Research Article

Meteorological drought analysis using Standardized Precipitation Index over Luni River Basin in Rajasthan, India

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Abstract
The study aimed to monitor the spatial extent and severity of drought events in the Luni River Basin using Standardized Precipitation Index (SPI), and hence, the long-term monthly precipitation records of 39 rain gauge stations (1973–2016) were used in the study. Both the long-term (24, 12, and 9 months) and short-term (6, 3, and 1 month) SPI were calculated to recognize the drought events and the percentage of the area covered by the severe drought conditions. The nonparametric Mann–Kendall test was performed for trend analysis in drought events to investigate the consistency of drought events. The frequency results of drought events revealed that Jalore station was the highest drought frequency station, while the lowest drought frequency was observed in Vijaynagar station. The annual SPI result showed that the following years witnessed major drought events: 1981, 1984, 1985, 1988, 1989, 1991, 1993, 1999, 2000, 2004, 2005, and 2008. Besides, the results of the Mann–Kendall test showed that a substantial portion of the eastern basin experienced an increase in the intensity of drought, while the western basin experienced a decrease in the severity of the drought. The comprehensive analysis is indicative of climate change, and there is a possibility that such droughts would become more common in the future in the Luni River Basin. The results of this study would help planners to develop sound policy on water resources and also assist in forecasting systems to provide advance warnings.

Keywords Rainfall analysis · Meteorological drought · Standardized Precipitation Index · Mann–Kendall test · Luni River Basin

1 Introduction

Drought is a natural hazard found in every climatic region of the world. However, its characteristics and severity vary considerably across the regions [1, 2]. Droughts are more prevalent and severe in arid and semiarid regions and may continue for weeks, months, years, or even decades. Meteorological drought prevails for a short period of time, followed by a catastrophic event due to insufficient precipitation [3]. However, a severe meteorological drought occurs when annual rainfall is less than 25% of the normal rainfall of that region [4]. In addition, drought also occurs due to water shortage, high water utilization, and unplanned utilization of water assets. Most Indian states are severely affected by recurrent and prolonged drought events, resulting in a significant number of negative impacts on water resources, ecosystems, and socioeconomic progress [5, 6]. In relation, agricultural productivity is also reduced due to this natural hazard [7–10]. Therefore, it is necessary to analyze the spatiotemporal characteristics and severity of droughts in a river basin to ensure proper utilization

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and sound improvement of water resources, economic progress, and agricultural activity.[11].

Although droughts cannot be avoided, their timely prediction can help to mitigate their adverse effects [12–15]. Drought events are becoming more recurrent and severe in recent years due to changes in the global climate [16]. Droughts are of various kinds, including agricultural, meteorological, hydrological, and socioeconomic droughts. Over the past few years, the number of scientific studies of drought indices has increased. Additionally, several attempts have been made on comparative analysis of different index methods for assessing drought. Such attempts index methods are the Palmer Drought Severity Index (PDSI) [17], Crop Moisture Index [18], Deciles [19], Rainfall Anomaly Index [20], FAO Water Satisfaction Index [21], Surface Water Supply Index [22], Bhalme and Mooley Drought Index [23], Index of Moisture Adequacy [24], Agro-hydro Potential [25], Standardized Precipitation Index (SPI) [26], and multiple indices of low river flow [27]. The SPI is, however, a compliant drought index recommended by the World Meteorological Organization (WMO). It is commonly used for the observation of drought by Mallya. et al. [28], Ahmad et al. [29], Yan et al. [30], Mondol et al. [31], Sabau et al. [32], Nury and Hasan [33], Rahman and Lateh [34], in the river basins Sebenik et al. [35], David and Davidova [36], Seçkin and Topçu [37], Arunvenkatesh et al. [38] and in Rajasthan by Amrit et al. [39], Reddy and Ganguli [40], Chhajer [41], Mundetia and Sharma [42]. The SPI is considered to be the most effective and reliable index for estimating drought [43]. It can be used for various timescales and regions by using precipitation data of the region [44].

In India, the projection or forecasting of drought conditions was carried out naturally and more extensively by a large number of researchers in Rajasthan [40–42, 45–47]. Dutta et al. [47] used VCI and SPI to study agricultural drought in Rajasthan and found that the dry season in mid-2002 resulted in crop stress. Mundetia and Sharma [42] keynoted that the Rajasthan is more vagarious drought frequency. They found that mild droughts had a greater tendency than moderate and severe droughts to cause severe drought. Chhajer et al. [41] studied drought in Jaisalmer, Rajasthan, by using SPI and other indices for the spatiotemporal assessment of drought and their characteristics. They also summarized the random appearance of dry and wet meteorological conditions in Jaisalmer, and the conditions have a shorter lifespan. Reddy and Ganguli [40] used gridded (0.5 × 0.5) monthly rainfall data to study the spatiotemporal patterns of drought occurrence in western Rajasthan by using the SPI values of the 6-month timescale (SPI-6). They observed that the number of drought-affected grids of western Rajasthan had been increased during the study period. Amrit et al. [39] monitored drought occurrence in Rajasthan by using the EDI and SPI and executed that the most severe droughts occurred in 1918. Moreover, they noticed that the drought frequency in northern, western, southwestern, and central Rajasthan was one in 3 years, whereas in eastern Rajasthan, it was one in 4 years. Hence, the growing concern about droughts in Rajasthan's Luni River Basin has made it urgent to define in detail the spatiotemporal characteristics and drought trends.

The main focus of the research work is to assess the spatiotemporal drought occurrences and their nature. The SPI_SL_6.exe program recommended by WMO [48] was used to calculate Standardized Precipitation Index. The spline interpolation method was used to obtain the spatial distribution of the drought frequency. The geostatistical analysis tool of ArcGIS 10.3 [49] was used for this purpose. For study, researchers were used 44 years of monthly rainfall data for the calculation of SPI. The present paper tried to conduct a spatial analysis of the meteorological drought attributes and assess temporal drought occurrences. The SPI values at the timescales of 1 month (SPI-1), 24 months (SPI-24), 12 months (SPI-12), 9 months (SPI-9), 6 months (SPI-6), and 3 months (SPI-3) were evaluated. This investigation reveals the extent, spatial patterns, severity of drought, and also identifies the trend in the meteorological drought of the study area. This study will assist water resource managers for improved management activities and policies to reduce the influence of drought in the study area.

2 Description of the study area

Since the last several decades, drought has been a common phenomenon in Rajasthan. Drought is closely related to the lack of rainfall combined with the high temperature in Rajasthan, India. The present study site is the Luni River Basin of Rajasthan, India, where the socioeconomic condition is primarily dependent on agriculture and allied sectors.

Luni River Basin has a semiarid climatic condition, lies in the parallel to the western part of the Aravalli Ranges, and characterized by high heat flow during summer. The area starches between 24° 30′ 00″ N–27° 10′ 00″ N and 71° 15′ 34″ E–75° 48′ 18″ E and covers an area of 78,380 km^2 (Fig. 1). In this area, precipitation occurs mostly from June to September because of the monsoon wind; non-monsoon precipitation is restricted or sporadic in this area. Most of the rivers originate from the oldest fold mountain chains of Aravalli Range. This mountain range serves a primary role in drought occurrences in this river basin. The eastern slope of the Aravalli mountain range obtains the Arabian Sea branch of monsoon first. Moreover,

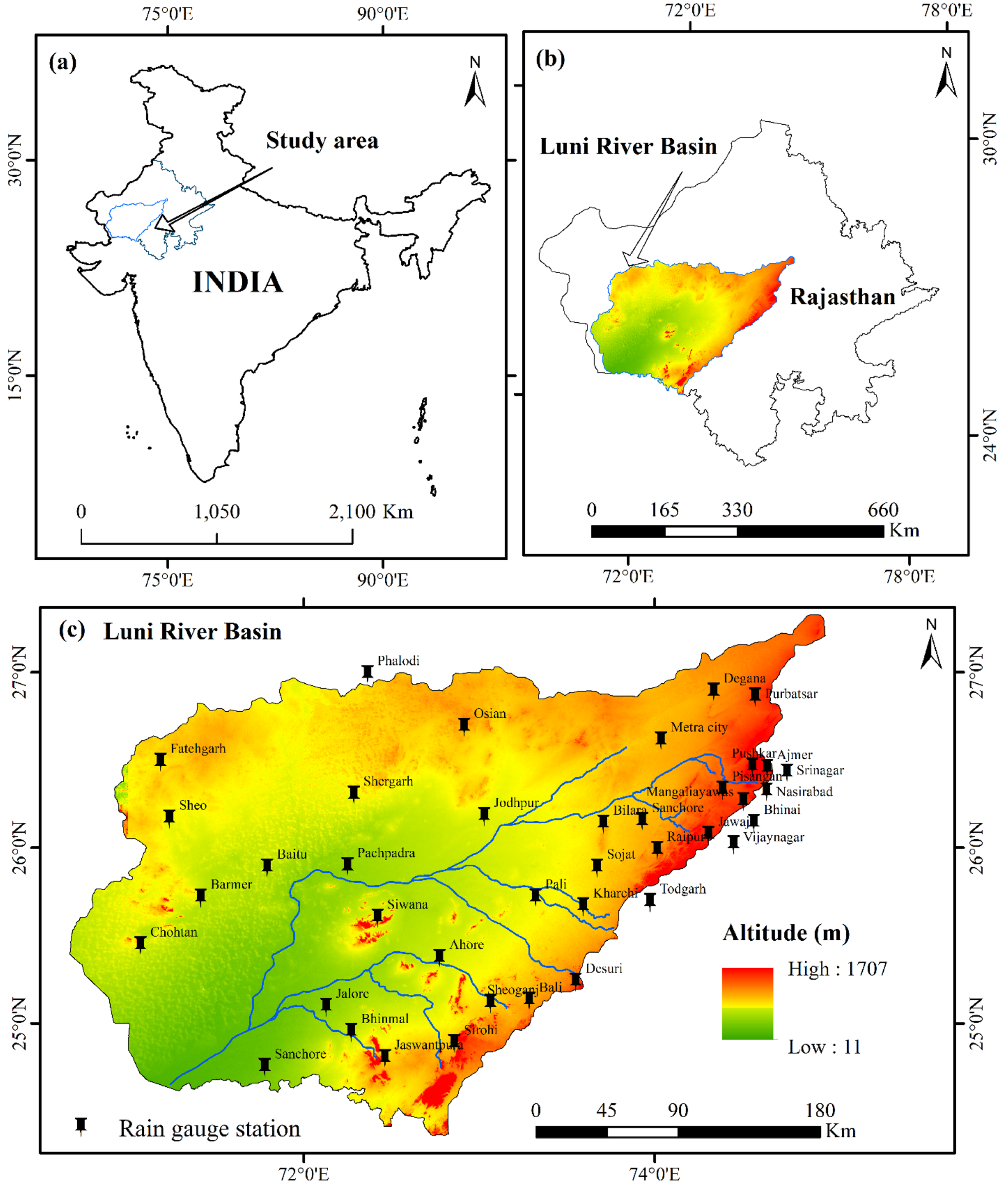


Fig. 1 Location map **a** the spatial location of Rajasthan in India, **b** location of Luni basin in Rajasthan, **c** location of the selected 39 rain gauge stations of Luni basin of Rajasthan

the eastern part of the ranges has higher precipitation, whereas the western part of the range has negligible rainfall. The average annual rainfall distribution has been decreased from the east to the west because of the variations in the relief pattern of the study area.

3 Method and materials

3.1 Data collection and inference of model parameters

The proposed work was processed by using 39 stations rainfall data over the Luni River Basin in Rajasthan from 1973 to 2016. The observed precipitation records were assessed from the archives of the Water Resources Department, Rajasthan. However, some of the stations have missing data, and therefore, we discarded the stations with missing data. After collecting, the data were subjected to check error or missing in the time series and found only less than 1% data were missing which was calculated using multiple imputation method. Several researchers [50–53] used such data because the quality of the data was maintained by the respective agency. In the study, we adopted ClimDex version 1.3 for further maintaining data quality. In order to control the data quality, unrealistic data and subroutine datasets such as (1) typographic error (i.e., 'O' instead of '0') (2) values < 0 (negative rainfall) were identified and corrected. After ensuring that data quality was maintained, station data were more than 90% consistent in carrying out this study.

Homogenization is a key issue in a climate-based analysis. Homogenization is usually a method of removing non-climatic changes in the dataset. A dataset with inhomogeneity creates many problems (biased trend, sudden breaks in the dataset), and therefore, homogeneity testing is performed to address these issues. In the present study, the homogeneity test was performed according to the study by Das et al. [54]. The annual average rainfall (1973–2016) in the study area varies from 198.9 (in Baitu station) to 669.27 mm (in Desuri station) with an average of 1505 mm, The standard deviations of annual rainfall vary from 305.32 (in Bali station) to 101.1 mm (in Phalodi station) (Table 1). By analyzing Table 1, it is observed that the data are positively skewed because the skewness coefficient is larger than zero. Platykurtic and leptokurtic distributions are observed because some values are smaller and some values are larger than zero.

3.2 Standardized Precipitation Index (SPI)

McKee et al. [26] was a key developer of SPI for monitoring the drought events. In this study, SPI was calculated on a 1-, 3-, 6-, 9-, 12-, and 24-month timescale for evaluation of meteorological drought in the Luni River Basin of Rajasthan. Generally, the calculation of SPI is done by setting the probability density function to the total precipitation. It has been done differently for every single month and location. After that, each probability function has been converted into the standard normal distribution [55].

The probability function was used to express the gamma distribution:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}x^{\alpha-1_{\mathrm{e}}-x/\beta} \tag{1}$$

here α denotes the appearance of parameters, β represents the range of the parameter, x denotes the amount of rainfall, and $\Gamma(\alpha)$ is the gamma function. The value of α and β parameters > 0.

The Gamma function $\Gamma(\alpha)$ can be expressed as follows:

$$\Gamma(\alpha) = \lim_{n\to\infty}\Pi_{v=0}^{n-1}\frac{n!n^{y-1}}{y+v} \equiv \int_0^{\infty} y^{\alpha-1}\mathrm{e}^{-y}\mathrm{d}y \tag{2}$$

α and β parameters must be estimated for adjusting the gamma distribution. Maximum likelihood solutions are used to accurately obtain α and β as follows [56]:

$$\widehat{\alpha} = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right) \tag{3}$$

$$\widehat{\beta} = \frac{\bar{x}}{\widehat{\alpha}}, \tag{4}$$

where

$$A = 1n\left(\bar{x}\right) - \frac{\sum 1n(x)}{n} \tag{5}$$

After that, α and β parameters are adopted to detect the increasing probability distribution function $G(x)$ of a given timescale:

$$G(x) = \int_0^x g(x)\mathrm{d}x = \frac{1}{\widehat{\beta}^{\widehat{\alpha}}\Gamma(\widehat{\alpha})}\int_0^x x^{\widehat{\alpha}}\mathrm{e}^{-x/\widehat{\beta}}\mathrm{d}x \tag{6}$$

By replacing $x/\widehat{\beta}$ with t, the above equation can be reduced as follows:

$$G(x) = \frac{1}{r(\widehat{\alpha})}\int_0^x t^{\widehat{\alpha}-1}\mathrm{e}^{-1}\mathrm{d}t \tag{7}$$

Rainfall is not continuous over time. Thus, to account for the zero value obtained when there is no rain. Edwards [57] proposed the true feasibility of non-exceedance $H(x)$ can be obtained as follows:

Table 1 Geographical location of stations with corresponding annual rainfall statistics

Sl. no.	Station	Lat	Long	Alt (m)	Mean (mm)	Median (mm)	Skew	Kurtosis	SD	CV (%)
1	Sojat	25.93	73.67	257	442.76	429.25	0.73	0.47	206.94	46.74
2	Bali	25.18	73.28	298	612.32	542.05	1.31	2.63	305.32	49.86
3	Desuri	25.28	73.55	376	669.27	647.5	1.2	2.68	289.65	43.28
4	Jaitaran	26.2	73.95	307	455.77	425	0.38	−0.44	181.9	39.91
5	Kharchi	25.67	73.58	267	488.34	504.95	−0.06	−0.38	251.16	51.43
6	Pali	25.78	73.33	218	433.75	381.8	0.8	0.08	221.37	51.04
7	Raipur	26.5	74.33	284	527.67	503.85	0.28	−0.51	218.44	41.4
8	Barmer	25.75	71.4	227	288.38	261	0.91	0.96	172.42	59.79
9	Chohtan	25.48	71.67	178	326.64	265.25	0.98	0.72	185.05	56.65
10	Pachpadra	25.93	72.27	102	286.99	249	0.49	−0.71	137.5	47.91
11	Sheo	26.18	71.25	233	240.18	225	0.19	−0.69	106.65	44.4
12	Siwana	25.48	72.42	184	381.93	306.5	1.15	1.28	209.22	54.78
13	Ahore	25.33	72.75	183	414.99	389.05	0.29	−1.02	198.98	47.95
14	Bhinmal	25.17	72.27	155	454.6	392.25	0.58	−0.42	253.31	55.72
15	Jalore	25.35	72.62	268	453.02	342.65	0.77	−0.32	242.89	53.62
16	Jaswantpura	24.8	72.47	272	524.1	508.2	0.57	−0.69	301.13	57.46
17	Sanchore	24.75	71.77	52	436.57	366.65	0.51	−0.87	259.62	59.47
18	Bilara	26.18	73.7	269	446.89	412.5	1.16	1.98	204.24	45.7
19	Jodhpur	26.3	73.33	231	384.48	366.5	0.42	−0.52	170.38	44.32
20	Osian	26.72	72.92	323	320.85	317.5	0.33	−0.37	121.05	37.73
21	Phalodi	27.13	72.37	225	227.65	224	0.82	1.42	101.1	44.41
22	Shergarh	26.33	72.3	258	278.81	263	0.57	0.67	142.98	51.28
23	Ajmer	26.45	74.62	480	554.92	533.4	0.55	0.1	185.3	33.39
24	Bhinai	26.67	74.67	440	496.83	503.5	−0.25	0.06	231.73	46.64
25	Jawaja	25.95	74.22	390	429.04	429.6	0.24	−0.26	239.54	55.83
26	Mangaliawas	26.28	74.62	438	358.64	381.15	0.47	−0.12	221.58	61.78
27	Nasirabad	26.28	74.73	429	558.99	553.25	−0.02	−0.23	233.5	41.77
28	Pisangan	26.4	74.38	438	453.3	423	0.28	−0.42	203.4	44.87
29	Pushkar	26.5	74.55	510	492.79	463	0.39	0.08	265.69	53.92
30	Srinagar	26.43	74.77	466	541.9	549	−0.43	0.74	182.02	33.59
31	Tatgarh	25.68	73.97	699	436	436.5	2.08	8.96	285.04	65.38
32	Vijaynagar	25.92	74.58	161	428.79	430	−0.44	0.12	170.22	39.7
33	Baitu	25.9	71.78	154	198.9	201	1.07	1.34	185.69	93.36
34	Dengana	26.9	74.33	353	453.51	409.5	2.7	11.38	250.52	55.24
35	Fategarh	26.5	71.18	224	198.02	187	0.55	−0.36	131.09	66.2
36	Meta city	26.63	74.03	312	453.51	409.5	2.7	11.38	250.52	55.24
37	Parbatsar	26.88	74.58	423	436.05	404.85	0.9	0.38	241.77	55.45
38	Sheoganj	25.11	73.06	260	524.18	483.25	1.59	4.8	290.36	55.39
39	Sirohi	24.88	72.86	312	615.36	532.6	1.09	1.2	317.51	51.6

$$H(x) = q + (1 - q)G(x) \tag{8}$$

where q denotes the possibility of a zero event, and m is the frequency of zeros in the time series dataset of rainfall. Thom [58] stated that q could be estimated by the following equation:

$$q = \frac{m}{n} \tag{9}$$

The present study used the latest SPI program (SPI_SL_6.exe), which is developed by the US National Drought Mitigation Centre of Nebraska University. The SPI severity drought classes are presented in Table 2.

3.3 Mann–Kendall (MK) test

The MK test was performed to assess the presence of monotonic tendency in the SPI time series dataset. The

Table 2 Drought classification by SPI values [26]

Sl. no.	Drought category	SPI value
1	Mild drought	0 to − 0.99
2	Moderate drought	− 1.00 to − 1.49
3	Severe drought	− 1.50 to − 1.99
4	Extreme drought	≤ − 2

test statistic (S) of a time series $x_1, x_2, x_3 \ldots$, and x_n can be calculated using the MK test as [59, 60]:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sign}\left(x_j - x_k\right) \tag{10}$$

where n defines the number of rain gauge stations and x_m and x_n denote the data point at time n.

$$\begin{aligned} \operatorname{sign}\left(x_{n}{\_}x_m\right) &= 1 \quad \text{if } x_{n}{\_}x_m > 0, \\ &= 0 \quad \text{if } x_{n}{\_}x_m = 0, \\ &= -1 \quad \text{if } x_{n}{\_}x_m < 0. \end{aligned} \tag{11}$$

Equation 12 was used for the calculation of S variance

$$\mathrm{VAR}(S) = \frac{1}{18}\left\{ n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p-1)(2t_p-5) \right\} \tag{12}$$

where n is the number of rain gauge stations, g denotes the total number of tied groups, and t_p is the number of ties of extent p.

There is a close relationship between statistic S and Kendall's τ coefficient. The relationship is calculated as follows:

$$\tau = \frac{S}{D} \tag{13}$$

where

$$D = \sqrt{\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{p=1}^{g} t_p\left(t_p - 1\right)}\sqrt{\frac{1}{2}n(n-1)} \tag{14}$$

If the sample size n is greater than 10, then S and VAR(S) is adopted to calculate normalized test statistic Z, applying the following equation:

$$Z\begin{cases} = \frac{S-1}{[\mathrm{VAR}(S)]^{\frac{1}{2}}} & \text{if} \quad S > 0, \\ = 0, & \text{if} \quad S = 0 \\ = \frac{S+1}{[\mathrm{VAR}(S)]^{\frac{1}{2}}} & \text{if} \quad S < 0. \end{cases} \tag{15}$$

Generally, the positive and negative values of Z statistics depict the increasing and decreasing trends, respectively. The null hypothesis (H_o) and the alternative hypothesis (H_A) depict the no trends and trends, respectively, in the selected time series [61, 62].

4 Results and discussion

4.1 Temporal variation of drought

The SPI-1, 3, 6, 9, 12, and SPI-24 were calculated, and thereafter, the drought events in the Luni Basin of Rajasthan recorded by the 39 rain gauges were distinguished. Table 3 shows the temporal distribution of the annual drought events from 1973 to 2016, and the distribution allows for the recognition of drought periods and their corresponding duration (years). The performance of SPI showed that more than 80% of stations were affected by droughts in the years 1974, 1980, 1981, 1984, 1985, 1986, 1987, 1988, 1991, 1999, 2002, 2004, and 2009. According to the results presented in the table, the most severe drought events occurred in Baitu Station during 1974–91.

The distributions of the SPI for each year are shown in Fig. 2. The results of the SPI showed that few stations exceeded the extreme wet event (SPI > 2) and extreme drought event (SPI < − 2). Based on the short-term SPI (3-and 6-month timescales), several drought periods have occurred during the study period. Specifically, from an agricultural point of view, one of the most severe drought events occurred during the monsoons in June 1984. During this event, more than 23% of the stations of the Luni River Basin were exposed to extreme and severe drought events, as shown in Fig. 2c. Another exceptional drought event occurred in June 1992. During this event, more than 16% of the stations experienced extreme and severe drought during a 3-month timescale. Drought events were observed in September 1974, 1987, and 2002 according to SPI-3 (Fig. 2d), and approximately 67%, 87%, and 46% of the stations were affected by extreme, severe, and moderate droughts, respectively. The incidence of severe and extreme drought (SPI-3) was relatively higher in June and September compared to December and March. Similarly, more than 33% of the stations experienced severe and extreme drought conditions in September 1974, while in September 1987 more than 74% of the stations experienced drought conditions with an SPI value of less than − 1.5. In addition, in September 2002, the analysis of SPI-6 revealed that more than 48% of the stations were affected by extreme and severe drought conditions (Fig. 2f). The annual SPI series also revealed that the drought was experienced in 1974, 1980, 1981, 1982, 1984, 1985, 1986, 1987, 1988, 1989, 1991, 1993,

Table 3 Maximum drought duration according to the annual SPI values

Sl. no.	Station	Drought year	Duration (year)
1	Sojat	1981–1982, 1985–1988, 2003–2004	8
2	Bali	1979, 1993, 2007, 2011–2013	6
3	Desuri	1981–1982, 1985–1987, 1999–2000, 2005, 2009	9
4	Jaitaran	1981–1982, 1985–1989, 2000, 2003	9
5	Kharchi	1985, 1988, 1998, 2006	4
6	Pali	1981–1982, 1984–1987, 1999–2000, 2003–2005, 2009	12
7	Raipur	1981–1984, 1986–1988, 2000, 2003–2004	10
8	Barmer	1980–1981, 1986–1988, 2000, 2009	7
9	Chohtan	1979, 1981, 1984–1987, 2000, 2005	8
10	Pachpadra	1974, 1978, 1981, 1985–1989	8
11	Sheo	1981–1991	11
12	Siwana	1981, 1986–1989, 2000–2002, 2005, 2012	10
13	Ahore	1981–1983, 1985–1988, 1996, 2001–2002, 2009	11
14	Bhinmal	1981, 1985–1989, 1999, 2001–2002	8
15	Jalore	1981–1982, 1986–1989, 2001–2005, 2009	12
16	Jaswantpura	1981–1982, 1985–1989, 1996, 1999–2000	10
17	Sanchore	1980, 1986–1987, 1999, 2001–2002, 2008–2009	8
18	Bilara	1981, 1986–1987, 2001–2003, 2009–2010	8
19	Jodhpur	1981, 1985–1989, 2005–2007	9
20	Osian	1986–1989, 2000, 2006–2009	5
21	Phalodi	1988–1989, 2000, 2005	4
22	Shergarh	1981, 1985–1987, 2005–2006	6
23	Ajmer	1981–1982, 1986–1991, 2000–2006	15
24	Bhinai	1980–1989, 2009	11
25	Jawaja	1986–1988, 2008–2011, 2016	8
26	Mangaliawas	1978–1980, 1982, 1986–1993	12
27	Nasirabad	1981–1982, 1985–1989, 2000, 2003	9
28	Pisangan	1974–1975, 1986–1988, 1992, 2009	7
29	Pushkar	1974–1975, 1986–1988, 1992, 2009	7
30	Srinagar	1987, 2000–2009	11
31	Tatgarh	1978, 1986–1987,1999–2000, 2004, 2008–2009	8
32	Vijaynagar	1980–1981, 1986–1987, 1999, 2009	6
33	Baitu	1974–1991	18
34	Dengana	1985–1991, 2002, 2012	9
35	Fategarh	1975, 1978–1979,1982–1989, 1992	12
36	Meta city	1974, 1981–1982, 1986–1989, 2001–2003	10
37	Parbatsar	1985–1991, 1994, 1999–2000, 2005–2007	13
38	Sheoganj	1981–1982, 1985, 1989–1991, 2005, 2009, 2014	9
39	Sirohi	1981–1982, 1985–1989, 2000, 2009, 2014	10

1999, 2002, 2004, 2005, and 2009. However, the highest frequency of severe and extreme droughts was found in 1974, 1987, 2002, and 2009 (Fig. 2g).

The proportion of stations experiencing meteorological drought events according to the threshold values of SPI-12 specified in Table 3 is presented in Fig. 3. The proportion of stations experiencing meteorological drought events in accordance with the SPI-12 threshold values is presented in Table 3 and Fig. 3. The values showed that approximately 74% of the stations experienced the maximum frequency of mild droughts in 2000. In 1986, almost 49% of the rain gauge stations were affected by moderate drought events. Approximately 31% and 44% of stations affected by extreme and severe drought events in 1987, respectively. The occurrence of drought event was least in 1997 (Fig. 3), followed by 2010 and 2015. However, the

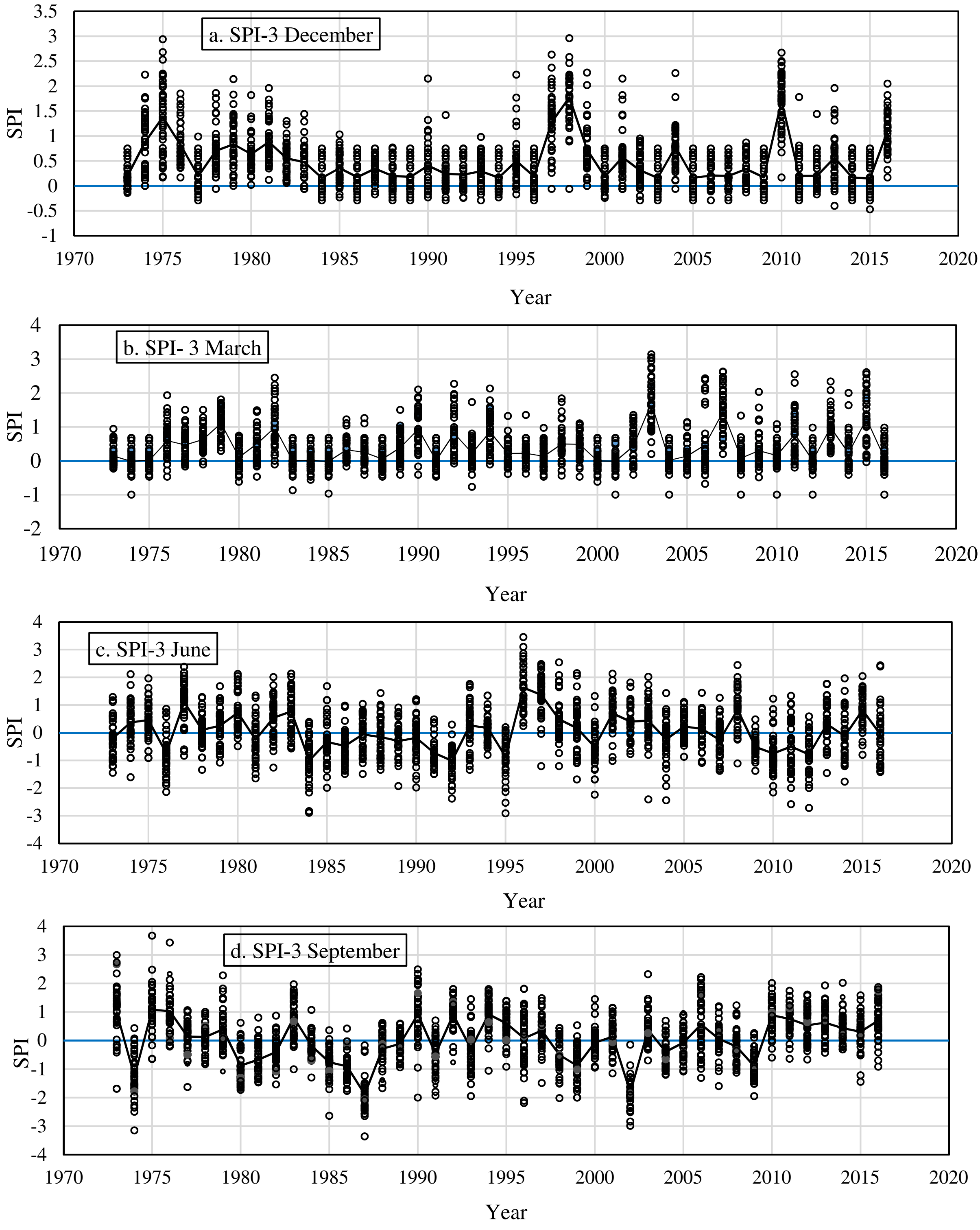


Fig. 2 Temporal SPI values according to the seasonal periods in 1973–2016. **a** SPI-3 for December, **b** SPI-3 for March, **c** SPI-3 for June, **d** SPI-3 for September, **e** SPI-6 for March, **f** SPI-6 for September, **g** SPI-12

maximum number of meteorological drought events was reported in 1974, 1985, 2002, and 2009. The most severe and prolonged drought events in the basin area were identified in 2002. In 2002, SPI-12 showed that approximately 43% of stations had severe and extreme drought conditions.

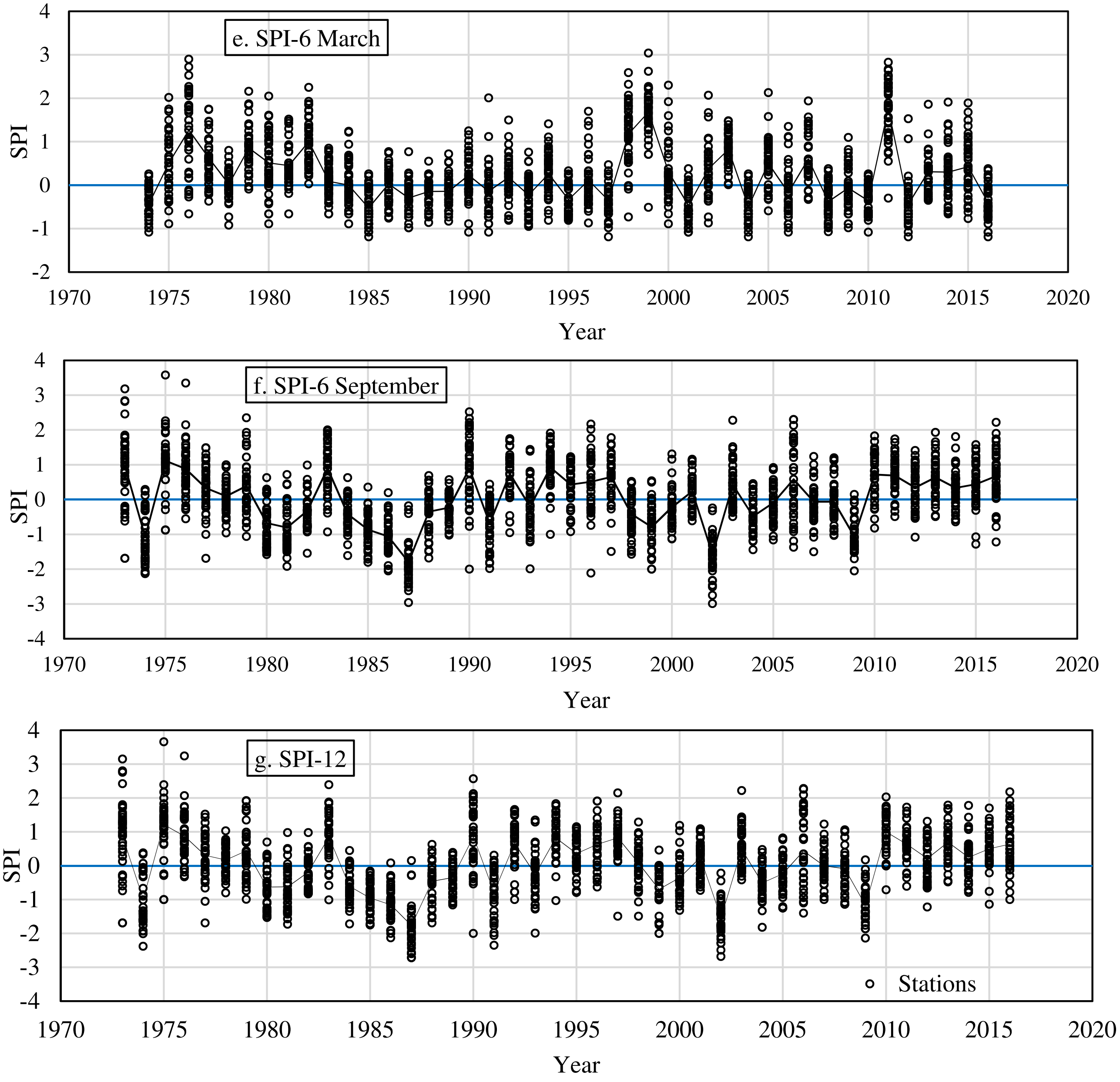


Fig. 2 (continued)

An overall analysis of the metrological event shows that a mixture of both dry and wet events is identified in the temporal study. Similar findings are found in the study of Mekonen et al. [63], Kalisa et al. [64]. In addition, the temporal study also shows that there are a lot of differences amongst these stations with regard to drought events. This may be due to the differences in climatic and geographic characteristics. Another interesting fact is that most of the stations experienced drought events during the period 1985 to 1990.

4.2 Spatial distribution of drought

The spatial extension of the drought was obtained using a spline interpolation method, as shown in Figs. 4 and 5. The incidence of various categories of drought events varied from regions and timescales. As shown in Figs. 4 and 5, there were a greater number of moderate drought effects compared with severe and extreme drought events between study periods. The highest drought frequency was observed in Dengana Station, where the average

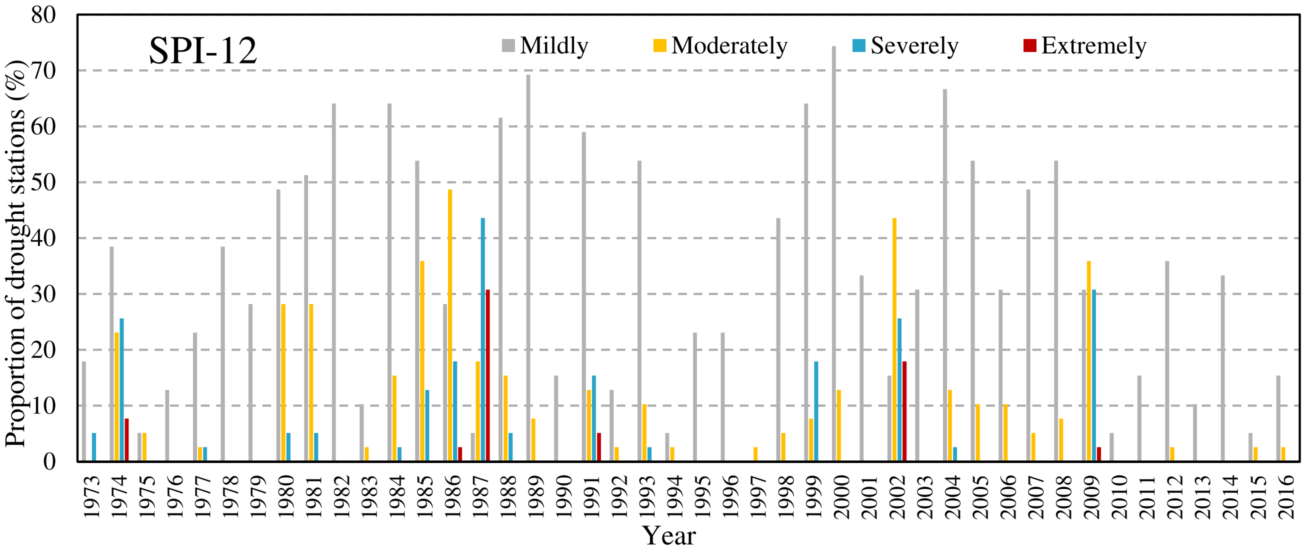


Fig. 3 Proportion of stations that experienced droughts according to SPI-12 during 1973–2016

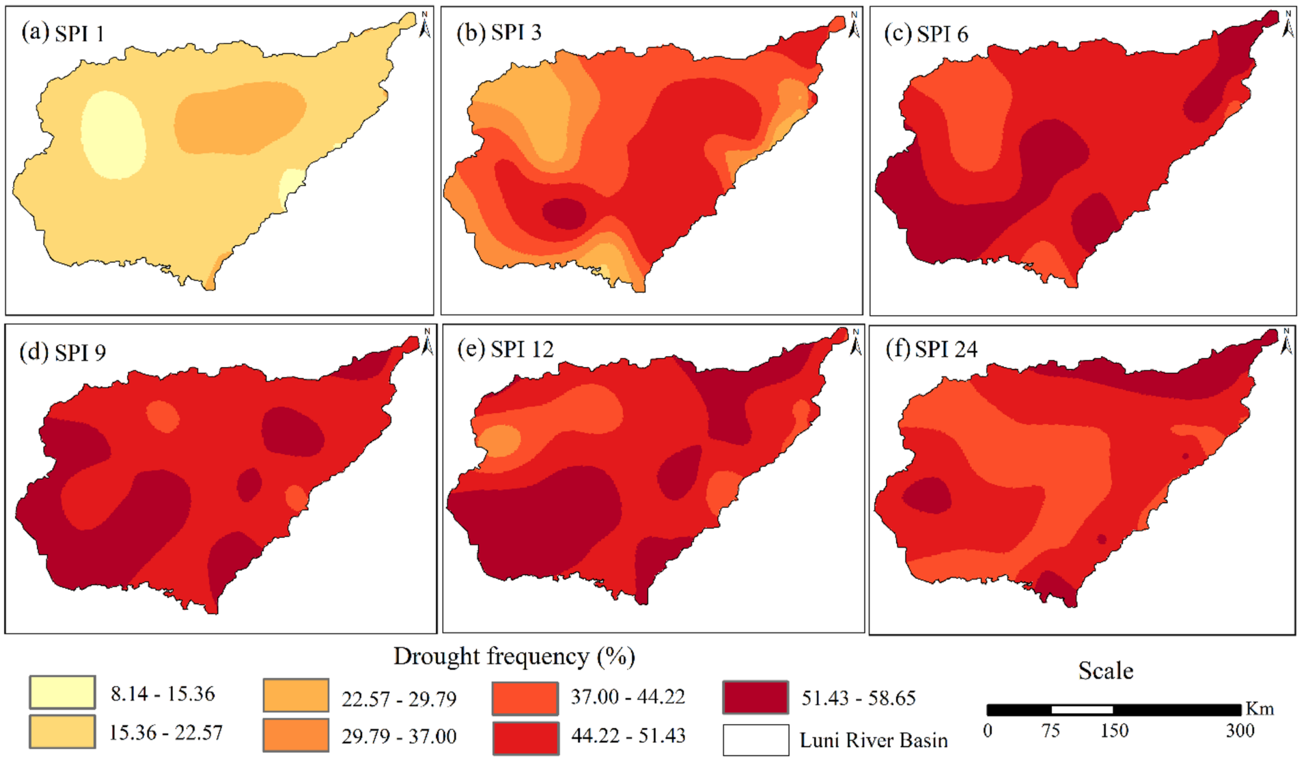


Fig. 4 Occurrence of drought events, **a** SPI-1, **b** SPI-3, **c** SPI-6, **d** SPI-9, **e** SPI-12, **f** SPI-24

drought frequency is 46.58%. The lowest drought frequency was observed at the Vijaynagar station, where the average drought frequency was 35%. For each timescale, the total number of severe (– 1.50 to – 1.99), moderate (– 1.00 to – 1.49), and mild (0 to – 0.99) drought events were considered. The results showed that recurring droughts were mostly observed for the 1-month timescale in the middle portions of the basin (15–23%) (Fig. 4a). For the 3-month timescale, the northeastern and southeastern areas of the basin experienced droughts

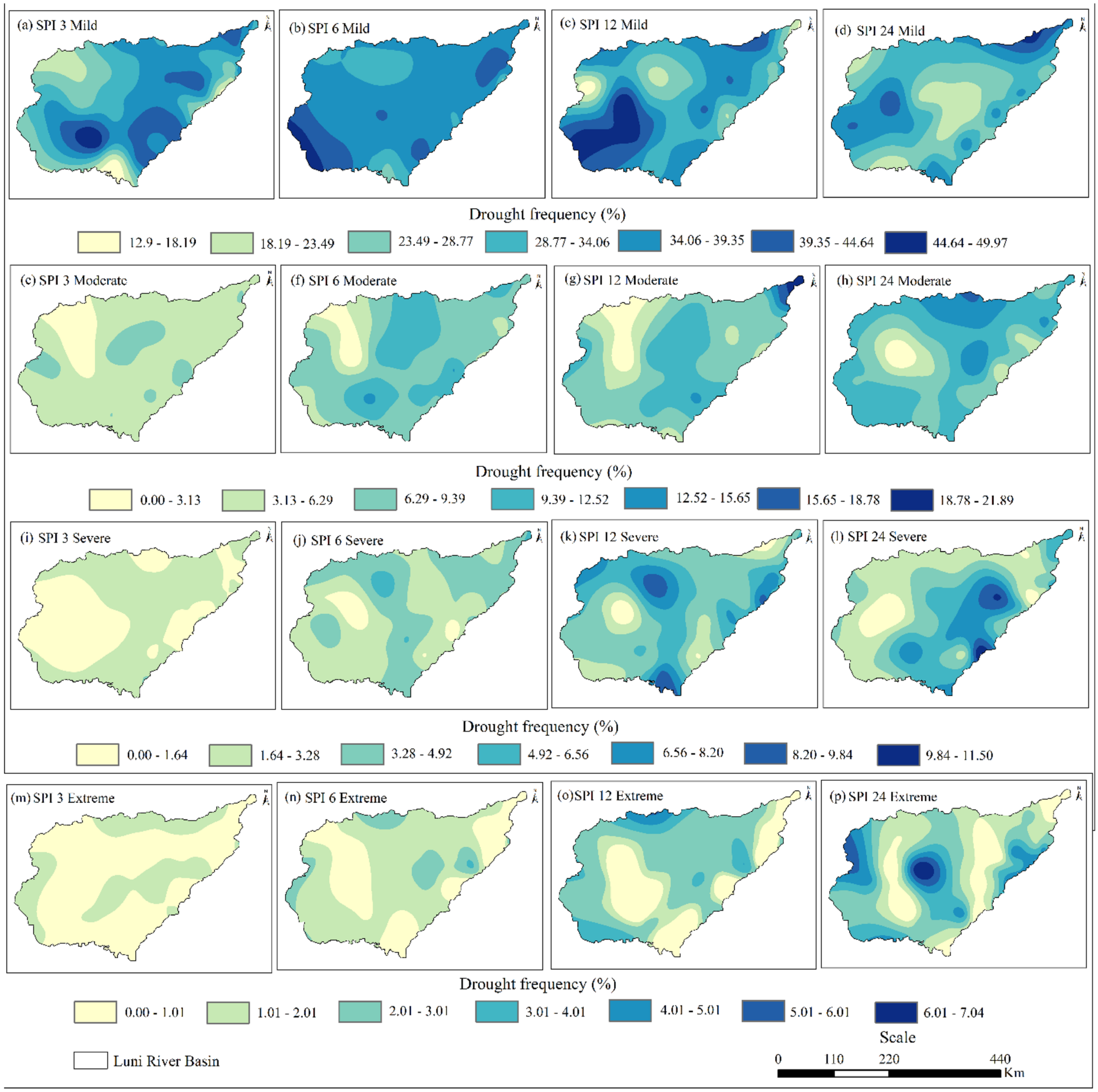


Fig. 5 Occurrence of drought events with the severity level, **a** SPI-3, mild, **b** SPI-6, mild, **c** SPI-12, mild, **d** SPI-24, mild, **e** SPI-3, moderate, **f** SPI-6, moderate, **g** SPI-12, moderate, **h** SPI-24, moderate, **i** SPI-3, severe **j** SPI-6, severe, **k** SPI-12, severe, **l** SPI-24, severe, **m** SPI-3, extreme, **n** SPI-6, extreme, **o** SPI-12, extreme, **p** SPI-24 extreme

most frequently (44%–51%) (Fig. 4b). Most of the area of the basin (86.16%) except the northwestern part of the basin, often experienced mild and above category droughts (44–59%) according to the 6-month timescale (Fig. 4c). Conversely, for the 9-month timescale, nearly high recurrences (51%–59%) of mild and above category droughts were seen in the southwestern part of the basin (Fig. 4d). According to SPI-12, the drought events revealed that most of the regions of the basin (except the northwestern part and few pockets of eastern part) experienced the drought most frequently (44–59%), covering about 85.63% of the basin area (Fig. 4e). On the other hand, the longer timescale of SPI-24 showed that recurrent droughts (44–59%) were observed in approximately 66.91% of the basin area and these areas were mostly identified in the northern, eastern, and southwestern parts of the basin (Fig. 4f).

The spatial mild drought pattern according to SPI-3 reveals that the drought occurrence mostly reoccurred (34–50%) in approximately 49.57% of the total study area, and these regions were mostly scattered in the southwestern and middle portion of the basin (Fig. 5a). According to SPI-6, a high-recurrence (34–50%) of mild drought zone on an area of 84.33% of the total basin area was observed, and these areas were mainly located in the middle and extreme southern portion of the Luni River Basin (Fig. 5b). According to SPI-12, mild droughts experienced in the focal segment of the southwestern part of the basin with a high recurrence value (34–50%) (Fig. 5c); the area covered approximately 53.79% of the basin. According to SPI-24, a longer timescale, mild droughts were observed in the central portion of the north and northeastern parts of the Luni River Basin with a high-recurrence value (34–50%); the area covered approximately 26.34% of the basin (Fig. 5d).

According to SPI-3, approximately 12% of the basin (Fig. 5e) experienced moderate drought events with a high-recurrence value (6–9%). The area was mainly in the focal segment of the basin. By contrast, a high-recurrence of moderate drought event was also observed in the extreme northwestern and eastern parts of the basin according to SPI-6 (Fig. 5f). According to SPI-12, regions in which moderate drought events occurred most regularly (9–22%) were found in the extreme northeastern and southeastern parts of the basin (Fig. 5g). These areas covered approximately 30% of areas of the basin. According to SPI-24, the moderate drought event zone with high-recurrence values (9–19%) was found mainly in the northwestern, middle-eastern, and also in the southeastern parts, covering approximately 60% area of the basin (Fig. 5h).

According to SPI-3, areas with severe droughts with high recurrence values (1.6–4.9%) were found to be predominantly in the northeast, southeast, southwest, and midwest regions (Fig. 5i) and to cover approximately 55.56% of the basin. Conversely, according to SPI-6, an exceptionally severe drought event (3.28–6.56%) was observed. At this scale, mainly the northern and eastern parts of the basin, with an area of about 45%, experienced severe droughts with high recurrence values (Fig. 5j). As shown in Fig. 5k (SPI-12), the northwestern part of the basin and a small portion of the eastern part experienced severe droughts of high recurrence (6.56–9.84%). The areas covered approximately 13.71% of the basin. According to SPI-24, a severe drought existence zone was found mainly in the western part of the basin, which was approximately 15% of the total area of the Luni River Basin (Fig. 5l).

By contrast, according to SPI-3, approximately 29% of the total basin area experienced extreme drought events with high-recurrence values (1–3%); the area was mainly located in the southwestern parts of the basin (Fig. 5m). According to SPI-6, high occurrence values (2–4%) of severe droughts were observed in the central and southwestern parts of the basin; the area covered 10.69% of the total basin area (Fig. 5n). According to SPI-12, the regions that experienced extreme droughts with high-recurrence values (3–6%) were predominantly situated in extreme northern and eastern parts of the basin; the area was 12% of the total basin area (Fig. 5o). According to SPI-24, an extreme drought occurrence zone with high-recurrence values (3–7%) was mainly situated in the extreme southern and northern portions of the study area. The zone occupied 29.75% of the total basin area (Fig. 5p). Spatial analysis shows that drought events vary from mild to severe drought among the stations. Similar findings were reported by Mundetia and Sharma [42], Dutta et al. [47], and Chhajer et al. [41]. It also recognizes that the western part of the basin is more prone to drought. This may be due to higher temperatures, lower rainfall, and different geographical locations.

4.3 Trend analysis of the SPI values

Figure 6 illustrates the trends in drought intensity according to SPI-6, SPI-9, SPI-12, and SPI-24, obtained by the Mann–Kendall test. The statistically significant trend was identified at three significance levels of 0.01, 0.05, and 0.10. Approximately 46.15%, 38.46%, 30.77%, and 33.33% of the rain gauge stations reported negative trends in SPI-6 (Fig. 6a), SPI-9 (Fig. 6b), SPI-12 (Fig. 6c), and SPI-24 (Fig. 6d), respectively.

Any significant declining trend was not detected in SPI-1. However, only three stations had a significant decreasing trend in SPI-3 values. These stations are Ajmer and Jawaja in the district of Ajmer and Sanchore in Jalore district.

A significant decreasing trend was observed in Ajmer, Jawaja, and Dengana stations at a 99% confidence level (SPI-6). However, a significant decreasing trend was observed at a confidence level of 95% in Srinagar and Sheoganj, and at a confidence level of 90% in Kharchi and Bilara. Significant positive trends were also identified at a confidence level of 99% in Barmer, Pachpadra, Sheo, Jaswantpur, Shergarh, Bhinai, Mangaliwas, Nasirabad, Pisangan, Vijaynagar, Baitu, and Fategarh; at a confidence level of 95% in Pushkar; and at 90% in Sojat and Chohtan (Table 4).

There was a significant decreasing trend in SPI-12 in the stations of Phalodi, Ajmer, Jawaja, Mangaliwas, Srinagar, Vijaynagar, Dengana, and Sheoganj. In SPI-24, similar trends were also found. Northwestern parts of the basin showed statistically significant positive SPI-value trends. In contrast, statistically significant negative trends in the

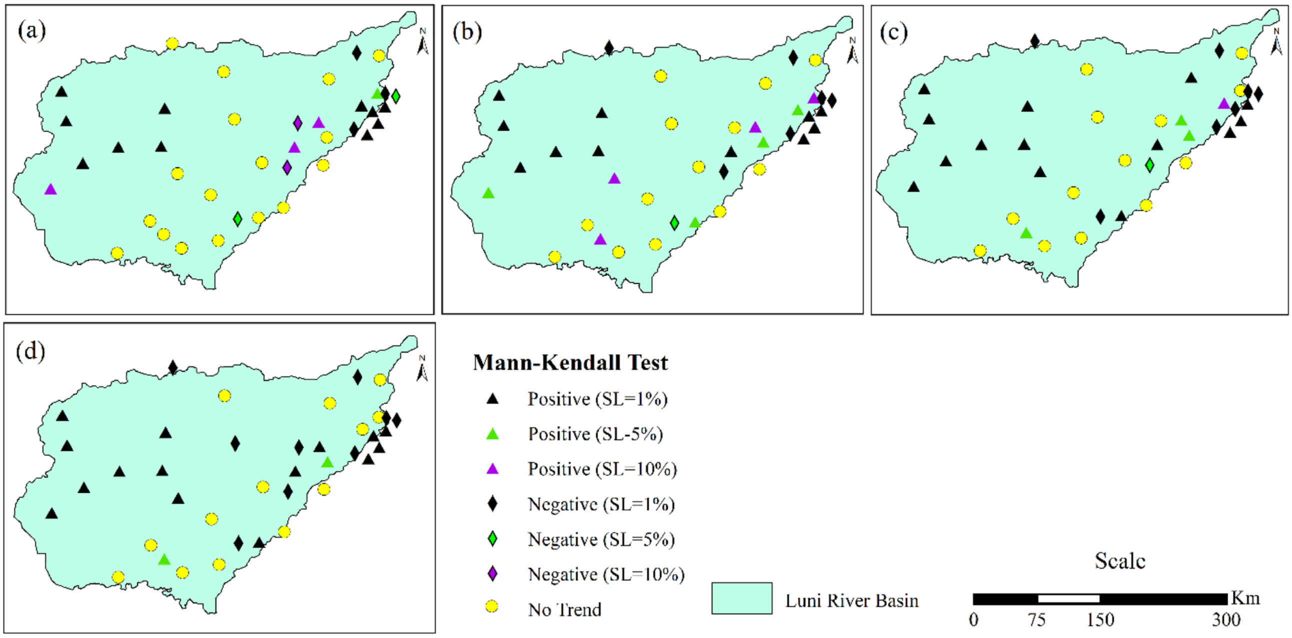


Fig. 6 Trend analysis for **a** 6-month SPI, **b** 9-month SPI, **c** 12-month SPI, **d** 24-month SPI

northeastern portion of the basin were identified. However, no trend was detected in the center of the basin. The linear trend of different SPI categories of Dengana station also showed sharp decreasing trends (Fig. 7).

It is interesting to note that SPI-1 and SPI-3 are unable to detect significant trends in drought events. However, SPI-12 and SPI-24 timescales are capable of detecting a significant trend. This means that the ability to detect trends is increased with the increase in SPI timescale. This finding is corroborated with the study of Mahajan and Dodamani [65]. In addition, the detection of significant drought trend is also increased with an increase in the SPI timescale.

5 Conclusion

Drought monitoring and assessment for improved management strategies and policy development are lacking in numbers of underprivilege drought-prone and economically backward regions in India, and such studies are exaggerated the spatial, temporal, and trend behavior of meteorological drought events through the SPI values of the Luni River Basin in Rajasthan. The SPI and the GIS techniques were adopted to identify the significant drought years and also to demarcate the significant drought-prone areas. The maximum drought periods and the corresponding duration were identified, and the results affirm that this basin was affected by some exceptional drought events. The various SPI timescales present distinctive drought periods and their intensities, which play a very crucial role in seasonal drought analysis. By using the data about drought occurrence, severity, spatial pattern, and trend analysis, detailed and efficient management and planning can be developed to mitigate droughts effectively. In summary, the study portrayed that since 1973, severe and extreme droughts occurred during fourteen years in the study area and after 1985, the occurrence of severe and extreme droughts increased. SPI-3 results revealed that the monsoon months are more vulnerable than the other seasons. Moreover, June is more prone to severe droughts, whereas September is more prone to extreme droughts.

The results of Z statistics showed the declining trend in SPI value was observed in the northeastern and southeastern parts of the study area. However, the western portion of the basin depicts an increasing trend of SPI values, while the middle portion of the study area has no identifiable trend.

As low precipitation, high fluctuation in the average rainfall and climate change, especially owing to regional and global warming, has a severe effect on the occurrence of drought. That said, it is crucial to prepare suitable drought management policies and effectively execute these policies with a more prominent association with and support from the government and private associations. The policies are required for the high and very-high drought-affected stations such as Chohtan, Jalore, Bilara, Dengana, Parbatsar, Sheoganj, and Sirohi. The influence of drought is enormous in the basin. In particular, farming and water divisions are the two most influenced aspects of this basin. Thus, the strategies related to the appropriate

Table 4 Trend analysis of drought severity in the study area

Sl. no.	Station	Test statistics (Z)					
		SPI 1	SPI 3	SPI 6	SPI 9	SPI 12	SPI 24
1	Sojat	0.57	0.64	1.68*	3.11***	3.94***	3.71***
2	Bali	−0.59	−0.54	0.77	2.39**	3.56***	3.11***
3	Desuri	−0.42	0.32	−0.25	0.07	0.57	0.67
4	Jaitaran	−0.03	0.15	0.33	0.72	1.32	−0.98
5	Kharchi	−0.68	−0.9	−1.90*	−2.23***	−2.46**	−3.88***
6	Pali	0.37	1.22	1.04	1.4	1.6	0.92
7	Raipur	0.18	0.48	1.19	1.99**	2.50**	2.18**
8	Barmer	0.93	2.06**	2.75***	2.62***	3.21***	4.33***
9	Chohtan	0.66	1.54	1.79*	2.48**	3.19***	6.48***
10	Pachpadra	1.87*	4.05***	5.43***	6.62***	7.90***	11.36***
11	Sheo	1.14	3.04***	4.67***	5.60***	7.15***	8.77***
12	Siwana	0.58	0.46	0.71	1.98*	3.01***	3.41***
13	Ahore	−0.74	−0.87	−0.57	0.21	0.8	0.88
14	Bhinmal	0.15	0.86	1.5	1.86*	2.25**	2.28**
15	Jalore	−0.18	−0.81	−0.88	0.35	0.84	−1.12
16	Jaswantpura	−0.33	0.83	1.95*	1.88*	2.09**	3.44***
17	Sanchore	−0.54	−1.76*	−1.65	−0.9	−0.65	0.56
18	Bilara	−0.4	−1.13	−1.81*	−1.21	−0.87	−4.84***
19	Jodhpur	−0.41	−0.78	−1.16	−1.16	−1.57	−2.82***
20	Osian	0.29	0.16	0.34	0.14	0.43	−0.15
21	Phalodi	−0.4	−0.6	−1.58	−3.06***	−3.80***	−6.63***
22	Shergarh	2.08**	3.14***	3.26***	3.45***	3.61***	5.48***
23	Ajmer	−1.08	−2.60***	−3.28***	−3.76***	−4.12***	−4.72***
24	Bhinai	1.28	2.75***	3.50***	3.28***	3.83***	5.38***
25	Jawaja	−1.38	−3.40***	−5.30***	−6.11***	−6.51***	−8.13***
26	Mangaliawas	1.7	4.27***	6.22***	6.49***	−6.79***	9.17***
27	Nasirabad	2.46**	5.21***	6.70***	7.33***	8.03***	8.93***
28	Pisangan	0.96	2.06**	2.63***	2.23**	1.95*	1.63
29	Pushkar	0.72	1.51	2.22**	1.84*	1.55	1.27
30	Srinagar	−0.75	−0.92	−2.34**	−3.32***	−3.81***	−5.91***
31	Tatgarh	−0.38	−0.58	−0.37	−0.4	0.04	0.66
32	Vijaynagar	0.99	2.25**	3.06***	2.86***	−3.90***	4.87***
33	Baitu	3.78***	8.14***	12.85***	14.15***	15.05***	15.42***
34	Dengana	−0.93	−1.82*	−2.75***	−3.02***	−3.16***	−4.67***
35	Fategarh	2.47**	5.46***	8.59***	10.00***	11.58***	14.50***
36	Meta city	0	0	0.65	1.65	3.16***	0.65
37	Parbatsar	0.07	0.1	0.24	0.27	0.48	0.96
38	Sheoganj	−0.93	−1.55	−2.44**	−2.51**	−2.86***	−4.36***
39	Sirohi	−1	−1.48	−1.2	−0.38	0.21	−1.1

[*] Statistically significant trends at the 10% significant level

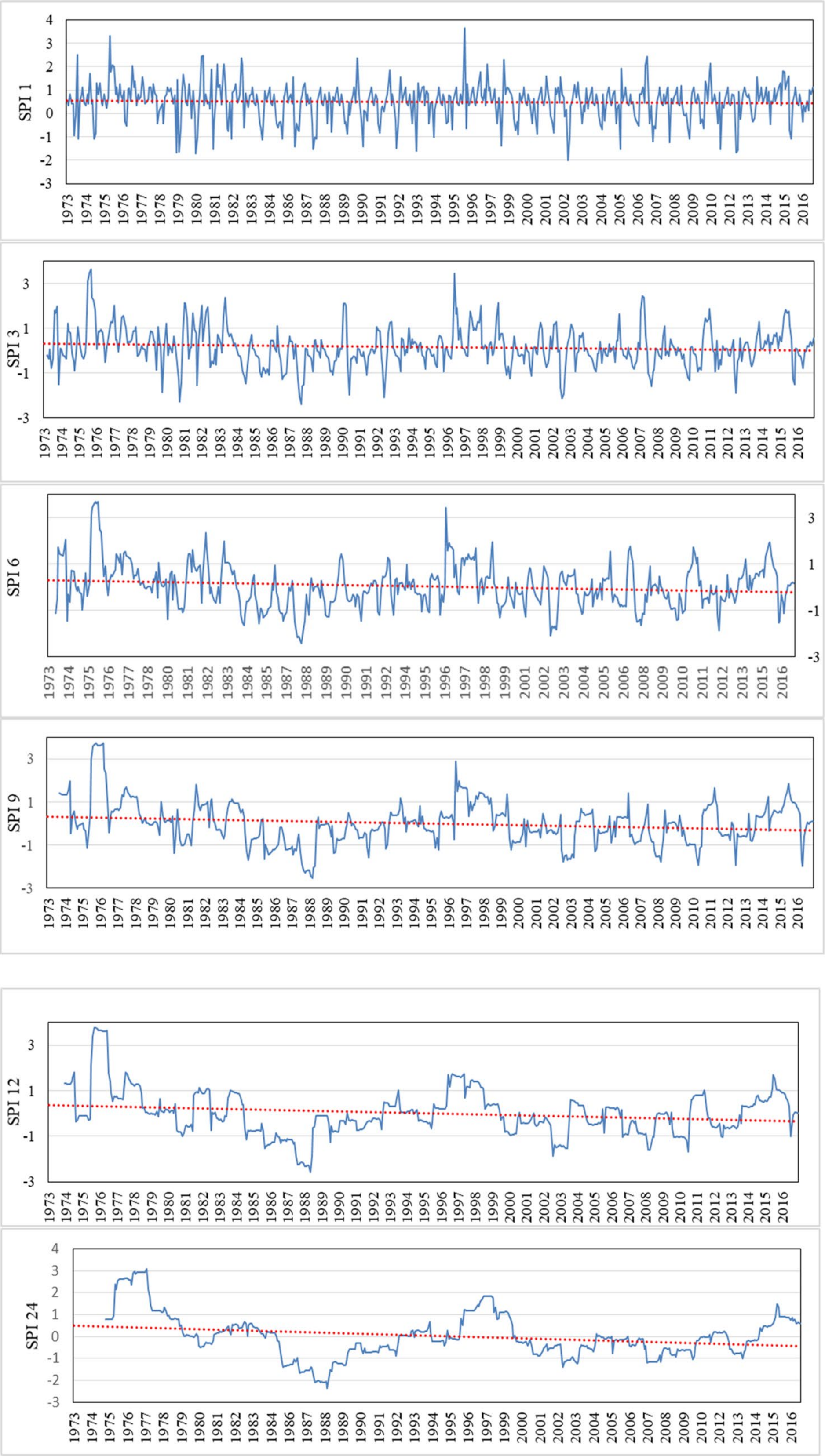
[**] Statistically significant trends at the 5% significant level

[***] Statistically significant trends at the 1% significant level

utilization of surface water and the ideal utilization of groundwater during farming should be consolidated into the moderation strategies and programs to alleviate the influence of droughts in the future, particularly in the severe and extreme drought zones of the various timescales.

Maximum agricultural areas of the watershed are fallen under the severe drought prone due to the adverse effect of Aravalli Mountain, less vegetation cover, and uneven distribution pattern of rainfall. The Aravalli Mountain is influenced not only by the uneven rainfall distribution but also the adverse effect of soil moisture content and

Fig. 7 Time series of the SPIs for the Dengana station, **a** SPI-1, **b** SPI-3, **c** SPI-6, **d** SPI-9, **e** SPI-12, **f** SPI-24



led to the developed agricultural drought. Non-suitable land and environmental management strategies affected the climatic condition in this watershed. Finally, this study assessed the trends of drought and its occurrence, and it is expected that this study will be a valuable guide toward understanding the nature of drought and will help in performing efficient management strategies to alleviate the problem of drought in this study area adequately.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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