The Pharma Innovation Journal 2022; SP-11(2): 348-357

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(2): 348-357

www.thepharmajournal.com
Received: 17-12-2021
Accepted: 20-01-2022

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Assessment of climatic variability over the Rajasthan state using Mann-Kendall test

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Abstract
Assessment of climate variability and change is required for impact assessment (to estimate variations which are likely to occur) and for policy development (to recommend possible solutions). Climatic variables such as temperature and rainfall determine the water availability, soil moisture availability, humidity evaporation and evapotranspiration etc. Present work carried out to study the statistical characteristics of rainfall (Monthly, Seasonal and Annual Rainfall) and temperature (monthly maximum and minimum temperature) over Rajasthan, India (1901–2002), which were examined using Mann-Kendall (MK) and Sen's slope estimator statistical tests. From statistical test results, it can be concluded that there is evidence of some change in the trend of rainfall of the Rajasthan. The maximum variation in the temperature was found in the minimum temperatures where both significant increase and decrease were observed in different regions.

Keywords: evaporation, climate, Mann-Kendall (MK), Sen's slope

Introduction
Climate is the long-term average weather conditions for a particular region. Over the recent past few centuries, the climate of the earth has varied significantly in terms of average weather conditions positively as well as negatively. Such significant variations in climatic conditions are referred to as 'climate change' (Ministry of Environment and Tourism, 2003). Climate change is one of the most important global environmental issues. It has been distinct from natural climate variability in terms of natural as well as anthropogenic activities which affects the composition of the earth atmosphere. Climate change can lead to various phenomenon i.e., desertification, intense storms, extreme events, melting of the polar ice caps, rising sea levels etc. United Nation Framework Convention on Climate Change (UNFCCC) defines climate change as: "A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Many climate change studies have been carried out in Indian context. As per these studies the annual mean surface air temperature rise by the end of the century ranges from 3.5°C to 4.3°C and significant changes in the frequency of natural disasters such as droughts, floods and cyclones are expected to take place. However, the impacts of climate change will not be uniform throughout India because of the differences in level of exposure to the impacts of climate change, differences in the vulnerability of people and their adaptive capacity to deal with the changes in the climate. Among the many sectors in India, the impacts of climate change on the agricultural sector has received considerable attention because of its high level of susceptibility to small changes in the climate and associated negative impacts on the people, especially, the poor and marginalized groups who are dependent on agriculture and allied activities for their livelihood. In India, 80% of annual rainfall comes from southwest monsoon, and very important for the whole country, especially for the low rainfall belts like Rajasthan state. Any kind of deficiency in monsoon, mostly because of climate change causes higher frequencies of droughts in these areas as high as once in every four years.

Changes in the global temperature and rainfall pattern have raised concern regarding the present and possible future conditions. The Intergovernmental Panel on Climate Change (IPCC) predicts that hot extremes, heat waves, and heavy precipitation are becoming more frequent in some regions in the world, and that Subtropical regions are likely to receive less rainfall due to climate change. The main characteristics of climate change are increases in average global temperature (global warming); changes in cloud cover and precipitation particularly over land; melting of ice caps and glaciers and reduced snow cover; and increases in ocean temperatures and ocean acidity – due to sea water absorbing heat and carbon dioxide from the atmosphere. Changes in the global temperature and rainfall pattern are likely to lead to severe water shortages and/or flooding and can cause melting of glaciers, flood, drought, soil erosion. Rising temperatures will cause shifts (changes) in crop growing seasons which affects food security and changes in the distribution of disease vectors putting more people at risk from diseases such as malaria and dengue fever. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) [2] dispelled many uncertainties about climate change. Warming of the climate system is now undeniable.

Various states of India also suffers the climate change hazards like drought and desertification , especially Rajasthan is the most affected zone in the Indian Territory. Various researchers had found the results regarding the water scarcity and desertification (Houérou, 1996 ; Costa and Soares, 2012; Hillel and Rosenzweig, 2002; Sivakumar 2007; Eslamian & Eslamian, 2017) [12, 3, 9, 17, 6] due to global climate change. According to Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC-AR4) the world indeed has become more drought prone with higher frequencies of extreme events (IPCC REPORT, 2007) [2]. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events (Meehl *et al*. 2007) [14].

In the context of Rajasthan, nearly 61% of the geographical area falls under arid/ semi-arid zone. Rajasthan is the most sensitive place which affected by climate change. Pant and Hingane, (1988) [15] studied the annual surface temperature and annual rainfall conditions over the north western region of India encompassing Rajasthan. They concluded that during the study period (1901-1982) annual surface temperatures declined and annual as well as monsoonal rainfall conditions increased, thus contradicting the research done by Winstanley (1973) [19]. Thar Desert in western Rajasthan is characterized by low and erratic rainfall, high air and soil temperature, intense solar radiation and high wind velocity. Context-specific interactions of these factors give rise to frequent droughts and famines. So we have conducted a study on Assessment of climatic variability over the Rajasthan state using Mann-Kendall test.

Material and Methods

Rajasthan is the largest state in the country and covers about 3, 42,000 square kilometers area. It is divided into 33 districts and is located between 69°30' to 78°17'E longitude and 23°30'to 30°12' N latitude. It stretches in two of India's major physiographic divisions, namely the Great Plains (Indian Desert) and the Central Highlands. Geologically, the state can be broadly divided into three natural regions, *viz*. (i) Aeolian sands (ii) Alluvium and (iii) Aravallis.

Statistical Analysis

The knowledge of statistics could be utilize efficiently in the field of hydrology, because hydrological events are highly erratic, random and complex in nature and are not dependent on physical and chemical laws, but completely depends on nature. They cannot be computed exactly by using any definite relationship, but can be predicted from historical data with the application of statistical tools. The various statistical properties evaluated include:

a) Arithmetic mean

Arithmetic mean is the measure of central tendency of given data. The following formula has been used for computing arithmetic mean is given below:

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N} \qquad (3.1)$$

Where

$\bar{X}$ =Arithmetic mean of given data

Xi = Event data

N = Total number of data used

I= event number.

b) Standard deviation

Square root of the mean square deviation is the standard deviation. The following formula has been used for computation of standard deviation:

$$\sigma = \sqrt{\frac{(x-\bar{x})^2}{N-1}} \qquad (3.2)$$

Where,

σ = Standard deviation

$\bar{x}$ = Mean of the rainfall data

N= Total no. of rainfall data

c) Coefficient of variance (Cv)

It is an important dispersion parameter for determining the variation amongst observations. It is computed as the ratio of standard deviation to the mean of given data. It is dimensionless statistical parameter, expressed in %.

$$CV = \frac{\sigma}{\mu} \times 100 \qquad (3.3)$$

Where,

μ = Mean of the given data

σ = Standard deviation

Trend Analysis

There are several approaches for detecting the trend in the time series. These approaches can be either parametric or non-parametric. Parametric methods assumed that the data should be normally distributed and free from outliers. On the other hand, non-parametric methods are free from such assumptions. The most popularly used non-parametric tests for detecting trend in the time series is the Mann-Kendall (MK) test.

It is widely used for different climatic variables. For original Mann-Kendall test, the time series must be serially independent in nature. However, in many real situations, the observed data are serially dependent (i.e., auto-correlated). The autocorrelation in the observed data will results in miss-interpretation of trend test results. Cox and Stuart stated that “positive serial correlation among the observations would increase the chance of significant answer, even in the absence of a trend”.

a) Mann Kendall (MK) Test

Mann Kendall test is a non-parametric statistical test widely used for the analysis of trend in climatologic and in hydrologic time series. The Mann-Kendall test has been employed by number of researchers (Taylor and Loftis 1989; Yu *et al*. 1993; Douglas *et al*. 2000; Yue *et al*. 2003; Burn *et al*. 2004) [18, 21, 5, 22, 4] to detect monotonic (increasing or decreasing) trends and is widely used for detecting trends in time series because it is simple and robust, accommodates missing values, and the data need not conform to any statistical distribution (Libiseller and Grimval 2002; Gibert 1987) [13]. Mann-Kendall test is useful because its statistic is based on the (+ or −) signs rather than the values of the random variables therefore, the trends determined are less affected by the outliers (Helsel and Hirsch 1992; Birsan *et al*. 2005) [8, 1].

The Mann-Kendall test statistic S is calculated using the formula:

$$\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} \operatorname{sgn}(x_j - x_i) \quad (3.4)$$

Where, sgn

$(x_j - x_i) =$ 1 if $(x_j - x_i) > 1$

0 if $(x_j - x_i) = 1$

-1 if $(x_j - x_i) < 1$

And N is the number of data points. This statistics represents the number of positive difference minus the number of negative difference for all the differences considered. For large sample size i.e. (N>10), the test is conducted using a normal distribution (Helsel & Hirsch, 1992) [8] with the mean and variance as follows:

$$E(S) = 0$$

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \quad (3.5)$$

Where, n is the number of data points.

However, if ties exist in the dataset then the expression for Var(S) has to be adjusted and becomes:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p-1}^{q} t_p(t_p-1)(2t_p+5)}{18} \quad (3.6)$$

Where, variable q and t_p in the above equation are number of tied groups and number of data values in the p^th group.

The test statistics Z is calculated as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{var}(S)}} \, if S > 0 \\ 0 \, if S = 0 \\ \frac{S+1}{\sqrt{\operatorname{var}(S)}} \, if S < 0 \end{cases} \quad (3.7)$$

If Z > +1.96 or Z < -1.96, the null hypothesis is rejected at 95% significance level.

b) Magnitude of trend

To identifying whether the trend exists the magnitude of the trend was also estimated by a slope estimator or β, which was extended by Hirsch *et al*. (1982) [10] from that proposed by Sen (1968) [16].

The Sen's slope estimator is non-parametric, linear slope estimator that work most effectively on monotonic data. Unlike linear regression, it is not greatly affected by gross data errors, outliers, missing data. The Sen's slope technique is used to determine the magnitude of the trend line. The approach involves computing slopes for all the pairs of ordinal time points using the median of these slopes as an estimate of the overall slope.

A positive value of β or trend indicates an upward trend, while a negative value of β indicates a downward trend (Xu *et al*. 2007; Karpouzos *et al*. 2010) [20, 11].

Sen's method proceed by calculating the slope as a change in measurement per change in time.

$$Q = \frac{R_i - R_i'}{i' - i}$$

Where, Q = slope between data points R'_i and R_i

R'_i= data measurement at time i'

R_i = data measurement at time i

i' = time after time i

sen's estimator of slope (Q') is computed as

Q' = Q ((N+1)/2) if N is odd

Q' = (Q (N/2) + Q ((N +2)/2))/2 if N is even

At the end Q' is computed by two sided test at 100 (1-α) % confidence interval and then a true slope can be obtained by the non-parametric test.

Results and Discussion

Statistical Characteristics of Monthly, Seasonal and Annual Rainfall

Basic statistical attributes of annual and seasonal (monsoon, pre-monsoon, post-monsoon and winter) rainfall events for the whole period of 102 years (1901–2002) of Rajasthan, such as mean, standard deviation (SD) and coefficient of variations (CV), were analyzed (Table 1). The mean and SD of the annual rainfall data of different districts varied from 185.07 to 942.23 mm and 86.53 to 258.39 mm, respectively. In case of seasonal rainfall, these values during pre-monsoon period varied from 9.80 to 28.89 mm and 8.47 to 24.22 mm respectively, during monsoon period the values varied from 161.28 to 899.28 mm and 79.72 to 261.09 mm respectively, during post monsoon period from 3.47 to 42.05 mm and 4.41 to 39.71 mm respectively and during winter the from 4.10 to 23.07 mm and 5.26 to14.36 mm respectively. These values indicate that the regions with high rainfall have less variability than the regions with relatively lower rainfall. The analysis of annual and seasonal rainfall records showed that the maximum rainfall was 1616.819 mm in Dungarpur during the year 1944, and minimum rainfall of 44.643 mm in Jaisalmer in 1969.

Trend Analysis

The Mann-Kendall and Sen's slope estimator has been used for the determination of the trend. The trend analysis is carried out for all the district of Rajasthan by using monthly, average annual and seasonal (Monsoon, Post monsoon, Pre-monsoon and winter) rainfall data. The brief details of the results are presented in the subsections.

Mann-Kendall test of rainfall series

a) Monthly trends

Table 2 shows the Z statistic values of rainfall of the selected stations in the monthly time scales using the MK test. MK test showed that approximately 27% of cases were having negative trend (either statistically significant or insignificant), and all remaining cases showed positive trend. In the monthly time scale, results indicated that 4 out of 384 cases showed statistically significant negative trend at the 10% level by using the MK test. In contrast, 37 cases showed statistically significant positive trends at the 10% level. It showed that in a monthly time scale the number of positive trends were much more pronounced than the negative trends in rainfall series.

b) Seasonal and annual trends

For the period 1901–2002, Table 3 shows the Z statistic values for the rainfall time series of the selected stations in the seasonal (monsoon, post monsoon, summer and winter) and annual time scales by using the MK test. In the seasonal time scale, all stations exhibited increasing trends in rainfall in post monsoon seasons. For pre-monsoon seasons all the stations showed positive trends except four stations. Strong positive trends in rainfall dominated primarily in post monsoon and pre-monsoon seasons. In monsoon, none of the districts were showed significant increasing and decreasing trend. Using MK test, ten stations were found to have decreasing insignificant trends in monsoon. MK test showed that fifteen stations had increasing significant trend in post monsoon and rest of the station had insignificant increasing trends.

In pre-monsoon, 11 stations showed significant trends. Notably, only Udaipur, Sirohi, Dungarpur and Banswara showed a decreasing insignificant trend in pre-monsoon seasons. In winter, all the station showed insignificant trends. In annual time scale, only three stations showed significant trends and rest of the stations showed insignificant trend (both positive and negative). Using the MK test, twenty one out of thirty two stations showed insignificant increasing trends, and only eight stations showed insignificant decreasing trend. Therefore, it may be concluded that the number of insignificant decreasing trends reduced considerably.

Trend Analysis of Magnitude of Rainfall Series

a) Monthly trends

Figure 1 shows the box plot of Theil-Sen's slopes of rainfall time series in a monthly time scale over Rajasthan, India. Notably, the line inside the boxes represents the median; however, the upper and lower lines of the boxes indicate the 75th and 25th percentile, respectively. Furthermore, the upper and lower parts of the whiskers (vertical lines) indicate the respective maximum and minimum values of the slopes of the rainfall time series. According to Fig. 1, medians of the only 1-month (September) slope is negative. This implies that the trend lines having the steepest negative slope during September. From the fig.4.1 it is noticed that the trend line has 0 slope during January, February, March, April, Novemeber and December which indicate that there is not trend during these months.

b) Seasonal and annual trends

For the period 1901–2002, Fig. 4.2, shows the box plot of slopes estimated in seasonal and annual time scales. According to Fig.4.2, the medians of slopes for all seasons and annual time scale are located above the zero line. The median of slopes in winter is lower compared with the other seasons. Table 3 shows the magnitude of trend for annual and seasonal rainfall series. In the annual rainfall series, the magnitude of the positive (increasing)trend fallin the range of 0.102 at Bikaner station to 1.343 at Alwar station. The magnitude of negative (decreasing) trend is found in the range of -1.345 at Dungarpur station to -0.013 at Chittaurgarh station. As expected, rainfall trends show large variability in magnitude and direction of trend from one station to another. All the stations have positive value of the Sen's estimator for the post monsoon seasons. In winter season out of thirty two stations sixteen stations showed negative trends and only twelve stations showed positive trend.

Trend analysis of long term Temperature series

In order to look into the climate change occurring in the state, Mann-Kendall trend test was conducted for monthly maximum and minimum temperature. The significance level of trends were identified and mapped. This enabled the identification of spatial variation in degree of climate change occurring in Rajasthan. Figure 3 shows the increasing and decreasing trend of maximum and minimum temperature being mapped for the different districts in four categorized season.

During the pre-monsoon and post-monsoon months entire Rajasthan had experienced a rising trend in maximum temperature as well as in minimum temperature. during the post monsoon months Jaisalmer, Jodhpur, Barmer, Jalor, Sirohi, Pali, Rajsamand, Udaipur, Dungarpur, Banswara, Chittaurgarh, Bhilwara, Bundi, Kota, Jhalawar, Baran, Dholpur districts have shown significant increase in trend of minimum temperature. During monsoon season all districts except Banswara and Jaisalmer showed decreasing trend in minimum temperature. During winter only Jaipur district experienced negative trend in maximum and minimum temperature.

The Mann-Kendall Z statistics values are presented in Table 4 and Table 5 for annual and seasonal temperature (maximum and minimum).

The highest value of the Mann-Kendall statistic Z were observed in the western part of the Rajasthan. For annual trend analysis Banswara district showed the maximum positive significant trend in the minimum temperature with a Mann- Kendall Z value of 4.66. The Western side of Aravali ranges experienced a rather steeper temperature rise than the eastern half.

During the pre-monsoon the 17 out of 32 districts have shown significant increase in trend in minimum temperature and 18 out of 32 district showed significant rising trend in maximum temperature. The Mann-Kendall Z value for these districts ranges between 1.09 to 3.56.

During the monsoon except Jaisalmer and Banswara districts entire Rajasthan has experienced a negative trend in maximum and minimum temperature which is reflected from Z values which vary from -3.16 to -0.15. Overall 15 districts have shown significant declining trend in maximum and minimum temperature. None of the districts during monsoon experienced significant rising trend.

During the post monsoon period entire Rajasthan experienced increasing trend in minimum as well as maximum temperature. The highest Z statistics value has been observed in Banswara district.

During winter months most part of the Rajasthan were found to have experienced an increasing trend in maximum and minimum temperature conditions except for Jaipur where, a declining trend, with a Mann-Kendall Z values of -0.38 in minimum temperature condition and -0.48 in maximum temperature condition, was observed.

Table 1: Statistics of rainfall for different districts of Rajasthan (1901-2002)

Station	Mean					Standard deviation (SD)					Coefficient of variation (CV)				
	A	PM	M	PoM	W	A	PM	M	PoM	W	A	PM	M	PoM	W
Alwar	608.8	24.9	546.4	14.4	23.1	173.2	19.5	167.8	16.0	14.4	28.4	78.2	30.7	111.7	62.2
Udaipur	790.7	15.0	745.4	23.0	7.3	233.0	14.1	233.8	27.0	8.4	29.5	94.4	31.4	117.5	114.2
Tonk	636.7	17.1	589.3	20.1	10.3	174.9	13.5	169.7	20.2	7.2	27.5	78.9	28.8	100.6	70.3
Sirohi	609.7	12.3	573.1	16.6	7.7	243.4	16.6	240.7	23.6	10.3	39.9	135.1	42.0	141.8	134.2
Ajmer	537.4	18.9	491.7	17.7	9.1	184.1	16.4	177.0	20.4	8.5	34.3	86.8	36.0	115.0	92.5
Sikar	472.5	24.7	418.9	11.6	17.3	155.3	20.6	145.5	13.0	13.3	32.9	83.4	34.7	112.2	76.8
Swaimadhopur	723.0	17.1	671.7	20.7	13.6	179.9	12.6	175.8	20.5	8.4	24.9	73.6	26.2	98.8	62.1
Rajsamand	610.8	20.1	557.5	23.3	9.9	198.9	18.3	195.0	28.2	10.1	32.6	91.1	35.0	121.1	101.8
Pali	522.1	16.1	482.1	17.1	6.8	199.8	16.6	193.5	22.0	7.2	38.3	103.4	40.1	128.3	106.2
Nagaur	411.4	21.8	366.9	12.0	10.8	159.4	20.8	148.7	14.6	10.8	38.7	95.5	40.5	122.5	100.7
Kota	803.7	11.9	744.6	35.5	11.8	178.0	9.8	173.6	32.3	8.6	22.2	82.3	23.3	91.0	73.4
Karauli	759.3	18.2	705.0	20.1	16.1	187.7	13.3	184.7	20.3	9.8	24.7	73.3	26.2	101.2	60.8
Jodhpur	314.7	17.3	280.2	9.6	7.6	128.0	17.7	120.5	12.6	9.3	40.7	102.5	43.0	131.1	122.1
Jhunjhunu	456.1	26.1	400.0	10.2	19.8	146.2	21.2	137.5	11.7	13.7	32.0	81.2	34.4	115.1	69.2
Jhalawar	912.7	10.0	848.9	42.0	11.8	200.2	8.5	195.8	39.7	10.5	21.9	84.6	23.1	94.5	89.5
Jalor	447.6	10.5	418.5	13.7	4.9	185.6	14.5	182.0	19.5	6.0	41.5	137.7	43.5	142.6	123.3
Jaisalmer	185.1	10.9	161.3	4.1	8.8	86.5	10.0	84.3	5.8	9.4	46.8	92.1	52.3	140.6	107.0
Hanumangarh	304.4	28.9	251.8	4.7	19.0	105.2	21.7	95.7	5.5	14.1	34.6	75.0	38.0	115.2	74.1
Ganganagar	234.5	28.2	186.7	3.5	16.2	89.8	22.4	79.7	4.4	13.9	38.3	79.3	42.7	127.0	85.9
Dungarpur	917.1	12.9	875.9	23.4	4.9	258.4	14.2	261.1	30.2	7.3	28.2	109.9	29.8	128.9	149.2
Dholpur	778.0	18.0	721.9	19.9	18.3	198.2	13.3	196.6	20.4	11.1	25.5	74.1	27.2	102.6	60.9
Jaipur	583.1	22.3	530.3	14.6	15.9	181.8	18.3	173.9	15.8	12.0	31.2	82.2	32.8	108.3	75.7
Dausa	671.2	20.3	617.8	17.0	16.1	187.6	15.9	181.8	17.9	10.9	27.9	78.5	29.4	105.5	67.5
Churu	354.7	28.1	303.4	6.8	16.4	130.6	23.8	118.8	7.8	13.2	36.8	84.5	39.2	113.3	80.7
Chittaurgarh	809.0	14.7	752.4	34.7	7.3	202.0	12.3	199.2	32.9	6.2	25.0	83.6	26.5	94.8	86.0
Bundi	731.3	14.5	675.5	30.7	10.7	177.7	11.9	172.7	29.0	7.6	24.3	82.3	25.6	94.5	70.7
Bikaner	255.5	26.0	213.6	4.2	11.7	108.5	24.2	97.0	5.4	11.7	42.5	93.3	45.4	127.6	100.1
Bhilwara	627.5	18.0	573.9	27.3	8.2	190.6	15.6	184.9	29.2	7.1	30.4	86.7	32.2	106.8	86.3
Bharatpur	698.2	21.6	640.2	15.8	20.6	191.6	16.6	188.6	17.5	12.3	27.4	76.8	29.5	110.6	59.8
Barmer	287.6	9.8	262.3	10.7	4.9	129.6	11.3	124.7	16.0	5.8	45.1	115.7	47.6	149.6	118.1
Baran	825.5	11.1	767.9	32.8	13.7	175.1	8.6	171.8	30.4	10.1	21.2	77.2	22.4	92.7	73.5
Banswara	942.2	10.2	899.3	28.6	4.1	227.9	9.0	230.0	30.2	5.3	24.2	88.3	25.6	105.4	128.4

Where, A=Annual; PM=Pre-Monsoon; M=Monsoon; PoM=Post-Monsoon; W=Winter

Table 2: Z statistics values of monthly rainfall using MK test for Rajasthan (1901-2002)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alwar	-0.211	0.734	1.391	0.600	2.758	2.128	0.703	1.746	-0.492	1.849	0.000	0.095
Udaipur	-0.076	-0.131	1.266	1.218	0.469	0.925	-0.989	0.306	-0.711	1.580	0.551	0.544
Tonk	0.245	0.313	1.273	1.315	1.608	1.850	0.081	1.232	-1.000	1.758	0.204	-0.755
Sirohi	-0.634	0.059	0.136	0.000	1.142	0.856	-0.110	-0.156	-0.442	2.258	0.000	0.000
Ajmer	0.320	0.430	1.341	1.044	1.781	1.845	1.116	1.058	-0.977	1.679	0.657	-0.994
Sikar	0.032	0.810	1.266	0.017	2.643	2.134	1.180	1.122	-0.775	1.893	0.000	0.102
Swaimadhopur	-0.096	0.539	1.276	1.544	1.966	1.683	-0.405	1.524	-0.763	2.018	0.330	-0.498
Rajsamand	-0.039	0.150	1.165	0.908	0.590	1.318	0.249	0.625	-1.104	1.747	0.545	0.054
Pali	-0.309	0.125	1.040	0.782	1.131	1.298	0.792	0.474	-0.914	1.871	0.883	-0.092
Nagaur	0.055	0.613	1.194	-0.284	2.596	1.995	1.590	0.520	-0.679	2.174	1.106	-0.204
Kota	0.338	0.762	1.456	1.479	1.388	1.457	-1.342	1.798	-1.561	1.542	0.198	-0.747
Karauli	-0.117	0.403	1.141	1.585	1.972	1.544	-0.480	1.342	-0.382	1.852	0.710	-0.854
Jodhpur	-0.058	0.606	0.642	-0.865	2.247	1.278	1.064	-0.017	-0.665	2.485	0.719	-0.651
Jhunjhunu	0.136	0.944	1.315	-0.108	2.669	2.001	1.110	0.786	-0.786	1.935	0.000	0.292
Jhalawar	0.625	0.777	1.882	1.555	1.203	1.706	-1.810	2.059	-2.024	1.407	0.033	-0.542
Jalor	-0.175	0.276	-0.521	3.586	1.544	0.937	0.278	-0.133	-0.509	2.142	0.000	0.000
Jaisalmer	0.153	0.397	0.026	-0.583	1.779	0.254	0.353	-0.630	-1.177	1.740	0.000	-1.713
Hanumangarh	0.226	1.330	1.700	-0.448	2.492	1.041	1.440	-0.006	-0.165	2.228	0.000	-0.458
Ganganagar	0.607	1.584	1.564	-0.298	2.310	0.538	1.353	-0.601	-0.119	2.009	5.294	-1.062
Dungarpur	0.479	-1.588	2.634	1.179	0.383	0.416	-2.053	0.312	-0.359	1.396	0.428	0.779
Dholpur	-0.259	0.231	1.022	1.671	1.984	1.243	-0.705	1.512	0.058	1.849	0.698	-0.649
Jaipur	-0.093	0.603	1.566	1.008	2.573	1.850	0.966	1.423	-0.428	1.824	1.102	-0.527
Dausa	-0.229	0.457	1.563	1.337	2.458	1.642	0.139	1.399	-0.283	1.966	0.822	-0.664
Churu	0.171	1.137	1.409	-0.469	2.695	1.446	1.070	-0.220	-0.619	2.416	0.000	-0.351

Chittaurgarh	0.312	0.646	1.491	1.478	0.752	1.816	-0.653	1.145	-1.752	1.535	0.156	-0.336
Bundi	0.301	0.497	1.367	1.476	1.376	1.579	-0.497	1.290	-1.451	1.588	0.217	-0.920
Bikaner	0.344	1.053	0.928	-0.705	2.325	0.746	0.786	-0.998	-0.515	2.208	2.471	-0.759
Bhilwara	0.403	0.639	1.199	1.186	1.220	1.741	0.590	0.908	-1.608	1.646	0.433	-0.858
Bharatpur	-0.319	0.591	1.350	1.435	2.544	1.527	0.000	1.428	0.029	1.866	1.442	-0.271
Barmer	-0.238	0.509	-0.702	-0.225	1.550	0.914	0.474	-0.023	-0.801	1.994	0.000	-1.627
Baran	0.361	0.671	1.348	1.351	1.324	1.376	-2.030	2.122	-1.399	1.431	-0.265	-0.574
Banswara	0.264	-1.421	2.331	0.860	-0.023	1.006	-2.423	1.012	-0.740	1.235	0.163	0.761

Table 3: Result for trend analysis (values of Sen's slope) of annual and seasonal rainfall time series (1901-2002)

Station	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter
Alwar	2.278	2.909	1.856	1.961	-0.012
Udaipur	-0.758	-0.356	-0.740	1.154	-0.494
Tonk	1.203	2.036	0.943	1.356	-0.179
Sirohi	-0.162	-0.061	-0.445	2.149	0.023
Ajmer	1.440	1.371	1.151	1.544	-0.040
Sikar	2.116	1.943	1.787	1.917	0.399
Swaimadhopur	1.301	2.631	0.833	1.533	-0.168
Rajsamand	0.324	0.084	0.260	1.185	-0.457
Pali	0.677	0.393	0.492	1.848	-0.445
Nagaur	1.561	1.336	1.480	2.091	0.405
Kota	0.468	1.972	0.214	0.694	0.416
Karauli	1.174	2.793	0.729	1.701	-0.283
Jodhpur	0.763	1.012	0.665	2.351	0.197
Jhunjhunu	1.897	1.931	1.359	2.039	0.526
Jhalawar	-0.040	1.827	-0.150	0.017	0.960
Jalor	-0.017	0.373	-0.150	2.221	-0.020
Jaisalmer	-0.110	0.486	-0.243	2.452	-0.781
Hanumangarh	1.492	1.648	1.336	2.520	0.538
Ganganagar	0.781	1.671	0.613	2.493	0.682
Dungarpur	-1.394	-0.385	-1.232	0.934	-0.477
Dholpur	0.960	2.839	0.607	1.773	-0.364
Jaipur	2.001	2.608	1.561	2.067	-0.208
Dausa	1.608	2.914	1.157	2.053	-0.439
Churu	0.995	1.700	0.688	2.437	0.416
Chittaurgarh	-0.017	0.717	-0.035	0.523	0.000
Bundi	0.885	2.012	0.619	0.928	0.110
Bikaner	0.324	1.399	-0.069	2.669	0.249
Bhilwara	1.052	1.249	0.827	0.937	0.246
Bharatpur	1.457	3.082	1.145	2.082	-0.679
Barmer	0.254	0.162	0.208	2.341	-0.266
Baran	0.208	2.018	-0.029	0.509	0.856
Banswara	-1.035	-0.541	-1.058	0.581	-0.682

Table 4: Z statistics values of minimum temperature using MK test for Rajasthan (1901-2002)

Station	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Alwar	0.12	1.74	-3.12	0.94	1.45
Udaipur	3.69	2.58	-0.43	3.06	4.13
Tonk	0.42	1.36	-2.12	1.26	1.51
Sirohi	3.80	2.91	-1.07	2.70	4.28
Ajmer	1.10	1.55	-1.97	1.49	2.38
Sikar	-0.08	2.03	-3.00	0.48	0.76
Swaimadhopur	0.79	1.50	-2.33	1.49	2.22
Rajsamand	3.34	2.30	-0.65	2.69	4.26
Pali	3.32	2.40	-1.16	2.36	4.30
Nagaur	1.33	2.06	-2.40	1.22	2.13
Kota	2.72	1.32	-0.72	2.68	4.37
Karauli	1.12	1.49	-2.57	1.67	2.69
Jodhpur	3.41	2.59	-1.11	2.16	4.29
Jhunjhunu	0.22	2.11	-3.12	0.59	1.41
Jhalawar	3.56	1.80	-0.21	3.51	4.92
Jalor	3.87	3.00	-1.29	2.71	4.44
Jaisalmer	4.05	2.93	0.10	2.37	4.06
Hanumangarh	1.92	2.70	-2.91	1.04	3.46
Ganganagar	2.36	2.54	-2.50	1.32	3.57
Dungarpur	4.23	3.32	-0.15	3.47	4.40
Dholpur	1.61	1.50	-2.92	1.99	3.79

Jaipur	-0.99	1.50	-3.12	0.34	-0.38
Dausa	-0.46	1.41	-3.16	0.72	0.44
Churu	1.42	2.24	-2.45	1.00	2.50
Chittaurgarh	3.42	2.09	-0.32	3.06	4.28
Bundi	2.16	1.09	-0.85	2.19	4.05
Bikaner	2.94	2.59	-1.82	1.72	3.46
Bhilwara	2.64	1.60	-0.82	2.44	4.26
Bharatpur	0.63	1.59	-3.11	1.19	2.60
Barmer	3.94	2.87	-0.15	2.80	4.52
Baran	3.43	1.75	-0.69	2.94	4.59
Banswara	4.66	3.56	0.20	3.68	4.49

Table 5: Z statistics values of maximum temperature using MK test for Rajasthan (1901-2002)

Station	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Alwar	0.069	1.868	-3.062	0.862	1.344
Udaipur	3.626	2.672	-0.520	3.137	4.002
Tonk	0.312	1.446	-2.018	1.417	1.342
Sirohi	3.701	2.955	-1.154	2.822	4.192
Ajmer	0.971	1.616	-1.989	1.483	2.197
Sikar	-0.150	2.041	-3.071	0.494	0.679
Swaimadhopur	0.798	1.665	-2.354	1.590	1.937
Rajsamand	3.296	2.307	-0.639	2.793	3.958
Pali	3.215	2.446	-1.209	2.406	4.192
Nagaur	1.278	2.090	-2.498	1.313	2.082
Kota	2.822	1.347	-0.700	2.767	4.036
Karauli	1.024	1.576	-2.666	1.686	2.553
Jodhpur	3.261	2.562	-1.157	2.417	4.198
Jhunjhunu	0.006	2.169	-3.183	0.457	1.081
Jhalawar	3.684	1.816	-0.185	3.533	4.597
Jalor	3.863	2.969	-1.177	2.880	4.357
Jaisalmer	3.973	2.914	0.052	2.894	3.877
Hanumangarh	1.590	2.666	-3.183	1.058	3.056
Ganganagar	2.122	2.354	-2.729	1.339	3.166
Dungarpur	4.198	3.296	-0.269	3.501	4.325
Dholpur	1.353	1.506	-2.897	2.062	3.441
Jaipur	-0.980	1.582	-3.250	0.324	-0.434
Dausa	-0.515	1.544	-3.377	0.836	0.275
Churu	1.197	2.388	-2.776	1.116	2.070
Chittaurgarh	3.475	2.157	-0.315	3.172	4.132
Bundi	2.249	1.110	-0.876	2.330	3.669
Bikaner	2.735	2.614	-1.908	2.038	3.400
Bhilwara	2.701	1.654	-0.873	2.443	3.976
Bharatpur	0.529	1.746	-3.169	1.339	2.356
Barmer	3.979	2.790	-0.214	3.094	4.325
Baran	3.331	1.807	-0.584	3.065	4.184
Banswara	4.678	3.510	0.147	3.730	4.421

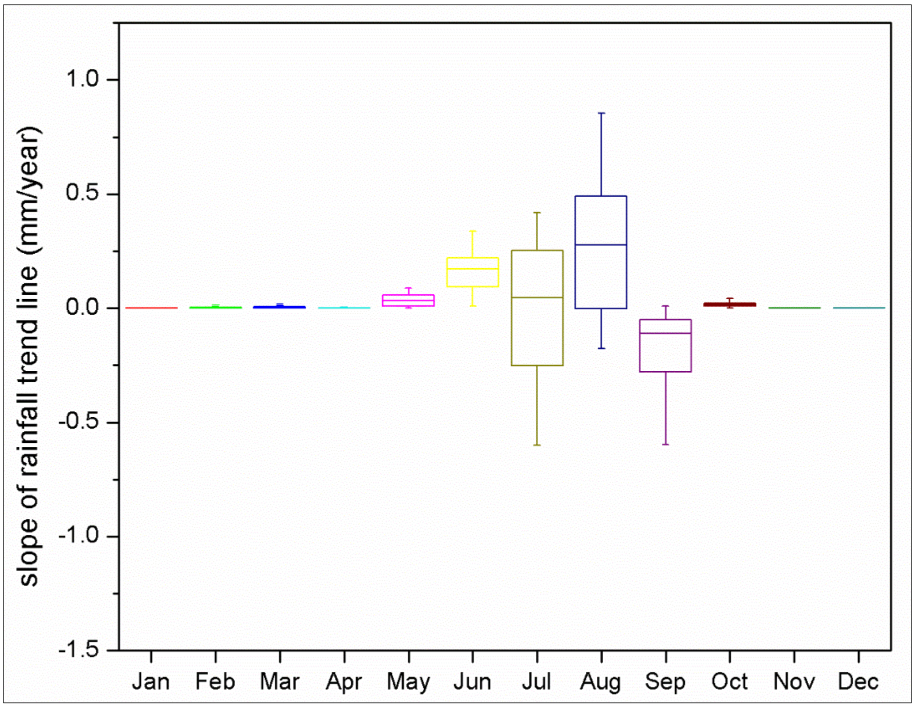

Fig 1: Box plot of Theil-Sen's slope for monthly rainfall time series of Rajasthan, India (1901-2002)

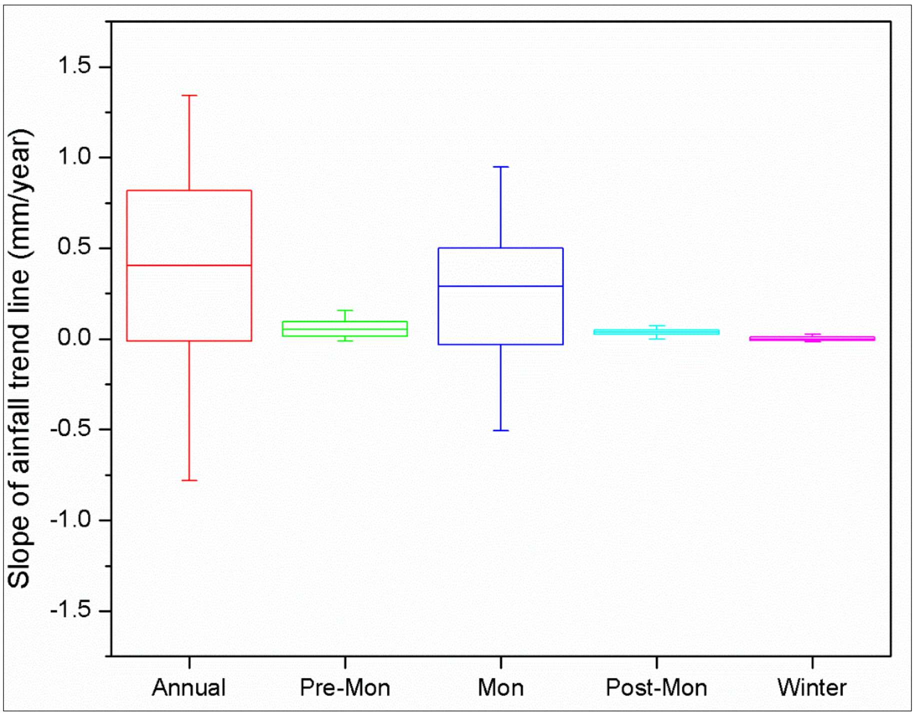

Fig 2: Box plot of Theil-Sen's slopes for annual and seasonal rainfall time series of Rajasthan, India (1901-2002)

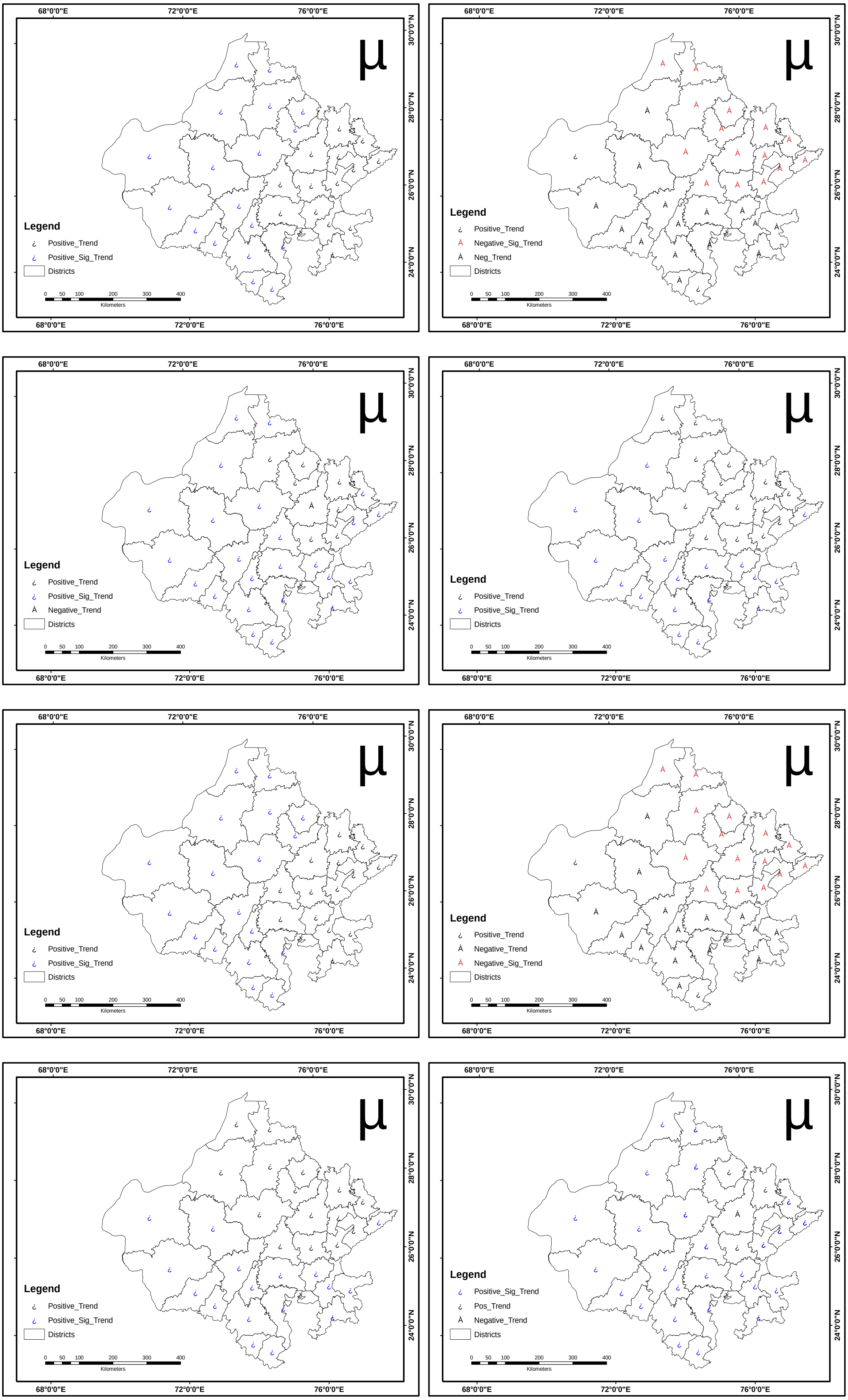

Fig 3: Mann Kendall Z Values of Maximum Temperature (a) pre monsoon, (b) monsoon, (c) post monsoon (d) winter and minimum temperature (e) pre monsoon, (f) monsoon, (g) post monsoon (h) winter

Conclusion

The study area covers all districts of Rajasthan. Rajasthan is the largest state in the country and covers about 3, 42,000 square kilometers area and is located between 69°30' to 78°17'E longitude and 23°30'to 30°12' N latitude.

To execute the objective of the study we analyzed the long term rainfall and temperature trend. In the present study, the trends in rainfall and temperature over Rajasthan, India (1901–2002), were examined using Mann-Kendall (MK) and Sen's slope estimator statistical tests. The Z values of Mann-Kendall and Sen's slope tests for rainfall represent both positive and negative trends in the study area. The months May, June, and October and shows significantly positive trend for rainfall for most of the districts whereas July and September shows significantly negative trend. The months July and September shows decreasing slope magnitude, November and December shows no trend value for all districts, and the remaining months show a positive trend value for most of the districts during 1901–2002 . The strongest positive annual rainfall trend line slope was found to be + 1.34 mm/year at Alwar station. It means that the annual rainfall of the Alwar district increased to about 134 mm in the last century. Over all, we observed annual and seasonal rainfall indicating both increasing trend and decreasing trend (1901–2002). This analysis also concluded that the number of decreasing trends increases considerably. From statistical test results, it can be concluded that there is evidence of some change in the trend of rainfall of the Rajasthan. The analysis of rainfall data and findings shall be useful for irrigation and agricultural managers and may play an important role in managing water resources in the basin.

The highest variation in the temperature was found at Alwar in minimum as well as in maximum temperature. maximum mean annual temperature was observed at Jaisalmer whereas minimum mean annual temperature was observed at Rajsamand under maximum temperature. During pre-monsoon maximum temperature was found to be 38.27 °C at Banswara under maximum temperatures. During monsoon months mean maximum temperature was found at Ganganagar in maximum temperature. The values of coefficient of variation for annual maximum temperature varies from 1.27 to 1.71whereas values of CV for annual minimum temperature varies from 2.16 to 2.86.

The maximum variation in the temperature was found in the minimum temperatures where both significant increase and decrease were observed in different regions.

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