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Variability and trends of rainfall using non-parametric approaches: A case study of semi-arid area

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सार – जलवायु जोखिम और कृषि जल प्रबंधन के लिए बेहतर निर्णय लेने के लिए वर्षा की परिवर्तनशीलता और प्रवृति के विश्लेषण का उपयोग किया जा सकता है। इस अध्ययन में 44 साल (1973-2016) के मासिक डेटा के आधार पर राजस्थान के अजमेर जिले के 19 स्टेशनों के वार्षिक, ऋतुनिष्ठ और मासिक वर्षा की प्रवृत्ति और परिवर्तनशीलता का मूल्यांकन करने का प्रयास किया गया है। गैर-पैरामीट्रिक मान-केंडल (MK), संशोधित मान-केंडल (mMK) और स्पीयरमैन के रो (SR) परीक्षण का उपयोग हासिल करने के लिए किया गया था कि क्या प्रवृत्ति की मात्रा की पहचान करने के लिए समय श्रृंखला में वृद्धि या घटने की प्रवृत्ति थी और सेन स्लोप (*Q*) अनुमानक लागू किया गया। परिणामों से यह पाया गया कि वार्षिक और मानसून की वर्षा दोनों में मध्य भाग में स्थित तीन स्टेशनों पर बढ़ने की प्रवृत्ति, और उत्तर-पश्चिमी तथा दक्षिण-पश्चिमी भाग में स्थित दो स्टेशनों पर घटने के रुझान को इस अध्ययन क्षेत्र में दिखाया गया है। वार्षिक और मॉनसून वर्षा दोनों में अधिकतम बढ़ते रुझानों का परिमाण गोइला $Q = +10.17$ mm/year and $+9.50$ mm/year) में देखा गया, जबकि जवाजा $Q = -6.76$ mm/year and -5.21 mm/year) में अधिकतम कमी का रुझान दिखाई दिया। मासिक पैमाने पर फरवरी में अधिक से अधिक स्टेशनों (सात) पर बढ़ने की प्रवृत्ति दिखाई दी और जुलाई में अधिकतम सात स्टेशनों (सात) में घटने की प्रवृत्ति को दिखाया गया। हमारे अध्ययन से मिली जानकारी से भविष्य में इस क्षेत्र में हाइड्रोलिक प्रक्रियाओं के आकलन और जल संसाधन योजना तथा प्रबंधन को टिकाऊ बनाने में मदद मिलेगी।

ABSTRACT. The analysis of variability and trends of rainfall can be used to assist better decision for climate risk and agricultural water management. This study makes an attempt to evaluate the trend and variability of annual, seasonal and monthly rainfall of 19 stations of Ajmer district, Rajasthan based on 44 year's monthly rainfall data (1973-2016). Non-parametric Mann-Kendall (MK), Modified Mann-Kendall (mMK) and Spearman's rho (SR) tests were used to achieve if there was an increasing or decreasing trend in the time series and the Sen's slope (*Q*) estimator was applied to identify the quantity of the trend. From the results, it was found that annual and monsoon rainfall both showed an increasing trend at three stations, located in the central part and a decreasing trend at two stations, located in the north-western and south-western part of the study area. The magnitude of maximum increasing trends in both annual and monsoon rainfall was observed at Goela ($Q = +10.17$ mm/year and $+ 9.50$ mm/year) while Jawaja ($Q = -6.76$ mm/year and $- 5.21$ mm/year) appeared with the maximum decreasing trends. On a monthly scale February showed an increasing trend at maximum number of stations (seven) and July showed a decreasing trend at maximum number of stations (seven). The information gathered from our study will help in future to estimate hydraulic procedures as well as to make sustainable water resource planning and management in this region.

Key words – Rainfall, Mann-Kendall, Spearman's Rho, Sen's slope, Ajmer.

1. Introduction

Rainfall is the most imperative hydro meteorological variable of climatic environment (Shafaei *et al.*, 2016) and analysis of its trend is very significant for water resource management, food security, energy security and future economic development of a country (Palsaniya *et al.*, 2016). It plays crucial role in agricultural field preparation, crop planting, irrigation, fertilizer use, crop productivity as well as in whole crop cycle in a region. Moreover, Ground water reserves, domestic water supply, soil moisture, the pattern of stream flows, runoff, hydroelectric power generation, food preferences, mode of living and even the behavioral responses of the people are altered by sufficient amount of rainfall (Jain *et al.*, 2012). According to Rahman *et al.* (2017) among all climatic parameters rainfall is the most significant, mainly because of its contribution to water demand for the crop. The arid or semi-arid region gets more attention in this context as rainfall occurrences are very irregular, insufficient and unpredictable in dry areas, resulting unequal economic growth in any region.

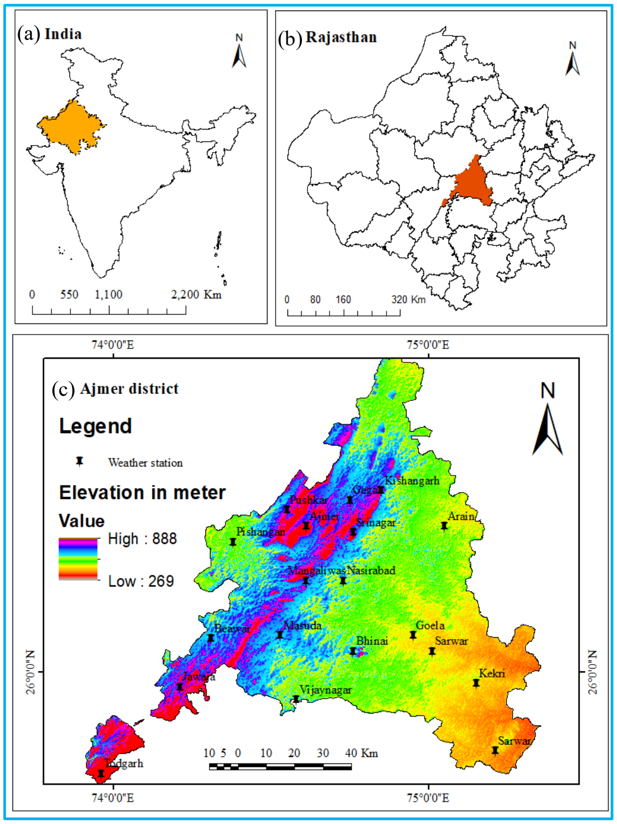
The semi-arid areas comprise around 15% of the world land area and approximately 15% of the world and 24% of the Asian human population made their habitat in this region (UNSO, 1997; Assessment, 2005). According to the World Atlas Desertification (Thomas, 1997) the semi-arid regions are referred to as the areas where ratio of mean annual rainfall to mean annual potential evapotranspiration ranges between 0.2 and 0.5. Out of India's total land area (329 million ha), about 29% (94 million ha) is under dry areas which are categorized into arid, semi-arid and dry sub-moist areas. Ajmer is a part of such semi-arid regions known as troublesome territory including deserts, forests, mountains, ravine and irregular rainfall. Usually, semi-arid ecosystem provide energy, food, forestry products, grazing for livestock and ecosystem services and this is a center of attraction of widespread environmental scientist due to its climatic extremeness, problems of poverty and agricultural amenities as well as economic development, mostly in developing countries (Fensholt *et al.*, 2012). According to Prasad *et al.* (2014), irregular rainfall and soil infertility are the main problems of such areas which restrict the production of crops. The use of rainwater in agriculture is one of the greatest techniques to overcome these problems. Hence, a proper knowledge of rainfall trend and its variability at local and regional dimension is prerequisite for various decision-making schemes in such dry areas.

Several previous studies have investigated the variability and trend of rainfall over India on the basis of annual and seasonal rainfall data for understanding the overall changes of rainfall where Chand *et al.* (2011); Jain *et al.* (2012); Arthi Rani *et al.* (2014), and Pingale *et al.* (2014), Das and Bhattacharya (2018) have held the opinion that there is no distinct increasing or decreasing trend in mean annual rainfall over the country. Some researchers have reported an increasing trend in rainfall over India (Goswami *et al.*, 2006; Jaswal *et al.*, 2015) where the works of Yin *et al.* (2016) and Meshram *et al.* (2017) have showed significant rainfall decreasing trends. Conversely, a number of studies have been conducted over Rajasthan where the present study is focused to assess the variability and trend of rainfall using the different model on the spatio-temporal basis (Singh *et al.*, 2014; Mundetia and Sharma, 2014; Meena *et al.*, 2016). However, a quality work has been done over Ajmer by Pingale *et al.* (2016) who analysed the climatic variability of Ajmer using climatic data for100 years *i.e.*, from 1903 to 2002 and concluded that there was no any significant trend in seasonal and annual rainfall at 0.01 significant level, though a noticeable increasing trend was found in wet day recurrence.

Non-parametric tests are very popular to identify the significant trend in time series data as it can tolerate outliers in the data that simply autonomous prerequisite (Chen *et al.*, 2007; Suhaila *et al.*, 2011). However, parametric tests are more effective than non-parametric tests but required data should be autonomous and normally circulated, which is rarely possible for time series data. The MK and SR tests are the agents of such non-parametric tests that exceptionally helpful to perceive the monotonic trend of long-term time series data of hydrology (Yue *et al.*, 2002a). According to Novotny and Stefan (2007) the results of MK and SR test are comparatively equal powerful for identifying monotonic trend in a long-term data series. Shadmani *et al.* (2011); Hajani *et al.* (2014); Ahmad *et al.* (2015); and Rahman *et al.* (2017) also used MK and SR test in their study to find out the monotonic trend of rainfall and revealed both methods are approximately similar powerful to test the rainfall trend in data series. In this study, an attempt has been made to evaluate the trend, variability and magnitude of trend of rainfall of Ajmer district in Rajasthan during the period from 1973-2016 using Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975) and Spearman's rho (SR) test (Spearman, 1904). However, modified Mann-Kendall (mMK) test (Hamed and Rao, 1998) has also been used where lag-1 autocorrelation is significant in the data series; and to estimate the magnitude of trend Sen's slope (Q) estimator (Sen, 1968) has used respectively.

2. General description of the study area

The study was conducted over nineteen meteorological stations of Ajmer district of Rajasthan, lying between latitudes 25°38′ N to25°58′ N and longitudes of 73°54′ E to 75°22′ E [Figs. 1(a-c)]. The locale is situated on the lower inclines of the Taragarh hills of Aravalli Mountain, at a detachment of 135 km from the state capital and 391 km from the capital of India and acquires its name from the major settlement of Ajmer. The ancient name of the city was 'Ajaymeru' which was derived from Sanskrit word 'Meru' meaning a hill and the word Ajay is used as succeeding adjective to mery (hill). The district is encompassed by the Pali district in the west, Nagaur district in the North, Jaipur and Tonk district touches in East and its southern limit is delineated by the Bhilwara and Rajsamand district. The total population of the district is 25,83,052 with an area of 8,481 km^2 (Govt. of India, 2011). Sub-division wise four remarkable physical features exist in the district and Aravalli range is the most



Figs. 1(a-c). Location map of the study area (a) India (b) Rajasthan (c) Ajmer district

distinctive and comes into distinction near the town of Ajmer. Disseminated hills, buried pediments and infrequent sand dunes with the considerable area under alluvium are the characteristics of this region. The region is characterized by a hot climate with extremely hot summer, average maximum and minimum daily temperature of the region are 31.62 °C and 18.58 °C respectively and moderate rainfall, with an average of 473 mm/year which is quite low to the state mean annual rainfall of 530 mm/year and most of the rain occurs in monsoon season. The district is situated more or less 486 meters above mean sea level (msl) and rich in feldspar, limestone, quartz, masonry stone, soapstone, mica, brick clay and asbestos. Steppe types of vegetation are generally found in most part of this region with dominating species are Dhokra, Khejra, Khair, Ber and Aranja.

3. Methodology and materials

The data used in the present article consists of the average monthly rainfall of 19 stations over Ajmer district of Rajasthan during the period from 1973 to 2016. The data collected from http://water.rajasthan.gov.in/content/water/en/waterresourcesdepartment/WaterManagement/IWRM.html. Some of the statistics of rainfall data are presented in Table 1. These statistics provided the arithmetic mean, median, skewness, kurtosis, standard deviation, variance and coefficient of variation respectively as sorted in the table. Arc 10.3 and R 3.5.1 software have been used for mapping and data analyzing purposes, whereas Inverse Distance Weighted (IDW) technique was used for interpolation of points values. The descriptions of the various methods used in this study are displayed in the following sections.

3.1. *Checking of the serial dependency and removal*

To analysis and detection of trend in a time series data autocorrelation is considered as one of the leading problems. The presence of autocorrelation in a time series data whether it is positive or negative may affects the testing and interpretation of trend (Hamed and Rao, 1998). According to Bayazit and Onoz (2008) in a time series data the rejection rate of autocorrelation is too large or gives incorrect result at the time of applying Mann-Kendall test statistics. Since, the degree of serial dependence intensifies by the variance of the Mann-Kendall test statistic, positive serial dependence in a time series data intensifies the Type I error and detect a significant trend when there was not actually realistic trend (Yue *et al.*, 2002b). Therefore, the presence of serial correlation for all the data series using lag-k autocorrelation coefficient (r_k) were analysed first in this study at 0.05 significance level for two tailed (upward and downward) test.

$$r_k = \frac{\sum_{k=1}^{N-K}(x_t - \overline{x_t})(x_{t+k} - \overline{x_{t+k}})}{\left[\sum_{k=1}^{n-k}(x_t - \overline{x_t})^2 (x_{t+k} - \overline{x_{t+k}})^2\right]^{0.5}} \tag{1}$$

where, r_k is the Autocorrelation function of time series x_t at lag k, x_t is observed data flow series, $\overline{x}$ is the mean of time series(x_t), N denote the total length of x_t time series, k is the maximum lag.

Since, the test is two-tailed, the alternative hypothesis is that the true r_k must be other than zero, however it may be positive or negative. The data of the time series are considered as serially correlated if r_k falls between the bigger and smaller margins of confidence interval (Anderson, 1942), otherwise the time series data are supposed to be serially independent. It was observed in this study some stations were significant autocorrelation at lag-1. Therefore, Hamed and Rao's (1998) modified Mann-Kendal technique was implemented in accounts for autocorrelation at lag-1 within long term time series data to find out the significant trend.

TABLE 1

Geographical location of stations with corresponding rainfall statistics

Station	Lat.	Long.	Alt (m)	Mean	Median	Skew	Kurtosis	Std. Dev.	Variance	CV (%)
Ajmer	26°27′N	74°37′E	561	554.92	533.40	0.55	0.10	185.30	34340.00	33.39
Sarwar	26°04′N	75°01′E	369	513.56	495.25	0.30	0.84	191.24	36570.00	37.24
Arain	26°27′N	75°03′E	365	461.45	418.00	0.17	-0.42	216.49	46870.00	46.91
Beawar	26°06′N	74°19′E	462	558.08	547.50	0.31	-0.62	212.99	45370.00	38.16
Bhinai	26°04′N	74°46′E	417	496.83	503.50	-0.25	0.06	231.73	53700.00	46.64
Gegal	26°32′N	74°45′E	462	341.63	341.50	0.42	-0.05	178.38	31820.00	52.21
Goela	26°07′N	74°57′E	363	317.19	278.50	0.41	-0.77	219.88	48350.00	69.32
Jawaja	25°57′N	74°13′E	494	429.04	429.60	0.24	-0.26	239.54	57380.00	55.83
Kekri	25°58′N	75°09′E	347	530.16	497.00	0.41	2.25	185.22	34310.00	34.94
Kishangarh	26°34′N	74°51′E	538	521.17	493.50	0.90	1.37	217.25	47199.69	41.69
Mangaliwas	26°17′N	74°37′E	468	358.64	381.15	0.47	-0.12	221.58	49097.70	61.78
Nasirabad	26°17′N	74°44′E	423	558.99	553.25	-0.02	-0.23	233.50	54521.77	41.77
Pishangan	26°24′N	74°23′E	393	453.30	423.00	0.28	-0.42	203.40	41370.00	44.87
Pushkar	26°30′N	74°33′E	480	492.79	463.00	0.39	0.08	265.69	70590.00	53.92
Sarwarr	25°45′N	75°13′E	337	541.90	549.00	-0.43	0.74	182.02	33130.00	33.59
Srinagar	26°26′N	74°46′E	514	436.00	436.50	2.08	8.96	285.04	81240.00	65.38
Todgarh	25°41′N	73°58′E	701	509.75	502.35	-0.36	-0.24	223.83	50100.00	43.91
Vijaynagar	25°55′N	74°35′E	414	428.79	430.00	-0.44	0.12	170.22	28980.00	39.70
Masuda	26°07′N	74°32′E	449	494.47	439.00	0.52	-0.02	272.65	74340.00	55.14

3.2. *Mann-Kendall test*

The Mann-Kendall (Mann, 1945; Kendall, 1975; Das *et al.*, 2019) test statistic (S) of the series x_1, x_2, x_3 ..., and x_n are calculated by using the following equation:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) \tag{2}$$

where, n is the quantity of information points, sign signifies the signum work, x_j and x_k speaks to the data points of time j and k

$$\begin{aligned} sign(x_j - x_k) &= +1 \; if \; x_j - x_k > 0 \\ &= 0 \; if \; x_j - x_k = 0 \\ &= -1 \; if \; x_j - x_k < 0 \end{aligned} \tag{3}$$

The variance of S, VAR(S) is computed by the following equation:

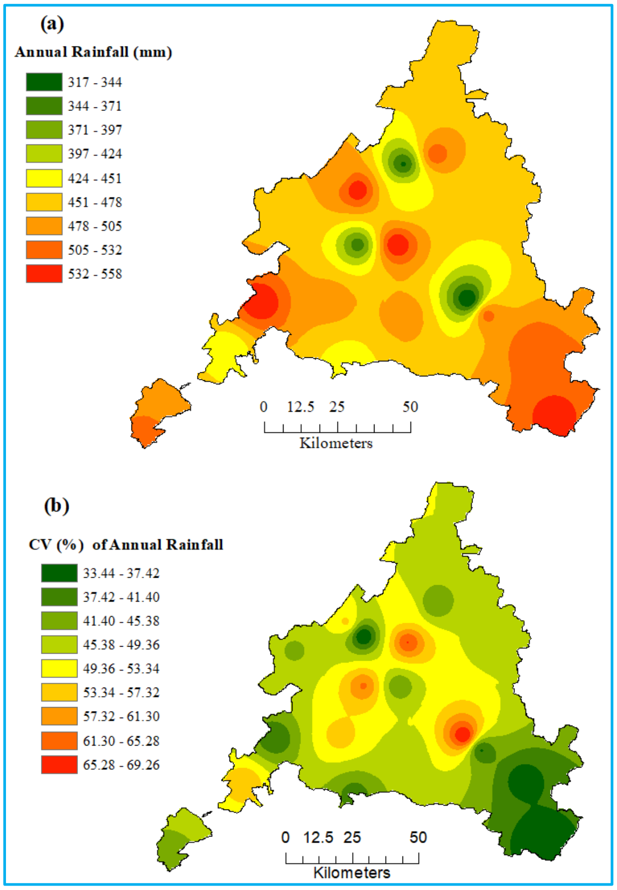
$$VAR(S) = \frac{1}{18}\left\{ n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right\} \tag{4}$$

where, 'g' denotes to the quantity of tied group's number which is a set of sample data with similar value and t_p indicates the extent of p^{th} ties number.

The estimation of (S) and VAR(S) are used to estimate process the standardized test measurement Z as takes after:

$$Z = \begin{cases} \dfrac{(S-1)}{\sqrt{Var(S)}}, & if \; S > 0 \\ 0, & if \; S = 0 \\ \dfrac{(S+1)}{\sqrt{Var(S)}}, & if \; S < 0 \end{cases} \tag{5}$$

Positive and negative value of Z indicates increasing and decreasing trends. To test null hypothesis (H_0), of no trend against the alternative hypothesis(H_a), of an upward or descending pattern at the $\alpha = 0.001, \alpha = 0.05$ and $\alpha = 0.01$ level of significance, H_0 is rejected if the estimation of Z is more prominent than $Z_{1-\alpha/2}$, which is acquired from the Pearson and Hartley's (1966) standard ordinary distribution table.



Figs. 2(a&b). Distribution of annual rainfall of Ajmer district (a) Spatial variability and (b) Co-efficient of variation

3.3. *Spearman's rho test*

The Spearman's rho (ρ)test measurement R and the standardized test statistic Z_{SR} are calculated by using the following equation

$$R = 1 - \frac{6\sum D^2}{n^3 - n} \tag{6}$$

$$Z_{SR} = R\sqrt{\frac{n-2}{1-R^2}} \tag{7}$$

where, R means rank co-efficient of relationship, D is the distinction of rank between combined things in two series, n and denotes the data series length. Positive estimation of Z_{SR} demonstrates increasing trend, while negative estimates of Z_{SR} shows decreasing trends in the time series. Null hypothesis (H_0) is rejected and a significant trend is present in the time series when the value of $|Z_{SR}|$ is greater than the value of $t_{(n-2,1-\frac{\alpha}{2})}$ at 5% significant level.

3.4. *Sen's Slope estimator*

To find out the exact quantity of slope (change/unit time) in a hydro-meteorological time series data Sen's slope (Sen, 1968) estimator is an ultimate choice. To obtain an estimate of slope Q, the slopes of N pairs of data are calculated by the following equation:

$$Q_i = \frac{x_k - x_j}{k - j}, \qquad i = 1, 2, \ldots\ldots N, \; k > j \tag{8}$$

where, x_k *and* x_j are the values of data at time k, j and; Q_i is the median slope respectively.

4. Results and discussion

4.1. *Exploratory statistics*

The rainfall statistics of 19 stations using 44 years' time series data represents the typical spatial distribution of rainfall over Ajmer and the majority of the stations are experienced much rainfall during the monsoon months (June-September) (Table 1). Mean maximum rainfall in the district was 786.16 mm, observed in the year 1976 while the mean minimum rainfall was 105.95 mm, observed in the year 1999. Skewness of the rainfall datasets varied between -0.44 in Vijaynagar to 2.08 in Srinagar and it was obvious from the Table 1 that the data are skewed since the skewness is larger than zero and most of them positively skewed. Similar results were found from the kurtosis of the data sets varied from -0.77 in Goela to 8.96 in Srinagar. Since, the values were smaller and larger than zero, the kurtosis indicates platykurtic and leptokurtic distribution. From Table 1 along with other evocative statistics, it was observed that the means of variance and coefficient of variance (CV) were 48383.11 and 47.18% correspondingly.

4.2. *Variability and trend of annual rainfall*

Spatial distribution and temporal variability of mean annual rainfall in Ajmer are appeared in Figs. 2(a&b). As shown in the figure, the average annual rainfall of Ajmer varied from 317.20 mm to 558.99 mm with CV from 33.44% to 69.26%. The long-term time series of annual rainfall showed that mean annual rainfall in the region was 473.61 mm with highest 558.99 mm ±233.50 with CV is 41.77% observed at Nasirabad station, located at the central part of the study area while the lowest mean annual rainfall was found at station Goela being magnitude of 317.19 mm ±219.88 with CV 69.32%. In addition, the coefficient of variation of rainfall of this region revealed that the variability was high in the central

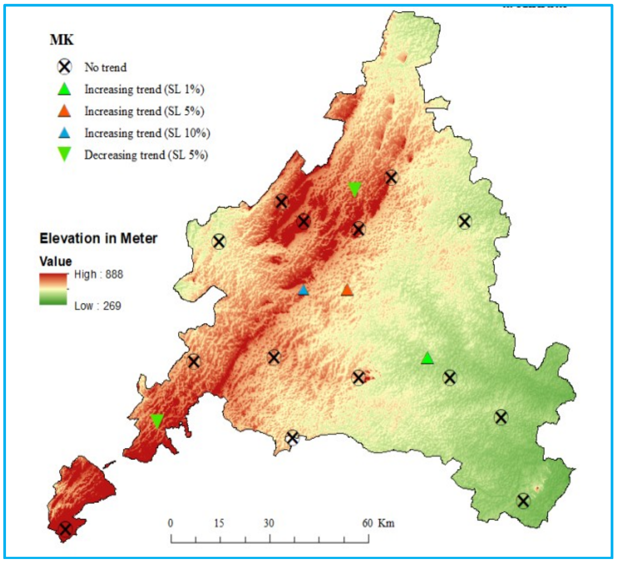


Fig. 3. MK trend of annual rainfall of Ajmer district

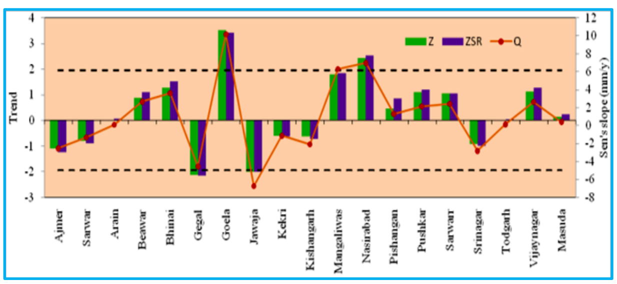
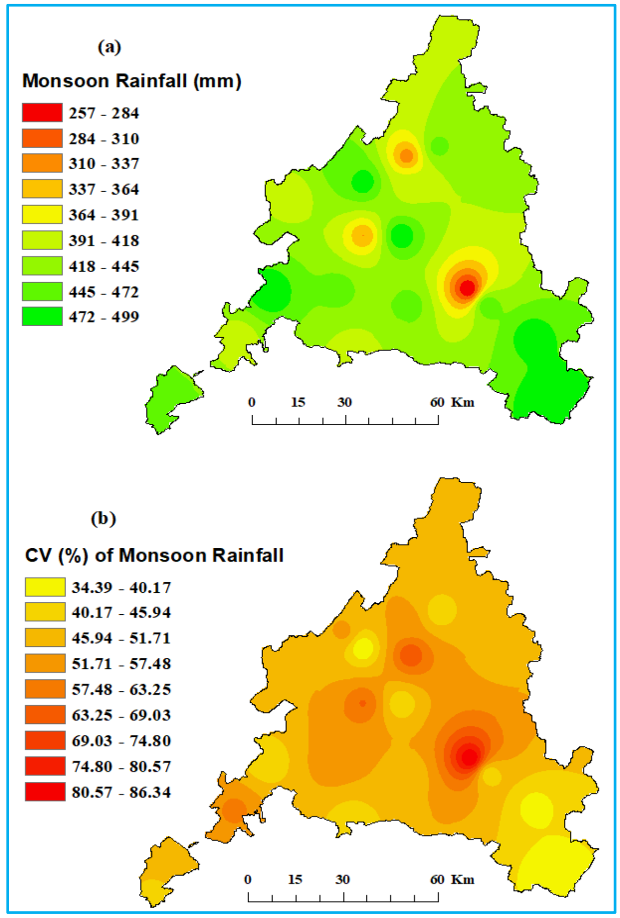


Fig. 4. Comparison of MK and Spearman's Rho of annual rainfall of Ajmer district



Figs. 5(a&b). Distribution of monsoon rainfall of Ajmer district (a) Spatial variability (b) Co-efficient of variation

part and quite low in the marginal periphery. Thus, the outer part of the region recorded more and evenly distributed rainfall than the middle portion. It may happen due to the semi-arid condition of the study region or huge loss of trees for rapid urbanization and emission of greenhouse gases in the central part than the outer part. High variability of rainfall amount was also observed in western Rajasthan for being an arid environment by Meena *et al.* (2016).

The results of MK and SR test for annual rainfall trend detection revealed both were very much comparative and they are presented in Table 2 and Fig. 4. The trend analysis depicted that the rainfall had a mixture of increasing and decreasing annual trends during the study period in Ajmer and they are shown in Fig. 3. Whereas, Pingale *et al.* (2016) found that there was no any measurable trend in annual rainfall in Ajmer at 0.01 significant level. On an average, more than half of the stations (53%) were statistically significant at 90% confidence level, near about half of the stations (42%) were significant at 95% confidence level whereas a small number of stations (16%) were significant at 99% confidence level by MK test. The trend tests also identified significant increasing trends at Goela, Mangaliwas and Nasirabad with the rate of 10.17 mm/year, 6.30 mm/year and 6.97 mm/year respectively whereas significant decreasing trend were identified at Gegal and Jawaja with the magnitude of 4.59 mm/year and 6.76 mm/year respectively [Fig. 7(b)]. The increasing trend of rainfall in such stations especially Goela, Mangaliwas and Nasirabad might be due to extreme heat flows and consequent rainfall.

4.3. *Variability and trend of seasonal rainfall*

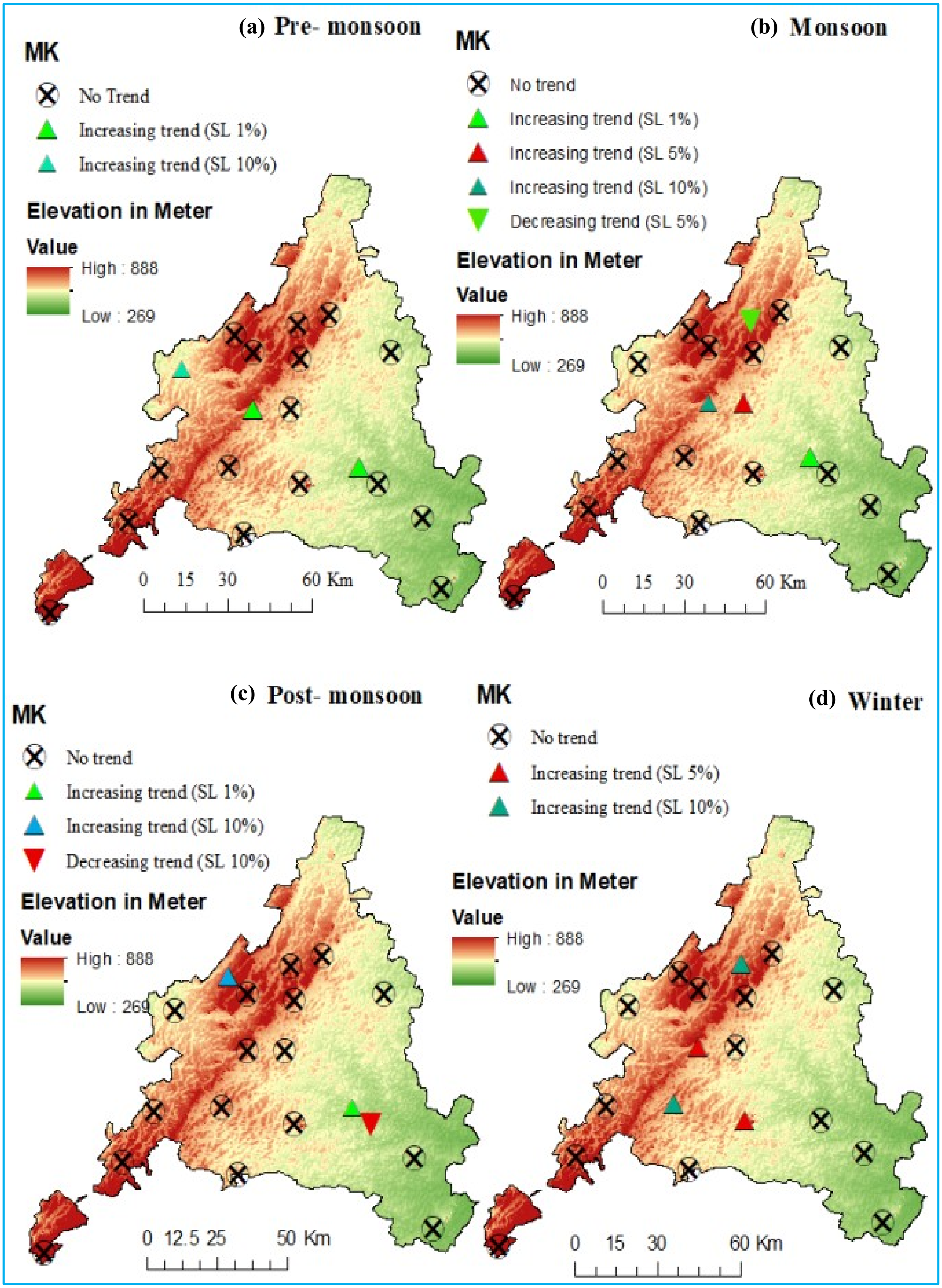
Seasonal spatio-temporal variability of rainfall in respect of monsoon in Ajmer are shown in Figs. 5(a&b). Average monsoon rainfall of the region varied from 256.82 mm in Goela to 499.12 mm in Beware whereas other season having an astonishing in character, pre-monsoon rainfall varied from 8.33 mm in Goela to 42.52 mm in Masuda, post-monsoon varied from 4.61 mm in Goela to 20.97 mm in Kishangarh and winter ranged from 3.14 mm in Mangaliwas to 15.37 mm in Nasirabad.

TABLE 2

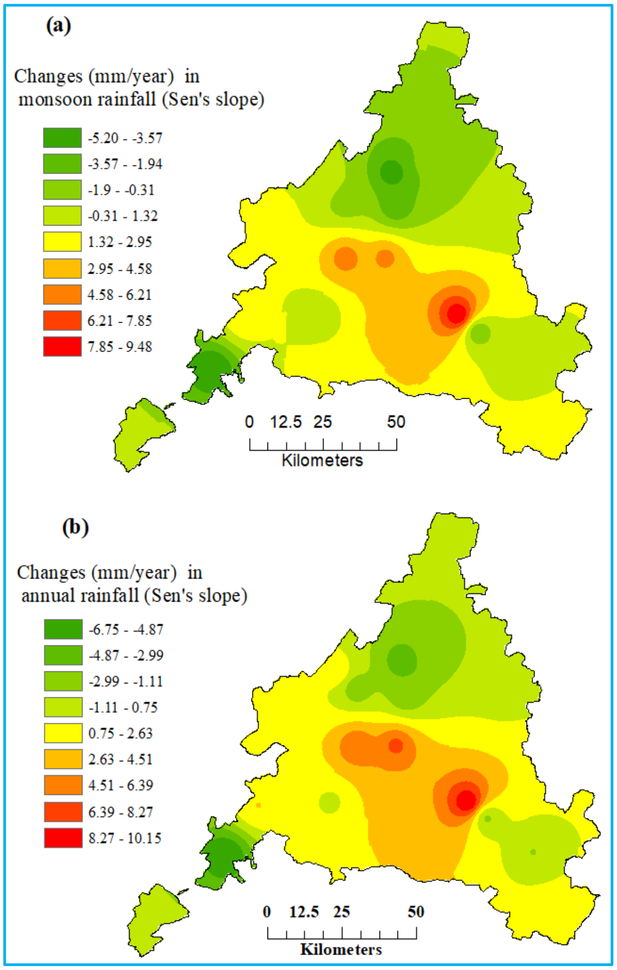
Trend of seasonal and annual rainfall of different stations of Ajmer district

Station	Test	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual
Ajmer	Z	-0.73	-0.83	-1.58	-1.18	-1.10
	Z_{SR}	-0.80	-0.83	-1.45	-1.15	-1.24
	Q	-0.13	-1.78	0.00	-0.14	-2.56
Sarwar	Z	-0.43	-0.65	-1.85***	-0.90	-0.81
	Z_{SR}	-0.24***	-0.66	-1.83***	-0.97	-0.9
	Q	0.00	-1.67	0.00	0.00	-1.35
Arain	Z	0.04	-0.10	0.00	0.29	0.03
	Z_{SR}	0.02	-0.12	0.10	0.38	0.06
	Q	0.00	-0.17	0.00	0.00	0.07
Beawar	Z	-0.43	1.02	-0.81	-0.50	0.89
	Z_{SR}	-0.40***	1.15	-0.80	-0.58	1.10
	Q	0.00	2.69	0.00	0.00	2.66
Bhinai	Z	0.25	1.04	-0.44	2.31**	1.28
	Z_{SR}	0.23	1.33	-0.40	2.28**	1.52
	Q	0.00	3.78	0.00	0.00	3.60
Gegal	Z	1.35	-2.12**	1.14	1.87***	-2.14**
	Z_{SR}	1.31	-2.19**	1.13	1.85*	-2.16**
	Q	0.00	-4.65	0.00	0.00	-4.59
Goela	Z	2.80*	3.52*	2.90*	3.10*	3.53*
	Z_{SR}	2.70*	3.16*	2.84*	3.17*	3.44*
	Q	0.00	9.50	0.00	0.00	10.17
Jawaja	Z	-0.49	-1.53	-1.12	-0.17	-2.02**
	Z_{SR}	-0.51	-1.58**	-1.19	-0.23	-2.02**
	Q	0.00	-5.21	0.00	0.00	-6.76
Kekri	Z	0.13	-0.15	-0.81	-1.30	-0.59
	Z_{SR}	0.25	-0.28	-0.73**	-1.23	-0.62
	Q	0.00	-0.22	0.00	0.00	-1.149
Kishangarh	Z	-0.13	-0.78	-0.08	-0.50	-0.63
	Z_{SR}	-0.17	-0.87	-0.04***	-0.51	-0.73
	Q	0.00	-1.71	0.00	0.00	-2.11
Mangaliwas	Z	2.86*	1.74***	-0.40	2.55**	1.80***
	Z_{SR}	2.93*	1.71	-0.35	2.51*	1.84***
	Q	0.00	5.53	0.00	0.00	6.30
Nasirabad	Z	1.05	2.19**	1.36	1.47	2.44**
	Z_{SR}	1.02	2.28**	1.39	1.52	2.53*
	Q	0.00	5.15	0.00	0.00	6.97
Pishangan	Z	1.76***	0.77	0.32	0.19	0.46
	Z_{SR}	1.68*	0.78	0.37	0.22	0.86
	Q	0.00	2.46	0.00	0.00	1.27
Pushkar	Z	1.63	0.59	1.80***	1.65	1.11
	Z_{SR}	1.57	0.73	1.77***	1.77***	1.21
	Q	0.00	1.23	0.00	0.00	2.15
Sarwarr	Z	-0.55	1.46	-0.65	-0.62	1.06
	Z_{SR}	-0.67	1.40	-0.54	-0.71	1.06
	Q	0.00	2.90	0.00	0.00	2.40
Srinagar	Z	0.35	-0.88	-1.10	0.66	-0.92
	Z_{SR}	0.43	-0.87	-1.02	0.73**	-1.00
	Q	0.00	-3.22	0.00	0.00	-2.84
Todgarh	Z	-0.64	0.14	0.47	-0.67	0.03
	Z_{SR}	-0.63	0.06	0.52	-0.69**	0.05
	Q	0.00	0.42	0.00	0.00	0.126
Vijaynagar	Z	0.42	1.24	-0.29	1.20	1.13
	Z_{SR}	0.36	1.33	-0.3	1.33	1.29
	Q	0.00	2.77	0.00	0.00	2.62
Masuda	Z	0.02	-0.11	-0.04	1.73***	0.14
	Z_{SR}	0.06	0.00	0.00	1.68*	0.25
	Q	0.00	-0.13	0.00	0.00	0.396

Z- Man-Kendall's normalized test Statistics; Z_{SR}- Spearman's normalized test statistics; Q- Sen's Slope *statistically significant at the 99% confidence level, **statistically significant at the 95% confidence level, ***statistically significant at the 90% confidence level



Figs. 6(a-d). Trend of Seasonal rainfall of Ajmer district (a) Pre-monsoon, (b) Monsoon, (c) Post-monsoon and (d) Winter



Figs. 7(a&b). Magnitude of trends of (a) monsoon and (b) annual rainfall of Ajmer district

The long-term time series of monsoon rainfall displayed mean monsoon rainfall in the region was 431.76 mm with highest 952.98 mm and lowest was 18.44 mm. The year of 1999 was the most significant year for Ajmer as all the station except Kekri and Arain facing rainfall deficiency due to very meager rainfall during all season in the district.

The pattern of rainfall depicted a mixture of increasing and decreasing trend also in seasonal rainfall in the study period (1973-2016). The results of both trend detection test MK and SR confirmed contradictory at some station in case of seasonal rainfall (Table 2). Stations Sarwar and Beware in pre-monsoon, Jawaja, Mangaliwas and Vijaynagar in monsoon, Kekri and Kishangarh in post-monsoon, Pushkar and Todgarh in winter showed asymmetrical trend while rest of the stations showed consistent results. Figs. 6(a-d) show the significant changes in seasonal rainfall by MK trend tests. Out of 19 stations, 3 stations were statistically significant in pre-monsoon and post-monsoon season, 4 stations were in monsoon and 5 stations were in the winter season. However, Pingale *et al.* (2016) observed there was no any significant trend in terms of seasonal rainfall in Ajmer at 90% confidence level. From pre-monsoon, Pishangan was statistically significant at 10% significance level, Mangaliwas and Goela were significant at 1% significance level and these three stations appearance increasing trend and the rate of increase were beyond belief (Q = 0.00). Narayanan *et al.* (2013) also observed significant increasing trend of pre-monsoon rainfall at 10% significance level in Ajmer during their study over western India. Stations Goela, Mangaliwas and Nasirabad were also showed the significant increasing trend different confidence level with the rate of 9.50 mm, 5.53 mm and 5.15 mm per year respectively in monsoon season, while a decreasing trend was observed at Gegal with the magnitude of 4.65 mm per year [Fig. 7(a)]. In post-monsoon season Goela and Pushkar showed significant increasing trend and Sarwar showed significant decreasing trend though the significant levels were quite different. On the other hand, around one fourth of the total stations (26%) were statistically significant in winter season and however, all were displayed increasing trend with the non-considerable rate (Table 2). The impacts of increasing aerosols on the Indian pre-monsoon and summer monsoon months can be correlated with the changes trend of rainfall over Ajmer.

4.4. *Variability and trend of monthly rainfall*

Variability of average monthly rainfall in Ajmer indicated that mean monthly rainfall was varied from 2.03 mm in December to 191.53 mm in July. The long-term time series of monthly rainfall showed that mean monthly rainfall in the region is 40.31 mm with highest 46.51 mm ±285.04 and CV 65.38 % recorded at Beawar and lowest rainfall is 24. 20 observed at Goela during the study period (1973-2016).

The results of monthly trend tests discovered that no statistically significant trends were found at Beawar, Kekri, Sarwar and Vijaynagar stations. The trend analysis identified significant positive trends at Sarwar and Arain in the month of February, Bhinai in January, February, March and September, Goela in all months except May and December, Mangaliwas in January, February, March and April, Nasirabad in March, April and August, Pushkar during March to May and August, Todgarh in March while Masuda showed increasing trend in February and March. On the other hand, the significant negative trends were detected at station Ajmer in July and November, Jawaja in May and July, Gegal, Kishangarh, Pishangan, Srinagar and Masuda in July (Table 3). The magnitude of highest increasing trend was observed at Goela in the

TABLE 3

Trend of monthly rainfall of different stations of Ajmer district

Station	Test	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Z	-1.20	0.35	0.06	-0.25	-0.99	-0.09	-3.12*	1.12	0.43	-1.10	-2.22**	-1.13
Ajmer	Z_{SR}	-1.21	0.36	0.10	-0.29	-1.06	-0.01	-3.18*	1.13	0.38	-1.03	-2.23**	-1.15
	Q	0.00	0.00	0.00	0.00	0.00	-0.06	-3.01	1.22	0.35	0.00	0.00	0.00
	Z	-0.88	1.90***	0.60	-0.43	-0.67	-0.46	-0.92	-0.53	0.89	-1.06	-1.46	-0.77
Sarwar	Z_{SR}	-0.87	1.88***	0.60	-0.56	-0.44	-0.41	-1.08	-0.69	0.77	-0.99	-1.41	-0.78
	Q	0.00	0.00	0.00	0.00	0.00	-0.18	-1.11	-0.57	0.33	0.00	0.00	0.00
	Z	0.00	2.54**	0.95	0.51	-0.97	0.12	-1.13	0.46	1.28	-0.44	0.26	-0.24
Arain	Z_{SR}	-0.05	2.55	0.99	0.50	-1.00**	0.20	-1.11	0.39	1.17	-0.36	0.28	-0.25
	Q	0.00	0.00	0.00	0.00	0.00	0.00	-1.34	0.55	0.31	0.00	0.00	0.00
	Z	0.00	-0.44	0.76	1.53	-1.12	0.24	-0.30	0.55	0.97	-0.49	-1.09	-0.72
Beawar	Z_{SR}	-0.16	-0.46	0.71	1.58	-1.19	0.16	-0.36	0.65	0.92	-0.51	-1.05	-0.71
	Q	0.00	0.00	0.00	0.00	0.00	0.09	-0.25	1.04	0.59	0.00	0.00	0.00
	Z	2.21**	2.32**	2.86*	0.19	-0.63	-0.15	-0.08	0.54	2.53**	-0.12	-0.77	0.42
Bhinai	Z_{SR}	2.28**	2.21**	2.94*	0.38	-1.02	0.02	0.02	0.84	2.47**	0.01	-0.76	0.08
	Q	0.00	0.00	0.00	0.00	0.00	0.00	-0.08	0.54	1.43	0.00	0.00	0.00
	Z	0.32	2.93	1.61	1.23	0.72	0.99	-2.73*	-0.05	1.43	0.77	1.17	0.52
Gegal	Z_{SR}	0.28	2.90*	1.56	1.30	0.82	1.02	-2.77*	-0.12	1.37	0.81	1.2	0.58
	Q	0.00	0.00	0.00	0.00	0.00	0.00	-3.24	-0.06	0.21	0.00	0.00	0.00
	Z	2.09**	2.15**	2.76*	2.26**	1.28	2.83*	1.65***	4.05*	3.24*	1.70***	2.15**	0.46
Goela	Z_{SR}	2.03**	2.25**	2.73*	2.43*	1.23	2.87*	1.25	2.79*	3.01*	1.63***	2.21	0.53
	Q	0.00	0.00	0.00	0.00	0.00	0.57	1.68	4.00	0.29	0.00	0.00	0.00
	Z	-0.99	0.89	1.25	0.21	-1.67***	-1.17	-2.69*	-0.35	0.42	-1.16	0.00	0.50
Jawaja	Z_{SR}	-1.02	0.93	1.26	0.23	-1.52	-0.81**	-2.48*	-0.42	0.38	-1.07	-0.04	0.58
	Q	0.00	0.00	0.00	0.00	0.00	-0.41	-3.38	-0.43	0.00	0.00	0.00	0.00
	Z	-0.88	-0.09	1.36	-0.41	-0.68	-0.60	-0.50	0.07	0.03	-0.89	-0.03	-1.19
Kekri	Z_{SR}	-0.84	-0.04	1.39	-0.28	-0.58	-0.39	-0.45	0.06	-0.25	-0.7	-0.02	-1.17
	Q	0.00	0.00	0.00	0.00	0.00	-0.25	-0.63	0.13	0.00	0.00	0.00	0.00
	Z	-0.78	0.81	-0.23	1.35	-0.72	0.06	-1.96**	1.06	-0.05	0.30	-0.44	-0.44
Kishangarh	Z_{SR}	-0.78	0.78	-0.21	1.39	-0.75	0.13	-1.92***	0.94	0.10	0.29	-0.39	-0.43
	Q	0.00	0.00	0.00	0.00	0.00	0.00	-2.83	1.05	-0.03	0.00	0.00	0.00
	Z	2.47**	2.76*	2.72*	2.49**	1.19	1.36	0.68	0.97	0.78	-0.17	-0.44	-1.09
Mangaliwas	Z_{SR}	2.01*	2.37**	2.77*	2.60*	1.03	1.20	0.86	1.06	0.92	-0.19	-0.41	-1.22
	Q	0.00	0.00	0.00	0.00	0.00	0.25	0.71	1.00	0.25	0.00	0.00	0.00
	Z	1.31	0.8	2.74*	2.30**	-0.23	0.86	0.32	2.32**	1.13	1.08	0.65	1.27
Nasirabad	Z_{SR}	1.13	0.78	2.69*	2.38**	-0.26	0.8	0.27	2.10**	1.00	0.98	0.65	1.29
	Q	0.00	0.00	0.00	0.00	0.00	0.50	0.36	2.93	0.67	0.00	0.00	0.00
	Z	0.92	1.40	1.19	1.54	0.40	-0.23	-1.77***	1.36	1.23	0.08	0.24	0.00
Pishangan	Z_{SR}	0.86	1.42	1.15	1.48	0.47	-0.21	-1.90***	1.21	1.12	0.07	0.23	0.02
	Q	0.00	0.00	0.00	0.00	0.00	0.00	-2.33	1.78	0.63	0.00	0.00	0.00
	Z	1.19	2.28**	2.55**	1.88**	0.31	0.69	-0.95	1.88**	1.46	1.25	1.04	-0.17
Pushkar	Z_{SR}	1.20	2.36**	2.49*	1.87***	0.37	0.64	-1.08	1.78***	1.38	1.24	1.02	-0.17
	Q	0.00	0.00	0.00	0.00	0.00	0.60	-1.44	2.83	0.44	0.00	0.00	0.00
	Z	0.05	-0.78	0.92	0.60	-1.49	0.65	0.20	0.67	0.00	-1.07	0.00	-1.07
Sarwarr	Z_{SR}	0.03	-0.77	0.93	0.6	-1.47	0.75	0.20	0.81	-0.16	-0.98	0.01	-1.06
	Q	0.00	0.00	0.00	0.00	0.00	0.37	0.35	1.07	0.00	0.00	0.00	0.00
	Z	1.54	1.05	0.43	0.87	-0.23	-0.39	-2.84*	0.07	0.23	-0.84	-0.89	-1.53
Srinagar	Z_{SR}	1.48	1.07	0.43	0.93	-0.14	-0.29	-2.66*	0.19	0.21	-0.88	-0.82	-1.48
	Q	0.00	0.00	0.00	0.00	0.00	0.00	-3.71	0.14	0.00	0.00	0.00	0.00
	Z	-1.12	0.13	1.71***	-0.24	-1.09	-1.04	-0.82	0.27	0.57	0.23	0.9	-0.12
Todgarh	Z_{SR}	-1.02	0.19	1.71	-0.19	-1.03	-1.06	-0.69	0.20	0.69	0.26	0.93	-0.13
	Q	0.00	0.00	0.00	0.00	0.00	-0.47	-1.19	0.60	0.00	0.00	0.00	0.00
	Z	0.46	1.48	1.23	1.26	-0.54	0.04	-0.03	0.56	1.11	-0.36	-0.12	-0.23
Vijaynagar	Z_{SR}	0.40	1.55	1.22	1.14	-0.54	-0.05	-0.02	0.56	1.01	-0.44	-0.13	-0.25
	Q	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.18	0.00	0.00	0.00
	Z	1.24	2.22**	1.96**	1.57	-0.15	0.56	-2.12**	1.02	0.65	-0.07	-0.12	0.00
Masuda	Z_{SR}	1.30	2.31**	1.91	1.61	-0.09	-0.58***	-2.08**	0.84	0.69	-0.05	-0.12	0.00
	Q	0.00	0.00	0.00	0.00	0.00	-0.05	-2.68	1.41	0.08	0.00	0.00	0.00

Z- Man-Kendall's normalized test Statistics; Z_{SR} - Spearman's normalized test statistics; Q-Sen's Slope *statistically significant trends at the 99% confidence level, **statistically significant trends at the 95% confidence level, ***statistically significant trends at the 90% confidence level month of August and the rate of increasing was 4.00 mm per year. Whereas, the magnitude of highest decreasing trend was observed at Srinagar in the month of July and the amount of decrease was 3.71 mm per year (Table 3). By analyzing the rainfall trend and climatic condition of the studied region it may be concluded that the negative trend was more recurrent than positive trend and it happens mainly because of a critical increase in air temperature and also the environmental change.

5. Conclusions

The present study was conducted to investigate the spatio-temporal trends and variability of annual, seasonal and monthly rainfall of Ajmer during the period of 1973 to 2016. The MK, mMK and SR tests were used to analyze the trend in the times series data and the results exhibited both the test were not similar in all cases. The magnitude of the trend was analyzed using Sen's slope estimator and it gave satisfactory results even in cases where the significant trend was not recognized by the MK, mMK or SR tests. The trend analysis depicted that the significant increasing trend was observed in the central part for both annual and monsoon rainfall whereas decreasing trend was observed in north-western and south-western part of the region for mean annual rainfall and south-western part for monsoon rainfall. In addition, the monthly trends also showed a mixture of positive and negative changes during the study period for all 19 stations and station Goela was considered as the most consistent as the other stations. However, most of the stations of the region did not represent any significant change in annual, monsoon and monthly rainfall bearing an evidence of sparse distribution of climate changing factors having an effect on rainfall patterns over Ajmer. Such irregular character of rainfall and spatial changes may cause variation in crop cycles, crop rotation as well as the total agricultural system of the district. To get precise annual and monsoon rainfall trend and to establish their relationship with the issue of climate change and agricultural system further studies are recommended.

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