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Research Article

Trend Analysis of Temperature and Rainfall of Rajasthan, India

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Increasing temperature and declining and erratic rainfall is one of the greatest global challenges. This study presents the trend analysis of temperature and rainfall in five divisional headquarters of Rajasthan, namely, Bikaner, Jaipur, Jodhpur, Kota, and Udaipur. The historic data of minimum and maximum temperature and rainfall for a period of 49 years from 1971 to 2019 were collected from Climate Research and Services, India Meteorological Department, Pune. Detection of trends and change in magnitude was done using the Mann–Kendall (MK) test and Sen's slope, respectively. The results of the study indicated a significant increase in both minimum and maximum temperature over time for all the five stations. However, rainfall showed a nonsignificant increasing trend for Kota and Udaipur district, whereas Bikaner, Jaipur, and Jodhpur detected a negative trend.

1. Introduction

Climate change is the most vulnerable change taking place worldwide. It directly or indirectly impacts our ecosystem, cropping system, lives, and livelihood of the society. The study of change in max and min temperatures as well as rainfall plays a key role in recognizing the adverse impact of change of climate to improve management practices to attain environmental sustainability into development planning. The first step to attain sustainability in terms of climate is to take observations, identifying threat areas and vulnerable regions and sectors. The research outputs and recommendations are needed to be added to the state and national policies. Subhash and Sikka [1] examined the fact about the rational relationships of trends between rainfall and temperature over the homogenous regions in India. It found no direct relationship among increasing max temperature and increasing rainfall or seasonwise trend over meteorological subdivisions of India. However, it was concluded that the relation has wide scale temporal and spatial dependence. Both rainfall and temperature are critical considerations of crop yield; therefore, precise simulation of these variables is important for agricultural economics as well as meteorology. However, in general, it is difficult to simulate temperature and rainfall simultaneously due to the high correlation between them [2, 3]. Meshram et al. [4] studied long-term rainfall data of Ken River basin, Central India, over the period 1901–2010; the study was centred on water resource planning for agriculture and provided useful results for sustainable water utilization policy making. Another study was conducted by Jain and Kumar [5] to review trend of rainy days, rainfall, and temperature across India. Sen's slope was used to evaluate the magnitude of trend followed by statistical significance done by the MK test. The mean max temperature showed an increasing trend, whereas mean min temperature was found increasing as well as decreasing over different areas. Gajbhiye et al. [6] studied precipitation trend of Sindh River basin, India, for the data of 102 years ranging from 1901 to 2002, and found significant increase in the trend in seasonal and annual rainfall in these years. It is thus imperative to undertake a systematic study of rainfall and temperature trends for farming policies associated with long-term planning in agriculture and related sectors, food security, energy security, tourism, and many commercial entities that are directly related to these two weather parameters.

In India, climate change is causing adverse impact on monsoon timing, temperature, and other weather parameters, thus imposing potential impacts on the atmosphere [7]. Even a marginal increase in temperature can result in heatwave incidents and serious damage and alterations in species of animals and plants [8]. Several researchers have concluded that the pattern and extent of warming over India or the Indian subcontinent over the previous century are comprehensively steady with the worldwide pattern and magnitude [9–11]. Mohammad and Goswami [12] worked on the temperature and precipitation data of 115 years duration from 1901 to 2015, for 139 major Indian cities of India, and found decreasing trend in northwest cities and increasing trend in southeast cities with regards to temperature and quite heterogeneous patterns of trend in the rainfall data with decreasing rainfall in eastern part as compared to the western part.

Global climate has changed sharply in recent decades and exposed a significant impact on social and economic well-being as well as on the environment putting our living and physical environment into remarkable and multidimensional risk [13, 14]. Local climatic data assessment helps to understand the risks associated with climatic variability. The trend of rainfall and temperature was analyzed by Khavse et al. [15] using meteorological data of years 1971–2013 for Raipur district of Chhattisgarh. The linear trend analysis showed a long-term change in rainfall and temperature using the MK test. A modelling was done through data mining techniques using knowledge discovery in the database process model for Ethiopia by designing for weather variability forecasting, and it was found to be 98% accurate [16].

It has been observed that the trend analysis of weather variability parameters is not frequently in use in the state of Rajasthan, and no such study has been reported previously for the region depicting past trends of weather parameters. The present study will be helpful in deciding the appropriate cropping pattern and water resource planning for agriculture at the study location; parallelly, it will also help to develop strategies for reducing the biotic and abiotic stress during crop production. However, the study has a limitation that only three weather parameters have been considered presently. If the data on crop productivity and other weather variables were also considered, a more reliable picture of the study had been produced.

As per observations, adaptive capacity of climate resilience is quite low in Rajasthan, whereas it suffers with high climatic sensitivity. Studies show that the climate change in Rajasthan is over and above the climatic variability. To deal with these issues, Climate Change Agenda for Rajasthan (CCAR) was formed under Rajasthan Environment Policy released in 2010. To incorporate CCAR, Rajasthan Environment Mission was set with major emphasis on several key areas during 2010–2014. The reports of Rajasthan State Action Plan on Climate Change say that the state is already dealing with water scarcity with highest chances of drought occurrences with a frequency of almost four out of every five years with extremely low and erratic rainfall and limited surface water resources. Climate change is thus one of the greatest threats to Rajasthan, and it is thus always starving to find best strategies to deal with the adverse situations occurring due to climate change. The present study is performed with an aim to assist in policy making on what can be an effective strategy for communicating the issue of climate resilience in Rajasthan, so that urgent areas of action may be identified.

2. Data and Methodology

The climate of Rajasthan: being the biggest, the territory of Rajasthan is particularly prone to the threat of climatic limits. The state has been perceived as one of the four most vulnerable states because of environmental change by the State Action Plan on Climate Change. It has 66% of its space as the Thar Desert is especially portrayed by low and inconsistent rainfall, high air and soil temperature, exceptional sun-powered radiation, and high wind speed. The situating of the great Aravalli runs neglects to make any orographic rainfall and corresponds to the cloud bearing breezes in the state during the rainstorm months. The Tropic of Cancer brings about high temperatures throughout the late spring. The arid and semiarid regions of the state experience high daily and occasional fluctuations in temperature. The midyear temperature averages around a range of 26–46°C. In winter, the temperature varies from 8°C to 28°C. The yearly rainfall aggregates to around 600 mm in the eastern and southeastern parts and just 100 mm in the western regions of the state.

2.1. Study Area. India's largest area occupying state Rajasthan is located in the northwestern part of the subcontinent. The areas selected for this study are Bikaner, Jaipur, Kota, Jodhpur, and Bikaner districts of Rajasthan which are the divisional headquarters of the state. The adjoining districts of these headquarters cover almost entire state, and climate change can be accessed for the state. The area of study and geographical position of selected districts are shown in Figure 1, and land details of the research area are given in Table 1.

2.2. Datasets. For this study, the historical data from the year 1971 to 2019 (49 years) were collected for rainfall, min temperature, and max temperature for Bikaner, Jaipur, Kota, Jodhpur, and Bikaner districts of Rajasthan [17]. The annual total rainfall and mean of min and max temperature were calculated and processed in Excel sheets to examine the trends and further analysis. The weather data from 1971 to 2015 were collected from the portal of Climate Research and Services India Meteorological Department, Pune, while the latest data of the period of 2015–2019 were obtained from the publication of Rainfall Statistics of India—2015–2019 [18].

2.3. Methodology. The data obtained from the above sources were tabulated and summary statistics, namely, mean, standard deviation (SD), and coefficient of variation (CV) were reported. For detecting the trends, time series graphs were plotted, and Mann–Kendall's test was used for the selected variables.

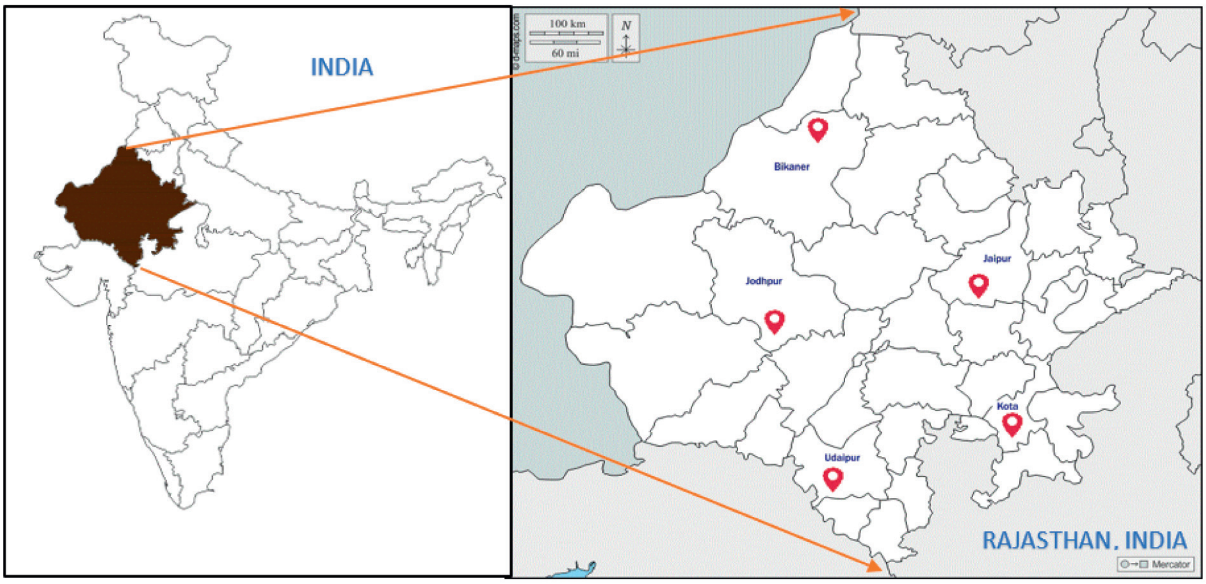

Figure 1: Map of the study area.

Table 1: The land details of the study area.

District	Latitude	Longitude	Area (sq. kms)	% area of the state
Bikaner	28°01′N	73°22′E	30247	8.84
Jaipur	26°55′N	75°52′E	11152	3.26
Kota	25°10′N	75°52′E	5098	1.49
Jodhpur	26°18′N	73°04′E	22850	6.68
Udaipur	27°42′N	75°33′E	12596	3.68

2.4. The Mann–Kendall's Trend Test. The significance of the trends was tested by a nonparametric test known as the Mann–Kendall (MK) test. It identifies trends in the data of time series. The test was introduced by Mann [19] and Kendall [20] and has been widely used in environmental time series [21]. The test compares the relative magnitudes of the sample data as well as the data values themselves.

Let x_1, x_2,...,x_n represent n data points, where x_j represents the data point at time j. The Mann–Kendall statistic (S) is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}\left(x_j - x_i\right), \qquad (1)$$

where sign is the well-known signum function. If either x_j or x_i is missing, then $\operatorname{sign}(x_j - x_i) = 0$ as per definition.

The trend is tested by calculating the test statistic

$$Z = \begin{cases} \dfrac{S-1}{(\operatorname{var}(S))^{1/2}}, & S > 0, \\ 0, & S = 0, \\ \dfrac{S+1}{(\operatorname{var}(S))^{1/2}}, & S < 0. \end{cases} \qquad (2)$$

For a sample size >10, a normal approximation to the MK test may be used. Variance of S is obtained as

$$\operatorname{var}(S) = \frac{n(n-1)(2n+5)}{18}, \qquad (3)$$

where n is the number of loads in the time series.

A very high positive value of S means an increasing trend, and a very low negative value represents a trend of decreasing nature. However, the statistical significance of the trend was tested by P value. A P value less than 0.05 was considered significant.

The slope within the time series was estimated by the formula proposed by Sen [22] and is given by Sen's slope estimator.

For all pairs of observations (x_i, x_j) with $1 \le j < i \le n$,

$$d_{ij} = \frac{x_i - x_j}{i - j}. \qquad (4)$$

2.5. Analysis Tools. We used Statistical Package for the Social Sciences (SPSS) package (trial version) for calculating descriptive statistics. Graphs were plotted using the polynomial regression function in Microsoft Excel and Mann–Kendall test, and Sen's slope was calculated using XLSTAT (trial version) package. XLSTAT is a statistical tool that allows to gain deep insight into your data and used for data preparation and visualization tools, parametric and nonparametric tests, modelling methods such as ANOVA, regression, generalized linear models, nonlinear models, data mining features such as principal component analysis, correspondence analysis, and clustering methods (agglomerative hierarchical clustering, K-means).

Table 2: Summary statistics for annual rainfall in mm (1971–2019) in the districts of Rajasthan.

	Bikaner			Jaipur			Jodhpur			Kota			Udaipur		
Month	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
January	4.3	5.8	134.9	5.7	8.1	142.1	3.3	7	212.1	5.7	10.8	189.5	2.6	6.3	242.3
February	10.2	8.3	81.4	10.1	9.1	90.1	5.1	6.2	121.6	6.9	9	130.4	2.5	4.8	192.0
March	7.4	8	108.1	5.6	8.1	144.6	2	5.2	260.0	6.1	8.2	134.4	1.8	4	222.2
April	8.3	8.1	97.6	10.5	8.8	83.8	9.2	6.4	69.6	4.5	7.4	164.4	5	4.3	86.0
May	23.5	12.8	54.5	17	10.9	64.1	19.6	10.5	53.6	10.6	8.2	77.4	16	8.1	50.6
June	42.1	20.8	49.4	65.1	28.4	43.6	46	21.1	45.9	72.4	30.5	42.1	72.7	30.6	42.1
July	93	40	43.0	200	80	40.0	129.4	52.7	40.7	250.5	98.8	39.4	187.5	76.3	40.7
August	62.2	43.4	69.8	191.5	100.9	52.7	126.2	66.5	52.7	243.2	126.2	51.9	204.6	101.6	49.7
September	33.4	42.4	126.9	61.4	97.3	158.5	51	64.9	127.3	86.7	122.5	141.3	91.2	100.5	110
October	13.1	40.5	309.2	19.1	92.6	484.8	6.6	61.6	933.3	19.5	116.4	596.9	13	95.4	733.8
November	2	38.6	1930.0	4.9	88.3	1802.0	2.9	58.8	2027.6	8	111	1387.5	12.5	91.1	728.8
December	1.6	36.9	2306.3	3	84.5	2816.7	1.6	56.3	3518.8	3.2	106.3	3321.9	1.9	87.2	4589.5

Table 3: Summary statistics for min temperature in °C (1971–2019) in the districts of Rajasthan.

	Bikaner			Jaipur			Jodhpur			Kota			Udaipur		
Month	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
January	7.0	1.7	24.3	8.3	1.6	19.3	9.3	1.8	19.4	10.9	2.5	22.9	6.8	2.4	35.3
February	10.6	7.6	71.7	11.3	8.1	71.7	11.9	8.5	71.4	13.7	9.8	71.5	8.6	6.3	73.3
March	16.5	11.4	69.1	16.7	11.7	70.1	17.4	12.2	70.1	19.1	13.6	71.2	14.2	9.7	68.3
April	22.7	15.0	66.1	22.3	15.0	67.3	23.1	15.6	67.5	25.0	17.2	68.8	19.7	12.9	65.5
May	27.3	18.2	66.7	26.4	17.9	67.8	27.1	18.5	68.3	29.1	20.1	69.1	24.3	15.9	65.4
June	29.2	20.4	69.9	27.5	19.8	72.0	27.7	20.3	73.3	28.6	21.8	76.2	25.1	17.7	70.5
July	27.1	21.5	79.3	25.4	20.7	81.5	26.9	21.4	79.6	25.6	22.4	87.5	23.6	18.7	79.2
August	27.1	22.3	82.3	24.2	21.2	87.6	25.6	22.0	85.9	24.5	22.6	92.2	22.9	19.3	84.3
September	25.3	22.6	89.3	23.6	21.5	91.1	23.9	22.2	92.9	24.3	22.8	93.8	19.8	19.3	97.5
October	19.7	22.4	113.7	19.3	21.3	110.4	19.1	21.9	114.7	20.9	22.6	108.1	16.5	19.1	115.8
November	13.1	21.7	165.6	13.7	20.7	151.1	14.4	21.3	147.9	15.9	22.1	139.0	11.7	18.5	158.1
December	8.1	20.9	258.0	9.3	20.0	215.1	10.4	20.6	198.1	12.2	21.5	176.2	8.1	17.9	221.0

3. Results and Discussion

We used both monthly and annually data to calculate the mean, standard deviation (SD), and coefficient of variation (CV) of rainfall, min, and max temperature. The monthwise basic statistical attributes of selected variables are presented in the subsequence tables for the five stations separately.

The figures for mean rainfall presented in Table 2 indicate that the region received less to scarce rainfall even in rainy season. The highest rainfall was observed in the months of July and August with less value of CV. Kota, Jaipur, and Udaipur received an average rainfall of more than 200 mm in monsoon months, whereas Bikaner received lowest rainfall with an average of 93 mm and 62.2 mm in the month of July and August. A further mining of data showed that the highest mean rainfall of 424.1 mm was received in the month of August during the year 1973 for Jodhpur district. In Kota, the rainfall as high as 675.8 mm was received in the year 2001. Similar figure was 630.0 mm in 1973, 256.1 mm in 1978, and 956.3 mm in 1981 for Udaipur, Bikaner, and Jaipur, respectively, in the month of July.

It is clear from Table 3 that the min temperature varied from 6.8 C in January to 29.2 C in June for all the selected stations of the states. Udaipur and Bikaner were found to be the coldest districts, whereas Kota showed a high value of min temperature throughout the year. The analysis further showed that the years 1988, 1994, 2008, 2009, and 2016 were comparatively hot as far as min temperature was concerned, where the highest min temperature was recorded more than 10 C for all the districts of Rajasthan.

It is evident from Table 4 that May is the hottest month of the year in the state where the max temperature shoots up to as high as about 42 C. Udaipur recorded lowest max temperature of 38.1 C, which may be because of its geographical location. Bikaner and Kota faced high mean temperature as compared to other districts. The analysis of mean monthly data further revealed that Kota and Bikaner recorded highest mean max temperature of 44.5 C in the year 2010 and 1978, respectively. Jaipur and Udaipur noted hottest in May in the year 1988, whereas Jodhpur observed the highest temperature of 43.1 C in the year 1998. The annual trends of min and max temperature and rainfall are represented through trendline graphs in Figure 2.

The MK test and Sen's slope were used to access the trends for min and max temperature and rainfall. Separate trend analysis was carried out on the selected variables, and the results of MK test along with the P value and Sen's slope giving the magnitude of trend are given in Table 5. It is evident from the table that a significant increasing trend exists for min temperature with P value <0.05 at all the five stations except Kota (P value $= 0.06$) where the increase was not observed to be significant at 5% level of significance. Max

Table 4: Summary statistics for max temperature in C (1971–2019) in the districts of Rajasthan.

	Bikaner			Jaipur			Jodhpur			Kota			Udaipur		
Month	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
January	23.2	3.5	15.1	22.5	3.5	15.6	25.2	3.8	15.1	22.8	4.9	21.5	22.7	7.1	31.3
February	26.4	18.9	71.6	25.5	18.2	71.4	28.1	20.1	71.5	26.2	18.9	72.1	24.2	17.8	73.6
March	32.4	24.2	74.7	31.6	23.5	74.4	33.8	25.5	75.4	32.4	24.2	74.7	30.9	23	74.4
April	38.4	28.5	74.2	37.4	27.7	74.1	38.8	29.4	75.8	38.3	28.4	74.2	36	26.9	74.7
May	42	31.6	75.2	40.7	30.7	75.4	40.4	31.9	79.0	41.5	31.5	75.9	38.1	29.5	77.4
June	41.6	33.5	80.5	39.4	32.3	82.0	40	33.4	83.5	39.1	32.9	84.1	35.6	30.6	86.0
July	36.8	34	92.4	33.6	32.5	96.7	35.9	33.8	94.2	32.6	32.8	100.6	30.6	30.6	100.0
August	37	34.4	93.0	31.9	32.4	101.6	33.9	33.8	99.7	30.7	32.6	106.2	29.7	30.5	102.7
September	37.2	34.7	93.3	34.1	32.6	95.6	35.4	34	96.0	32.6	32.6	100.0	29.4	30.4	103.4
October	35.5	34.8	98.0	33.2	32.7	98.5	35.4	34.1	96.3	32.3	32.5	100.6	31.9	30.5	95.6
November	30.5	34.4	112.8	28.8	32.3	112.2	31.1	33.8	108.7	28.7	32.2	112.2	28.9	30.4	105.2
December	25.1	33.8	134.7	24.2	31.7	131.0	26.7	33.3	124.7	24.9	31.7	127.3	25.2	30	119.0

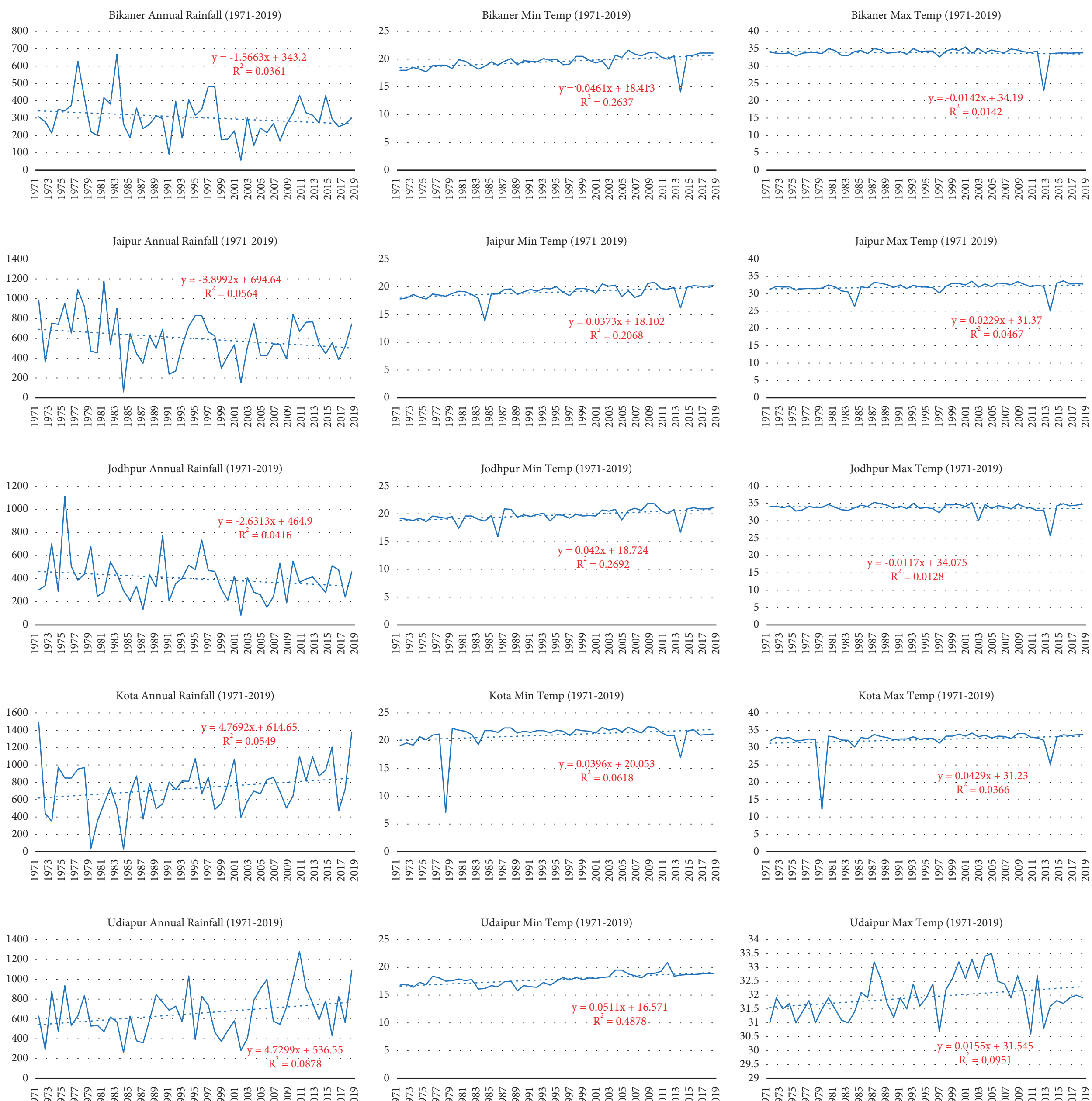

Figure 2: Annual trends of rainfall, min, and max temperature from 1971 to 2019.

Table 5: Trend analysis of temperature and rainfall using the MK test (at 5% level of significance).

Station	Temperature (min)				Temperature (max)				Rainfall			
	S statistic	Value (*P*)	Sen slope	Trend	S statistic	Value (*P*)	Sen slope	Trend	S statistic	Value (*P*)	Sen slope	Trend
Bikaner	644	0.00	0.05	Increasing	65	0.57	0.001	Increasing	−104	0.37	−1.07	Decreasing
Jaipur	549	0.00	0.04	Increasing	428	0.00	0.029	Increasing	−145	0.21	−3.69	Decreasing
Jodhpur	595	0.00	0.04	Increasing	75	0.51	0.006	Increasing	−99	0.39	−1.35	Decreasing
Kota	217	0.06	0.02	Increasing	392	0.00	0.025	Increasing	199	0.08	5.35	Increasing
Udaipur	644	0.00	0.05	Increasing	304	0.00	0.018	Increasing	208	0.07	4.60	Increasing
	Annual rainfall trend (1971–2019)				Min temperature trend (1971–2019)				Max temperature trend (1971–2019)			

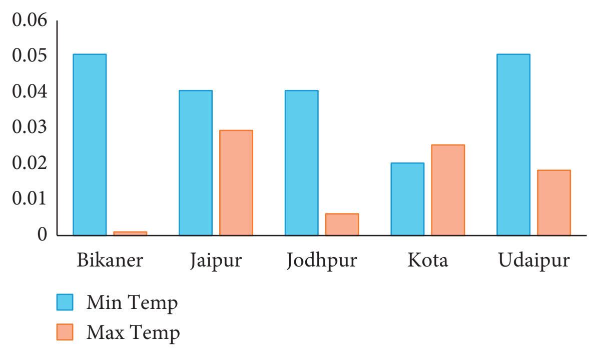

Figure 3: Sen's slope for temperature at different stations.

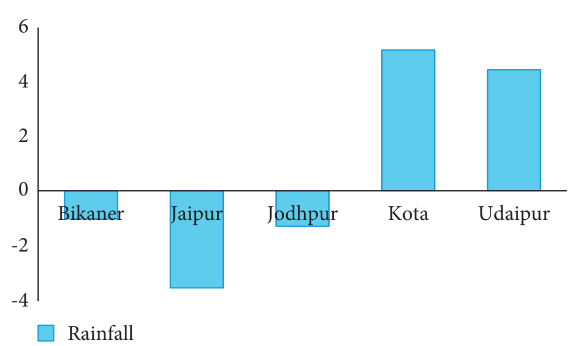

Figure 4: Sen's slope for rainfall at different stations.

temperature also showed a significant increasing trend for Jaipur, Kota, and Udaipur stations. Sen's slope values, shown in Figure 3, also show a positive trend for temperature at all the five stations.

Though, Bikaner and Jodhpur districts showed an increasing but nonsignificant trend with *P* value of 0.57 and 0.51, respectively. However, both positive and negative trends were identified in rainfall data. Rainfall showed a nonsignificant declining trend for Bikaner, Jaipur, and Jodhpur stations having Sen's slope of −1.07, −3.69, and −1.35 magnitude, respectively, while Kota (5.35) and Udaipur (4.60) exhibited an increasing trend (Figure 4). These finding confirm the results obtained by Deoli et al. [23] who also reported similar trends for temperature and rainfall in Udaipur district.

These findings clearly indicate that the global trend of climate change is persisting in the state of Rajasthan also, whose major area already falls under hot and dry climatic conditions, and this is a matter of great concern for all.

4. Conclusion

The trends in three major climatic parameters, namely, min and max temperature and rainfall through nonparametric approach are attempted to be investigate in the present study. Both temperature and rainfall showed considerable variation in different months as well as in the last five decades. It is evident from the data summary that the state is receiving very less to scarce rainfall which is also unevenly distributed within the whole state. Besides this, it is also showing a declining trend particularly in Bikaner, Jaipur, and Jodhpur districts. Kota and Udaipur showed an increase in rainfall, but it is not statistically significant. For min and max temperature, all the stations showed a significant positive trend. Results were confirmed by the MK test and Sen's slope estimator. In conclusion, these findings can be taken as an indicator of change in temperature and rainfall that are occurring in the state during last 50 years and can be used for future projection studies. Increasing temperature and decreasing rainfall are already a major concern for environmentalist, climatologists, farmers, policy makers, and society at large, and in such situation, the findings of this study are very imperative for an agrarian economy like ours.

Data Availability

For this study, the historical data for the year 1971–2019 (49 years) were collected for rainfall, minimum temperature, and maximum temperature for Bikaner, Jaipur, Kota, Jodhpur, and Bikaner districts of Rajasthan. The weather data from 1971 to 2014 were collected from the portal of Climate Research and Services India Meteorological Department, Pune (https://cdsp.imdpune.gov.in/), while the latest data from the period of 2015–2019 were obtained from the publication of Rainfall Statistics of India, 2015–2019 (https://hydro.imd.gov.in/hydrometweb/(S(youz4bzdpt0j4c455zbrxgut))/landing.aspx).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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