	0.63	N.C.P.	0.54	N.C.P.	Y
Kurwai	0.33	N.C.P.	0.22	N.C.P.	0.34	N.C.P.	Y
Lateri	0.99	N.C.P.	0.30	N.C.P.	0.36	N.C.P.	Y

Note: N.C.P.: No Change Point; C.P.: Chang Point and Y: Yes

4.2.2 Monthly rainfall Change point test

It is clearly seen from Table 4.19 to Table 4.13 that the years of CPs identified by the three tests are not exactly similar for the rainfall series of all the stations. Slight deviations in CPs identified by different tests, i.e. the SNHT, Pettitt`s and Buishand`s tests, are also found in other studies performed in other parts of India. The CPs identified by the SNHT at four stations are Berasia, Ghairatganj in July (1973, 1990) and Begumganj, Gayaraspur in August (1985,1997) respectively.

The CPs identified by the Pettitt`s test are Gayaraspur in 1999, Ghairatganj, Begumganj in 1994 and at Berasia, Bairagarh in 1996. The detected Change points by Buishand's test at Begumganj, Ghairatganj in 1994, and at Basoda & Gayaraspur in 1996 and 1997 respectively.

In the month of august, CPs are identified by all three tests i.e. SNHT, Pettitt`s test and Buishand's test at some stations like, Gayaraspur (1999), Ghairatganj (1994) and Begumganj (1994).

Table 4.9: Results of Homogeneity test of June rainfall series on different stations.

Stations	Pettitt's test		SNHT		Buishand`s test		Homo-geneity
	p	Result	p	Result	p	Result	
Bairagarh	0.75	N.C.P.	0.77	N.C.P.	0.87	N.C.P.	Y
Berasia	0.29	N.C.P.	0.06	N.C.P.	0.06	N.C.P.	Y
Begumganj	0.56	N.C.P.	0.74	N.C.P.	0.53	N.C.P.	Y
Ghairatganj	0.61	N.C.P.	0.19	N.C.P.	0.40	N.C.P.	Y
Goharganj	0.35	N.C.P.	0.91	N.C.P.	0.75	N.C.P.	Y
Raisen	0.71	N.C.P.	0.72	N.C.P.	0.92	N.C.P.	Y
Silwani	0.89	N.C.P.	0.26	N.C.P.	0.61	N.C.P.	Y
Basoda	0.10	N.C.P.	0.16	N.C.P.	0.30	N.C.P.	Y
Gyaraspur	0.07	N.C.P.	0.99	N.C.P.	0.87	N.C.P.	Y
Kurwai	0.97	N.C.P.	0.11	N.C.P.	0.12	N.C.P.	Y
Lateri	0.85	N.C.P.	0.31	N.C.P.	0.38	N.C.P.	Y

Note: N.C.P.: No Change Point; C.P.: Chang Point and Y: Yes

Table 4.10: Results of Homogeneity test of July rainfall series on different stations.

Stations	Pettitt's test		SNHT		Buishand`s test		Homo-geneity
	p	Result	p	Result	p	Result	
Bairagarh	0.74	N.C.P.	0.52	N.C.P.	0.48	N.C.P.	Y
Berasia	0.79	N.C.P.	0.00	N.C.P.	0.23	N.C.P.	Y
Begumganj	0.48	N.C.P.	0.87	N.C.P.	0.93	N.C.P.	Y
Ghairatganj	0.05	N.C.P.	0.30	N.C.P.	0.14	N.C.P.	Y
Goharganj	0.14	N.C.P.	0.18	N.C.P.	0.23	N.C.P.	Y
Raisen	0.44	N.C.P.	0.80	N.C.P.	0.49	N.C.P.	Y
Silwani	0.54	N.C.P.	0.78	N.C.P.	0.46	N.C.P.	Y
Basoda	0.45	N.C.P.	0.17	N.C.P.	0.41	N.C.P.	Y
Gyaraspur	0.98	N.C.P.	0.40	N.C.P.	0.87	N.C.P.	Y
Kurwai	0.48	N.C.P.	0.36	N.C.P.	0.36	N.C.P.	Y
Lateri	0.03	C.P.	0.08	N.C.P.	0.04	C.P.	N

Note: N.C.P.: No Change Point; C.P.: Chang Point and Y: Yes, N: No.

Table 4.11: Results of Homogeneity test of August rainfall series on different stations.

Stations	Pettitt's test		SNHT		Buishand`s test		Homo-geneity
	p	Result	p	Result	p	Result	
Bairagarh	0.02	C.P.	0.21	N.C.P.	0.08	N.C.P.	Y
Berasia	0.03	C.P.	0.07	N.C.P.	0.06	N.C.P.	Y
Begumganj	0.01	C.P.	0.02	C.P.	0.01	C.P.	N
Ghairatganj	0.10	N.C.P.	0.09	N.C.P.	0.04	C.P.	Y
Goharganj	0.14	N.C.P.	0.16	N.C.P.	0.08	N.C.P.	Y
Raisen	0.17	N.C.P.	0.21	N.C.P.	0.07	N.C.P.	Y
Silwani	0.13	N.C.P.	0.28	N.C.P.	0.09	N.C.P.	Y
Basoda	0.12	N.C.P.	0.10	N.C.P.	0.05	N.C.P.	Y
Gyaraspur	0.05	N.C.P.	0.03	C.P.	0.01	C.P.	N
Kurwai	0.36	N.C.P.	0.38	N.C.P.	0.17	N.C.P.	Y
Lateri	0.32	N.C.P.	0.31	N.C.P.	0.14	N.C.P.	Y

Note: N.C.P.: No Change Point; C.P.: Chang Point and Y: Yes, N: No.

Table 4.12: Results of Homogeneity test of September rainfall series on different stations.

Stations	Pettitt's test		SNHT		Buishand`s test		Homo-geneity
	p	Result	p	Result	p	Result	
Bairagarh	0.47	N.C.P.	0.83	N.C.P.	0.88	N.C.P.	Y
Berasia	0.86	N.C.P.	0.40	N.C.P.	0.50	N.C.P.	Y
Begumganj	0.81	N.C.P.	0.81	N.C.P.	0.81	N.C.P.	Y
Ghairatganj	0.36	N.C.P.	0.92	N.C.P.	0.75	N.C.P.	Y
Goharganj	0.64	N.C.P.	0.98	N.C.P.	0.85	N.C.P.	Y
Raisen	0.38	N.C.P.	0.60	N.C.P.	0.39	N.C.P.	Y
Silwani	0.85	N.C.P.	0.99	N.C.P.	0.90	N.C.P.	Y
Basoda	0.72	N.C.P.	0.95	N.C.P.	0.83	N.C.P.	Y
Gyaraspur	0.98	N.C.P.	0.64	N.C.P.	0.82	N.C.P.	Y
Kurwai	0.81	N.C.P.	0.47	N.C.P.	0.23	N.C.P.	Y
Lateri	0.30	N.C.P.	0.87	N.C.P.	0.67	N.C.P.	Y

Note: N.C.P.: No Change Point; C.P.: Chang Point and Y: Yes

Table 4.13: Results of Homogeneity test of October rainfall series on different stations.

Stations	Pettitt's test		SNHT		Buishand`s test		Homo-geneity
	p	Result	p	Result	p	Result	
Bairagarh	0.64	N.C.P.	0.85	N.C.P.	0.78	N.C.P.	Y
Berasia	0.83	N.C.P.	0.49	N.C.P.	0.70	N.C.P.	Y
Begumganj	0.99	N.C.P.	0.16	N.C.P.	0.83	N.C.P.	Y
Ghairatganj	0.96	N.C.P.	0.92	N.C.P.	0.93	N.C.P.	Y
Goharganj	0.58	N.C.P.	0.73	N.C.P.	0.55	N.C.P.	Y
Raisen	0.05	N.C.P.	0.87	N.C.P.	0.65	N.C.P.	Y
Silwani	0.40	N.C.P.	0.99	N.C.P.	0.95	N.C.P.	Y
Basoda	0.81	N.C.P.	0.86	N.C.P.	0.93	N.C.P.	Y
Gyaraspur	0.62	N.C.P.	0.84	N.C.P.	0.73	N.C.P.	Y
Kurwai	0.18	N.C.P.	0.78	N.C.P.	0.69	N.C.P.	Y
Lateri	0.01	C.P.	0.97	N.C.P.	0.96	N.C.P.	Y

Note: N.C.P.: No Change Point; C.P.: Chang Point and Y: Yes

4.3 TREND ANALYSIS

The climatic variables were analysed for the annual and monthly scale using the Mann-Kendall test and Spearman`s rho test for the whole series at 5% level of significance i.e. $\alpha = 0.05$. The positive values of Zmk statistics indicated increasing trends in climatic variables while negative values of Zmk showed decreasing trends for the significant and non-significant climatic variables. After the MK test and Spearman`s rho test, the Sen's slope estimator was applied to find out the change per unit time of the trends observed in the time series of all climatic variables.

4.3.1 Annual trend analysis

The MK and SR tests were also applied in order to study trends in the annual rainfall over the study period (1970–2014). Table 3 shows the MK and SR tests results for significant trend, which were similar for both tests in tested time series. Magnitude of annual trend of all stations during 1970 to 2014 as shown in Fig. 4.1. Among, 11 study stations, none of them exhibit any significant trend in the annual time series except Berasia with decreasing trend (2.17 mm/year).

Table 4.14: Test results of annual rainfall trends during 1970-2014.

Stations	MK test			SR test		
	Zmk	p	Trend	S	Zsr	Trend
Bairagarh	-1.83	0.07	#	-1.87	-1.92	#
Berasia	-2.17	0.03	*	-2.12	-2.21	*
Begumganj	-1.89	0.06	#	-1.76	-1.80	#
Ghairatganj	-0.15	0.88	#	-0.21	-0.21	#
Goharganj	-0.12	0.90	#	-0.09	-0.09	#
Raisen	-1.22	0.22	#	-1.18	-1.18	#
Silwani	-0.41	0.68	#	-0.36	-0.36	#
Basoda	-0.03	0.98	#	-0.06	-0.06	#
Gyaraspur	0.02	0.99	#	-0.21	-0.20	#
Kurwai	0.77	0.44	#	0.78	0.77	#
Lateri	0.46	0.65	#	0.58	0.57	#

Note: * & # indicates significant and non-significant trend respectively at 95% confidence level (+ for increasing trend and – for decreasing trend).

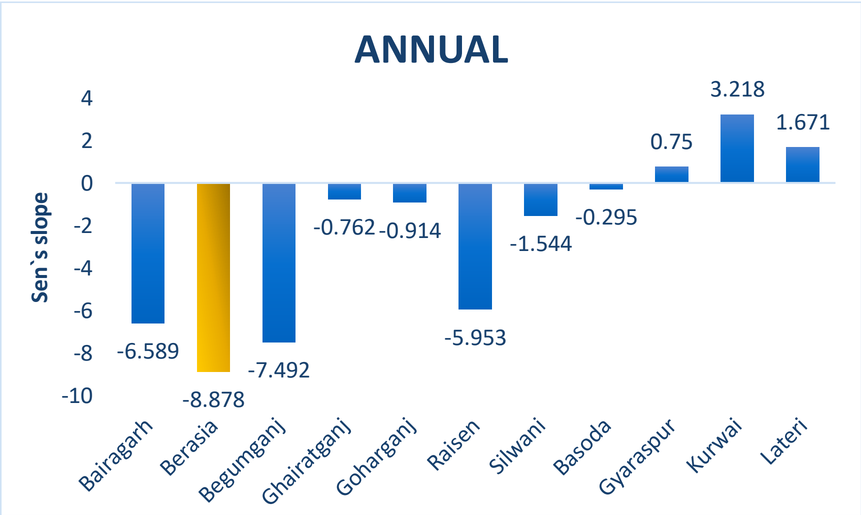


Fig. 4.1: Sen`s slope magnitude of annual trend of all stations during 1970 to 2014. (Note: Blue Bar: Non-significant trend, Orange Bar: Significant trend)

4.3.2 Monthly trend analysis

The results of the application of the MK and SR tests for trend identification of monthly rainfall were similar and they are summarized in Table 4.15. As shown, monthly rainfall had a mixture of increasing and decreasing trends as shown in Fig. 4.2 to Fig. 4.5. The trend tests revealed no statistically significant trends at Silwani, Basoda, and Kurwai stations in all months. The seven stations out of eleven stations i.e. Bairagarh, Berasia, Begumganj, Goharganj, Ghairatganj, Raisen and Gayaraspur showing significant decreasing trend during the august month only (Fig. 4.4). At Ghairatanj and Lateri stations, the monthly rainfall trend was significantly increasing in the month of July over the period of analysis (Fig. 4.3). The results for slope`s magnitude of significant trends (in monthly scales) indicated that maximum increasing trends observed at Goharganj and Ghairatganj stations with the rate of 4.97 mm/month and 3.96 mm/month respectively. And more rapid decreasing trend observed at Gyaraspur (-9.86 mm/month) and Begumganj (-7.09 mm/month) stations. The trends of the monthly rainfall for the above-mentioned stations are presented in Fig. 4.6 and Fig. 4.7.

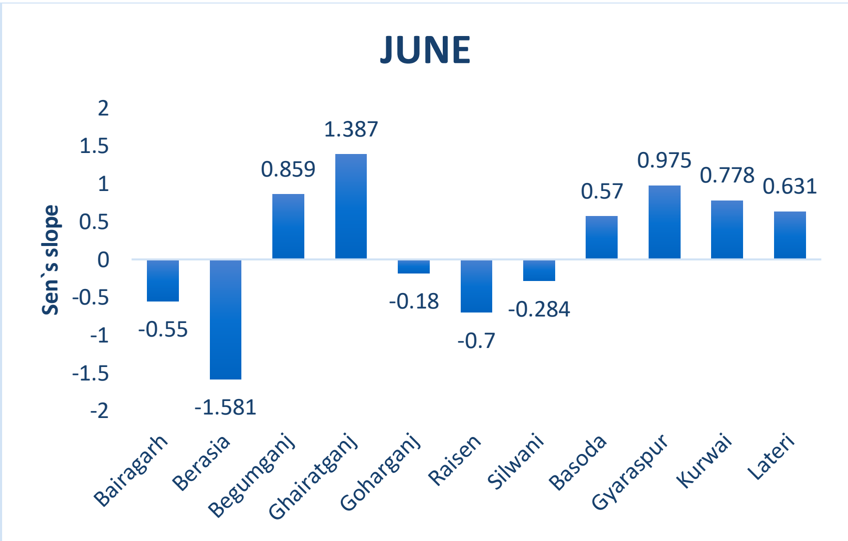


Fig. 4.2: Trend magnitude of June month of all stations during 1970 to 2014. (Note: Blue Bar: Non-significant trend)

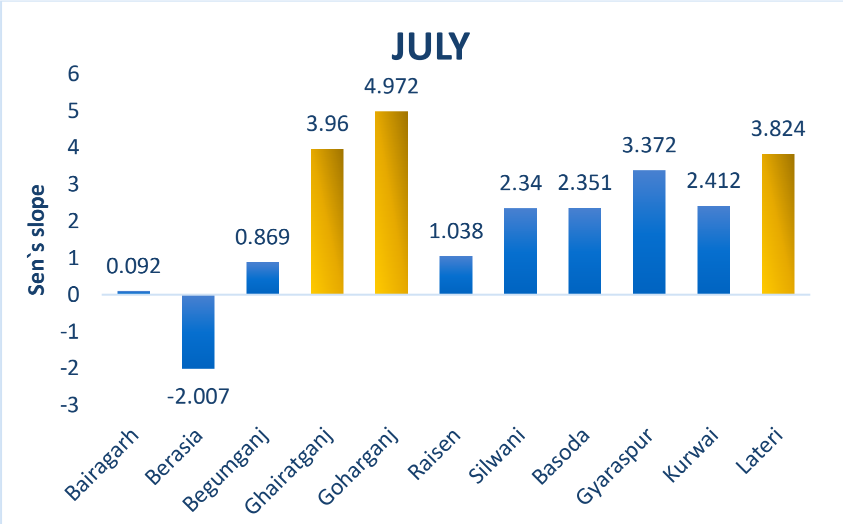


Fig. 4.3: Trend magnitude of July month of all stations during 1970 to 2014. (Note: Blue Bar: Non-significant trend, Orange Bar: Significant trend)

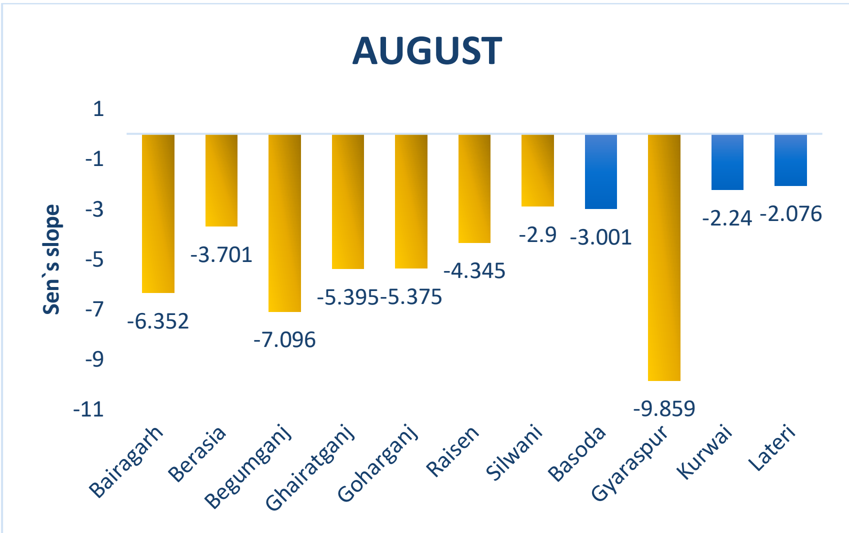


Fig. 4.4: Trend magnitude of August month of all stations during 1970 to 2014. (Note: Blue Bar: Non-significant trend, Orange Bar: Significant trend)

Table 4.15: Z statistics of MK/SR tests for monthly rainfall series 1970-2014.

Stations		**JUN**	**JUL**	**AUG**	**SEP**	**OCT**
Bairagarh	MK	-0.47	0.06	**-2.89**	-0.24	0.07
	SR	-0.47	0.05	**-3.05**	-2.17	0.62
Berasia	MK	-1.51	-0.94	**-2.08**	0.10	-0.67
	SR	-1.60	-0.80	**-2.46**	0.20	0.37
Begumganj	MK	0.81	0.41	**-3.46**	-1.16	0.92
	SR	0.75	0.38	**-3.68**	-1.22	0.93
Ghairatganj	MK	1.38	**2.19**	**-2.31**	-0.64	1.07
	SR	1.58	**2.14**	**-2.25**	-0.56	1.06
Goharganj	MK	-0.16	**2.08**	**-2.31**	0.75	-0.57
	SR	-0.32	2.01	**-2.24**	0.66	0.50
Raisen	MK	-0.65	0.52	**-2.08**	-0.30	0.29
	SR	-0.54	0.66	**-2.08**	-0.45	1.73
Silwani	MK	-0.25	1.05	-1.85	1.07	0.21
	SR	-0.28	1.00	-1.85	0.92	0.24
Basoda	MK	0.46	1.13	-1.56	0.47	0.28
	SR	0.47	1.11	-1.57	0.45	1.41
Gyaraspur	MK	0.23	0.86	**-2.42**	0.66	0.64
	SR	0.17	0.66	**-2.32**	0.72	1.77
Kurwai	MK	0.81	1.23	-1.35	1.55	1.51
	SR	0.86	1.36	-1.43	1.63	3.21
Lateri	MK	0.87	2.68	-1.01	0.25	**-0.25**
	SR	0.79	2.84	-1.04	0.29	**2.17**

Note: Bold value indicate significant trend at 95% confidence level (+ for increasing trend and – for decreasing trend).

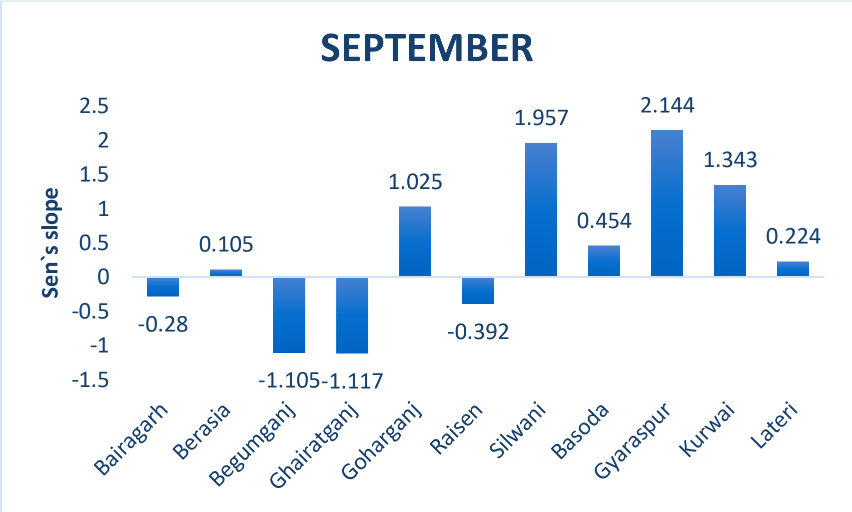
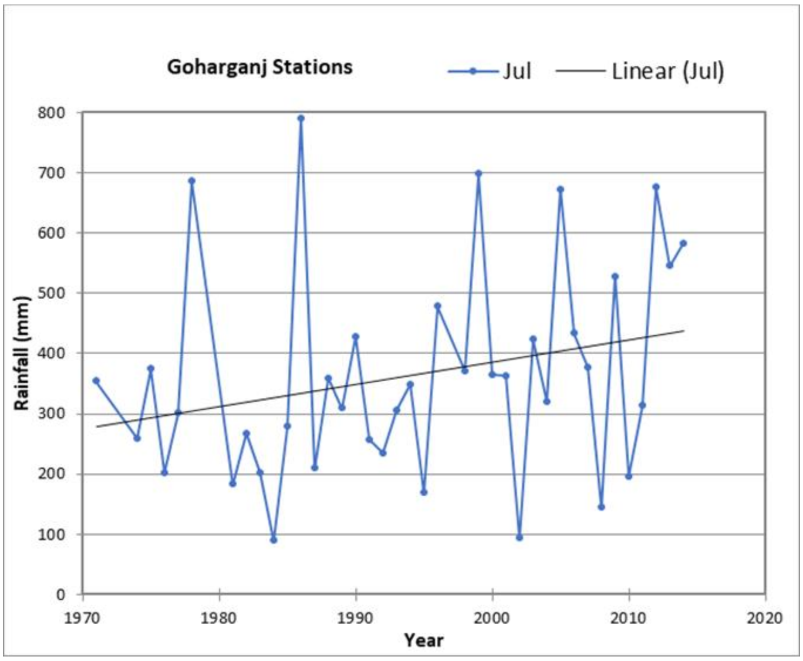
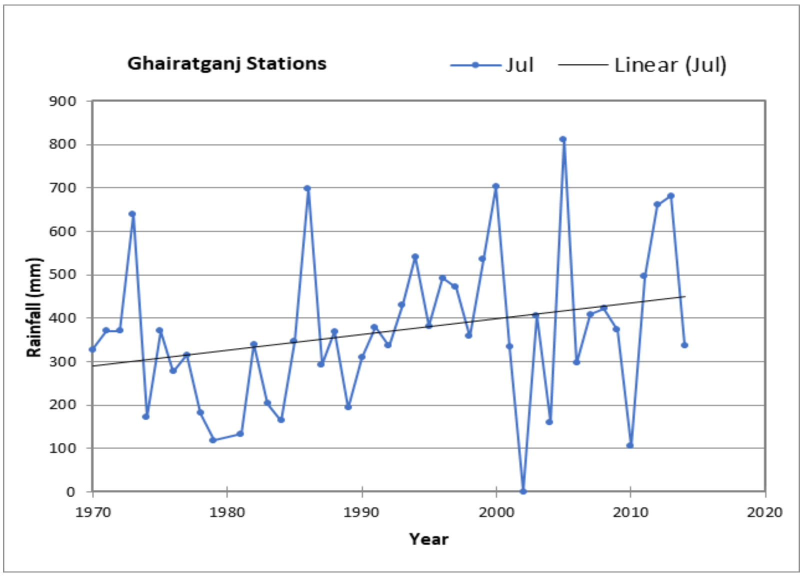


Fig. 4.5: Trend magnitude of September month of all stations during 1970 to 2014. (Note: Blue Bar: Non-significant trend)

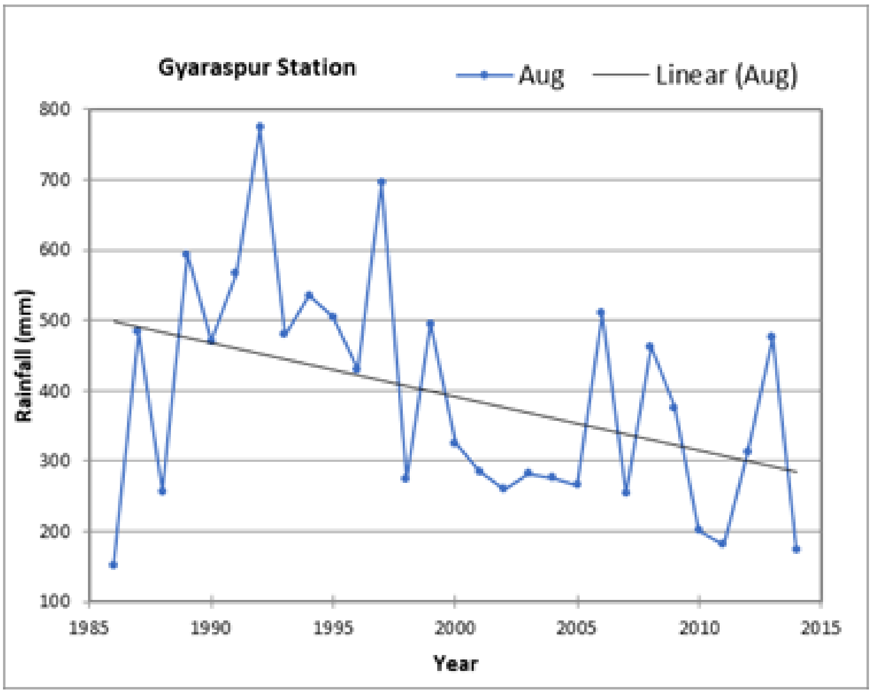


(A)

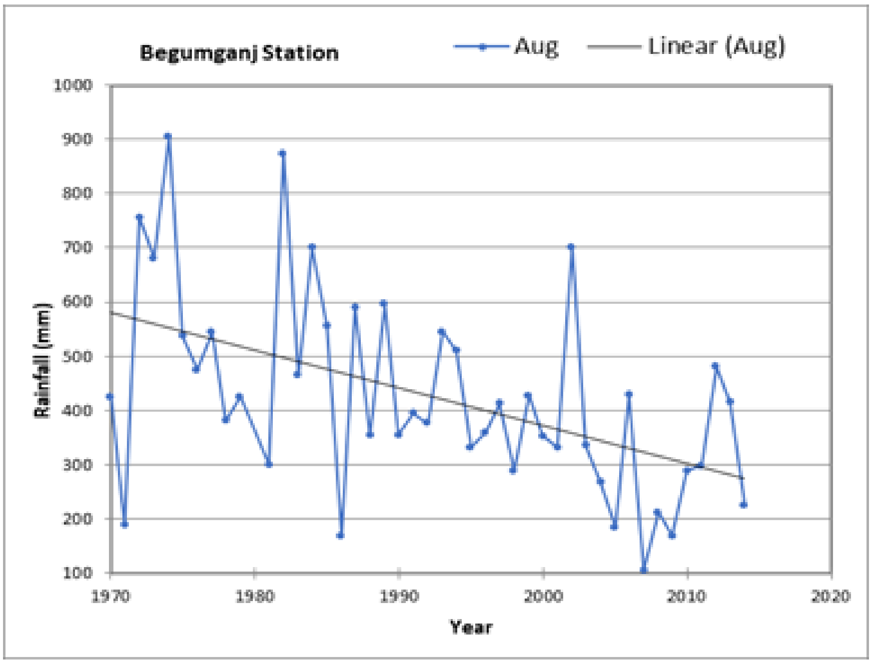


(B)

Fig. 4.6: Maximum significant monthly rainfall trend at (A) Goharganj and (B) Ghairatganj stations during 1970-2014.



(C)



(D)

Fig. 4.7: Minimum significant monthly rainfall trend at (C) Gyaraspur and (D) Begumganj stations during 1970-2014.

4.3.3. Comparison of the MK and SR Tests for detection of trend existence

The results obtained using both tests indicate that the analogous values of MK and SR tests (ratio of significant cases to total tested cases) for detections of trend in rainfall were 16% and 18%, respectively. Therefore, these tests had similar performance at the 5% significant level for analysis of trends. In cases where the detection of significance by means of the two tests was different, values of significant level of trend acceptance exhibited low difference. Yue et al. (2002a) also confirmed similar performance of MK and SR tests for analysis of trends.

4.4 Spatial analysis of rainfall series

The spatial interpolation technique (Singh and Chowdhury, 1986; Lebel et. al., 1987) is employed to determine the spatial pattern of meteorological variable using ArcGIS. The Geographical information system (GIS) tool is widely used in the processing of spatially distributed hydrological modelling (Maidment, 1991; Eldho et. al.,2006; Jat et. al.,2009). In recent time, GIS interpolation methods has widely used to show the spatial distribution of climate change variable and it provides the layout and drawing tools essential to present the outcomes visually.

Thus, in present study spatial distribution of temporal trend in annual and monthly rainfall as detected by the Mann-Kendall statistics method to each station in the Upper Betwa basin, temporal of trends of annual and monthly rainfall are tested at the $\alpha = 0.05$ level of significance. These temporal trends are then interpolated by using the Kriging Interpolation method to show their spatial distributions. Finally, positive and negative rainfall trends and its significance levels were shown in spatial map with different colours and symbols (Fig, 4.8 to Fig. 4.12). The change magnitude of trend as percentage of mean expressed in Table 4.16, of all 11 stations.

Table 4.16: Percentage change of all stations during 1970 – 2014.

Stations	**Jun**	**July**	**Aug**	**Sep**	**Annual**
	% Change	**% Change**	**% Change**	**% Change**	**% Change**
Bairagarh	-17.63	1.11	**-71.35**	-7.97	-26.91
Berasia	-53.25	-29.18	**-52.37**	3.44	**-42.82**
Begumganj	22.98	10.93	**-73.36**	-25.32	-28.45
Ghairatganj	49.27	**46.99**	**-57.94**	-25.23	-2.95
Goharganj	-5.04	**53.37**	**-55.15**	22.87	-3.30
Raisen	-23.48	12.63	**-45.72**	-10.15	-23.60
Silwani	-9.14	26.71	**-33.15**	41.63	-5.98
Basoda	17.58	31.40	-36.20	13.59	-1.28
Gyaraspur	15.66	21.87	**-73.02**	28.83	1.72
Kurwai	23.50	33.30	-28.10	42.79	14.43
Lateri	23.52	**55.76**	-25.69	6.50	7.74

Note: Stations have significant trend represented by Bold values.

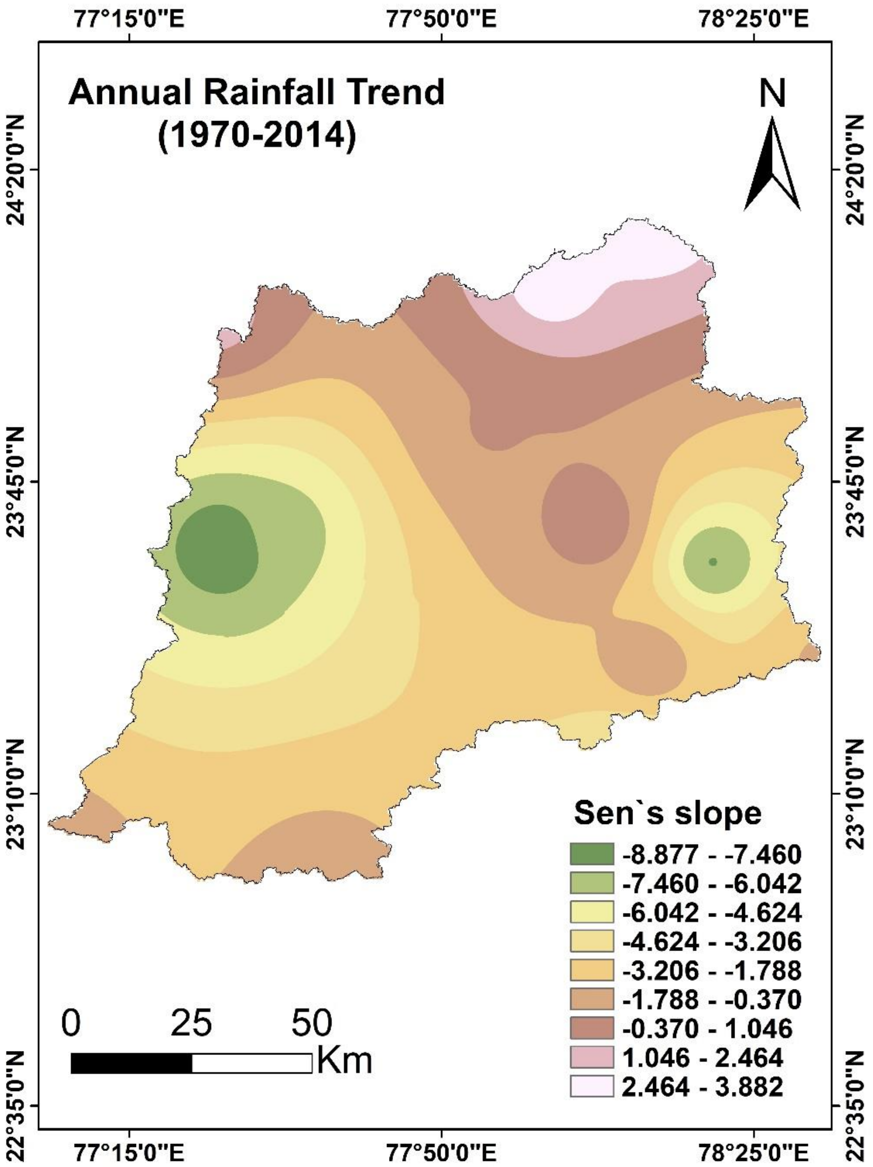


Fig 4.8: Spatial distribution of magnitude of annual rainfall trend during 1970–2014.

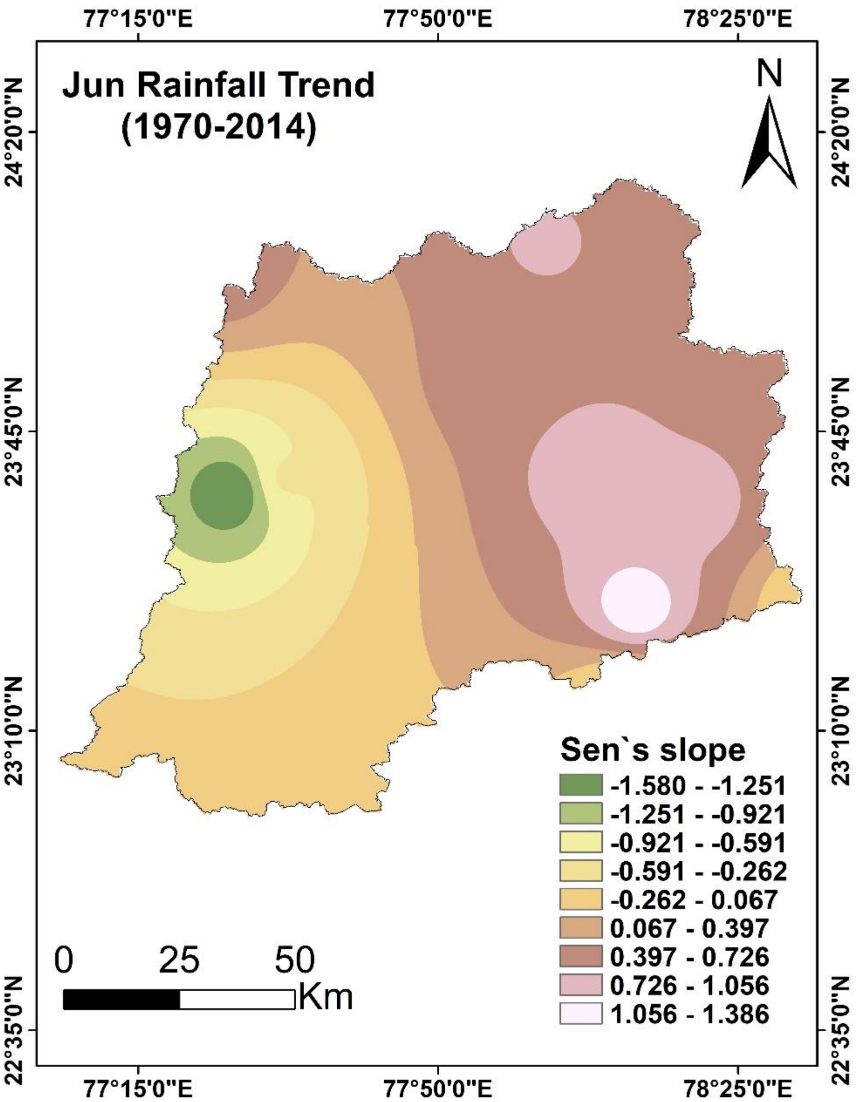


Fig.4.9: Spatial distribution of rainfall trends in June month during 1970–2014.

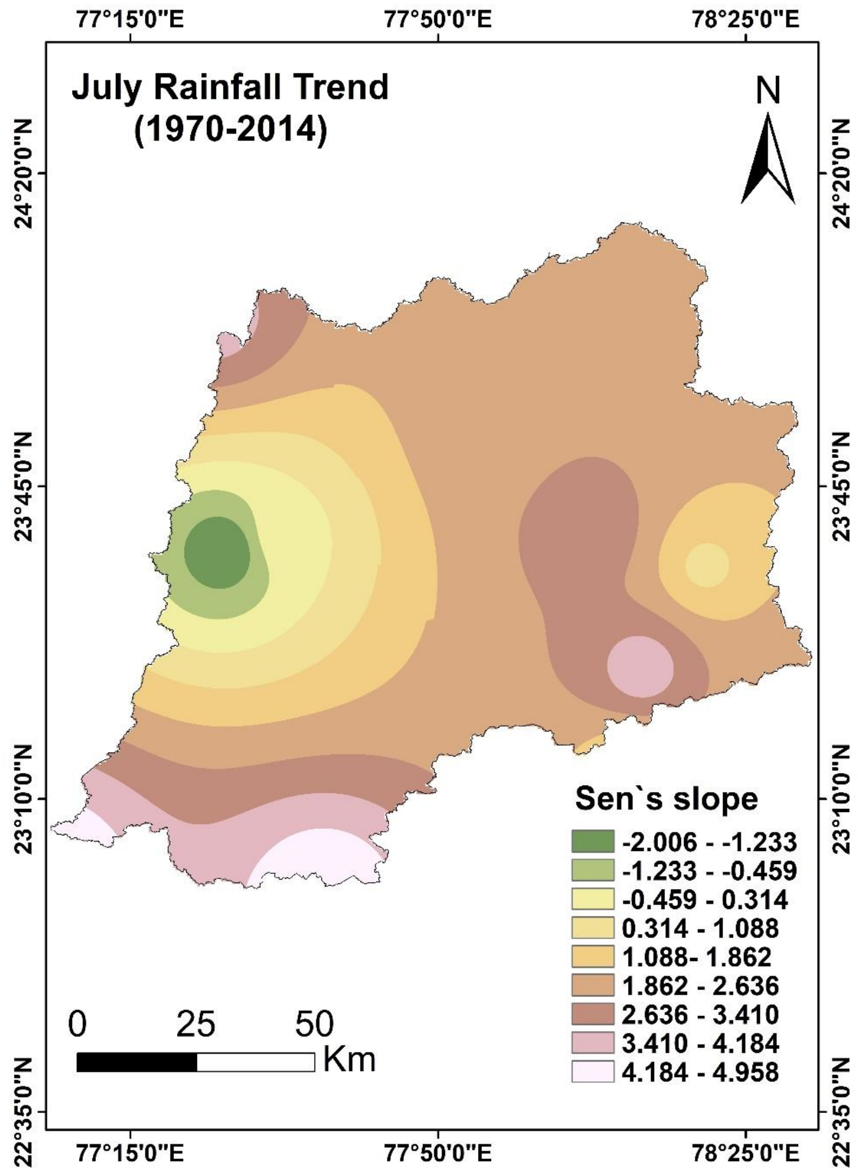


Fig.4.10: Spatial distribution of rainfall trends in July month during 1970–2014.

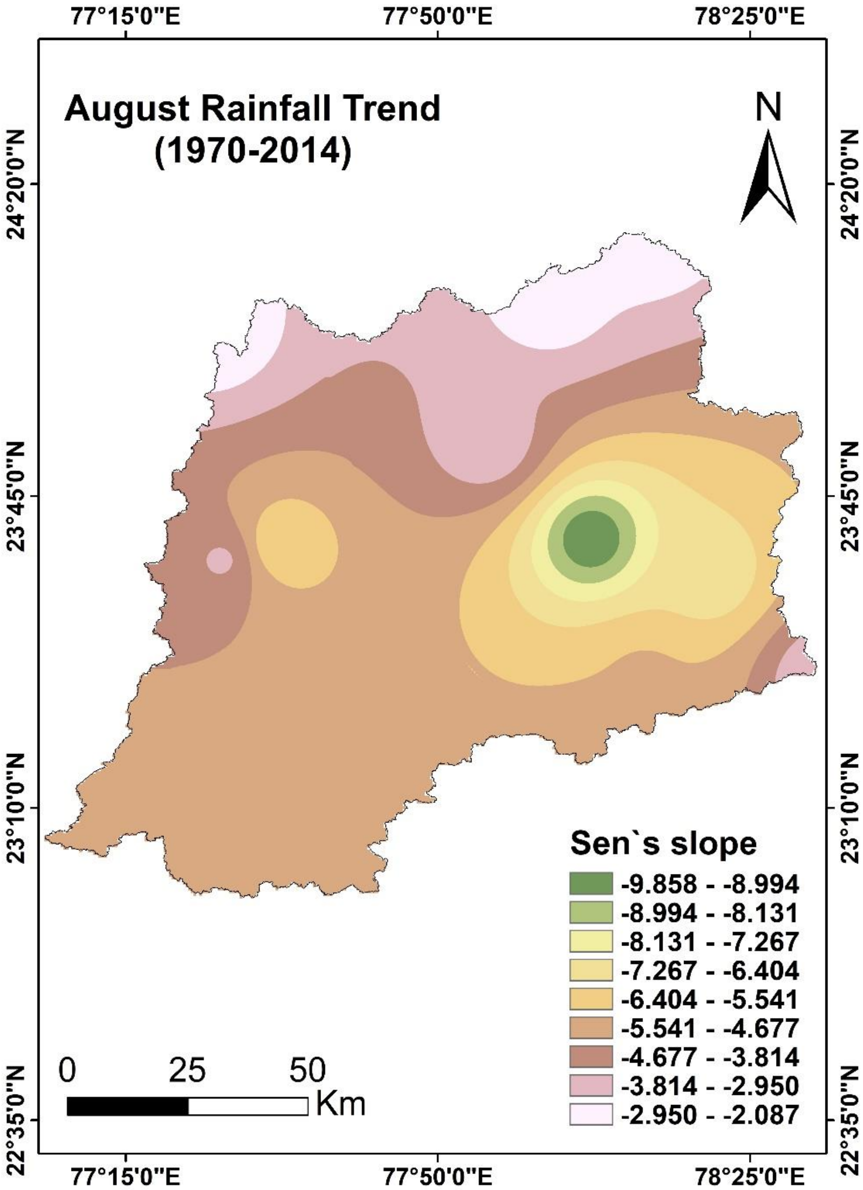


Fig.4.11: Spatial distribution of rainfall trends in August month during 1970–2014.

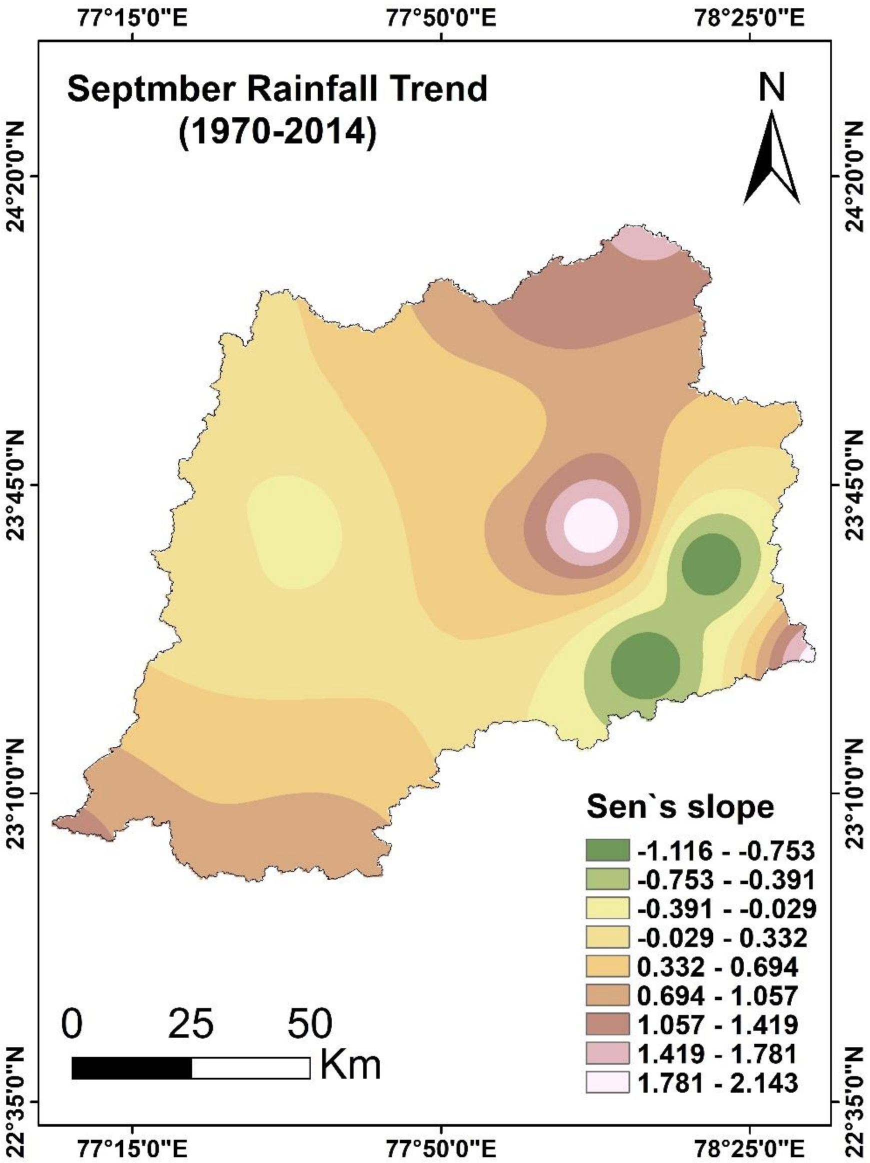


Fig.4.12: Spatial distribution of rainfall trends in September month during 1970–2014.

4.5 Trend analysis for periods 1970–1992 and 1993–2014

The gradual trends in the annual rainfall were identified for the entire 45-year (1970–2014) period and for the two-short period (i.e. 1st period is 1970-1992 and

2nd period is 1993-2014), by applying two non-parametric tests and their results are summarized in Table 4.16.

In the annual rainfall of 1st time period, based on the results of the M–K test, only two stations (Gyaraspur and Lateri) revealed positive rainfall trends and the rest nine stations showed declining trends of the annual rainfall (Table 4.16). Whereas, in the rainfall of 2nd time period the increasing trends could be observed only at three stations, i.e. Goharganj, Kurwai, and Lateri. However, two stations with negative rainfall trends obtained from the M–K test was found to be statistically significant. In case of the complete 45-year rainfall series, the statistically significant declining trends of the annual rainfall were present at one stations, i.e. Berasia (9.16mm/year).

The results of the SR test revealed the negative trends in the annual rainfall of 1st period at nine of total eleven stations (Table 4.16). The positive rainfall trends were present only at Gyaraspur (1.88 mm/year) and Lateri (1.08 mm/year) stations. Similar to the results of the M–K tests, none of the positive or negative rainfall trends obtained from the was found to be statistically significant, except at Raisen and Berasia stations with decreasing rainfall trends. In entire 45-year rainfall period, the statistically significant trends were observed only at one stations, i.e. Berasia ($\alpha = 0.05$),

It is obvious from the above interpretations that the results of the two non-parametric trend identification tests are in good coherence to each other for the 45-year annual rainfall series of all eleven stations. Thus, the obtained results indicating presence of the significant rainfall trends at one stations i.e. Berasia are quite strong and precise. This finding indicates that the rainfall in the study area is considerable falling. It is apparent that the gradual trends are generally visible over a relatively long duration of time such as the 45-year period of the entire rainfall series in this study. The presence of the gradual trends could not be dominating in either of two short duration rainfall sub-series.

The magnitudes of the increasing or decreasing trends were estimated by using Sen's slope method and some of them results are presented in Figure 4.5 and all results are summarised in Table 4.16 and Table 4.17.

Table 4.16: MK and SR test results for annual rainfall trends during 1st, 2nd and entire period.

Stations	MK test			SR test		
	1st period	2nd period	Entire Period	1st period	2nd period	Entire Period
Bairagarh	-1.39	-0.70	-1.83	-1.52	-0.66	-1.92
Berasia	-1.44	-2.84*	-2.17	-1.57	-3.14*	-2.21
Begumganj	-2.00	-1.38	-1.89	-1.72	-1.30	-1.80
Ghairatganj	-0.12	-0.52	-0.15	-0.22	-0.33	-0.21
Goharganj	-0.94	0.35	-0.12	-0.52	0.28	-0.09
Raisen	-0.85	-2.38*	-1.22	-0.66	-2.56*	-1.18
Silwani	-0.73	-0.37	-0.41	-1.03	-0.31	-0.36
Basoda	-0.80	-0.80	-0.03	-0.86	-0.89	-0.06
Gyaraspur	1.52	-0.88	0.02	1.88	-0.95	-0.20
Kurwai	-0.05	0.41	0.77	-0.03	0.38	0.77
Lateri	1.00	0.00	0.46	1.08	0.26	0.57

Where, * value shows significance trend at $\alpha = 0.05$.

Table 4.18: Sen's slope magnitude of rainfall trends during 1st, 2nd and entire period.

Stations	Slope magnitude		
	1st period	2nd period	Entire Period
Bairagarh	-12.80	-7.61	-6.589
Berasia	-17.70	-23.61	-8.878
Begumganj	-17.38	-16.14	-7.492
Ghairatganj	-2.10	-8.61	-0.762
Goharganj	-7.94	4.98	-0.914
Raisen	-8.14	-27.49	-5.953
Silwani	-13.00	-3.38	-1.544
Basoda	-7.75	-7.75	-0.295
Gyaraspur	46.40	-16.61	0.750
Kurwai	-1.14	4.03	3.218
Lateri	11.64	0.50	1.671

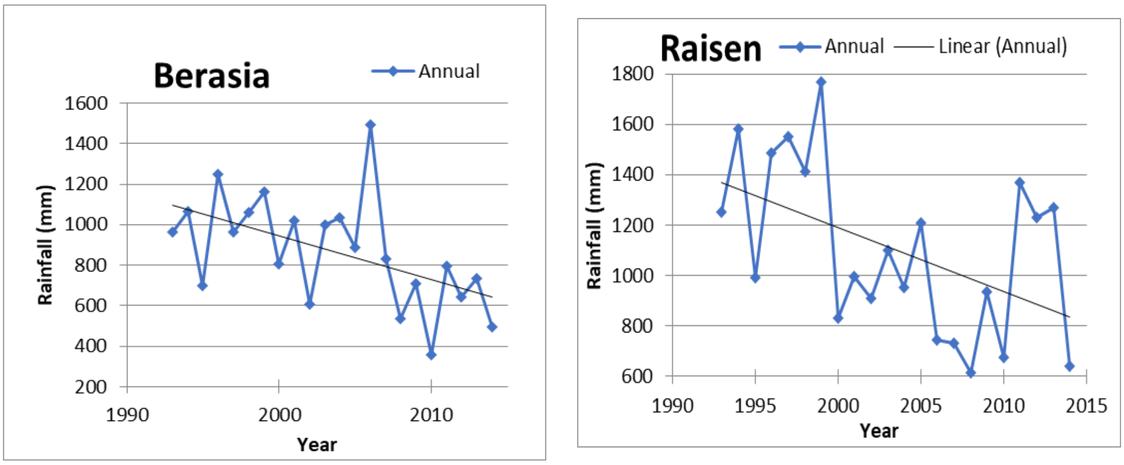


Fig.4.13: Variations of monthly rainfall at stations with most significant trends during the 1st, 2nd and entire period.

Chapter V

CONCLUSION

Long term rainfall over study area, was analysed for spatial and temporal trend at monthly and annual basis. In annual series, magnitude of trend varies from -8.88 mm/year at Berasia to 3.22 mm/year at Kurwai and only at Berasia station shows significant decreasing trend. Most of the stations i.e. Bairagarh, Berasia, Begumganj, Goharganj, Ghairatganj, Raisen and Gayaraspur showing significant decreasing trend during the august month. Overall, a declining trend is observed over basin. These declines will affect agriculture, livestock, forestry as well as fisheries. Trend and change point detection techniques is very fruitful for future prospective i.e., irrigation as well as water resources planning and associated with real world problem.

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