Standardized precipitation index based dry and wet conditions over a dryland ecosystem of northwestern India

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\textbf{ABSTRACT}

Droughts are extreme meteorological and hydrological events having severe impacts on the natural environment and socioeconomic conditions of the affected region especially over a dryland ecosystem like Rajasthan state in northwestern India. Therefore, in this paper an attempt has been made to investigate the dry and wet conditions over the state based on standardized precipitation index (SPI). For this study, diurnal rainfall data of 33 stations have been procured and used for the period 1961–2017. The analysis has been carried out at different time scales i.e. early, mid, late, whole \textit{rabi} season and annually. To examine the trends in rainfall and SPI, Mann-Kendall test has been applied. Spatial plotting of rainfall and SPI has been done by means of inverse distance weighting interpolation technique. The analysis has shown an increasing trend in annual SPI over majority of stations (23 stations), with significant increasing trend at 5 stations (significant at 95\% confidence level). Seasonally, incremental drying conditions have been witnessed during mid- and late \textit{rabi} seasons, which are opposite to early \textit{rabi} season when about 70\% of the stations have witnessed wetting conditions. Almost all the stations have evidenced severely dry years except Banswara, Barmer, Nagaur and Sirohi stations. Overall, the northwestern, southeastern and northeastern parts have suffered from high drought severity, whereas central regions have relatively low severity of droughts. Finally, the results of this study may be beneficial for decision makers in formulating water management policies to mitigate the impact of dryness and wetness.

1. Introduction

Drought events and their related impacts on society and environment are expected to increase due to changing climate (Bates et al., 2008; Dai, 2011; Romm, 2011). Over the years, several drought indices such as Palmer Drought Severity Index (PDSI) (Palmer, 1965), Rainfall Anomaly Index (RAI) (Van Rooy, 1965), Surface Water Supply Index (SWSI) (Shafer & Dezman, 1982), Palfai Aridity Index (PAI) (Palfai, 1990), Standardized Precipitation Index (SPI) (Mckee et al., 1993), Vegetation Condition Index (VCI) (Kogan, 1995), Effective Drought Index (EDI) (Byun & Wilhite, 1999), Reconnaissance Drought Index (RDI) (Tsakiris et al., 2007), Perpendicular Drought Index (PDI) (Ghulam et al., 2007), Standardized Runoff Index (SRI) (Shukla & Wood, 2008) and Standardized Precipitation Evaporation Index (SPEI) (Vicente-Serrano et al., 2010) have been developed and used by scientists for identification and management of drought around the world. Mishra and Singh (2011) have comprehensively reviewed the merits and demerits of these indices under diverse conditions. Of the above indices, SPI suggested by Mckee et al. (1993) have distinct merits consisting of simplicity to calculate, broader applicability, tailored for multiple time scale, incorporates only rainfall as input data and least affected by geographical and topographical differences (Bazrafshan et al., 2014). Of late, SPI has been extensively used in estimation, monitoring, watching and forecasting of droughts universally (Spinoni et al., 2014) as well as in several realms namely, Africa (Dhurme et al., 2019; Dutra et al., 2013), Europe (Barker et al., 2016; Karabulut, 2015), North America (Ford & Labosier, 2014), South America (Seiler et al., 2002), West Asia (Awchi & Kalyana, 2017; Mossad & Alazba, 2018; Mustafa & Rahman, 2018; Zakhem & Kattaa, 2016) and South-East Asia (Bong & Richard, 2019; Du & Shi, 2013; Kundu et al., 2020; Rahman et al., 2018; Zin et al., 2013). Apart from this, SPI has been modelled using geostatistical techniques to generate spatial maps (Bhuiyan et al., 2006; Sharafati et al., 2020).

India has a history of droughts, facing 22 major droughts between 1871 and 2002. Likewise, about 16\% of its total geographical area is drought prone, annually affecting approximately 50 million people (Prabhakar & Shaw, 2008). Droughts are of major concern in Rajasthan state of India because much of the state is highly drought prone experiencing drought very frequently (Dutta et al., 2015). The state has witnessed recurring and prolonged droughts of about 3–4 years in a cycle of 5 years with water scarcity almost every year, resulting a disruption in the socio-economic development. Pingale et al. (2014) have reported a significant increasing trend in temperature differences.
over Rajasthan, which is expected to have an impact on rainfall and probably on drought. Recently, few studies have specifically quantified meteorological drought based on rainfall data at regional scales in India (Kundu et al., 2015, 2020). But a detailed investigation regarding meteorological drought based on rainfall data over Rajasthan state, using standard drought indices is not available. To fill this research gap, an investigation of meteorological drought over the state is essential for making mitigation plans to reduce the impact of drought. Therefore, this study aims (1) to determine the dry and wet conditions based on SPI at multiple time scales such as early season (June to August), mid-season (August to September), late season (September to October), whole kharif season (June to October) and annually (January to December) over the state of Rajasthan using rainfall records between 1961 and 2017 and (2) to detect direction of trends in SPI values by means of Mann–Kendall test. The study of SPI for early, midand late segments of kharif season has been considered because drought during different time spans of kharif period leads to varied influences on growth of crops. Also, it has been attempted to reveal the contribution of rainfall deficit in early, mid and late segments of the whole kharif season deficits. The study of intra-seasonal differences has far-reaching importance because every crop stage has its individual susceptibility to moisture and water availability.

2. Materials and methods

2.1. Study area

The state of Rajasthan, situated in northwestern parts of India is the largest state of country. It covers a large area of 3,42,239 km² occupying about 10.4% of the India’s total geographical area. The state extends between 23°30’ to 30°11’ north latitudes and 69°29’ to 78°17’ east longitudes (Figure 1). The height above sea level in the state varies from 6 to 1698 m. The state has a variety of topographic features, which can be undoubtedly delimited as the Thar Desert in the northwest with arid hills, sandy plains in the northeast, the Aravalli Hills in the centre, extending from north to south, and southeastern plateau. The Thar Desert is India’s largest desert, which covers approximately 70% area of the state. The state is characterized by less rainfall, high temperature differences, high evapotranspiration, frequent droughts, lack of perennial rivers, scarce vegetal cover, nomadic population and dependency of human on animal rearing. The onset and duration of monsoon significantly controls the performance of kharif season crops. The yield of crops during kharif and rabi seasons are sensitive to rainfall and wetter years are normally associated with higher yields.

2.2. Data and methods

Daily rainfall data of 33 stations have been used for 57years period (1961–2017), which are well spread over the Rajasthan state (Figure 1). The data has been acquired from the online portal of Department of Water Resources, Government of Rajasthan, Rajasthan, India (www.waterresources.rajasthan.gov.in). Geographical location and elevation information of the stations have been given in Table 1. The diurnal rainfall data is available in the dataset from the year 1957; however, the year 1961 is considered as the base of year as the data is consistent for the selected 33
stations only after 1961. Nevertheless, few stations have missing rainfall observations which are filled-in before undertaking further analysis. The normal ratio method has been considered to determine the rain depths of missing days with regard to the station by taking into account the rain depths of 3 adjoining stations. Estimation of missing rainfall data has been made to support the flow of data for computation as well as to enhance the precision of SPI results. Finally, the daily rainfall data have been aggregated to monthly, seasonal and annual values for each station, which have been used to develop SPI in order to identify dry and wet conditions.

2.2.1. Computation of SPI

Technically, SPI has been determined by bisecting the difference between the mean seasonal rainfall and its long-term seasonal rainfall mean by its standard deviation, which is mathematically expressed as:

\[
SPI = \frac{X_{ij} - X_{im}}{\sigma}
\]  

where, \(X_{ij}\) is the seasonal-monthly rainfall at \(i\)th station and \(j\)th observation, \(X_{im}\) the long-term rainfall mean and \(\sigma\) is its standard deviation. At least a minimum of 30 years of long-term rainfall data is required to determine SPI because the shorter one is likely not to arrest the signals of climatic variability (Wu et al., 2005). Further, rainfall is statistically not equally categorized, therefore, the records of long-term rainfall is then matched into a standard normal distribution function using gamma probability distribution, with a mean of zero and variance of one (Sönmez et al., 2005). Mckee et al. (1993) have classified the SPI series into eight categories of dry and wet conditions (Table 2).

2.2.2. Statistical analysis

In this study, introductory statistical analyses such as the sum, frequencies, percentiles, mean, standard deviation (SD), coefficient of variation (CV), skewness (\(C_s\)) and kurtosis (\(S_k\)) have been performed between the period 1961 to 2017. To notice the trends in rainfall and SPI series at multiple time scales Mann–Kendall test
have been used. The presence of statistically significant trend has been considered at 95% confidence level.

2.2.3. Mann-Kendall test

Mann–Kendall is a non-parametric trend test, which has been applied widely to assess the direction of trends in hydrological studies (Singh et al., 2020). This test considers each value of data in time series for distinction with all successive values. Initially, the test statistics \( S \) is expected to be 0, and if the value of data in successive time cycles is greater than a data value in the earlier time span then \( S \) is enhanced by 1, and vice-versa. The outcome of all such actions gives the last value of \( S \). The Mann–Kendall statistics \( S \) has been characterized as:

\[
S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k)
\]

\[
\text{sgn}(x_j - x_k) = \begin{cases} +1, & \text{if } x_j - x_k > 0 \\ 0, & \text{if } x_j - x_k = 0 \\ -1, & \text{if } x_j - x_k < 0 \end{cases}
\]

where, \( x \) represents specific data period, \( x_j \) and \( x_k \) are data values at time \( j \) and \( k \) (\( j > k \)) respectively, \( n \) is the length of time series and \( \text{sgn} \) denotes the signum function.

Positive (negative) statistics of \( S \) indicate an increasing (falling) trend. This test accepts that there are not several tied records in the dataset. The variance of \( S \) has been calculated as:

\[
\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum r(r-1)(2r+5)}{18}
\]

where, \( r \) and \( \sum \) refers to the range of any specified tie and essence of all ties, respectively. A tie is a class of representative records having the identical value. In circumstances, where the sample size \( n > 10 \), the model normal variable \( Z_s \) has been calculated as:

\[
Z_s = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}}, & \text{if } S < 0 \end{cases}
\]

where, \( Z_s > 0 \) displays rising trends, while \( Z_s < 0 \) shows declining trends. Trends have been examined at a precise a significance level and in cases of \( Z_s > Z_{1-\alpha/2} \), null hypothesis will be invalid.

2.2.4. Preparation of thematic maps

To identify the spatial pattern of rainfall and drought severity, the inverse distance weighting (IDW) interpolation technique has been used. The IDW technique is a simple and widely used interpolation technique. This interpolation technique weights the influence of every contributing locations by a normalized inverse of the interval from the master point to the interpolated point. It presumes that each contributing point has a local effect which declines with increment in interval. It weights the locations nearer to the operating points, larger than those farther away. The interpolation of rainfall and drought severity using IDW technique has been done by ArcGIS 10.2 software.

3. Results

3.1. Temporal variation and spatial distribution of rainfall

Between 1961 and 2017, the average amount of annual rainfall over the Rajasthan state has been 583 mm having a standard deviation of 221 mm. The maximum amount of annual rainfall has been 839 mm in the year 1975, which has been more than thrice the lowest quantity of 277 mm in the year 2002 (Table 3). Whole kharif season (June to October) has the highest amount of rainfall, reckoning about 92% and has varied from 75 to 100% of the annual total rainfall. Early season (June to August) rainfall has varied from 55 to 93%. Mid (August to September) and late season (September to October) have recorded nearly 47 and 16% of the annual total rainfall, respectively (Figure 2). There has been a substantial variation in rainfall across the 33 stations of Rajasthan. Average annual rainfall has been the highest (1070 mm) at Banswara station followed by Pratapgarh (937 mm) and Jalalwar (936 mm). Conversely, Barmer station has displayed the maximum variability (60%) in annual rainfall having a standard deviation of 166 mm (Table 1).

Seasonally, the 33 stations have demonstrated a homogeneous pattern in rainfall distribution except the mid- and late season (Figure 3). However, the actual season-wise distribution of rainfall has varied among the 33 stations. On the average, early season rainfall has accounted for 80.4% of the annual total at Sawai Madhopur station, around 79.7% at Pratapgarh and Baran and 79.6% at Bundi. Mid-season rainfall has been accounted as 51.5% of the annual total at Banswara station followed by about 50% at Chittaurgarh and 49.8% at Dhaulpur. Among the stations, late season rainfall has varied from 11 to 19% of the annual total

### Table 3. Statistical summary of rainfall at different time scales over the dryland ecosystem of north western India (1961–2017)

| Description | Early Season (mm) | Mid-Season (mm) | Late Season (mm) | Whole kharif Season (mm) | Annual (mm) |
|-------------|------------------|----------------|------------------|-------------------------|-------------|
| Mean        | 449.0            | 272.0          | 92.8             | 534.4                   | 583.4       |
| SD          | 99.5             | 98.5           | 55.3             | 124.1                   | 221.1       |
| CV          | 22.2             | 36.2           | 59.6             | 23.2                    | 37.9        |
| Skewness    | 0.15             | 0.29           | 1.00             | 0.03                    | 0.09        |
| Kurtosis    | -0.09            | -0.82          | 2.04             | -0.50                   | -0.61       |
| Minimum     | 195.2            | 126.6          | 14.7             | 236.6                   | 276.7       |
| Maximum     | 677.9            | 500.1          | 296.4            | 801.9                   | 839.3       |
Rainfall with an average of about 16%. Contrarily, whole kharif season rainfall has ranged from 79 to 97% among the stations with the highest share of 97% from Banswara station, which has been followed by Bundi and Dungarpur stations with a share of 95% from each station.

### 3.2. Occurrence of dry and wet years

Depending on threshold values of SPI (Table 2), seasonal and annual SPI values between 1961 and 2017 have been computed for 33 stations over the dryland ecosystem and have been presented in Figure 4. Annually, all stations have experienced either dry or wet conditions for a period of 20 years or longer over the study period of 57 years. Independently, each station has experienced 25–34 dry years and 23–32 wet years, some of which have been severe. Most importantly, almost all stations have evidenced both severely wet and dry conditions except Banswara, Barmer, Dausa, Jaisalmer, Nagore and Sirohi stations. Likewise, about twenty-eight stations have witnessed
severely wet conditions for 4 years or longer, encompassing 4 years at 14 stations, 5 years at 9 stations, 6 years at 5 stations and 7 years only at Churu station. Meanwhile, 27 stations have evidenced severely dry conditions for 1 year or longer, encompassing 1 year at seven stations, 2 years at nine stations, 3 years at 5 stations, 4 years at four stations and 5 years at two stations. The early season has witnessed a range of 28–41 dry and 16–29 wet years during the 57 years record, whereas only 15 stations have experienced severely dry years for longer than 1 year. Meanwhile, 25 stations have evidenced severely wet years for 4 years or longer encompassing the highest one at Jalor station for 7 years. The mid-season has experienced a mix of dry and wet years, which has ranged from 25–38 and 19–32 years, respectively. Further, only 15 stations have evidenced severe dry years and nearly all the stations have evidenced severely wet years for 3 years or longer. Surprisingly, none of the year during late season has experienced severely dry years, however, severely wet years have been witnessed from 2 to 8 years. Finally, whole kharif season has experienced both wet and dry years like annual time span and 26 stations have evidenced severely wet years for 4 years.

**Figure 4.** Percentage occurrence of dry and wet years based on SPI series at different time scales: (a) early season, (b) mid-season, (c) late season, (d) whole kharif season and (e) annual over the dryland ecosystem of northwestern India (1961–2017).
or longer. Likewise, almost all the stations have evidenced severely dry years except Banswara, Barmer, Nagaur and Sirohi stations.

3.3. Temporal variation and spatial distribution of dry and wet years

Between 1961 and 2017, SPI time series has been computed at different time scales for dryland ecosystem and has been summarized in Table 4 and graphically has been presented in Figure 5. Noticeably, drought severity has changed with time and a mix of dry and wet years have been observed. During the 57 years study period, there have been only 2 years with moderate drought (1987 and 2002) during early kharif season. Apart from this, none of the year has witnessed a severe and extreme drought event during the season. Likewise, during the mid- and late kharif seasons none of the year have experienced a moderate, severe and extreme drought. The whole kharif season have experienced two moderate drought years (1987, 2002). Based on the whole kharif season SPI plots (Figure 5(d)), the study period between 1961 and 2017 can be coarsely grouped into 5 uninterrupted surplus and deficit phases: (i) slight deficit phase (1979 to 1982); (ii) slight surplus phase (1994 to 1998); (iii) oscillating phase (2003 to 2017); (iv) highest peak deficit year (2002) and (v) highest peak surplus year (1975).

On 12-month time lag SPI plots (Figure 5(e)), it is evident that there is a complete absence of severe and extreme drought events over dryland ecosystem. However, two moderate drought events have been witnessed in the years 2002 and 1987 with SPI values of −1.45 and −1.08, respectively. Like the whole kharif season, 5 uninterrupted surplus and deficit phases have been witnessed in the annual SPI: (i) slight deficit phase (1962 to 1966); (ii) slight surplus phase (2010 to 2017); (iii) oscillating phase (2003 to 2017); (iv) highest peak deficit year (2002) and (v) highest peak surplus year (1975). Also, Table 4 shows the same number of moderate drought years during early, whole kharif season and at annual time scale. The years 2002 and 1987 have been found the most drought-affected years during early, whole kharif season and at annual time scales, whereas mid and late seasons have been observed most drought affected in the year 2000 and 1968, respectively. Correlation analysis of whole kharif season SPI values with early, mid- and late-season SPI values have recorded a correlation coefficient to the tune of 0.91, 0.78 and 0.63 (N = 57), respectively. Nonetheless, all the correlation coefficients values have been found significant at 99% confidence level (p = 0.00).

The estimation of drought severity over a specified region gives useful information for water management. Spatially, there are distinct spatial differences in dry and wet
wet conditions at multiple time scales (Figure 6). A visual inspection of early season has displayed that high drought severity mainly occurs in pockets located in northeastern and southwestern parts (Figure 6(a)). During the season, SPI values has varied from −0.58 at Jalor to −0.88 at Sirohi. The drought severity has spread widely in eastern and central parts during mid-season and severity values have been observed between −0.54 (Barmer) and −0.91 (Bharatpur) (Figure 6(b)). In late season, low drought severity has occurred widely with the exception of very small pockets in eastern and central parts (Figure 6(c)). The SPI values have varied from −0.48 (Tonk) to −0.77 (Udaipur), which is the lowest among all time spans. In whole kharif season, the drought severity is chiefly concentrated in southeastern and northeastern parts (Figure 6(d)). During the season, SPI values have ranged from −0.66 (Nagaur) to −0.84 (Udaipur), which is almost in tune with the SPI values of annual time span. The drought severity at annual time span has decreased both from west to east and south to north (Figure 6(e)). The annual high drought severity chiefly centres in north, northeast

Figure 5. Temporal distribution of SPI series at different time scales: (a) early season, (b) mid-season, (c) late season, (d) whole kharif season and (e) annually over the dryland ecosystem of northwestern India (1961–2017).

Figure 6. Spatial distribution of SPI series at different time scales: (a) early season, (b) mid-season, (c) late season, (d) whole kharif season and (e) annual over the dryland ecosystem of northwestern India (1961–2017).
and southwest, with a maximum SPI value of $-0.86$ at Dungarpur. Conversely, low severity has concentrated in pockets spreading over northern and eastern parts, with the lowest severity at Sawai Madhopur station. Overall, northwestern, southeastern and northeastern parts have suffered from high drought severity, whereas central regions have relatively low severity of droughts.

### 3.4. Trend analysis of rainfall and SPI series

Spatial patterns in trends of rainfall and drought with their level of significance have been presented in Figures 7–8. A visual inspection of spatial patterns in trends of rainfall and SPI series at all time scales nearly confirms each other except during the mid- and late season. The mean annual rainfall has shown a marginal non-significant upward trend over the dryland ecosystem. Interestingly, 3 years running average has shown a cyclic pattern of mean annual rainfall under the changing climatic conditions. The station-wise mean annual rainfall has revealed a significant rising trend over Barmer, Churu, Ganganagar, Jaisalmer and Pratapgarh stations. Apart from these 5 stations, Banswara, Bikaner, Chittorgarh, Dholpur, Dungarpur, Hanumangarh, Jalore, Jhalawar, Rajsamand, Sawai Madhopur and Tonk stations have shown increasing non-significant trends, whereas Baran, Dausa, Jaipur and Kota stations have shown non-significant decreasing trends. Rest of the stations have shown almost constant trends in the mean annual rainfall. Whole *kharif* season has replicated the similar trends, whereas the other three seasons have experienced a mix of significant positive trends in rainfall among the stations. Interestingly, none of the station has witnessed a significant negative trend in rainfall through the 5 selected time scales (Figure 7).

Drought severity is opposite to the rainfall trend analysis. Therefore, in this study, while examining droughts, positive (increasing) trends suggest wet conditions, whereas negative (decreasing) trends indicate dry conditions. At all-time scales, the overall trend of SPI series has been found positive in the dryland ecosystem. Remarkably, at all-time orders, only Baran station, despite the level of significance, have witnessed increased dry conditions (negative trends) during the study period. At early season time scale, significant positive trends (wet conditions) have been noticed at Chittaurgarh and Pratapgarh stations (southern parts), whereas at mid- and late season time spans, a mixture of non-significant positive and negative trends have been observed (Figure 8). Largely speaking, incremental drying conditions have been witnessed in mid- and late *kharif* seasons, which is opposite to early *kharif* season when about 70% of the stations have witnessed wetting conditions. Conversely, during mid- and late *kharif* season, more than 55% of the stations have experienced dry conditions and have been found clustered in northern and eastern parts only. At whole *kharif* season time scale, significant increasing wet conditions (positive trends) have been noticed at Ganganagar (in north), Jaisalmer (in west) and Pratapgarh (in south) stations. Finally, at

![Figure 7. Spatial distribution of trend in rainfall along with their level of significance at different time scales: (a) early season, (b) mid-season, (c) late season, (d) whole *kharif* season and (e) annual over the dryland ecosystem of northwestern India (1961–2017).](image-url)
annual time scale, drought trends remain alike at Ganganagar, Jaisalmer and Pratapgarh apart from Barmer and Churu stations. Finally, it is important to point out that almost at all time scales, the western, northern and southern parts of the dryland ecosystem have experienced more wetter conditions (significant at 95% confidence level), whereas northeastern, eastern and southeastern regions have witnessed increased drier situations, though statistically it has been found non-significant. The increased drier situations in northeastern, eastern and southeastern regions are, in reality, noteworthy for the water resource planning and management since these areas are chief producers of various food grain crops, causing a massive threat to food grain productivity. Also, the poor water availability can negatively impact the maintenance of valuable tree species diversity (Sharafati et al., 2020).

4. Discussion

This study has been attempted to investigate the temporal variations and spatial patterns of rainfall and SPI. The analysis has been performed at different time scales i.e. early, mid, late, whole kharif season and annual. The rainfall has shown an increasing trend in mean annual rainfall over Barmer, Churu, Ganganagar, Jaisalmer and Pratapgarh stations, which has been found consistent with Singh et al. (2001). The spatial pattern of mean annual rainfall has shown a systematic decline in the rainfall amounts from southeastern to western and northwestern parts.

It can be attributed to the presence of Aravalli Mountains, which reduces the rainfall occurrence towards westward from southeast. Though, some recent studies have shown increasing trends in rainfall over the western arid region (Kumar et al., 2010; Meena et al., 2019; Mondal et al., 2015). This increasing trend in mean annual rainfall in arid region of western Rajasthan can be highly beneficial for agriculture and recharging of groundwater. The frequency of dry and wet years have been found nearly equal for early, late and whole kharif season but at the annual time scale a greater number of positive SPI events have been witnessed, showing higher chance of rainfall excess, consistent with Kumar et al. (2010), Mondal et al. (2015), and Meena et al. (2019). The years 2002 and 1987 have been found the most severe drought years, consistent with Bhuiyan et al. (2006), Dutta et al. (2013), and Dhakar et al. (2013). No significant upward and downward trend has been observed in SPI during different time scales, however, Dhakar et al. (2013) have shown a declining trend in SPI in mid-season. The high correlation among whole kharif season SPI values and early season suggests towards the determination of whole kharif season drought. These results suggest that the moderate to extreme shortage in rainfall during early season cannot be reimbursed with the rainfall during mid -and late seasons. Moreover, the western parts of the state experience less amount of rainfall, therefore, droughts occur frequently over this region. Earlier, Narain et al. (2006) have also observed that drought occurs once in
2–3 years in the western parts particularly over Jaisalmer, Jodhpur, and Pali districts of the state. Surprisingly, the SPI values have shown wet conditions over the western parts which may be attributed to the recent increase in the rainfall over this region. Guhathakurta et al. (2017) have also shown a decreasing trend in drought condition over most western parts of the country.

5. Conclusions

From the results of this study, it can be concluded that SPI is an important index for evaluating the temporal variations and spatial patterns of dry and wet situations over an area. Depending on diurnal rainfall data of 33 stations for the period between 1961 and 2017, this study has evaluated the seasonal and annual dry and wet conditions over the dryland ecosystem of northwestern India. During the study period, none of the time span has experienced a moderate, severe and extreme drought except moderate droughts of 1987 and 2002 in early, whole kharif season and at annual time scales. Conversely, mild droughts have been experienced more frequently. Mild droughts have been experienced consecutively for a period of 5 or more years only once during the early (1965–1969) and whole kharif seasons (1984–1989), twice at the annual time scale (1962–1966 and 1984–1989) and thrice during the mid (1978–1982, 1985–1989 and 1998–2003) and late seasons (1978–1982, 1985–1989 and 2000–2004). Dry conditions have more frequency during early, mid, late and whole kharif seasons, whereas at annual time scale the dryland ecosystem has become wetter. The wet conditions imply the abundance of water, therefore, construction of water harvesting structures for the management of water resources need to be explored. On the other hand, the higher occurrence of dry conditions during intra-seasons (early, mid- and late kharif seasons) and whole kharif season may have serious consequences because every crop stage has its individual susceptibility to moisture and water availability in the region. In view of the increased frequency of drier conditions, food production may be affected due to falling water availability during the crucial crop growth period of the entire kharif season. This may also have far reaching effects over the dryland ecosystem where mass population revolve around agriculture for their livelihood. The maximum correlation coefficient value of early season with that of the whole kharif season suggests that it is the early season rainfall which may largely determine the whole kharif season drought over the dryland ecosystem. Finally, the outcome of this study could be an essential step toward addressing the issue of drought and can be used as a guide for the proper utilization water resources in the study area. The results of this study suggest that the SPI-based drought patterns can be integrated with agricultural and hydrological parameters for quantifying drought risk. Apart from this, due to large differences in drought severity at different timescales, it is recommended that the SPI should be used for drought monitoring in combination with other indices and approaches such as vulnerability assessments and remote sensing techniques.

Disclosure statement

No potential conflict of interest has been reported by the authors.

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