Statistical Analysis of Precipitation Over Kota (India) from 1981 to 2020

Kuldeep, Sohil Sisodiya, and Anil. K. Mathur

Abstract Variation in precipitation amounts and distribution patterns leads to changes in general atmospheric circulation, cloud cover, surface albedo, and concentrations of air pollutants in the context of climatic variability. Industrial, residential, and agricultural water demands largely depend on rainfall. Even rainfall variability significantly affects people's livelihood. This study evaluates the temporal variation in rainfall for the Kota district of Rajasthan state in India. Eight rainfall monitoring stations were utilised to collect precipitation data for 40 years (1981–2020). Trend analysis has been performed for monthly, seasonal, and annual rainfall series with the help of Mann–Kendall (non-parametric) and linear regression (parametric) trend tests. Standardised rainfall anomaly and wetness index were estimated to determine the excess in total annual rainfall. The monthly distribution of precipitation is contrasted with the help of the precipitation concentration index. Both non-parametric and parametric trend tests estimate an increasing trend in precipitation for February, March, June, July, August, and September months, reflecting an increase in the total annual precipitation for the research area. The analysis of precipitation data shows a very high inter and intra variability in annual rainfall (C.V. = 169.45). A very high non-uniformity of rain is observed from the analysis of PCI. The maximum concentration of precipitation (~84.50) took place in monsoon months. Annual rainfall has significantly increased over the last four decades, indicating

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the need for proper rainwater management and utilisation plans to take maximum benefits shortly.

Keywords Trend analysis · Mann–Kendall trend test · Standardised rainfall anomaly · Wetness index · Precipitation concentration index

1 Introduction

The biggest challenge facing humanity in the twenty-first century is worldwide climate change and its severe consequences on the environment. Climate change is directly linked with variations in rainfall patterns, hydrological cycle, moisture content, melting of ice, extreme conditions, and the frequency and intensity of extreme events [1].

Increased emission of greenhouse gases (CO_2, CH_4, N_2O, and halocarbons) has been the leading cause of global warming since the 1950s. Global warming is responsible for the rise in the mean temperature of the earth's surface, leading to climate change [2]. All the important sectors, such as ecological, biological, meteorological, and socio-economic, are directly or indirectly affected by global climate change [3]. Hence, it is a point of attention in research worldwide. The long-term variation in rainfall trends is analysed regularly to estimate the significant impact of climate change. Quantitative analysis of temporal rainfall distribution for a region is crucial for hydraulic structure modelling, hydrological modelling, surface water modelling, flood forecasting, agriculture modelling, groundwater modelling, evaporation modelling, crops scheduling, etc. [4, 5].

India is situated in a tropical monsoon zone and receives almost 80% of annual rainfall in June, July, August, and September due to the Southwest monsoon with more significant spatiotemporal variability [6, 7]. Several studies have been conducted in different parts of the world on rainfall variability for various purposes in the literature, but almost negligible studies have been available for Kota.

This paper examines the trends for annual, seasonal, and monthly rainfall series for Rajasthan (India) Kota district (1981–2020) using the Mann–Kendall (non-parametric) trend test and linear regression (parametric) trend test. Standardised rainfall anomaly and wetness index are estimated to determine the excess in total annual rainfall. The monthly distribution of precipitation is contrasted with the help of the precipitation concentration index (PCI). The coefficient of variation measures the dispersion of rains.

2 Study Area and Data Source

Kota is the south-eastern district of Rajasthan state, India, and its geographical area lies between 75° 37′ and 77° 26′ longitude and 24° 25′ and 25° 51′ latitude. The maximum width and length of Kota are 54 km (east to west) and 153 km (north to south), respectively. The geographical area of the Kota district is 5217 km^2 and has shaped like Dumber [8]. The population of Kota district as per the census of 2011 was 1,951,014 [9]. The total number of registered vehicles was 885,737 in 2020 as per the Rajasthan Transport department [10]. The total number of industrial areas and industrial units were 19 and 12,908, respectively, as per the MSME report, 2015 [11].

Rainfall data were collected for 40 years (1981–2020) from eight rainfall monitoring stations daily, and these monitoring stations, along with the study area, are shown in Fig. 1. The GPS coordinates of each monitoring station are tabulated in Table 1. The total rainfalls reading during the observation period for all the monitoring stations was 116,880, i.e., 14,610 readings for each sampling location. Each year is categorised into three seasons: Summer (March, April, May, and June), rainy (July, August, September, and October), and Winter (January, February, November, and December) [12].

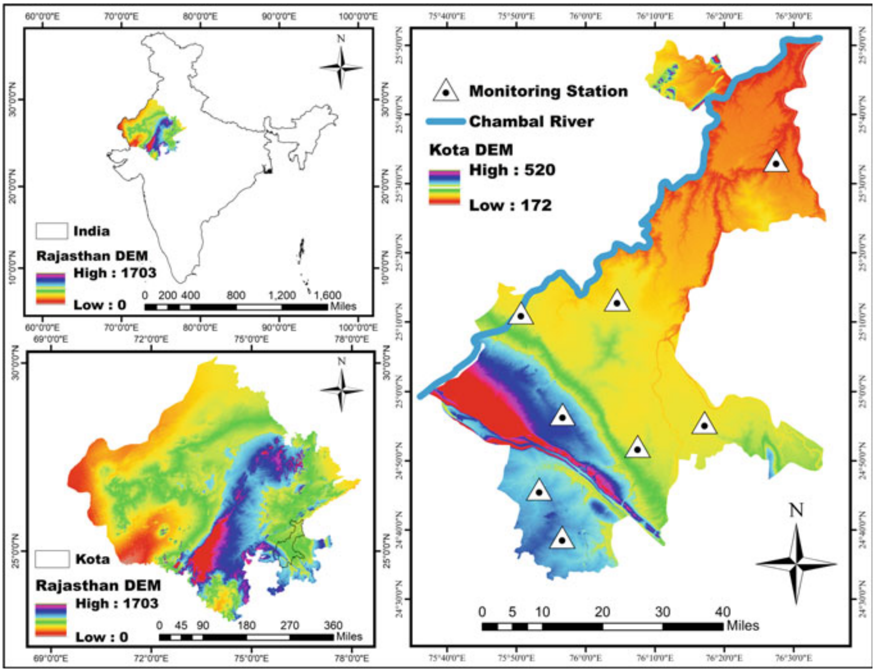

Fig. 1 Area of interest for study along with rainfall monitoring station

Table 1 GPS coordinates for precipitation monitoring station at Kota district, Rajasthan

Code	Station	Longitude	Latitude
MS-1	Digod	76.075	25.220
MS-2	Ladpura	75.844	25.188
MS-3	Pipalda	76.457	25.556
MS-4	Ramganjmandi	75.943	24.649
MS-5	Sangod	76.285	24.925
MS-6	Mandana	75.944	24.945
MS-7	Kanwas	76.124	24.868
MS-8	Chechat	75.888	24.765

3 Trend Analysis and Precipitation Indices

3.1 Trend Analysis

It has been performed for annual, seasonal, and monthly rainfall series using the linear regression trend test (parametric) and the non-parametric trend test (Mann–Kendall test).

3.1.1 Linear Regression Trend Analysis

Linear regression trend test is computed to define the extent of the linear relationship between precipitation (dependent variable) and time (independent variable). It predicts the value of rainfall concerning time. The regression equation is as follows [13]:

$$Y = ax + b \tag{1}$$

where a is the slope of the line and b is the intercept.

3.1.2 Mann–Kendall Trend Analysis

The null hypothesis and alternative hypothesis are tested against each other in Mann–Kendall test. The null hypothesis supposes no trend in precipitation-time data series, while the alternative hypothesis assumes a trend. The following equations govern Mann–Kendall test [14]:

$$R = \sum_{K=1}^{n-1} \sum_{L=K+1}^{n} \operatorname{sign}(X_L - X_K) \tag{2}$$

$$\mathrm{sign}(T_L - T_K) = \begin{Bmatrix} 1 & \text{if } X_L - X_K > 0 \\ 0 & \text{if } X_L - X_K = 0 \\ -1 & \text{if } X_L - X_K < 0 \end{Bmatrix} \tag{3}$$

The variance for the R-statistic can be calculated through Shreepada Devi et al. [16]:

$$\sigma^2 = \frac{[(2n+5)(n-1)n)}{18} \tag{4}$$

The standard test is defined by Kumar et al. [15]:

$$Z_R = \begin{Bmatrix} \frac{R-1}{\sigma} \text{ for } R > 0 \\ 0 \text{ for } R = 0 \\ \frac{R+1}{\sigma} \text{ for} R < 0 \end{Bmatrix} \tag{5}$$

3.2 Normal Annual Rainfall (NAR)

The 30-year consecutive rainfall series average is termed as normal annual rainfall. The rainfall series for the present study is categorised into monthly, seasonal, and yearly precipitation-time data series. The up-gradation of normal annual rainfall takes place after every 10 years, and its trend was predicted. Normal annual rainfall is calculated through the following equation [14]:

$$\mathrm{NAR} = \frac{\sum_{i=1}^{30} P_i}{30} \tag{6}$$

where P_i Denotes the rainfall that occurred in the ith year.

3.3 Precipitation Concentration Index (PCI)

It defines the non-uniformity and uniformity of precipitation over a given period. The highest PCI's value denotes a more significant non-uniformity of precipitation. The following equation is used to calculate PCI's value:

$$\mathrm{PCI} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} * 100 \tag{7}$$

Table 2 Categorisation of PCI and SRA values

PCI	Rainfall category	SRA	Drought severity
< 10	Uniform precipitation distribution	< −1.65	Extreme
11–15	Moderate precipitation concentration	−1.65 to −1.28	Severe
16–20	High precipitation concentration	−1.28 to −0.84	Moderate
> 20	Very high precipitation concentration	> −0.84	No drought

The PCI values are characterised into the following categories, as shown in Table 2.

3.4 Standardised Rainfall Anomaly (SRA)

Drought severity is expressed through standardised rainfall anomalies. The most negligible SRA's value denotes the maximum possibility of draught. The following equation is used to calculate SRA's values:

$$\mathrm{SRA} = \frac{\left(P_i - \overline{P}_i\right)}{S} \tag{8}$$

where S = standard deviation of rainfall time series and P_i = the rainfall in the ith year.

The SRA's values are characterised into the following categories, as shown in Table 2.

3.5 Wetness Index ($\mathbf{W_i}$)

The precipitation ratio for a given year over the mean annual precipitation is the index of wetness and expressed on a percentage basis.

$$W_i(\%) = \frac{\text{Precipitation in a particular year at a place}}{\text{Normal Annual precipitation}} * 100 \tag{9}$$

A value less than 100 of the wetness index denotes a rainfall deficiency equivalent to the deficit from 100, i.e., Rainfall Deficiency = 100 – Wetness Index. Rainfall deficiency is categorised into large deficiency (30–45%), serious deficiency (45–60%), and the disastrous deficiency (> 60%).

3.6 Coefficient of Variation (C.V.)

The coefficient of variation measures the dispersion of precipitation. It is used to determine the reliability of an average and provide a basis for controlling the variability. It can be calculated through the following equation:

$$\text{C.V.}(\%) = \frac{\text{The standard deviation of precipitation}}{\text{Average Precipitation}} * 100 \quad (10)$$

3.7 Dependable Rainfall

The data of rainfall-time series should be arranged in descending order and then ranked accordingly to determine dependable rainfall. The dependable rainfall is calculated for 50, 75, and 90% dependency in this research work. It can be calculated through the following equation:

$$\text{Precipitation Occurrence } (\%) = \left(\frac{\text{Rank}}{\text{Total number of observations}}\right) * 100 \quad (11)$$

4 Results and Discussions

The maximum, minimum, and average precipitation on a monthly, seasonal and annual basis, along with standard deviation, is shown in Table 3. The intra-annual rainfall variability (PCI) is evaluated for the entire data set (1981–2020). PCI lies between 22.97 and 52.15, indicating a very high non-uniformity of rainfall in each year, i.e., a very high concentration of rainfall in a particular part of a year. Monsoon average and percentage are computed to identify the reason behind more significant non-uniformity.

Precipitation indices are tabulated in Table 4. It is found that the southeast monsoon, which takes place in the rainy season (July, August, September, and October) every year responsible for 62.50–97.37% of the total rainfall of a year. On average, monsoon rainfall contributed nearly 84.50% of the total rainfall and explained the large PCI values.

Significant monthly rainfall variability has been observed. The average coefficient of variation was 169.45, while maximum variability in precipitation was seen in December (285.51) and minimum variability in precipitation was obtained for August (47.62). The overall coefficient of variation and PCI values are very high and indicate significant inter- and intra-annual variations in the precipitation.

Table 3 The maximum, minimum, and average precipitation in millimetres along with standard deviation

Sr. No.	Period	Average	Maximum	Minimum	Standard deviation
1	January	4.76	32.38	0.00	8.45
2	February	5.45	39.04	0.00	10.56
3	March	3.30	46.00	0.00	8.31
4	April	4.20	38.25	0.00	8.15
5	May	8.37	82.20	0.00	18.52
6	June	83.17	475.50	2.09	81.80
7	July	257.43	653.12	18.53	123.73
8	August	273.72	636.54	49.59	130.36
9	September	98.08	308.25	6.75	68.02
10	October	20.26	161.56	0.00	38.85
11	November	6.00	72.60	0.00	15.28
12	December	3.19	50.14	0.00	9.11
13	Winter	4.85	25.96	0.00	5.69
14	Summer	24.76	119.25	3.54	20.27
15	Rainy	162.37	312.31	64.84	48.53
16	Annual	63.99	112.98	32.47	18.14

Table 4 Precipitation Indices along with annual total and average rainfall

Precipitation indices	Average	Maximum	Minimum
Total	767.94	1355.76	389.6
Average	63.99	112.98	32.46667
PCI	31.96	52.15	22.96774
Monsoon average	649.49	1249.26	259.36
Monsoon percentage	84.50	97.37	62.50
Coefficient of variation	169.45	285.51	47.62
SRA	2.65	7.82	−0.57
Wetness index	102.13	180.31	51.81

Normal annual rainfall based on the average of 30 consecutive years was 60.68 mm and 64.64 mm for 1981–2010 and 1991–2020, respectively. Standardised rainfall anomaly was calculated to determine interannual variability of rainfall. The SAR value ranged from −0.57 (2002, the driest year) to 7.81 (2008, the Wettest year). The average value of SRA is greater than −0.84, avoiding any possibility of drought.

Analysis of the wetness index revealed that 2019 was the wettest year ($W_i = 180.31$), while 2002 was the driest year ($W_i = 51.81$) due to the amount of rainfall that took place in these years. The rainfall observed in 2002 and 2019 were 389.6 (Lowest) and 1355.76 (Highest) mm, respectively. Rainfall dependability is critical

Table 5 Trend test statistics along with rainfall dependability

Time	Kendall's tau	Slope	Rainfall dependability		
			50%	75%	90%
January	−0.127	−0.089	0.125	0	0
February	0.060	0.047	0	0	0
March	0.040	0.166	0	0	0
April	−0.080	0.010	0.66	0	0
May	−0.072	−0.027	1.42	0.42	0
June	0.162	1.658	63.25	35.1	19.31
July	0.124	0.61	244.88	190.04	123.18
August	0.034	0.97	256.75	180.85	134.23
September	0.006	0.41	87.85	48.34	15.52
October	−0.247	−1.06	3	0	0
November	0.018	−0.257	0	0	0
December	0.071	−0.103	0	0	0
Total	0.032	0.194	751.35	652.55	545,375

to maintaining sustainable use of water. Hence, dependable rainfall (90, 75, and 50%) for other months has been calculated and shown in Table 5. June, July, August, and September are the southwest monsoon months when maximum precipitation occurs and is available to complete water demands in the remaining months. An inspection of Table 5 reveals significant positive trends exist for precipitation over the previous four decades (1981–2020). A substantial increase in monsoon rainfall reflects the possible impact of climate change.

The slope of regression analysis for precipitation illustrates the falling and rising trends of precipitation at different time intervals; rising and falling values specify the trends of increased and decreased rainfall, respectively. In January, May, October, November, and December, the slope of the precipitation data series is falling, i.e., a reduction in the monthly rainfall in respective months. The most negative slope, −1.06, was obtained for August. The slope of precipitation for the remaining months shows rising trends; the rising slope had the highest value of 1.65 in June. Rainfall trends (1981–2020) are tabulated in Table 6 and graphically presented in Figs. 2 and 3.

Table 6 Precipitation trends analysis obtained through linear regression over four decades

Month	1981–90	1991–00	2001–10	2011–20
January	Decremental	Decremental	Decremental	Decremental
February	Incremental	Incremental	Decremental	Decremental
March	Decremental	Decremental	Incremental	Incremental
April	Decremental	Decremental	Incremental	Incremental
May	Decremental	Incremental	Decremental	Decremental
June	Incremental	Incremental	Incremental	Decremental
July	Decremental	Incremental	Incremental	Decremental
August	Decremental	Decremental	Decremental	Decremental
September	Decremental	Incremental	Incremental	Incremental
October	Incremental	Decremental	Incremental	Decremental
November	Decremental	Decremental	Incremental	Incremental
December	Incremental	Incremental	Incremental	Decremental

5 Conclusions

The following conclusions are derived from this study:

- Different aspects of water resources planning and management rely on the rainfall occurring in a given region. This study has been made to determine the variation in temporal presentation for the Kota district in Rajasthan, India.
- Rainfall trend analysis has been performed for monthly, seasonal, and annual precipitation using linear regression (parametric) and Mann–Kendall (non-parametric) trend test for the duration of 1981–2020. For a particular year, excessive rainfall in the research area was determined using a wetness index and standardised rainfall anomaly.
- The monthly distribution of precipitation was calculated through the precipitation concentration index. A very high non-uniformity has been observed in rainfall distribution. Almost 85% of total annual rainfall is contributed through a southeast monsoon in the rainy season.
- Mann–Kendall and regression analyses test predict increasing trends for February, March, June, July, August, and September. As an outcome, total annual precipitation exhibits a positive trend.
- Over the last four decades (1981–2020), a significant increase in total precipitation was observed, highlighting greater water availability in the Kota that needs development and restoration of water reservoirs, proper rainwater harvesting, and a drainage management program to avoid the risk of flood.

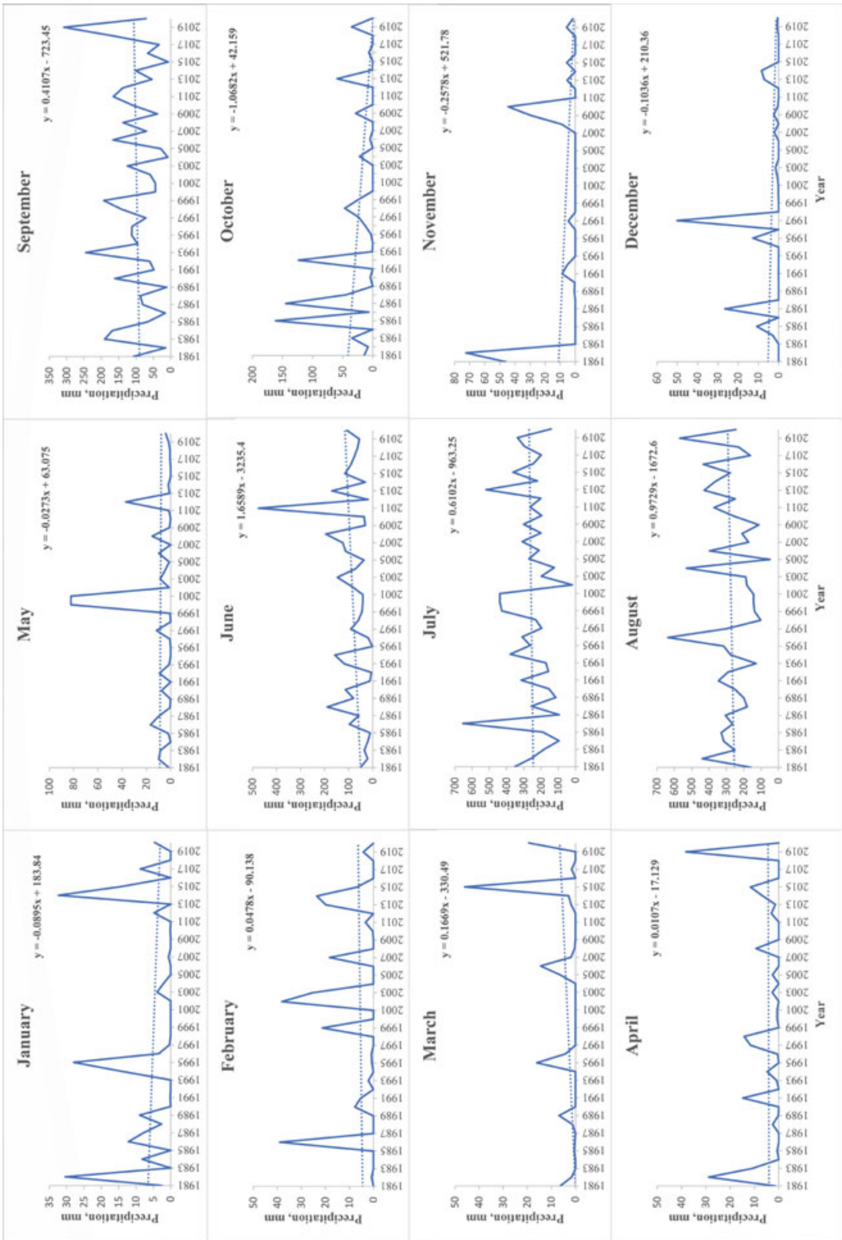

Fig. 2 Variation in the monthly, seasonal, and annual rainfall trends from 1981 to 2020

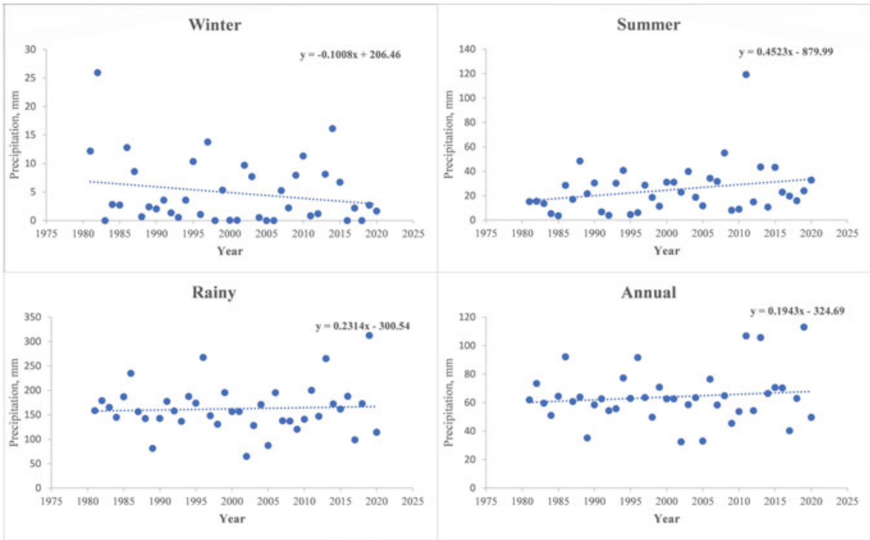

Fig. 3 Seasonal and annual rainfall trends from 1981 to 2020

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Conflict of Interest The authors declare that they don't have any conflict of interest.

Data Statement The data utilised in this research work are freely available and provided to anyone if needed.

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