Rainfall Trend Analysis of Punjab, India using Statistical Non-Parametric Test

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ABSTRACT

Annual, seasonal and monthly variations in rainfall trend in Punjab, India for 102 years (1901–2002) were analysed using statistical non-parametric tests - the Modified Mann-Kendall (MMK) test and Sen's slope which indicated rising trend in rainfall in all the districts.

Key words: Rainfall trend, modified Mann-Kendall test, seasonal, annual, variations, Punjab.

INTRODUCTION

During the last few decades, as a result of the climate change[1] variation in rainfall pattern has drawn a lot of attention for protection of the food production and available fresh water[2]. Some rising trend of precipitation including monsoon rainfall is observed in central Asia, whereas a decrease is found in the south Asia[1]. The Indian climate is mainly characterized by monsoon rainfall which is well supported by several studies[3-6]. Major parts of India are facing decline in precipitation during the monsoon time and also the climate changes have put a massive pressure on water resources in India leading to the analysis on a large as well as regional scale. Punjab, the bread basket of the country, is also facing severe water stress due to the intensified agriculture as reported in many studies[7-32].

In this study, variations in rainfall trend in Punjab, India for 102 years (1901–2002) were analysed using statistical non-parametric tests - the Modified Mann-Kendall (MK) test and Sen's slope with an objective to examine the rainfall trend from 1901 to 2002. The rainfall trend analysis in 17 districts of Punjab will help the planners to understand the recent scenario of climate change in this area.

Study Area

The study area is Punjab which lies between (Fig. 1) 29.30° - 32.32° N latitudes and 73.55° - 76.50° E longitudes with a coverage of 50,362 sq. km. It comprises of Indo-Gangetic plains and is bordered on the west by Pakistan and surrounded by the states Jammu and Kashmir, Himachal Pradesh, Haryana and Rajasthan. Punjab is an agriculture dominated state and the crops mainly grown are rice, wheat, jowar, soybean, cotton and sugarcane. Presently, Punjab state has 20 districts and is benefitted by number of rivers namely the Sutlej, Beas, Ravi and Ghaggar.

The climate of Punjab is typically subtropical with ranging from 0°C in winters to 47°C in summers with an average annual rainfall in the range of 58 cms to 96 cms. About 80% of the rainfall is recorded in monsoon seasons (June to September); the pre-monsoon season commences from March up to May, post-monsoon in October and November, and winter from December to February.

MATERIALS AND METHODS

Monthly rainfall data of 17 districts of Punjab consisting of on a 0.5 degree latitude-longitude grid interpolated from 1901 to 2002[33] available at http://www.indiawaterportal.org/metdata has been used in this study. The raw station data from seven different sources corrected using a modified version of the Global Historical Climatology Network (GHCN) method. The seasonal analysis of rainfall was carried out for pre-monsoon (April-June), monsoon (July-September), post-monsoon (October-November) and winter season (December-March).

The magnitude of the trend in the seasonal and annual series was determined using the Sen's estimator[34] and statistical significance of the trend in the time series was analysed using Modified Mann-Kendall (MMK) test[35].

For determining the magnitude of trend in a time series Sen's estimator[34] is used which has been widely used for determining the magnitude of trend in hydro-meteorological time series[36-37]. In this method, the slopes (T_i) of all data pairs are first calculated by

$$T_i = \frac{x_j - x_k}{j - k} \qquad ...(1)$$

for i = 1,2,……..,N

where x_j and x_k are 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

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

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

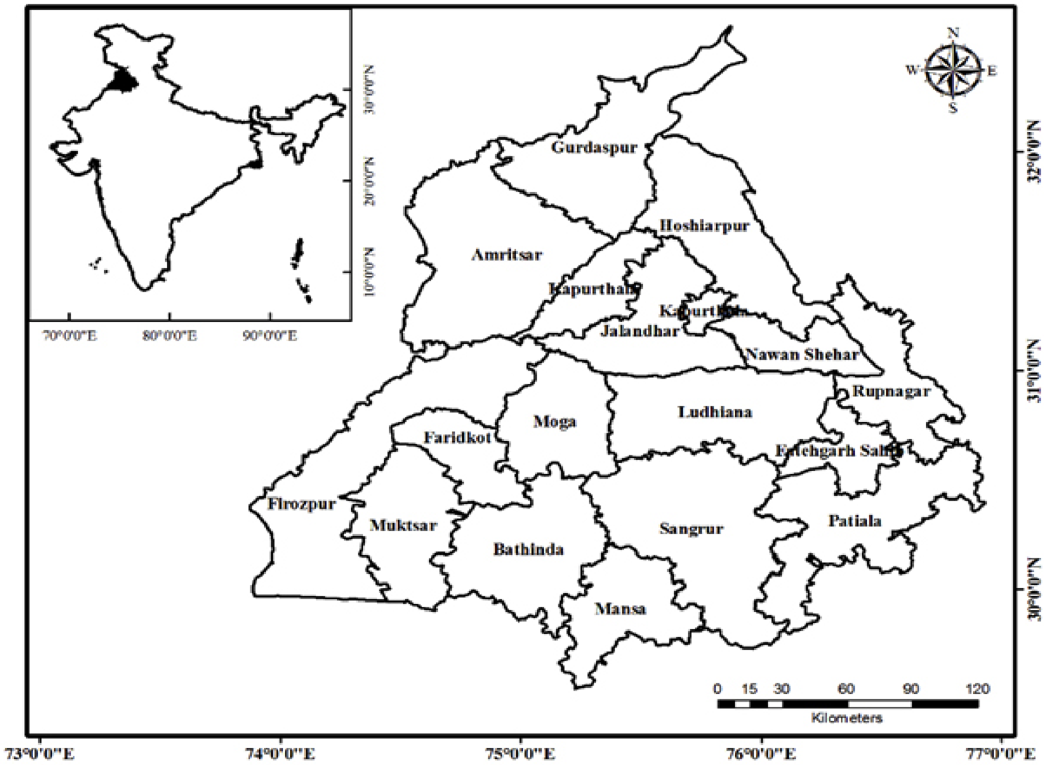

Fig. 1: Study area showing location of 17 districts

To ascertain the presence of statistically significant trend in hydrologic climatic variables such as temperature, precipitation and stream flow with reference to climate change, nonparametric Mann-Kendall (MK) test has been employed by a number of researchers[38-40]. The MK method searches for a trend in a time series without specifying whether the trend is linear or non-linear. In the present study, the MK test was also applied. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. No pre-whitening of the data series was carried out as the sample size is large ($n \geq 50$) and slope of trend was high (> 0.01)[41].

The statistics (S) is defined as[42]

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}(x_j - x_i) \qquad ...(3)$$

where N is number of data points. Assuming $(x_j - x_i) = \theta$, the value of $sgn(\theta)$ is computed as follows:

$$\operatorname{sgn}(q) = \begin{cases} 1 & f \quad q > 0 \\ 0 & f \quad q = 0 \\ -1 & f \quad q < 0 \end{cases} \qquad ...(4)$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N>10), the test is conducted using a normal distribution[43] with the mean and the variance as follows:

$$E[S] = 0 \qquad ...(5)$$

$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k (t_k - 1)(2t_k + 5)}{18} \qquad ...(6)$$

where n is the number of tied (zero difference between compared values) groups, and t_k is the number of data points in the *k*th tied group. The standard normal deviate (Z-statistics) is then computed as[44]:

Table 1: Seasonal distribution of average rainfall in different districts in Punjab

S. No	District	Annual		Pre-monsoon		Monsoon		Post-monsoon		Winter	
		Mean (mm)	CV*	Mean (mm)	% of Annual	Mean (mm)	% of Annual	Mean (mm)	% of Annual	Mean (mm)	% of Annual
1	Amritsar	469.9	0.32	49.9	10.6	364.1	77.5	9.2	2.0	46.8	10.0
2	Bhatinda	334.1	0.29	31.6	9.5	269.8	80.8	5.3	1.6	27.3	8.2
3	Faridkot	336.4	0.31	33.7	10.0	268.7	79.9	5.2	1.6	28.7	8.5
4	Fatehgarh Sahib	516.8	0.25	36.8	7.1	429.4	83.1	9.5	1.8	41.0	7.9
5	Firozpur	319.9	0.31	33.6	10.5	251.6	78.7	5.4	1.7	29.4	9.2
6	Gurdaspur	639.9	0.29	63.6	9.9	497.8	77.8	12.3	1.9	66.3	10.4
7	Hoshiarpur	634.5	0.27	54.0	8.5	509.9	80.4	11.4	1.8	59.3	9.3
8	Jalandhar	513.0	0.29	43.7	8.5	416.6	81.2	9.4	1.8	43.3	8.4
9	Kapurthala	493.9	0.30	44.1	8.9	397.3	80.5	8.8	1.8	43.6	8.8
10	Ludhiana	474.2	0.27	37.0	7.8	390.4	82.3	8.3	1.7	38.5	8.1
11	Mansa	353.3	0.29	30.0	8.5	290.8	82.3	6.1	1.7	26.4	7.5
12	Moga	384.1	0.31	35.4	9.2	308.9	80.4	7.0	1.8	32.8	8.6
13	Muktsar	302.5	0.31	31.3	10.3	240.4	79.4	4.7	1.5	26.3	8.7
14	Nawanshahr	595.4	0.26	44.2	7.4	488.7	82.1	10.9	1.8	51.6	8.7
15	Patiala	525.8	0.24	37.3	7.1	437.0	83.1	10.2	1.9	41.4	7.9
16	Roopnagar	637.0	0.24	44.3	6.9	526.8	82.7	11.8	1.9	54.1	8.5
17	Sangrur	405.3	0.28	33.7	8.3	332.8	82.1	7.1	1.7	31.7	7.8

*CV = coefficient of variation

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & f \quad S > 0 \\ 0 & f \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & f \quad S < 0 \end{cases}$$
...(7)

If the computed value of %Z%> $z_{\alpha/2}$, the null hypothesis (H_o) is rejected at á level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% confidence level.

Trend analysis using the MMK test

In this method, the effect of all significant autocorrelation coefficients is removed from a dataset[45]. For this purpose, a modified variance of S, designated as Var(S)*, was used as follows:

$$Var(S) = \frac{n}{n^*}$$
...(8)

where n* = effective sample size. The n/n* ratio was computed directly from the equation proposed by Hamed and Rao[45] as

$$n/n^* = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n} (n-i)(n-i-1)(n-i-2) r_i$$
...(9)

where n = actual number of observations, and r_i = lag-i significant autocorrelation coefficient of rank i of time series. Once Var(S) * was computed from Eq. (8), then it was substituted for Var(S) in Eq. (7). Finally, the Mann-Kendall Z was tested for significance of trend, comparing it with threshold levels, i.e. 1.645 for 10 %, 1.96 for 5 % and 2.33 for 1 % level of significance.

RESULTS AND DISCUSSION

Temporal and spatial distribution of rainfall

The rainfall characteristics showing mean seasonal, mean annual and coefficient of variation of the annual rainfall of different districts of Punjab are reported in Table 1. It is evident from Table 1 that Gurdaspur district received the maximum mean annual rainfall (639.9 mm) whereas Muktsar district received the minimum mean annual rainfall (302.5 mm). The contribution of monsoon rainfall varies from 77.5 % (Amritsar) to 83.1% (Fatehgarh Sahib and Patiala). The coefficient of variation (CV)

Table 2: Percent change in magnitude of rainfall in different districts in Punjab using Sen's slope

S. No.	District	Change									
		Annual		Pre-lMonsoon		Monsoon		Post-Monsoon		Winter	
		β	%	β	%	β	%	β	%	β	%
1	Amritsar	1.46	31.67	0.16	33.38	1.22	34.27	0.04	44.49	-0.02	-3.44
2	Bhatinda	1.23	37.74	0.13	42.35	1.03	39.17	0.03	56.28	0.03	11.16
3	Faridkot	1.07	32.35	0.10	30.23	0.91	34.40	0.02	43.93	0.01	3.10
4	Fatehgarh Sahib	1.14	22.58	0.13	35.50	0.92	21.74	0.03	35.20	-0.03	-7.00
5	Firozpur	0.92	29.45	0.10	29.57	0.79	31.82	0.02	44.29	0.01	3.21
6	Gurdaspur	1.42	22.68	0.22	35.31	0.95	19.54	0.05	42.40	-0.01	-1.71
7	Hoshiarpur	1.11	17.91	0.17	31.65	0.80	15.95	0.04	35.74	-0.03	-5.38
8	Jalandhar	1.20	23.86	0.14	33.61	0.97	23.70	0.04	41.29	-0.04	-8.62
9	Kapurthala	1.27	26.23	0.15	34.05	1.03	26.54	0.04	40.70	-0.03	-7.55
10	Ludhiana	1.20	25.90	0.13	35.02	0.97	25.23	0.03	41.53	-0.03	-7.22
11	Mansa	1.11	32.04	0.11	36.64	0.88	30.74	0.03	47.50	0.01	3.87
12	Moga	1.39	36.88	0.12	35.89	1.15	38.08	0.03	48.60	0.00	-0.82
13	Muktsar	0.82	27.78	0.09	28.54	0.66	27.90	0.02	46.40	0.02	6.86
14	Nawanshahr	1.02	17.54	0.15	33.58	0.72	15.08	0.03	29.61	-0.04	-7.71
15	Patiala	1.20	23.28	0.14	39.20	0.91	21.34	0.04	35.82	-0.03	-7.45
16	Roopnagar	0.86	13.80	0.15	34.77	0.63	12.25	0.02	21.25	-0.04	-7.48
17	Sangrur	1.35	33.88	0.13	37.87	1.11	33.97	0.03	48.01	0.00	0.00

of the annual rainfall varies from 24% (Patiala and Roopnagar to 32% (Amritsar).

The percent change in distribution of rainfall in all districts of Punjab is shown in Table 2 indicating a positive change in all the districts in annual, pre-monsoon, monsoon, post-monsoon seasons and in 7 districts in winter season. Similar results were obtained for Punjab by Kumar et al. (2010)[46] but negative trend in north India were observed by Chhabra et al. (2014).

Rainfall trends

The magnitude of the trend in annual and seasonal rainfall as determined using the Sen's estimator is given in Table 2. Trends of rainfall variations show that annual and seasonal rainfall (except winter season in Amritsar, Fatehgarh Sahib, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Moga, Nawanshahr, Patiala and Roopnagar) increased over all districts but the magnitude of trend varies from one district to another. The increase in annual rainfall over different districts varied between 1.459 mm/year (for Amritsar district) to 0.824 mm/year (for Muktsar district) with an overall average of 1.164 mm/year. Further, the increase was, in general, higher for the districts in north-west and the least for the districts in south-west which implies that the rainfall variability in the State is likely to increase in the future.

As evident from table 2 that the rainfall increased in pre-monsoon, monsoon and post-monsoon in all the districts and in winter season in some districts (Bhatinda, Faridkot, Ferozepur, Mansa, Muktsar and Sangrur). In the monsoon season, the maximum increase is of the order of 1.223 mm/year for Amritsar and minimum increase is for Muktsar district (0.632 mm/year). All the districts have shown the same direction of trend for annual and monsoon rainfall, perhaps because the monsoon season has the major contribution of annual rainfall. The decreasing trend in winter season rainfall is found to vary from -0.040 mm/year (Roopnagar) to -0.003 mm/year (Moga).

The Modified Mann-Kendall (MMK) z-test (10%, 5% and 1% level of significance) applied to annual and seasonal rainfall over different districts. The annual and seasonal rainfall at 10% and 5% level was found non-significant in all the districts. The results of MMK z-test at 1% level are shown in Table 3 which indicates that the majority

Table 3: Modified Mann Kendall (MMK) Z-test for significance of trend (1% level)

S. No	District	Annual	Pre-monsoon	Monsoon	Post Monsoon	Winter
1	Amritsar	S*	NS **	S	NS	NS
2	Bhatinda	S	S	S	NS	NS
3	Faridkot	S	NS	S	NS	NS
4	Fatehgarh Sahib	S	NS	NS	NS	NS
5	Firozpur	S	S	S	NS	NS
6	Gurdaspur	NS	S	NS	NS	NS
7	Hoshiarpur	NS	NS	NS	NS	NS
8	Jalandhar	S	S	S	NS	NS
9	Kapurthala	S	S	NS	NS	NS
10	Ludhiana	S	NS	S	NS	NS
11	Mansa	S	NS	S	NS	NS
12	Moga	S	S	S	NS	NS
13	Muktsar	S	NS	NS	NS	NS
14	Nawanshahr	NS	NS	NS	NS	NS
15	Patiala	S	NS	NS	NS	NS
16	Roopnagar	NS	NS	NS	NS	NS
17	Sangrur	S	S	S	NS	NS

S*= significant, NS**=non-significant

of districts show significant trend in annual, pre-monsoon and monsoon seasons rainfall. Out of the 17 districts studied, annual rainfall of only four districts (Gurdaspur, Hoshiarpur, Nawanshahr and Roopnagar) showed non-significant trend. Monsoon rainfall also indicated positive significant trend for 9 districts while decreasing trend found in eight districts (Fatehgarh Sahib, Gurdaspur, Hoshiarpur, Kapurthala, Muktsar, Nawanshahr, Patiala and Roopnagar). The increasing trend in pre-monsoon rainfall was found significant for 7 districts. The rainfall in post-monsoon and winter season was found non-significant for all the districts.

CONCLUSIONS

The trend detection analysis of rainfall for 17 districts of Punjab has indicated an increasing rainfall trends in annual, monsoon, pre-monsoon and post-monsoon seasons. However, MKK test indicates that the rainfall trend has been observed only in annual, monsoon and pre-monsoon seasons at 1% level of significance. Winter rainfall is found decreasing in 11 districts. In future, the variability of rainfall is likely to increase in Punjab. Rainfall has a rising trend at some districts in south-west Punjab namely Bhatinda and Moga which currently receive low annual rainfall. The increasing trend in annual and monsoon rainfall was found statistically significant in 11 and 9 districts, respectively. Although the rainfall in post-monsoon and winter season was found to be non-significant for all the districts, any reduction in winter rainfall will result in exploitation of groundwater for irrigating the Rabi crops.

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