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Temporal analysis of rainfall and drought characteristics over Jalore District of S-W Rajasthan

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ABSTRACT

Drought forecasting is being considered an important tool to help understand the rainfall pattern and climate change trend. Drought is a prolonged period of months or years in which an area, whether surface water or groundwater, becomes insufficient in its water supplies. Drought is considered as the most difficult but least known environmental phenomenon, impacting more persons than any other. There are several indices used to classify droughts. For this study, precipitation-based drought indices are considered (i.e., SPI, RAI and Percentage Departure of Rainfall). The objective of the research is to examine and determine the possible rainfall trends over the Jalore district of South-West Rajasthan in Luni river basin. In this research, trend analysis using the rainfall data from the years 1901 to 2021 was carried out on a monthly, seasonal and annual basis. To define the current trend path, the Mann-Kendall test and Sen's slope estimator test were used. In order to detect the trend and its change in magnitude over a particular period of time, Sen's slope estimator was used. During the southwest monsoon, declining rainfall leads to short-term meteorological droughts, which have severe effect on the agriculture sector and Jalore district's water supplies, while rising rainfall during other seasons tends to mitigate the severity of drought. The result of research reveals that there is rise of pre-monsoon and post-monsoon rainfall, but it also depicts a fall in the annual rainfall which reflects in reduced Winter and S-W monsoon rainfall.

Key words: drought, Jalore, Mann-Kendall test, Sen's slope, SPI, trend analysis

HIGHLIGHTS

- To assess possible drought severity and duration in the Jalore district of S-W Rajasthan region.
- The study also deals with identification of drought patterns, and changes with the 121 years of the time span.
- Trend analysis is carried out using Mann-Kendall test to quantify the rainfall pattern & characteristics.
- To estimate the magnitude of trend using Sen's slope.

1. INTRODUCTION

Drought forecasting is considering an important tool to help the decision maker (Belayneh *et al.* 2014). Drought is a prolonged period of months or years in which an area, whether surface water or groundwater, becomes insufficient in its water supplies (Jonathan & Raju 2017). Drought is considered as most difficult but least known environmental phenomenon, impacting more persons than any other (Pal & Al-Tabbaa 2009; Rathore & Jasrai 2013). It affects access to water in various parts of the earth according to its severity (Mondal *et al.* 2015). The decrease of productivity (Ciais *et al.* 2005), decreasing flow in streams, drainage, surface and ground water supplies (Smakhtin 2001), reduces the hydropower production (Van Vliet *et al.* 2016) and increasing the wildfires are some of the major impacts of droughts. (Allen *et al.* 2010; Mundetia & Sharma 2015). Drought is categorized into four categories such as Agricultural, Meteorological, Hydrological, and socio-economic drought (Kallis 2008) for better understanding (Khaniya *et al.* 2020).

Because of this reason, trend analysis of rainfall becomes very important for the study of droughts (Oliver 1980). Trend analysis is the process of predicting the future trend, by looking at past and current trends (Ganguly *et al.* 2015; Jain *et al.* 2013). Trend analysis of precipitation and drought helps in the sustainable management of water resources (Perera *et al.* 2020; Anushka & Upaka 2020).

There are several indices used to classify the droughts (Chelu 2019). Different indices used different parameters for drought analysis. But for this study, precipitation-based drought indices are considered (i.e., D%, SPI, and RAI) (Mehta & Yadav 2021a). The variability of the standardized precipitation index (SPI) was examined at 3, 6, 9 and 12-month intervals (Hajani *et al.* 2014; Ramkar & Yadav 2019). By applying the Mann–Kendall test at the 5% significance level, trends of 3, 6, 9 and 12 monthly SPI outcomes were examined (Mehta & Yadav 2019, 2020). Sen's slope technique was used to determine the linear slopes of the trends (Ghasemi *et al.* 2021). Therefore, systematic water resources and emergency recovery plans need to be developed and successfully applied to consider weather cycles and past droughts (Mukherjee 2017).

The RDI was introduced by Tsakiris and Vangelis, in which they suggested a technique for assessing the intensity of drought severity due to meteorological factors. It takes seed evapotranspiration along with precipitation as an input parameter (Tsakiris & Vangelis 2005). To examine the preparedness level and the mitigation mechanism to mitigate the risk of drought in the region, Prabhakar discussed the issues and impacts related to the climate change in the Indian subcontinent (Prabhakar & Shaw 2008).

For this time, meteorological data from the Jalor region of S-W Rajasthan were used for the period 1901–2021. The study has been carried out to investigate and assess the potential trend of rainfall over the Jalor district of South-West Rajasthan. The goal of the current work is to carry out a comprehensive drought quantification for one of the India's drought-prone, semi-arid river basins. Identifying and evaluating the effects of drought in semi-arid regions is one of the main goals of this work.

2. STUDY AREA

Jalore district falls into the drought-prone, semi-arid Luni river basin and hence it is considered as a study area for the current research. The district is situated between latitudes of 24° 37′ 00″ to 25° 49′ 00″ and longitudes of 71° 11′ 00″ to 73° 05′00″ with an area of 10,640 sq· kms (3.11% of the state). The cumulative number of Jalore villages is 802. It has 3 metropolitan town as well. According to Census 2011, the Jalore district's population is 18,28,730 with a male and female population of 9,36,634 and 8,92,096 respectively (Mehta & Yadav 2020, 2021b).

The district's average annual precipitation is 445.4 mm. The annual precipitation falls steadily from the south-eastern region to the northwestern region. Except during the SW monsoon season, the climate of the Jalore district is dry. Figure 1 shows the location of the Jalore district in India.

The cold season is from December to February and from March to June it is followed by summer. The post monsoon season is between mid-September and the end of November. According to past data, once every two years, this district experiences either moderate or normal drought (Mehta & Yadav 2021b). Soils with deep gravel encrusted with Calcium carbonate ($CaCO_3$) are usually shallow in this area. The soil composition usually ranges from sandy-to-sandy loam, but the soil is loamy alluvium in deltaic areas of the south-to-southwest portion of the Luni River. The hydrological element most affected in the event of drought is precipitation.

3. DATA COLLECTION AND ANALYSIS

India was divided into 36 sub-divisions according to IMD (Indian Meteorological Department). Data for this district was collected from the IITM (Indian Institute of Tropical Meteorology, Pune) and India-WRIS. From the year 1901 to 2021, homogeneous monthly rainfall (mm) data was collected (121 years). Within these constraints the selected network consists of 9 uniformly distributed stations across Jalore for which rainfall data are available from the year 1901 to 2021.

4. METHODOLOGY

In the present study, trend analysis of rainfall is examined in the first part and in the second part meteorological drought analysis is carried out on the basis of rainfall. For meteorological drought analysis, four climatic seasons is considered as per IMD (Indian Meteorological Department) namely southwest monsoon i.e. (June to September), post monsoon i.e. (October– December), winter i.e. (January– February) and pre monsoon i.e. (March–May). Data analysis from the year 1901 to 2021 was carried out for seasonal rainfall as well as for annual rainfall. The concept of meteorological drought is based on the degree of dryness and dry period duration as per National Drought Mitigation Center (NDMC). Although there are various studies on rainfall characteristics on different

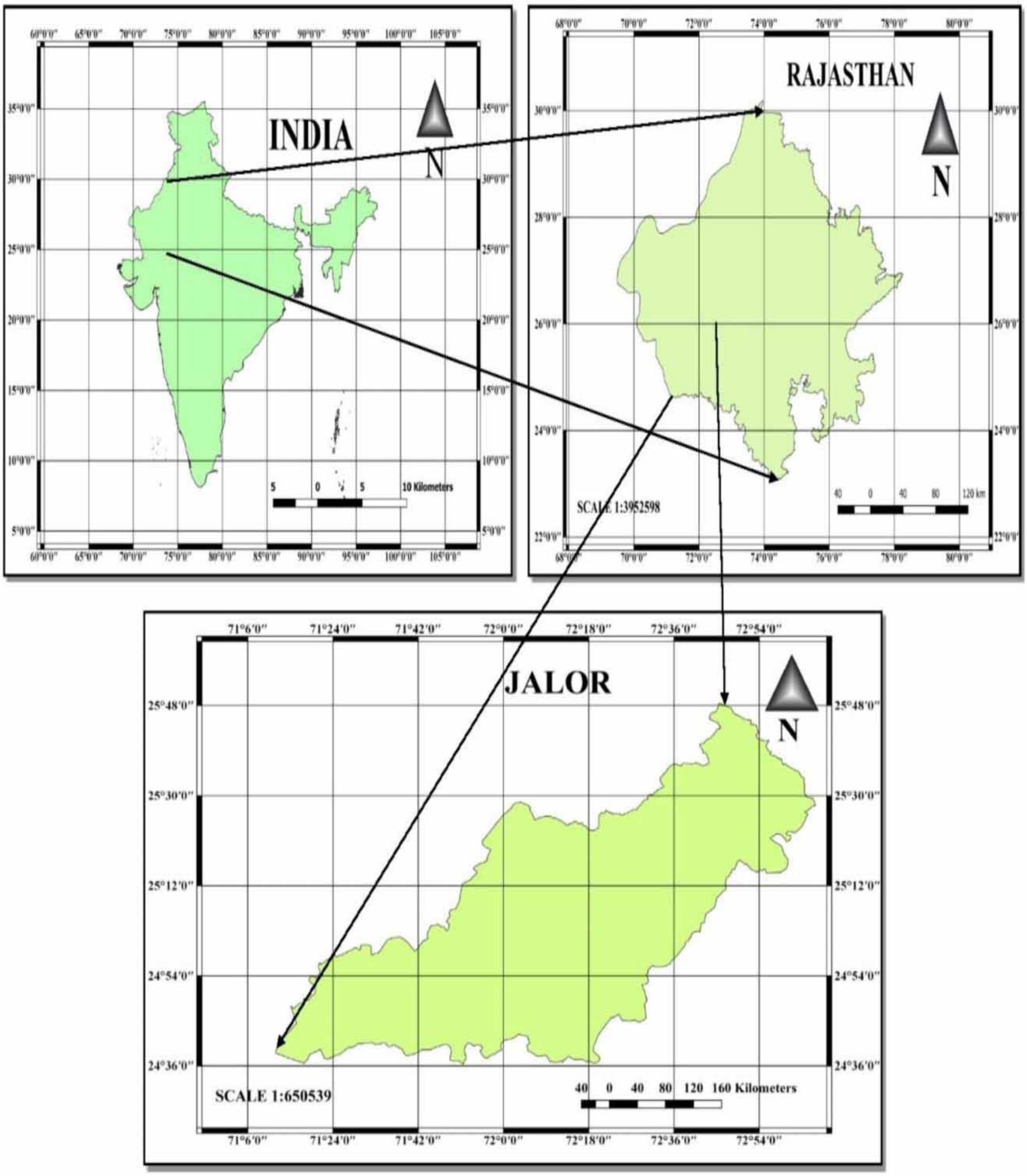

Figure 1 | Location of Jalore District in India.

scales, such as spatial and temporal, none are intended to understand the pattern in concentration of precipitation as well as the drought scenario across the State of Rajasthan (Mehta & Yadav 2020). Thus, different techniques and methods for climate data and drought analysis have been used to analyze the temporal variation of rainfall as well as drought scenario (Thomas & Prasannakumar 2016).

4.1. Rainfall characteristics

The rainfall data were aggregated to prepare monthly, seasonal and annual time series for the study region. Statistical parameter like mean, standard deviation, co-efficient of variation, maximum and minimum were computed for monthly, seasonal and annual time series of rainfall data (Mehta & Yadav 2021a). Southwest region is arid and semi-arid of Rajasthan state where monsoon is the only element which contributes climate seasonality (Sonali & Kumar 2013). Thus, the rainfall is taken into consideration for climate change analysis as per hydrological year (June-May).

4.2. Trend analysis

There are number of methods available for trend detection in terms of rainfall. Statistical approaches without considering serial correlation are available, such as (1) Slope based tests: Least Squares Linear Regression (LR), Sen's Slope Estimator (SS), and (2) Rank based tests: Mann-Kendall (MK) test, Spearman Rank Correlation (SRC) test, and so on (Verma *et al.* 2016). The statistical approaches considering effects of serial correlation are pre-whitening (PW), Trend Free pre-whitening (TFPW), and Variance Correction (VC) with the Mann-Kendall test (MK-CF1) by Jain *et al.* (2013) and Variance Correction (VC) with the Mann-Kendall test (MK-CF2) (Ganguly *et al.* 2015). For the present analyses, the Mann-Kendall test was used for trend detection over the values of rainfall time series at 5% significance level. To analyze the trend of rainfall and temperature, the rank based non- parametric Mann-Kendall (MK) test and slope-based Sen's Slope (SS) estimator were conducted on rainfall and temperature time series of 121 years. The Mann- Kendall (MK) test and Sen's Slope (SS) estimator were performed by using the XLSTAT 2016.

In the present study of rainfall data, the preparation of monthly, seasonal, and annual time series for study region was aggregated. Statistical parameter like mean, standard deviation, co-efficient of variation, maximum and minimum were computed for monthly, seasonal, and annual time series of rainfall data (Sonali & Kumar 2013). To analyze the trend of rainfall and temperature, rank based non- parametric the Mann- Kendall (MK) test and slope-based Sen's Slope (SS) estimator were conducted on rainfall and temperature time series of 121 years. The Mann-Kendall (MK) test and Sen's Slope (SS) estimator were performed by using XLSTAT 2016 (Mehta & Yadav 2021c).

The Mann-Kendall (MK) test follows a computational procedure in which n is the number of data points in a time series and xj and xi are two sequential data sets of the time series. Each data value of the time series is compared with other subsequent data. If the data value of the later time period is higher than the earlier, one data value than the statistics S is incremented by 1; on the other hand, if the value is lower than the earlier data value then the statistics S is decremented by 1 (Mehta & Yadav 2020). The final result of statistics S is calculated by the net result of these two increment and decrement data values. The statistics S of the Mann-Kendall (MK) test is calculated by Equations (1) and (2).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}\,(x_j - x_i) \tag{1}$$

$$\text{sign}\,(x_i - x_j) = \begin{cases} -1\,; & (x_j - x_i) < 0 \\ 0\,; & (x_j - x_i) = 0 \\ 1\,; & (x_j - x_i) > 0 \end{cases} \tag{2}$$

where, x_j and x_i are the data values in years j and i respectively.

If the number of data points in the time series is less than 10 than the value of |S| is compared directly to the distribution S or in other cases where the number of data points in the time series is greater than 10 then the value of statistic S is distributed by the mean and variance shown in Equations (3) and (4).

$$E(S) = 0 \tag{3}$$

$$\text{Var}\,(S) = \frac{n(n-1)(2n+5) - \sum_{p-1}^{q} t_p(t_p - 1)(2t_p + 5)}{18} \tag{4}$$

Performing the Mann-Kendall test by XLSTAT, one more statistic, Kendall's tau, is obtained which shows the correlation between the two variables in the time series. The same as the Mann-Kendall test and Spearman rank correlation test, Kendall's tau is also a rank-based correlation test (Jain *et al.* 2013). Values of Kendall's tau lie between −1 to +1. In this, positive correlation indicates that the ranks of two variables increase together while negative values of correlation imply that the rank of one variable is increased and other is decreased (Mondal *et al.* 2015).

The slope- based test for trend detection used in this paper was Sen's Slope (SS) Estimator. The method used for analysis of trend was Sen (1968), which measures the magnitude of trend as given in Equation (5).

$$\text{Sen's Slope} = \text{median}\left[\frac{Y_i - Y_j}{(i-j)}\right];\, j < i \tag{5}$$

4.3. Drought analysis on basis of rainfall

Based on the degree of dryness and length of the dry period, meteorological drought is specified (NDMC). Many researchers typically use the Departure Analysis of Rainfall (D %), Rainfall Anomaly Index (RAI) and Standardized Precipitation Index (SPI) methods for drought analysis of rainfall (Thomas & Prasannakumar 2016).

4.3.1. Departure analysis of rainfall

The percentage departure (D %) of annual rainfall is calculated using Equation (6) in order to consider the drought years.

$$D\% = \frac{X_i - X_m}{X_m} \times 100 \tag{6}$$

where, X_m – mean annual rainfall from the annual rainfall series (X_i).

Steps for calculation of rainfall departure:

- Calculate mean of annual rainfall from observed annual rainfall data for station.
- To calculate rainfall departure, subtract the annual rainfall of the year from the mean rainfall of the year.
- Find out 75% of mean rainfall and calculate the drought year. If the value of annual rainfall of the year is less than 75% of mean rainfall, then it is called a drought year.
- After calculating the drought year calculate the departure from mean rainfall.

4.3.2. Rainfall anomaly index (RAI)

This index involves a rating method that is determined to attribute magnitudes to positive and negative rainfall anomalies using Equation (7) (Van Rooy 1965).

$$\mathrm{RAI} = \pm 3\frac{\mathrm{P} - \bar{\mathrm{P}}}{\bar{\mathrm{E}} - \bar{\mathrm{P}}} \tag{7}$$

where P = measured precipitation, $\bar{\mathrm{P}}$ = mean precipitation, and $\bar{\mathrm{E}}$ = average of 10 extrema (mean of ten highest precipitation records in the period).

4.3.3. Standard precipitation index (SPI)

SPI is a common meteorological drought index among the various drought indices, which is determined for a desired time solely on the basis of a long-term precipitation record (Mehta & Yadav 2021a, 2021b, 2021c). SPI has achieved worldwide applicability due to its predictive accuracy and inherent probabilistic nature. The ability to explain both short-term and long-term effects of drought on different time scales and to compare drought conditions between regions with different climatic conditions and different time periods (Chelu 2019). It was developed to evaluate the parameters of drought over several timescales, reflecting the effect of drought on the accessibility of water resources. To derive different drought parameters, SPI can be computed on a variety of time scales and for different water variables such as soil moisture, ground water, and so on.

In this study we used the Drin C application, which is a drought indices calculator for calculating SPI. Drin C considers the hydrological year from October to September to compute indices.

5. RESULTS AND DISCUSSION

5.1. Rainfall characteristics over Jalore District

Descriptive statistics (Table 1) of rainfall were prepared on a monthly, seasonal, and annual scale for 1901–2021 (121 years). Annual mean rainfall (from the year 1900–01 to 2021–22) is 440.315 mm with SD equal to 217.539. During the entire period of 121 years, the annual minimum and maximum rainfall is 0.6 mm and 1020.760 mm. Annual Co-efficient of Variance (CV) is 49.4%, which implies a very high inter-annual variability of annual rainfall over the Jalore district. During the 121 years, the months of July and August contribute the maximum percentage of rainfall (161.149 and 146.269 mm) to the annual rainfall. The winter months (January-February) and pre-monsoon months (March, April, and May) together contribute 0.6% and 1.3% of rainfall to the annual

Table 1 | Statistics of monthly seasonal and annual rainfall over Jalore district for 121 years

	Rainfall (mm) for Jalore District					
Month	**Mean**	**SD**	**CV (%)**	**% Contribution to annual**	**Minimum**	**Maximum**
Jan	1.992	4.849	243.4	0.5	0.000	27.170
Feb	3.064	8.494	277.2	0.7	0.000	57.180
Mar	2.562	11.432	446.2	0.6	0.000	117.490
Apr	1.865	4.262	228.5	0.4	0.000	24.040
May	7.166	15.063	210.2	1.6	0.000	101.820
Jun	37.117	32.985	88.9	8.4	0.000	150.840
Jul	161.149	130.941	81.3	36.6	0.050	725.330
Aug	146.269	122.462	83.7	33.2	0.050	566.040
Sep	65.698	77.737	118.3	14.9	0.050	370.940
Oct	8.464	20.449	241.6	1.9	0.000	140.110
Nov	4.000	14.954	373.9	0.9	0.000	115.630
Dec	0.968	3.691	381.3	0.2	0.000	30.370
Annual	440.315	217.539	49.4	100.0	0.600	1020.760
Pre-monsoon	11.593	19.474	168.0	2.6	0.000	120.360
S-W monsoon	410.234	211.821	51.6	93.2	0.200	986.800
Post-monsoon	13.432	24.914	185.5	3.1	0.000	140.180
Winter	5.056	9.811	194.0	1.1	0.000	57.270

budget. Post-monsoon months (October-December) contribute 1.5% rainfall to the annual budget. On average, January and February receive 1.992 and 3.064 mm of mean rainfall, while March, April, and May receive 2.562, 1.865 and 7.166 mm of rainfall respectively. The degree of variability of rainfall events as per the CV is considered as per Table 1. The CV of all months except July and August is more than 85%, hence all months excluding July and August have extremely high variability of rainfall. July and August have a CV of 81.3% and 83.7%, implying very high inter-annual variability. Rainfall characteristics for seasonal rainfall show that the maximum share of annual rainfall greater than 90% is received in one spell of the southwest monsoon (410.234 mm) contributing 93.2% to the annual rainfall (Table 1). Post-monsoon season also receives normal rainfall of about 13.432 mm, which contributes 3.1% of rainfall to the annual budget. The CV of the southwest monsoon is 51.6%, which indicates the very high inter-annual rainfall variability. Winter, pre-monsoon and post- monsoon seasons have comparatively higher CV values than Southwest monsoon ($CV > 55\%$) showing extremely high inter-annual variability of rainfall.

5.2. Rainfall trend analysis over Jalore District

By performing trend analysis results it can be seen that the monthly rainfall of July shows an insignificant increasing trend ($p = 0.483$), while August shows a decreasing trend ($p = 0.955$) Annual rainfall shows an insignificant increasing trend ($p = 0.281$). Trend analysis for seasonal rainfall shows no trend for winter and post-monsoon, while pre-monsoon and s-w monsoon show an insignificant increasing trend ($p = 0.246$ and $p = 0.411$) respectively, (Table 2; Figure 2 and 3).

5.3. Drought analysis based on rainfall

The drought characteristics of the study area were analyzed based on drought indices such as percentage departure of rainfall (D %), rainfall anomaly index (RAI), and standardized precipitation index (SPI). Departure analysis of rainfall during the entire study period of 121 years was computed on seasonal and annual scales. In this study, a drought year was identified by two methods: (i) drought classification of IMD (Attri & Tyagi 2010; Thomas *et al.* 2015), and (ii) classification of regional rainfall distribution based on departure percentage (IMD).

Table 2 | Summary of the Mann-Kendall test for rainfall trend data 1901 to 2021 over Jalore District

Rainfall period	Kendall's tau	Trend interpretation	Mann-Kendall test *p*-value (two tailed test)	Sen's slope	Test interpretation
January	0.009	Rising	0.895	0	No trend
February	−0.101	Falling	0.122	0	No trend
March	−0.060	Falling	0.367	0	No trend
April	0.165	Rising	0.012	0	No trend
May	0.033	Rising	0.601	−0.00076	No trend
June	0.080	Rising	0.195	0.082	Insignificant increasing trend
July	0.043	Rising	0.483	0.175	Insignificant increasing trend
August	−0.004	Falling	0.955	−0.016	Insignificant decreasing trend
September	0.063	Rising	0.305	0.077	Insignificant increasing trend
October	−0.008	Falling	0.903	0	No trend
November	0.015	Rising	0.830	0	No trend
December	−0.060	Falling	0.379	0	No trend
Winter	−0.065	Falling	0.299	−0.00065	No trend
Pre-monsoon	0.072	Rising	0.246	0.014	Insignificant increasing trend
S-W monsoon	0.051	Rising	0.411	0.455	Insignificant increasing trend
Post monsoon	0.023	Rising	0.716	0	No trend
Annual	0.066	Rising	0.281	0.52	Insignificant increasing trend

5.3.1. Rainfall departure analysis (D%) for Jalore District

The annual rainfall departure analysis shows that during the study period there was hardly any severe drought. The technique investigated the decade-wise percentage of annual and seasonal rainfall departure and number of

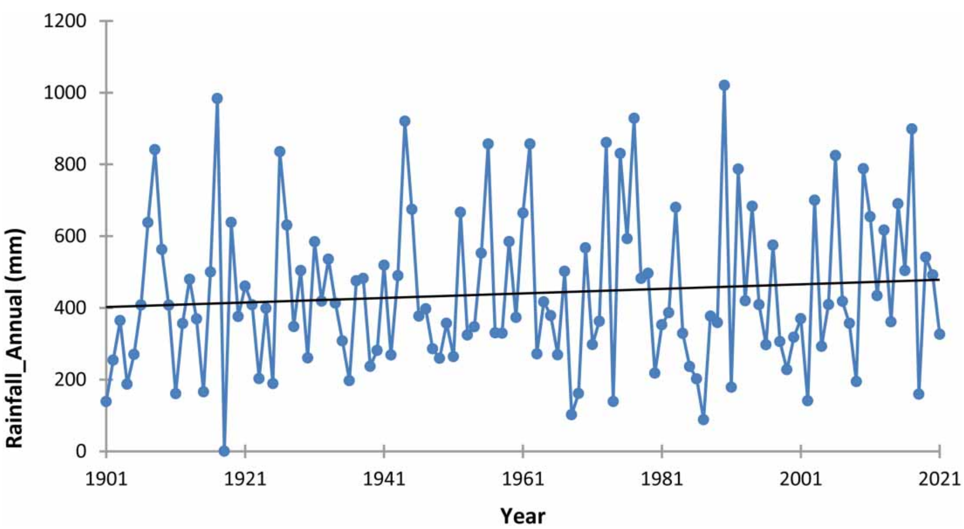

Figure 2 | Time series of annual rainfall (1901 to 2021) over Jalore District.

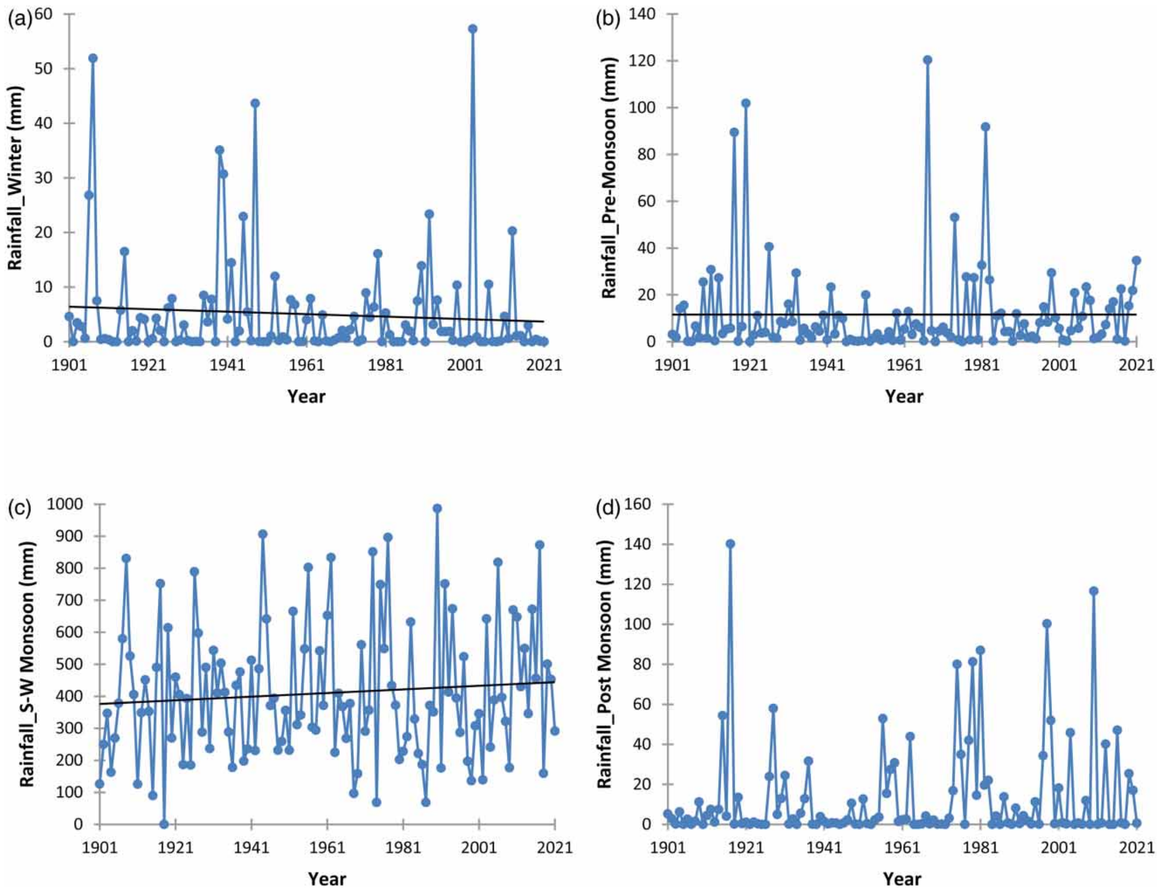

Figure 3 | Time series of rainfall during (a) winter (b) pre-monsoon (c) southwest monsoon and (d) post-monsoon for 1901 to 2021 over Jalore District.

years with excess, deficit, and scanty rainfall. The seasonal rainfall departure study also reveals that, relative to annual or southwestern monsoon rainfall, the departure of rainfall during the post-monsoon, winter and pre-monsoon seasons shows significantly greater inter-decadal. On a time series of D% values of varying scales for each year, the Mann–Kendall test applied (Table 3) indicates a significantly increasing trend of D% of post-monsoon rainfall, reflecting the increasing trend of post-monsoon rainfall. In addition, a significant causative relationship with D% of southwest monsoon, post-monsoon and pre-monsoon rainfall is shown by D% of annual rainfall ($p < 0.05$) (Figure 4).

5.3.2. (RAI) Rainfall Anomaly Index for Jalore District

Rainfall Anomaly Index was computed and classified on annual rainfall (Van Rooy 1965; refer Table 2). As per the classification of the rainfall regime, there is no extremely dry (Figure 5) year during the entire study period (1901–02 to 2021–22) of 121 years. From the current study, overall, 67 years are classified as drought years

Table 3 | Results of the Mann–Kendall test for percentage departure trends (D %) of various scales (1901–02 to 2020–21) for Jalore District

Percentage departure	Mann-Kendall test *p*-value (two-tailed test)	Sen's slope
Annual	0.297	−0.013
Southwest monsoon	0.246	0.124
Post-monsoon	0.411	0.111
Winter	0.716	0.000
Pre-monsoon	0.281	0.118

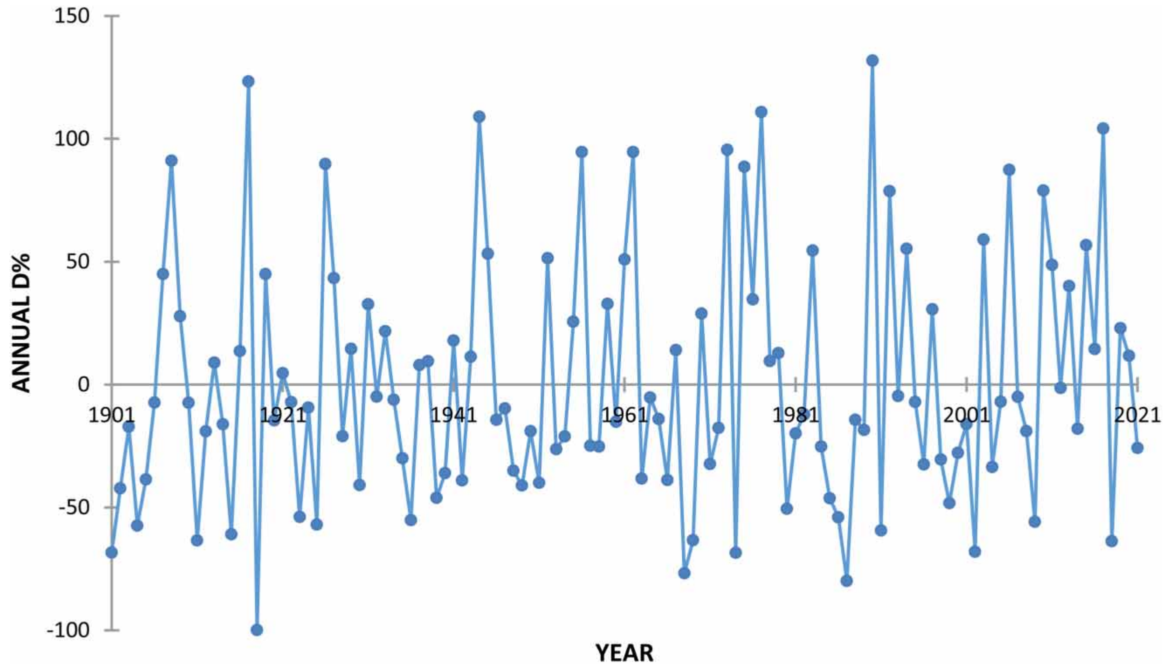

Figure 4 | Rainfall Departure Analysis (D%) for Jalore District.

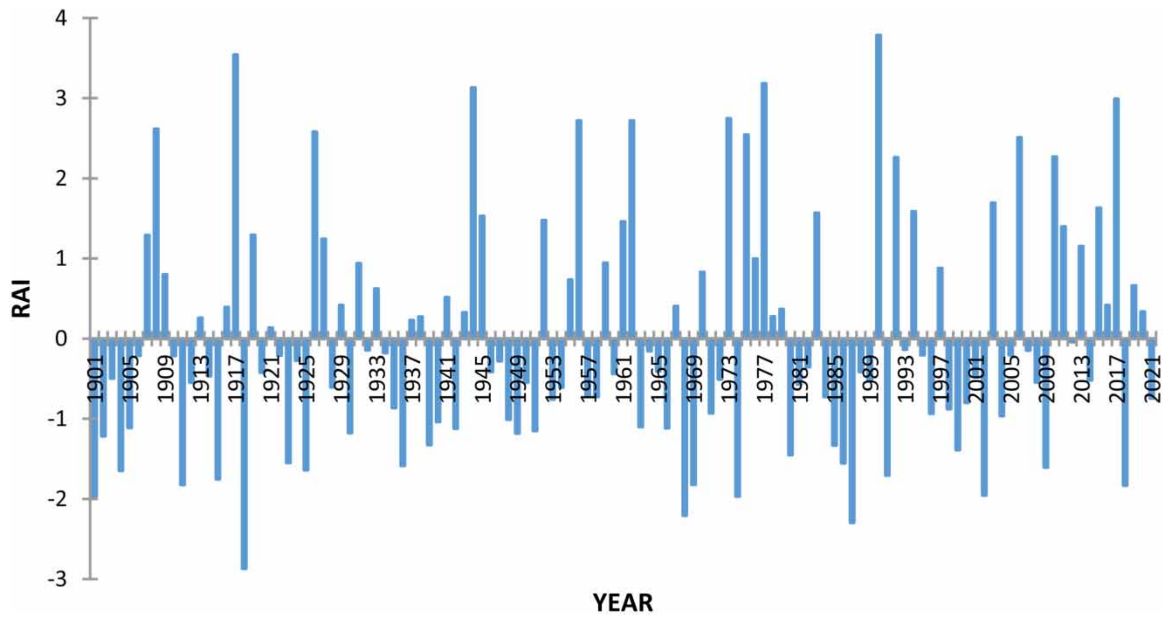

Figure 5 | Rainfall Anomaly Jalore District during 1901–02 to 2021–22.

from 121 years using the RAI index. Years with the slightly dry, moderately dry and very dry regimes are presented in Table 4.

5.3.3. Standardized Precipitation Index over Jalore District

Three-month SPI for the months of October-December, January-March, April-June, and July-September were considered for the calculation. Figure 6 shows the time series of 3-month SPI for all four time frames. SPI of all the years shows that a total of 98 drought events were found during all four-month time frames (October-December, January-March, April-June and July-September). Among all 98 years of drought events, 75 years are recorded with moderately dry, 11 years with severely dry and 12 years with extremely dry rainfall regime. 6 month and 9-month

Table 4 | Rainfall regime over Jalore district for period 1901–02 to 2021–22

Sr. No.	Very dry rainfall regime	Moderate dry rainfall regime	Slightly dry rainfall regime
1	1901	1902	1903
2	1904	1905	1928
3	1911	1918	1935
4	1915	1920	1938
5	1939	1923	1940
6	1960	1925	1942
7	1969	1930	1946
8	1974	1936	1963
9	1987	1948	1971
10	2002	1949	1989
11	2004	1951	1992
12	2006	1953	2000
13	2007	1955	2001
14	2009	1957	2003
15	2010	1959	2005
16	2012	1962	2018
17	2017	1965	
18		1968	
19		1972	
20		1976	
21		1978	
22		1980	
23		1981	
24		1983	
25		1985	
26		1986	
27		1991	
28		1993	
29		1995	
30		1997	
31		1999	
32		2019	
33		2020	
34		2021	
Total	**17 years**	**34 years**	**16 years**

SPI were analyzed for intermediate drought events. 6-month SPI for the months October-March and April-September were considered for the calculation. Figure 7 shows the time series of 6-month SPI for two time frames. Among all 57 years of drought events, 29 years are recorded with moderately dry, 14 years with severely dry and 14 years with extremely dry rainfall regime. The calculation for 9-month SPI time frame of October-June 9 months was considered as shown in Figure 8. Among all 39 years of drought events 17 years are recorded with moderately dry, 9 years with severely dry and 13 years with an extremely dry rainfall regime. Temporal variation of long-term drought events for 12-month SPI (October-September) and its drought characteristics are given in Figure 9. Among all 31 drought events, 17 years are recorded with moderately dry, 5 years with severely dry, and 9 years with extremely dry events.

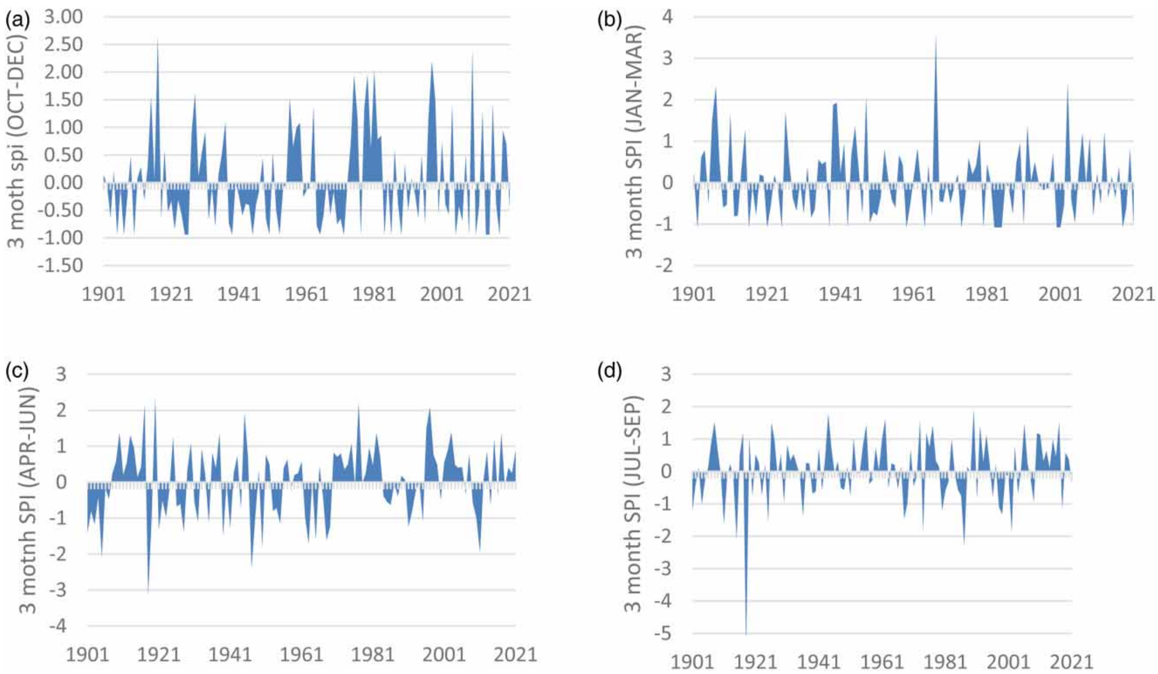

Figure 6 | Standardized Precipitation Index SPI of 3-month step for (a) Oct-Dec (b) Jan-Mar (c) Apr-Jun and (d) Jul-Sep over Jalore District.

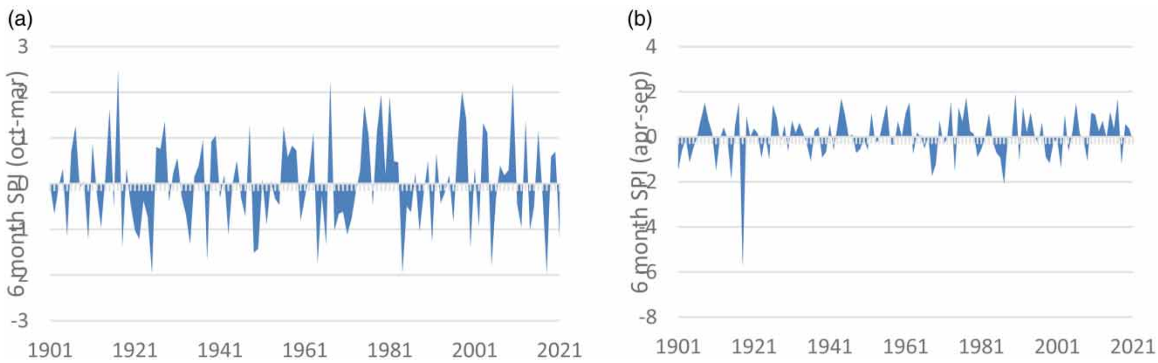

Figure 7 | Standardized Precipitation Index (SPI) of 6-month SPI for (a) Oct-Mar, (b) Apr-Sep over Jalore District.

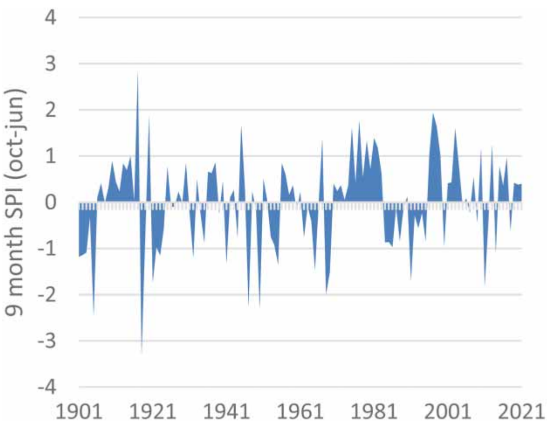

Figure 8 | Standardized Precipitation Index (SPI) for 9 months (October-June) over Jalore.

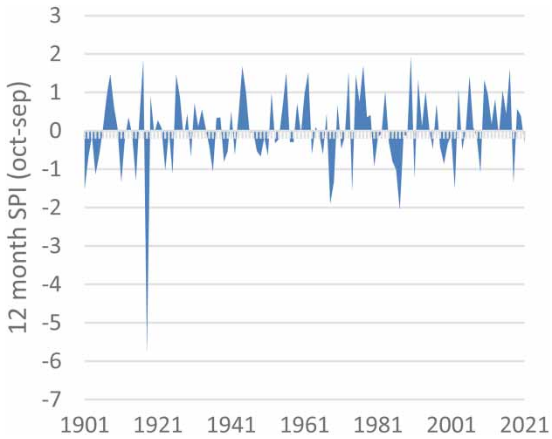

Figure 9 | Standardized Precipitation Index (SPI) for 12 months (October-September) over Jalore.

6. CONCLUSION

Drought assessment of the Jalore district is presented based on temporal analyses. For the period of 121 years (from the year 1901 to 2021), the temporal analysis was performed using D%, RAI and SPI. The extent of drought-prone regions was evaluated on the village scale. The findings of the trend analysis for Jalore district are: (i) Pre-monsoon and post-monsoon rainfall have positive trends, (ii) winter, S-W monsoon and annual rainfall in the Jalore district show a negative trend. The annual and seasonal rainfall within 5–10 years shows inconsistent frequency, which agrees with the periodicity of the El Niño-Southern Oscillation (ENSO). There have been eleven (11) instances of drought years in the Jalore district with 27.3% to 49% below the average annual rainfall in the area. From the above results of different indices for different time scale (i.e., 3 months, 6 months, 9 months, and 12 months), it is clearly observed that near normal droughts occurred most frequently, and severe drought events occurred least frequently. In planning the proposed mitigation measures to minimize the effects of drought, the conclusion drawn from this work will be very important to be considered. The extreme droughts of the years 1986, 1987, 1991, 2003, 2008, 2012 and 2020 were below the average annual rainfall of 58.7%, 82.7%, 69.4%, 78.7%, 67.3%, 56.3 and 74.6% respectively. The forecasts for SPI 12 and RAI are even better and can be utilized as long-term planning tools for water resource managers within the country. This illustrates a lack of water supply for areas plagued by drought. Identifying rural villages vulnerable to drought and the improvements needed in water conservation policies can help bridge the gap between water availability, supply, and demand, and will help policy makers and local administrators to take effective drought relief measures.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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