

# A Climatic Trend Assessment of Temperature and Precipitation in Rajasthan

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## ABSTRACT

*Rising temperatures along with decreasing and irregular rainfall represent a major global concern. This study examines trends in temperature and rainfall across five divisional headquarters of Rajasthan—Bikaner, Jaipur, Jodhpur, Kota, and Udaipur. Historical records of minimum and maximum temperatures, as well as rainfall data spanning 50 years (1970–2020), were obtained from the Climate Research and Services of the India Meteorological Department in Pune. Trend detection and the magnitude of changes were analyzed using the Mann–Kendall (MK) test and Sen’s slope method. The findings reveal a significant upward trend in both minimum and maximum temperatures at all five locations. In contrast, rainfall exhibited a slight but statistically insignificant increase in Kota and Udaipur, while Bikaner, Jaipur, and Jodhpur showed a declining trend.*

**Keywords:** Climate Change; Temperature Trend; Rainfall Variability; Mann–Kendall Test; Sen’s Slope

**Mathematics Subject Classification (MSC) 2020:** 62P12; 86A08; 62G32; 60G70; 86A10.

## 1. Introduction

Climate change is one of the most serious and sensitive global issues today. It affects ecosystems, agricultural systems, human life, and livelihoods both directly and indirectly. Studying changes in maximum and minimum temperatures along with rainfall is essential to understand the harmful effects of climate change and to support better environmental management and sustainable development planning. The first step toward sustainability is to monitor climatic conditions, identify vulnerable regions, and recognize risk-prone sectors. The findings of such studies should be incorporated into both state and national policy frameworks. Subhash and Sikka [1] analyzed rainfall and temperature trends across homogeneous regions of India and observed that there is no simple direct relationship between increasing temperature and rainfall trends. Instead, these relationships vary significantly over time and space. Since rainfall and temperature strongly influence crop productivity, accurate analysis of these variables is important for agricultural planning, economic development, and meteorological studies. However, modeling both variables together is challenging due to their complex interdependence. Meshram et al. [4] examined long-term rainfall patterns in the Ken River basin (1901–2010) and highlighted their importance for water resource management and sustainable agricultural planning. Similarly, Jain and Kumar [5] reviewed rainfall, rainy days, and temperature trends across India using the Mann–Kendall test and Sen’s slope, finding mixed trends in temperature and regional variations in rainfall patterns. Gajbhiye et al. [6] studied over a century of rainfall data in the Sindh River basin and reported an overall increasing trend in seasonal and annual rainfall. In India, climate change is significantly affecting monsoon behavior, temperature patterns, and other weather conditions. Even small increases in temperature can lead to heatwaves and cause major impacts on biodiversity. Studies also suggest that warming trends in India

are consistent with global climate change patterns. Mohammad and Goswami [12] analyzed long-term climate data from 139 Indian cities and found regional variations, with increasing temperature trends in some areas and decreasing or uneven rainfall patterns across the country.

Recent decades have seen rapid global climate change, which has strongly affected environmental, social, and economic systems, increasing overall risk. Local climate analysis is therefore important for understanding vulnerability. Khavse et al. [10] studied rainfall and temperature trends in Raipur district using statistical methods and found noticeable long-term climatic changes. Research using advanced data mining techniques has also achieved high accuracy in forecasting weather variability. However, such trend-based studies are still limited in Rajasthan. This region is highly vulnerable to climate change due to low adaptive capacity and high climatic sensitivity, especially water scarcity and frequent drought conditions. The Rajasthan government has initiated policies such as the Climate Change Agenda for Rajasthan (CCAR) and the Rajasthan Environment Mission to address these challenges. According to the State Action Plan on Climate Change, Rajasthan experiences frequent droughts and highly erratic rainfall, making it one of the most climate-sensitive regions in India.

Therefore, climate change poses a major threat to Rajasthan, and there is a strong need to develop effective adaptation strategies. The present study aims to support policy-making by identifying key areas of concern and improving climate resilience planning in the state.

## 2. Data and Methodology

### Climate of Rajasthan

Rajasthan, the largest state in India, is highly vulnerable to climatic extremes. According to the State Action Plan on Climate Change, it is considered one of the most climate-sensitive states in the country. Around 60–70% of its geographical area is covered by the Thar Desert, which is characterized by low and erratic rainfall, high air and soil temperatures, intense solar radiation, and strong winds. The Aravalli Range does not effectively obstruct the southwest monsoon winds, resulting in limited orographic rainfall in the region. Moreover, the Tropic of Cancer passes through the state, contributing to very high summer temperatures. Both arid and semi-arid regions experience significant diurnal and seasonal temperature variations. Summer temperatures generally range from 30°C to 45°C, with extreme conditions reaching up to 47–48°C in western districts. In winter, temperatures usually vary between 8°C and 28°C, although minimum temperatures can occasionally drop below 5°C in some areas. Annual rainfall shows strong spatial variation, with eastern and south eastern regions receiving about 500–700 mm, while the western desert regions receive only around 100–200 mm. Rainfall is also highly variable from year to year.

#### 2.1 Study Area:

Rajasthan, located in the northwestern part of India, is the largest state in terms of area. The study focuses on the districts of Bikaner, Jaipur, Kota, and Jodhpur, which serve as divisional headquarters. The surrounding districts of these regions collectively represent most parts of the state, allowing for a comprehensive assessment of climate change patterns. The land-related information and study area details are presented in Table a.

#### 2.2 Datasets:

The study utilizes historical climate data spanning 50 years, from 1970 to 2020. Data on rainfall, minimum temperature, and maximum temperature were collected for the selected districts. Annual total rainfall and average minimum and maximum temperatures were calculated and organized using Excel for trend analysis. Data from 1970 to 2015 were obtained from the Climate Research and Services portal of the India Meteorological Department (IMD), Pune. More recent data (2015–2018) were sourced from the publication Rainfall Statistics of India (2015–2018).

#### 2.3 Methodology:

The collected data were systematically tabulated, and key statistical measures such as mean, standard deviation (SD), and coefficient of variation (CV) were computed. Time series graphs were created to visualize trends, and the Mann–Kendall test was applied to detect significant trends in the selected climate variables.

**Table a: Presents the details of the study area**

District	Latitude	Longitude	Area(sq.km)	percentageArea(%)	Weather Characteristics
Bikaner	28°01' N	73°22' E	30,247	8.84	Arid and hot desert Weather with low rain fall
Jaipur	26°55'	75°49'	11,152	3.26	Semi – arid Weather with moderate rain fall
Kota	25°10'	75°52'	5,098	1.49	Relatively humid with higher monsoon rain fall
Udaipur	24°35'	73°41'	12,596	3.68	Moderately humid due to hilly terrain
Ajmer	26°27'	74°38'	8,481	2.48	Semi – arid Weather with irregular rain fall

**2.4 Mann–Kendall Trend Test:**

The significance of trends was evaluated using a non-parametric statistical method known as the Mann–Kendall (MK) test. This test is commonly applied to detect trends in time series data. It was originally developed by Mann [11] and Kendall [9], and has since been widely used in environmental time series analysis [7]. The MK test assesses both the relative magnitude of the data and the direction of changes over time, allowing for the identification of increasing or decreasing trends.

Consider a sequence of observations  $y_1, y_2, \dots, y_m$  where  $y_k$  denotes the recorded value at time k. The test computes the Mann–Kendall statistic  $M_s$  by comparing each observation with all subsequent observations and evaluating the sign of their differences:

$$M_s = \sum_{j=1}^{m-1} \sum_{k=j+1}^m \text{sign}(y_k - y_j)$$

where the signum function is defined as:

$$\text{sign}(y_k - y_j) = \begin{cases} +1, & y_k - y_j > 0 \\ 0, & y_k - y_j = 0 \\ -1, & y_k - y_j < 0 \end{cases}$$

If either  $y_j$  or  $y_k$  is missing, the comparison contributes zero to the summation.

To assess the significance of the detected trend, the standardized test statistic  $M_z$  is calculated as:

$$M_z = \begin{cases} \frac{M_s - 1}{\sqrt{\text{Var}(M_s)}}, & M_s > 0 \\ 0, & M_s = 0 \\ \frac{M_s + 1}{\sqrt{\text{Var}(M_s)}}, & M_s < 0 \end{cases}$$

For datasets containing more than ten observations, the statistic approximately follows a normal distribution. The variance of  $M_s$  is estimated using:

$$\text{Var}(M_s) = \frac{m(m - 1)(2m + 5)}{18}$$

where m represents the number of observations in the series.

A positive value of  $M_s$  indicates an increasing trend, whereas a negative value suggests a decreasing tendency. Larger absolute values of  $M_s$  correspond to stronger trends. Statistical significance was evaluated using the p-value criterion, and trends with  $p < 0.05$  were considered statistically significant.

The magnitude of the trend was further quantified using the Sen’s slope estimator. For every pair of observations  $(y_j, y_k)$  satisfying  $1 < k < j \leq m$ , the slope estimate is computed as:

$$t_{jk} = \frac{y_j - y_k}{j - k}$$

The median of all calculated values  $t_{jk}$  represents Sen’s slope, providing a robust estimate of the rate of change within the time series.

**2.5 Statistical Analysis and Visualization Tools**

Data analysis was carried out using several statistical and visualization software packages. Descriptive statistics were generated with the trial version of SPSS to summarize and interpret the dataset. Trend graphs and curve fitting were developed in Microsoft Excel using polynomial regression techniques. The Mann–Kendall trend test along with Sen’s slope estimator was performed in XLSTAT. This software provides a broad range of analytical capabilities, including data pre-processing,

visualization, hypothesis testing, regression modelling, ANOVA, generalized and nonlinear models, as well as multivariate and data mining techniques such as principal component analysis, correspondence analysis, hierarchical clustering, and K-means clustering.

**Table b: Statistical summary of annual rainfall variability (mm) across the districts of Rajasthan from 1970 to 2020**

	Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Bikaner	Mean	4.6	10	7.1	8.6	24	43	95	64	34	13.5	2.2	1.8
	SD	5.98	8.5	7.81	8.17	13.44	21.5	41.8	43.52	42.5	40.5	41.8	40.50
	CV	130	85	110	95	56	50	44	68	125	300	1900	2250
Ajmer	Mean	4.9	8.7	5.3	7.8	18.4	58.6	175.2	168.7	70.3	16.2	5.6	2.4
	SD	6.7	7.9	6.8	7.2	10.1	25.3	72.4	85.6	94.1	101.8	89.7	81.3
	CV	136.7	90.8	128.3	92.3	54.9	43.2	41.3	50.7	133.9	628.4	1601.8	3387.5
jaipur	Mean	5.9	10.3	6.0	10.8	17.5	66	205	195	62	20	5.2	3.2
	SD	8.26	9.06	9.0	8.86	11.38	29.04	84.05	103.3	99.2	96	93.6	89.6
	CV	140	88	150	82	65	44	41	53	160	480	1800	2800
kota	Mean	6	7.2	6.5	4.8	11	74	255	240	88	20	8.5	3.5
	SD	11.1	9.72	9.10	7.68	8.25	31.08	99.45	124.8	123.2	120	110.5	115.5
	CV	185	135	140	160	75	42	39	52	140	600	1300	3300
Udaipur	Mean	2.8	2.7	2.0	5.5	16.5	73	190	205	95	14	12.8	2.1
	SD	6.72	5.13	4.4	4.95	8.25	30.66	77.9	102.5	104.5	105	92.16	94.50
	CV	240	190	220	90	50	42	41	50	110	750	720	4500

**Table c: Descriptive statistics of minimum temperature (°C) across the districts of Rajasthan during the period 1970–2020**

	Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Bikaner	Mean	7.2	10.8	16.8	23	27.6	29.5	27.4	27.3	25.6	19.9	13.4	8.3
	SD	1.8	7.8	11.5	15.2	18.4	20.7	21.8	22.5	22.9	22.8	22	21.2
	CV	25	72.2	68.5	66.1	66.7	70.2	79.6	82.4	89.5	114.6	164.2	255.4
Ajmer	Mean	8.1	10.9	16.9	22.5	26.3	27.2	25.2	24.3	22.8	18.7	13.2	9.1
	SD	2.0	7.9	11.8	15.1	17.8	19.8	20.7	21.4	21.2	21	20.1	19.5
	CV	24.7	72.5	69.8	67.1	67.7	72.8	82.1	88.1	93	112.3	152.3	214.3
jaipur	Mean	8.5	11.5	17	22.6	26.7	27.8	25.7	24.5	23.8	19.5	13.9	9.5
	SD	1.7	8.3	11.9	15.3	18.2	20.2	21.1	21.6	21.9	21.7	21.1	20.4
	CV	20	72.2	70	67.7	68.2	72.7	82.1	88.2	92.0	111.3	151.8	214.7
kota	Mean	11.1	14	19.4	25.3	29.5	28.9	25.9	24.7	24.5	21.1	16.2	12.5
	SD	2.6	9.9	13.8	17.5	20.4	22.1	22.8	23	23.2	22.9	22.5	21.8
	CV	23.4	70.7	71.1	69.2	69.2	76.5	88	93.1	94.7	108.5	138.9	174.4
Udaipur	Mean	7.0	8.9	14.5	20	24.6	25.4	23.9	23.1	20.1	16.8	12	8.3
	SD	2.5	6.5	9.9	13.1	16.1	18.0	19.0	19.6	19.7	19.5	18.9	18.3
	CV	35.7	73	68.3	65.5	65.4	70.9	79.5	84.8	98	116.1	157.5	220.5

### 3. Weather Analysis and Discussion

Monthly and annual datasets were analyzed to estimate the mean, standard deviation (SD), and coefficient of variation (CV) for rainfall as well as minimum and maximum temperature. The month-wise statistical characteristics of the selected climatic variables for the five stations are presented in the following tables.

The rainfall statistics presented in Table b reveal considerable spatial and seasonal variability across the districts of Rajasthan. Most of the rainfall was concentrated during the monsoon season, particularly in July and August, where comparatively lower CV values indicated relatively stable rainfall patterns during these months. Among the selected districts, Kota, Jaipur, and Udaipur recorded average monthly rainfall exceeding 200 mm during the monsoon period, whereas Bikaner experienced the lowest rainfall, with average values of 95 mm in July and 64 mm in August. Further examination of the dataset indicated

that Jodhpur received its highest monthly mean rainfall of 424 mm during August 1973. Similarly, extreme rainfall events were also observed in other districts, including 674.8 mm in Kota during 2001, 630.0 mm in Jaipur during 1981, 256.1 mm in Bikaner during 1978, and 956.3 mm in Udaipur during July 1973. These findings highlight the irregular and highly fluctuating nature of rainfall distribution in Rajasthan.

Table c indicates considerable seasonal and spatial variation in minimum temperature across the selected stations of Rajasthan. The lowest minimum temperature was recorded in January (7 °C), while the highest occurred in June (29.5 °C). Among the districts, Udaipur and Bikaner experienced relatively cooler conditions, whereas Kota consistently maintained higher minimum temperatures throughout the year. The analysis also revealed that the years 1988, 1994, 2008, 2009, and 2016 were notably warmer, with minimum temperatures exceeding 10 °C in all districts of the state. The Mann–Kendall (MK) test and Sen’s slope estimator were applied to evaluate trends in minimum and maximum temperature as well as rainfall. Separate analyses were conducted for each variable, and the corresponding MK test results, p-values, and Sen’s slope magnitudes are presented in Table d. The findings indicate a significant upward trend in minimum temperature at all five stations with p-values below 0.045, except for Kota, where the increase was not statistically significant at the 5% significance level ( $p = 0.06$ ).

**Table d: Temperature and rainfall trend analysis using the MK test (5% significance level)**

Station	Temperature(min)				Temperature(max)				Rain – fall			
	S	Value	Sen	Trend	S	Value	Sen	Trend	S	Value	Sen	Trend
	statistic	(p)	slope		statistic	(p)	slope		statistic	(p)	slope	
Bikaner	618	0.00	0.04	increase	82	.49	.003	increase	-118	0.34	-1.15	decrease
Jaipur	532	0.00	0.05	increase	401	0.00	.027	increase	-156	0.18	-3.42	decrease
Kota	236	0.05	0.03	increase	376	0.00	.023	increase	214	0.06	5.08	increase
Udaipur	629	0.00	0.05	increase	328	0.00	.020	increase	221	0.05	4.82	increase

## Conclusion

The present study examined long-term changes in major climatic parameters, including minimum temperature, maximum temperature, and rainfall in Rajasthan using non-parametric statistical methods. The analysis revealed noticeable fluctuations in temperature and rainfall patterns over different months and across the last five decades. The findings indicate that Rajasthan experiences generally low and unevenly distributed rainfall, with several districts such as Bikaner, Jaipur, and Jodhpur showing a declining rainfall trend. In contrast, Kota and Udaipur exhibited a slight increase in rainfall, although the trend was not statistically significant. The study further demonstrated a consistent rise in both minimum and maximum temperatures across most districts, reflecting the increasing influence of climate variability and global warming in the region. The Mann–Kendall test and Sen’s slope estimator confirmed the existence of significant warming trends. These climatic changes are likely to affect agriculture, water resources, ecosystems, and livelihoods, particularly in arid and semi-arid regions like Rajasthan. Overall, the results highlight the urgent need for sustainable climate adaptation strategies, improved water management practices, and region-specific agricultural planning. The study also provides a valuable baseline for future climate projection and environmental research in Rajasthan.

Bikaner showed increasing but statistically non-significant trends, with p-values of 0.49 and 0.51, respectively. Rainfall trends varied across regions, declining in Bikaner, Jaipur, and Jodhpur, while increasing in Kota and Udaipur. Similar results were also reported by Deoli et al. [3] for Udaipur district. These findings suggest that the impacts of climate change are becoming more evident in Rajasthan, raising concerns due to its predominantly hot and dry climate.

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