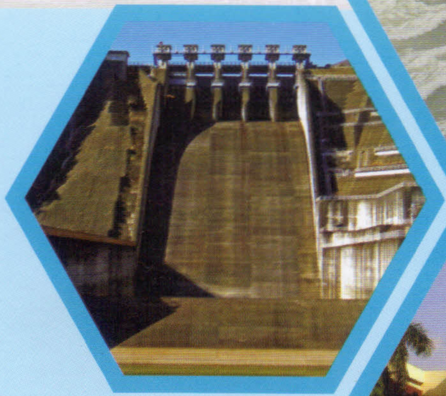
HYDRO 2014 INTERNATIONAL

XIX International Conference on
Hydraulics, Water Resources, Coastal & Environmental Engineering

December 18-20, 2014

Souvenir



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THE INDIAN SOCIETY FOR HYDRAULICS (ISH)

SPATIAL AND TEMPORAL DISTRIBUTION OF RAINFALL TRENDS IN BIST-DOAB REGION OF PUNJAB (1901–2010)

M. K. Nema[1] S. K. Jain[1] P.K. Mishra[1]
[1]*National Institute of Hydrology, Jal Vigyan Bhawan, Roorkee – 247 667 (INDIA)*
Email: mxnema@gmail.com

ABSTRACT

It has been established that the global climate changes are real and these could have imperative effects on various environmental variables including rainfall in many countries around the world. Changes in precipitation regime directly affect water resources management, agriculture, hydrology and ecosystems of a region. For this reason it is important to investigate the changes in the spatial and temporal rainfall pattern in order to improve water management strategies and improve the exiting approaches. In this study, an analysis has been made to study the spatial and temporal variability of rainfall over the period of 110 years (1901-2010) on annual, seasonal and monthly basis in order to understand the regional pattern of rainfall in Bist-doab region of Punjab. Non-parametric statistical method (Mann–Kendall rank correlation method) is employed in order to verify the existence of trend in annual, seasonal and monthly rainfall and the distribution of the rainfall during the year. The magnitude of the trends have also been analyzed using the Sen's slope estimator. To explore the spatial distribution of trends of rainfall the detected trends were spatially interpolated using spatial analysis techniques in a GIS environment. The results show the existence of a generalized negative trend for the entire region.

Keywords: *Mann-Kendall Test, Sen Slope, Bist-doab, Lower Sutlej*

1. INTRODUCTION:

The variation in amount and duration of Indian monsoon rain was reported by many researchers (Satyanarayana and Srinivas, 2008, Vijay Kumar et.al. 2010). Significant increasing or decreasing trends in Indian monsoon precipitation led to spatial heterogeneity in precipitation (Krishnamurthy et al, 2009) and temporal variation in trends by aggregating precipitation over large areas receiving varied amounts of rainfall was reported by Goswami et.al., (2006). The spatial distribution of increasing or decreasing trends in extreme rain events across India has been well documented using a variety of statistical methods by different workers (Ghosh et al, 2011). Study conducted for whole India by Kumar et.al. (2010) indicates that in terms of percentage of mean per 100 years, Punjab and Haryana states witnessed a large increasing trend in annual rainfall. Based on duration and recurrence intervals Gill et.al. (2013) studied the spatial and temporal variation of extreme rainfall events in central Punjab and found that recent decade i.e. 2000-2012 showed much variation in rainfall extremes with highest rainfall event in 2011 and lowest during 2002. Bist-doab region of the Punjab state has been selected for the study in views of its important contribution in agricultural production for the country. The land surface of Punjab is one of the most fertile plains of India and understanding of the various hydro-climatic variables shall be very useful for future planning and management of the water resources in optimum way. With the foresaid context and view the present study was conducted to analyze rainfall data for trends or changes in the Bist-doab region of Punjab.

2. MATERIAL AND METHODS

2.1 Study Area

The study was undertaken actually for the plains of the lower Sutlej of Punjab State, which is also popularly known as Bist-doab region of Punjab. The geographic extent of the study area lies between the 30°45'-32°30'N latitude and 74°45'- 76°45'E longitude with a range of altitudinal profile of 106m in the southern to 953m in the northern part. The Punjab plains are largely flat and featureless and it is formed of Pleistocene and the sub recent alluvium deposited by the rivers of the Indo-Ganagetic system. The study area falls under nine districts of Punjab state namely Amritsar, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Moga, Nawanshehar and Rupnagar (Fig 2.1). Climate of the study area is semi-arid, hot and subtropical monsoon type with cold winter and hot summer. It is mainly influenced be the Himalayas in the North and the 'Thar' desert of Rajasthan in the south and south-west. It receives about 456 mm of average annual rainfall with huge variability in space as well as in time. About 75% of average annual rainfall is received during monsoon months. July and August are rainiest month. Agricultural in the major industry in the region, hence the majority of land use belong to agriculture land. The study area is about 13,229 km^2 up to Harike Barrage which is the confluence of the Sutlej and Beas rivers, located at downstream of Bhakra dam.

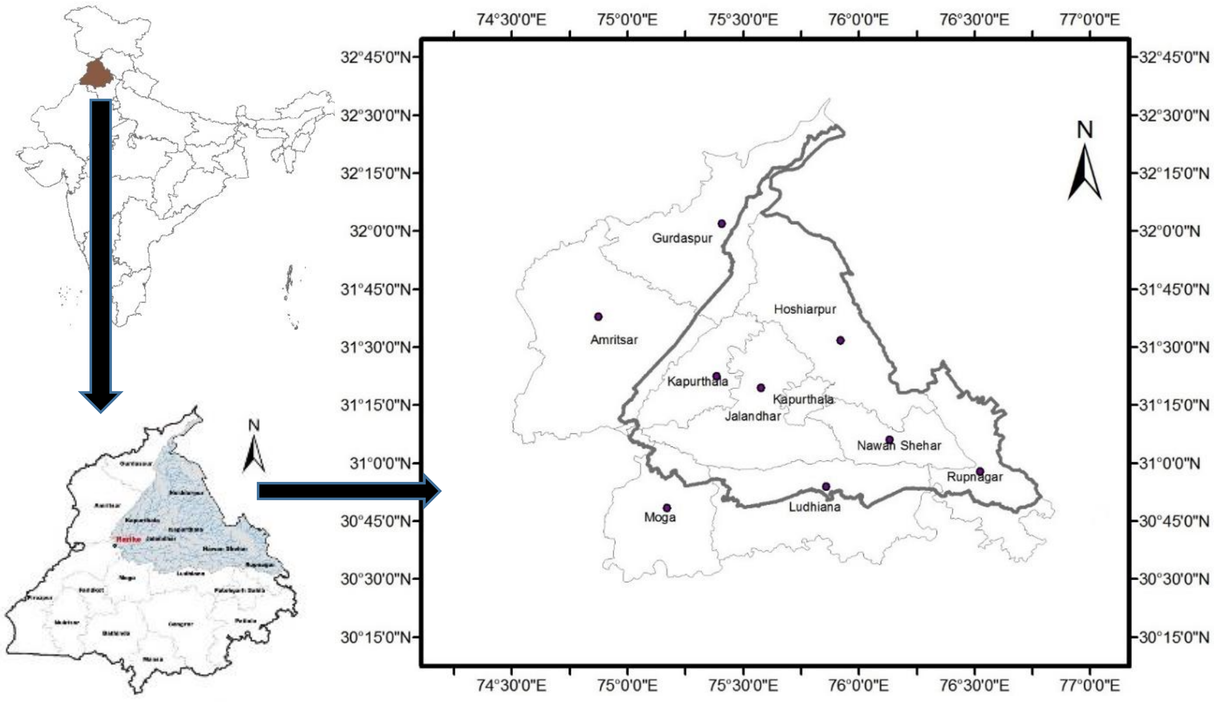

Fig 2.1 Location of the Study Area

2.2 Data used

Monthly rainfall data from 1901–2010 for nine district headquarters stations across the Bist-doab region of the Punjab state of India have been analyzed to describe any changes in annual, seasonal and monthly rainfall amount. The district-wise rainfall data was obtained by simple linear averaging from the gridded data of the CRU dataset. The data was downloaded from the India water portal (http://www.indiawaterportal.org/) which has been originally publicly available at the website of Centre of Environmental Data Archival Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia in Norwich, UK (http://badc.nerc.ac.uk).The box plot given blow (Fig 2.2) represents the major statistical characteristics such as a data set's lowest value, highest value, median value, and the size of the first and third quartile of the rainfall data () from1901-2010 for the concerned districts of the study area. It is deceptive from Fig. 2.2 that the rainfall is decreasing from northern part of the region towards the south-western part for the said study period. Vicinity of the northern parts to the Shiwaliks foot hills could be one of the reason for this. The box plots of Seasonal analysis of the entire monthly rainfall data (1900-2010) based on the three prominent and distinct seasons viz. pre-monsoon or spring season (March – May), southwest monsoon season (June – October), northeast monsoon season or winter season (from November of the last year to February of the current year) along with annual rainfall was also carried out for better interpretation and understanding of the trend.

2.3 Trend detection test

Standardized Precipitation Index (SPI) series were computed by subtracting the mean and dividing by the standard deviation of the precipitation series (Shreshtha et al. 2000; Pant and Kumar 1997). The SPI data series were then subjected to trend analyses by two established statistical techniques: standard parametric technique, such as linear trend analysis (Borgaonkar and Pant 2001) and non-parametric test, such as Mann-Kendall test (Kendall and Stuart 1961). The magnitude of the trends at all nine districts stations has also been determined with Sen' Slope estimator method (Sen, 1968). Mann-Kendall test, which is also known as Kendall's τ statistic, has been widely used to test for randomness against trend in hydrology and climatology. It is a rank-based procedure, which is robust to the influence of extremes and good for use with skewed variables.

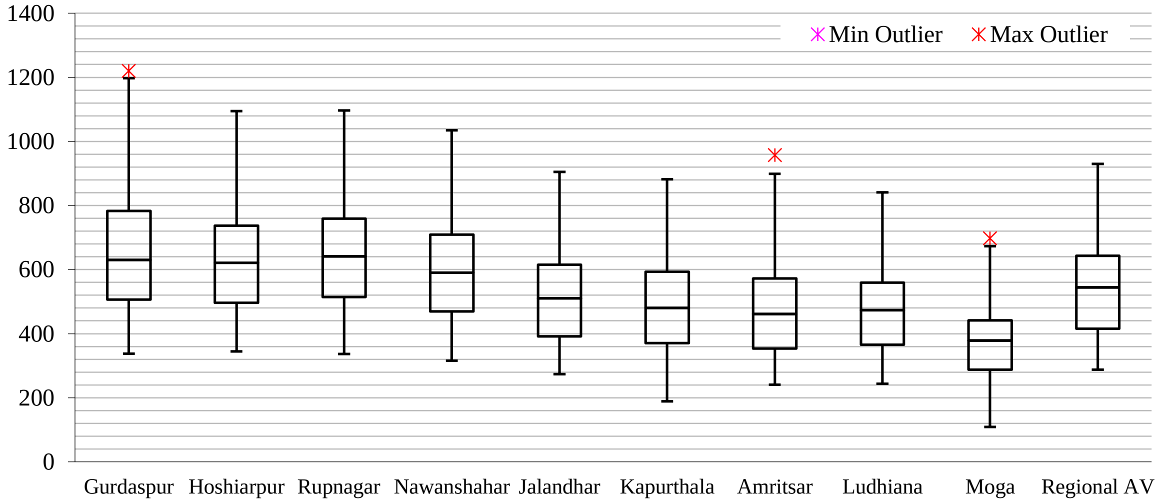

Fig 2.1 Box plot of the rainfall data (1901-2010) for districts (North to South) of study area.

Mann (1945) originally used this test and Kendall (1962) subsequently derived the test statistic distribution. This test allows to inquire on the presence of a tendency of long period in rainfall data, without having to make an assumption about its distributional properties. Moreover the non-parametric methods are less influenced by the presence of outliers in the data (Lanzante, 1996).According to this test, the null hypothesis H_0 states that the de-seasonalized data (x_1, ….., x_n) is a sample of n independent and identically distributed random variables. The alternative hypothesis H_1 of a two-sided test is that the distributions of x_k and x_j are not identical for all $k, j \leq n$ with $k \neq j$. The test statistic S, which has mean zero and a variance computed by Equation (3), is calculated using Equations (1) and (2), and is asymptotically normal (Hirsch et al. 1982):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k) \quad (1)$$

$$Sgn(x_j - x_k) = \begin{cases} +1 & if\ (x_j - x_k) > 0 \\ 0 & if\ (x_j - x_k) = 0 \\ -1 & if\ (x_j - x_k) < 0 \end{cases} \quad (2)$$

$$Var(S) = \left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5) \right] \Big/ 18 \quad (3)$$

The notation t is the extent of any given tie and $\sum_t$ denotes the summation over all ties. In cases where the sample size n > 10, the standard normal variate z is computed by using Equation (4) (Douglas *et al.*, 2000). In a two-sided test for trend, H_0 should thus be accepted if $|z| \leq z_{\alpha/2}$ at the α level of significance. A positive value of 'S' indicates an 'upward trend'; likewise, a negative value of 'S' indicates 'downward trend':

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S-1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \quad (4)$$

The Mann-Kendall test has two parameters that are of importance to trend detection. These parameters are the significance level that indicates the trends strength and the slope magnitude estimates that indicates the direction as well as the magnitude of the trend. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

2.4 Magnitude of the Trend

The magnitude of the trend in a time series was determined using a non-parametric method known as Sen's slope estimator method (Sen, 1968). This Method assumes a linear trend in the time series. In this method, the slope (T_i) of all pairs are first calculated by

$$T_i = \frac{X_j - X_k}{j-k} \text{ for i } = 1,2,3 \ldots\ldots\ldots \text{N} \quad (5)$$

Where X_j and X_k area data values at time j and k (j>k) respectively. The median of these N values of T_i is Sen's estimator of slope which is calculated as

$$\beta = \begin{cases} T_{\frac{N+1}{2}}, & N\ is\ Odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right), & N\ is\ Even \end{cases} \quad (6)$$

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

2.5 Spatial analysis of Rainfall Trends

To explore the spatial distribution of the detected trends on annual and seasonal basis, the Z - value of Mann-Kendall test was interpolated using ArcGIS 9.3 based on each stations slope value for the entire study period (1901-2010). The Spline method uses an interpolation method that estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points. The Z-value maps of the study area for annual as well seasonal rainfall trends were prepared which are useful to determine the Z statistics of Mann-Kendall test at any point location in the study area.

3. RESULTS AND ANALYSIS

3.1 Mann-Kendell Test

The results for the non-parametric Mann-Kendall (MK) test applied to ascertain the significance of trends along with the Z- values of the individual districts for monthly time series and seasonal and annual time series are shown in Table 3.1 and Table 3.2 respectively. The results indicated that, during the primary monsoon month i.e. July seven districts out of total nine districts area showing increasing rainfall at statistically significance level of more than 95% and four of them are supporting this trend at 99% significance level. This is followed by the pre-monsoon month May in which, five districts are confirming rising trend of rainfall with significance level of more than 95% and two districts out of this five are also supporting the trend at 99% significance level. The negative z-values of January and December months' time series for all the districts are depicting the decreasing trend of rainfall but without any significant level. District Gurdaspur is supporting the rising trend of rainfall in all months expect six months of January, April, June, September, November and December.

It is apparent from the results table 3.1 that the study area as a whole is supporting the rising trend Monsoon season and spring season with statistically significance level of more than 95%. Monsoon contributes around 80% of total annual rainfall, the annual rainfall series is also affirming the rising trend. The monsoon season series is having rising trend at 95% significance level for all the districts except Hoshiarpur. Five out of the nine districts have this significance level at 99%. Similarly in the spring season series, six out of nine districts are having statistically significant rising trend. Although, in the winter season series six districts are showing falling rainfall trend and three are showing rising trend, none of them are statistically significant.

Table 3.1: Z-Value of MK Test for monthly series of rainfall data

SN	District	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Amritsar	-0.34	2.05*	1.93	-0.48	2.24*	1.56	2.84**	1.94	1.44	1.96*	2.01*	-0.56
2	Gurdaspur	-0.50	2.50*	2.25*	0.31	2.64**	1.11	2.77**	2.28*	0.49	1.96*	1.56	-0.48
3	Hoshiarpur	-0.85	1.45	1.42	-0.35	1.21	0.60	2.37	0.55	-0.29	1.26	0.60	-0.55
4	Jalandhar	-0.74	1.60	1.91	-0.05	1.59	1.22	2.91**	1.61	1.08	1.41	0.31	-0.61
5	Kapurthala	-0.93	1.33	1.52	-0.45	0.75	0.20	2.65**	1.11	1.06	0.22	-0.47	-1.51
6	Ludhiana	-0.40	1.18	1.84	-0.16	2.07*	1.68	2.39*	1.26	1.44	1.88	0.92	-0.38
7	Moga	-0.49	1.21	1.59	-0.84	1.63	0.48	1.90	1.64	1.16	0.78	1.69	-0.65
8	Nawanshahar	-0.57	1.41	1.95	-0.32	2.66**	1.55	1.84	0.89	1.00	1.79	0.44	-0.42
9	Rupnagar	-0.57	1.09	2.05*	0.38	2.24*	1.42	2.33	1.59	1.06	1.03	0.44	-0.16
10	Study Area	-0.49	1.63	2.06*	0.01	2.37*	1.37	2.63**	1.81	1.08	1.88	1.37	-0.30
Significance Level: *95%; **99%; ***99.9%													

The analysis of annual series is very similar to Monsoon series, as except Hoshiarpur districts all the districts are having statistically significant upward trends. Gurdaspur district is having highest significance level of more than 99.9% for annual series. It is evident from the Table 3.1., Table 3.2 and Fig 3.1 that there are rising trend of precipitation over the last century in most of the districts of north-west Punjab state.

Table 3.2: Z-Value of MK Test for Annual and Seasonal series of rainfall

SN	District	Annual	Monsoon	Spring	Winter
1	Amritsar	3.25**	3.07**	2.07*	0.14
2	Gurdaspur	3.47***	2.99**	2.42*	1.53
3	Hoshiarpur	1.75	1.38	1.56	-0.25
4	Jalandhar	3.12**	2.81**	2.20*	-0.46
5	Kapurthala	2.51*	2.56*	1.11	-1.09
6	Ludhiana	3.07**	2.69**	2.45*	-0.09
7	Moga	2.72**	2.56*	1.32	-0.44
8	Nawanshahar	2.68**	2.17*	2.47*	-0.06
9	Rupnagar	2.96**	2.58**	2.81	0.00
10	Whole Study Area	3.07**	2.76**	2.40*	0.16
Significance Level: *95%; **99%; ***99.9%					

In order to get the study area's response the Z-values of annual and seasonal time series also have been interpolated using spline method. The Z-value maps of the study area for annual as well seasonal rainfall trends are presented in the Fig. 3.1. Z-value maps of the area are useful to determine the Z statistics of Mann-Kendall test at any point location in the study area. The annual average rainfall of the lower Sutlej is supporting the rising trend with more than 95% significance level in most of the area. The analysis of the rainfall data by parametric and non-parametric statistical test and the magnitude of trends supports the rising trend over the study area. While analysing the results presented in the various tables and figures one can easily conclude that the only winter season is not supporting any trend but the monsoon and the annual rainfall in the region has been increased over the last century.

3.2 Magnitude of trend:

The magnitude of the trend in the rainfall time series, as determined using the Sen Estimator, is given in Tables 3.3 and 3.4. The analysis of trends of rainfall variations by districts shows a large variability in the magnitude and direction of trend from one district to another. Monthly analysis of district rainfall indicated that the majority of the districts have very little or no change in non-monsoon months (Table 3.3) and the monsoon months witnessed increasing rainfall in the majority of districts.

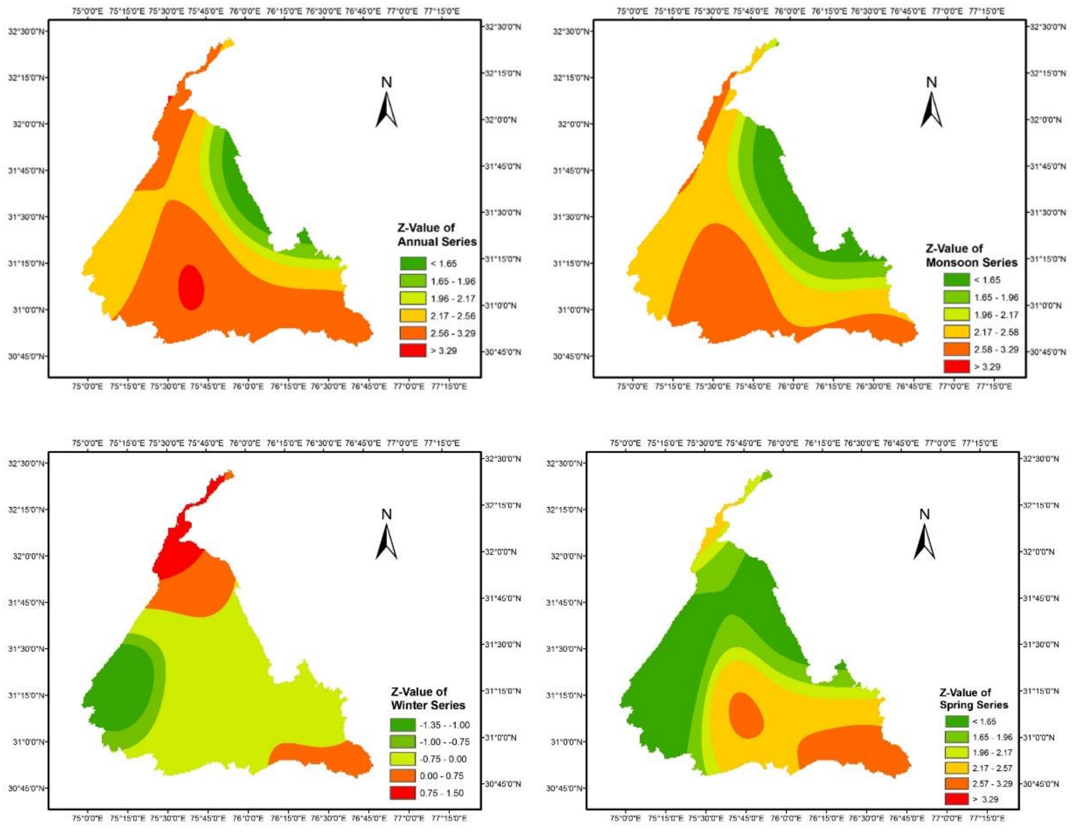

Fig 3.1 Mann-Kendall Z-Statistic for Annual, Monsoon, winter and spring rainfall trend

Table 3.3 Sen Estimator of slope (mm/year) for monthly rainfall.

SN	District	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Amritsar	-0.01	0.07	0.08	-0.01	0.07	0.13	0.66	0.36	0.21	0.02	0.00	-0.01
2	Gurdaspur	-0.03	0.14	0.11	0.01	0.09	0.13	0.82	0.53	0.08	0.03	0.00	-0.01
3	Hoshiarpur	-0.04	0.07	0.06	-0.01	0.04	0.07	0.64	0.11	-0.05	0.02	0.00	-0.01
4	Jalandhar	-0.03	0.05	0.07	0.00	0.04	0.11	0.64	0.30	0.18	0.01	0.00	-0.01
5	Kapurthala	-0.03	0.05	0.05	-0.01	0.03	0.02	0.60	0.24	0.18	0.00	0.00	-0.02

6	Ludhiana	-0.01	0.04	0.06	0.00	0.06	0.11	0.49	0.25	0.21	0.02	0.00	0.00
7	Moga	-0.01	0.03	0.04	-0.01	0.04	0.04	0.37	0.28	0.12	0.00	0.00	0.00
8	Nawanshahar	-0.03	0.06	0.07	-0.01	0.08	0.15	0.43	0.20	0.19	0.02	0.00	-0.01
9	Rupnagar	-0.03	0.05	0.08	0.01	0.07	0.15	0.56	0.34	0.21	0.01	0.00	0.00
10	Study Area	-0.02	0.07	0.08	0.00	0.07	0.11	0.59	0.33	0.17	0.02	0.00	-0.01

On analyzing the estimates of the slope (mm/year) for annual and seasonal rainfall series of all the districts (Table 3.4), it is implicit that three districts experienced decreasing rainfall in the winter season. The maximum reduction was found for Kapurthala (-0.08 mm/year). The maximum increase out of 9 districts was experienced by Gurdaspur in rainfall (1.95 mm/year annually and 1.56 mm/year Monsoon season) followed by Rupnagar (1.72 mm/year annually and 1.31 mm/year Monsoon season) and Amritsar (1.53 mm/year annually and 1.31 mm/year Monsoon season). Considering the study area as a whole, the rate of rise of rainfall over last century comes out be of an order of 1.42mm/year based on annual time series.

Table 3.4: Sen Estimator of slope (mm/year) for Annual and seasonal rainfall.

SN	District	Annual	Monsoon	Spring	Winter
1	Amritsar	1.53	1.31	0.16	0.02
2	Gurdaspur	1.95	1.56	0.23	0.17
3	Hoshiarpur	0.89	0.69	0.11	-0.03
4	Jalandhar	1.37	1.19	0.14	-0.03
5	Kapurthala	1.21	1.13	0.08	-0.08
6	Ludhiana	1.22	0.95	0.14	0.00
7	Moga	0.90	0.78	0.07	-0.02
8	Nawanshahar	1.32	0.99	0.16	0.00
9	Rupnagar	1.72	1.31	0.19	0.00
10	Whole Study Area	1.42	1.18	0.16	0.01

4. CONCLUSIONS

The understanding of spatial and temporal distribution and changing pattern of precipitation is most fundamental and primary input required for any kind of planning and management of water resources. The aim of this work was to study rainfall trend in Bist-doab region of Punjab and spatial distribution of the annual as well as seasonal and monthly precipitation series for the period of 1900-2010 were analyzed. Punjab state holds place of pride among the Indian States for its outstanding achievements in agricultural development productivity. Agricultural productivity is sensitive to global climatic changes and therefore the tracking of these changes in terms of trend is essential to generate variable predictions about impact of change in climate and variability. Most frequently used non-parametric Mann-Kendall test and simple linear regression technique was used to identify the significant trends of rainfall in this study and the magnitude of the trends were ascertained by the well-established Sen' slope estimator method. Overall annual rainfall showed increasing trend at almost all the districts with certain significance level. Average rainfall of the study area was 546mm. The highest average annual rainfall is estimated at Gurdaspur district (661mm) and lowest at Moga district (379mm). While looking at the trend analysis part the maximum increase was 1.95 mm/year and the maximum decrease was -0.08 mm/year. Over the complete study area, the annual rainfall showed an increasing trend and the rate of rise was estimated 1.42 mm/year. Seasonal analysis showed that monsoonal rainfall increased statistically significant over all districts except Hoshiarpur district. Spring rainfall increased over 6 districts with statistically significance levels. Winter rainfall at five districts showed falling trend but these are not at significance levels. The annual rainfall trends fully indorsing to the monsoon trend, which implicit the dominance of the monsoon for rainwater arability in the region. The study indicated a clear pattern of rainfall trends in the study area with less variability, this could be due to homogeneous geographic and climatic conditions of the districts falling the study area.

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