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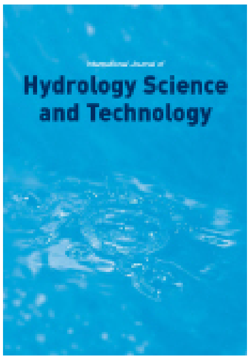


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# Meteorological drought analysis in Pali District of Rajasthan State using standard precipitation index

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# Meteorological drought analysis in Pali District of Rajasthan State using standard precipitation index

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**Abstract:** Droughts are very devastating natural hazards that affects large extent of land and causes great economic losses. Droughts are determined by a deficit of water availability over a long time period, due to consistently below average precipitation in that region. The study aimed to discuss the effects of drought with its various features and the frequency of occurrence. To analyse the meteorological drought the study utilises the standard precipitation index (SPI) at different time scales, i.e., 3, 6, 9 and 12 months. Monthly rainfall data for 1901–2002 were utilised from 47 meteorological stations scattered in the study area to assess SPI values. The drought severity and duration are also estimated. The analysed result shows that most of the drought events fall in mild drought category according to the SPI classification. However, the severe drought events were much harmful on some part of the study area due to its low annual rainfall rates. The analysis would help to determine the risk of future droughts in the region, to analyse their effects on economy, the environment, and society, and to take steps to mitigate the impact of droughts.

**Keywords:** meteorological drought; risk; SPI; Pali.

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## 1 Introduction

Droughts are environmental disasters that are very destructive, destroying huge area of land and causing significant economic damages (Mehta and Yadav, 2020). Droughts are determined by a shortfall in the supply of water for a long time period, owing to the region's consistently below average precipitation. These situations compounded by meteorological factors such as increasing temperatures or high winds intensify (Mishra and Singh, 2010). It affects all-natural processes and human activities which, without water resources, are not possible (Katz et al., 1986).

Droughts decreases the primary productivity (Ciais et al., 2005), streamflow, runoff, surface and ground water resources (Smakhtin, 2001), electricity production (Van Vliet et al., 2016) and increase the rate of tree mortality and wildfires (Allen et al., 2010). At the end large economical losses occur due to droughts in particular regions. In India many regions are facing droughts due to climate change and other factors. Rajasthan is one of the highly drought prone region of India. In Rajasthan, Barmer and Jalor faces 11 droughts in 1980–2009. Sirohi faces 12 droughts in same duration. But more severely Pali faces 14 droughts and Sri Ganganagar faces 15 droughts in this 30-year span. Droughts are very complex in nature. This thing can be understood by various definitions of droughts, factors affecting the droughts and many other complex relationships which show its characteristics (Heim, 2002). Generally, droughts are occurring over large regions, but they did not damage the structures like floods. So, practically it is extremely hard to analyse the tangible and intangible impacts on droughts (Khaniya et al., 2020). It is quite hard to assess and quantify the impacts of droughts on that region (Mehta and Yadav, 2021). For better understanding, droughts are classified in following types: meteorological drought, hydrological drought, agricultural drought, socio-economic drought (Kallis, 2008).

The entire globe has been experiencing a surface warming pattern, with a mean surface temperature increment of 0.85°C from 1880 to 2012 (Perera et al., 2020a, 2020b). Drought is considered most complex but least understood natural phenomenon, which affect more people than any other hazards. Because of this reason, trend analysis of rainfall becomes very important for study of droughts. Trend analysis is the process of predicting the future trend, by looking at past and current trends. Trend analysis of precipitation and drought helps in sustainable management of water resources (Mehta and Yadav, 2021). There are number of indices used to classify the droughts. Different indices use different parameters for drought analysis. Standardised precipitation index (SPI) is the most widely accepted index that only uses precipitation as input data (McKee et al., 1993). The reason of its wide range of acceptance is its simplicity. It is also used to evaluate performances of new indices.

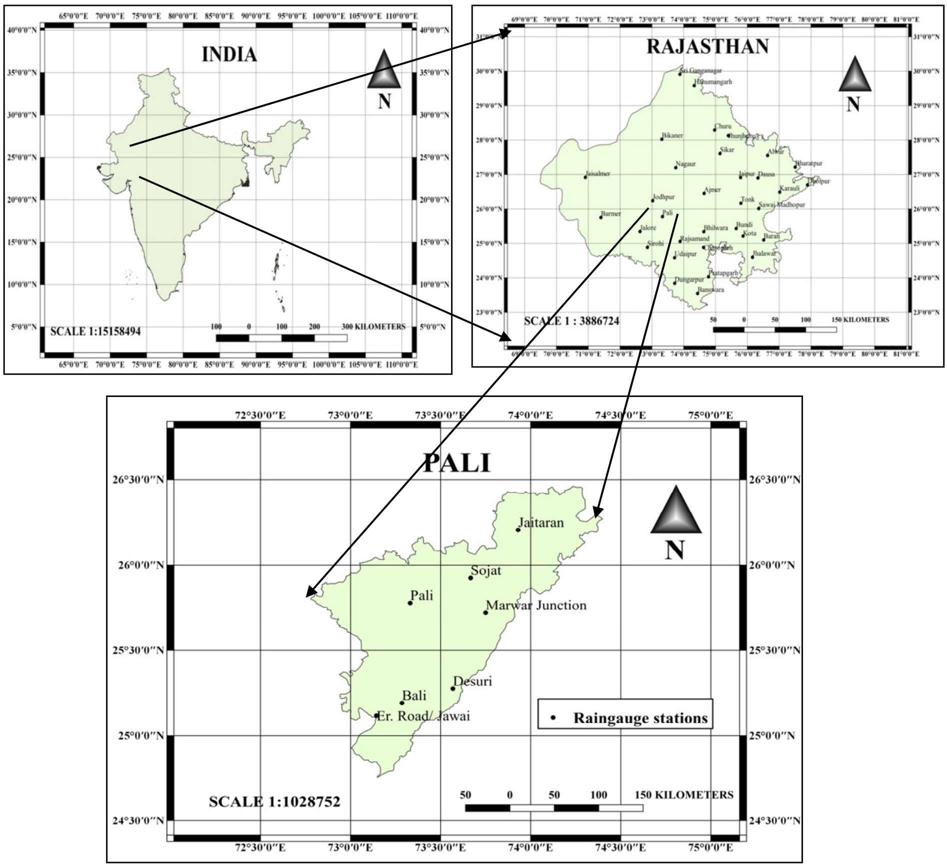
The variability of the SPI was investigated at 1, 3, 6, 9 and 12 months intervals. The trends of 1, 3, 6, 9 and 12 monthly SPI results were analysed by applying Mann-Kendall test at the 5% significance level. The linear slopes of the trends were calculated with a Sen's slope technique. Meteorological data from of the Pali District of S-W Rajasthan were used for 1901–2002. The research uses the SPI for meteorological drought at various time scales, i.e., 3, 6, 9 and 12 months. Monthly rainfall data for 1901–2002 was used to calculate SPI values from 47 meteorological stations distributed throughout the study region. The drought severity and duration are also estimated.

## 2 Study area

Location of Pali District is in the central part of Rajasthan as shown in the Figure 1. It is bounded by Nagaur District in North direction, Ajmer and Rajsamand in East direction, Udaipur and Sirohi in South direction and Jalor, Barmer and Jodhpur districts in West direction. Pali is located between 24° 44' 35.60" to 26° 27' 44.54" North latitude and 72° 45' 57.82'' to 74° 24' 25.28'' East longitude on the Map as shown in Figure 1. Pali covers 12,378.9 sq km area in Rajasthan state. Pali District is also an important part of 'Luni river basin'. It also contains the western slopes of Aravali ranges.

Pali District is made by 960 towns and villages, of which ten are block headquarters as well. Total population of the district as per Census 2011 is 1,820,251. The Pali District's overall climatic conditions vary slightly different from the typical arid western Rajasthan. During its peak months, the summer season increases the temperature to 46°C–47°C (May–June). Owing to the green and hilly areas adjoining it, a wide difference in temperature is found. During the months from December to January, the winters in Pali are moderately cool. The temperature dips to 4°C–5°C range in these months. Monsoon brings break from long summer. The precipitation is fairly good but erratic in Pali. Average annual precipitation of the district is 450.7 mm. Topography of Pali is quite assorted. Central part of the Pali is relatively flat and undulating while the Aravalli ranges constitute hills in the eastern periphery and tie the district with Ajmer, Rajsamand, and Udaipur districts. Supreme part of the district falls under Luni river basin, where negligibly parts in the south fall within West Banas and Sabarmati river basins. General topographical elevation in the district ranges between 150 m to 300 m above mean sea level. The majorly affected meteorological parameter on drought event is precipitation.

**Figure 1** Location of Pali District, Rajasthan State (see online version for colours)




## 3 Data collection and analysis

For this study, monthly precipitation data of Pali District is collected for 1901–2002. In the above study, drought analysis is addressed using drought indices calculator, i.e., Drin C for Pali District, a south west region of Rajasthan state of India. Data for this district was collected from the Indian Institute of Tropical Meteorological, Pune (IITM).

## 4 Methodology

In the present study, rainfall characteristics is carried out in the first part and in the second part meteorological drought using SPI is carried out.

### 4.1 Rainfall characteristics

Pali District is semi-arid of Rajasthan state where monsoon is the only element which contributes climate seasonality. Thus, the rainfall is taken into consideration for climate change analysis as per hydrological year (June–May).

### 4.2 Standardised precipitation index

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, etc. SPI is a most common meteorological drought index among the various drought indices, which is evaluated on the basis of long-term rainfall records for a selected duration namely 3 months, 6 months, 9 months and 12 months respectively. Due to its statistical precision and inherent probabilistic nature, SPI has gained worldwide applicability, the ability to define short-term as well as the long-term impact of droughts across the different time scales and suitability to compare the conditions of drought between the areas having different time periods and climatic conditions (Mohammed et al., 2019). It is used to predict the parameters of drought for multiple series of time that indicate the effect of drought on the availability of water resources (McKee et al., 1993). To derive different drought parameters SPI can be computed on a variety of time scales and for different water variables such as soil moisture, groundwater, etc. (Shah et al., 2015). Results obtained by using the above steps are then used to evaluate the cumulative probability of an observed time scale and precipitation events for the given month. The resulting cumulative probability is then converted into the standard normal random variable, Z variable with a mean of zero and a single 1 value of SPI (Abramowitz et al., 1965; Mokhtarzad et al., 2017). When the values of SPI are consistently negative or less than (–1) then it is said that drought has occurred and it get ends when the SPI value is positive. The overall positive summary of the SPI is known as the magnitude of drought for all months during a drought event (Chelu et al., 2019). The assessment of the ratio of the magnitude of the drought to its duration results in the intensity of drought, and the severity of the drought can be performed using Table 1 (Hayes et al., 1999). In this study we used Drin C application which is a drought indices calculator for calculating SPI. Drin C consider the hydrological year from October to September to compute indices.

**Table 1** Classification of rainfall regime based on standard ranges of SPI

| *SPI values* | *Rainfall regime* |
|---|---|
| ≥ 2.00 | Extremely wet |
| 1.50–1.99 | Very wet |
| 1.00–1.49 | Moderately wet |
| –0.99 to 0.99 | Near normal |
| –1.00 to –1.49 | Moderately dry |
| –1.50 to –1.99 | Severely dry |
| ≤ –2.00 | Extremely dry |

*Source:* Hayes et al. (1999)

# 5 Result analysis

## 5.1 Rainfall characteristics

Descriptive statistics (Table 2) of rainfall was prepared on monthly, seasonal, and annual scale for 1901–2002 (102 years). Annual mean rainfall (1900–2001 to 2002–2003) is 522.1 mm with SD equals to 199.759. During the entire period of 102 years, annual minimum and maximum rainfall is 130.1 mm and 1,226.6 mm. Annual co-efficient of variance (CV) is 38.3% which implies the very high inter annual variability of annual rainfall over Pali District. During the 102 years, July and August months contribute the maximum percentage of rainfall (180.10 mm and 162.20 mm) to the annual rainfall. The winter months (January–February) and pre-monsoon months (March, April, and May) together contribute 0.55% and 1.0% rainfall to annual budget while post monsoon months (October–December) contribute 1.2% rainfall to annual budget. On an average January and February receives 3.02 mm and 2.57 mm mean rainfall, while March, April, and May receives 4.17 mm, 3.54 mm and 8.37 mm rainfall respectively. Coefficient of variance (CV) of all month except July and August, is more than 70% hence all the months excluding July and August have extremely high variability of rainfall. July and August month has CV of 56.5% and 67.4% implying very high inter annual variability.

**Table 2** Statistics of monthly seasonal and annual rainfall over Pali District for 102 years

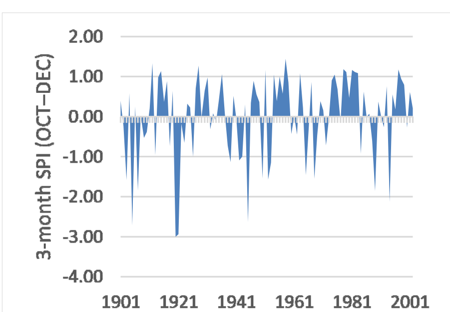
| *Month* | *Rainfall (mm) for Pali District* | | | | | |
|---|---|---|---|---|---|---|
| | *Mean* | *SD* | *CV (%)* | *% contribution to annual* | *Minimum* | *Maximum* |
| Jan | 3.02 | 4.36 | 144.5 | 0.6 | 0.0 | 19.0 |
| Feb | 2.57 | 5.25 | 203.9 | 0.5 | 0.0 | 40.9 |
| Mar | 4.17 | 10.32 | 247.2 | 0.8 | 0.0 | 73.9 |
| Apr | 3.54 | 6.01 | 170.0 | 0.7 | 0.0 | 30.1 |
| May | 8.37 | 11.71 | 139.9 | 1.6 | 0.0 | 60.1 |
| Jun | 50.78 | 46.17 | 90.9 | 9.7 | 1.1 | 208.3 |
| Jul | 180.10 | 101.84 | 56.5 | 34.5 | 10.7 | 474.4 |
| Aug | 162.20 | 109.37 | 67.4 | 31.1 | 3.6 | 465.4 |
| Sep | 89.04 | 86.59 | 97.2 | 17.1 | 2.4 | 334.2 |
| Oct | 9.60 | 13.71 | 142.8 | 1.8 | 0.0 | 57.1 |
| Nov | 7.51 | 15.76 | 209.8 | 1.4 | 0.0 | 79.9 |
| Dec | 1.20 | 2.53 | 211.2 | 0.2 | 0.0 | 11.5 |
| Annual | 522.1 | 199.759 | 38.3 | 100.0 | 130.1 | 1,226.6 |
| Pre-Monsoon | 16.1 | 16.6312 | 103.4 | 3.1 | 0.0 | 79.1 |
| S-W Monsoon | 482.1 | 193.45 | 40.1 | 92.3 | 116.9 | 1,110.5 |
| Post-Monsoon | 18.3 | 21.8715 | 119.4 | 3.5 | 0.0 | 104.9 |
| Winter | 5.6 | 6.30507 | 112.7 | 1.1 | 0.0 | 40.9 |

Rainfall characteristics for seasonal rainfall shows that maximum share of annual rainfall greater than 90% is received in one spell of southwest monsoon (482.1 mm) contributing 92.3% to annual rainfall (Table 2). Post monsoon season also receives normal rainfall of about 18.3 mm, which contributes 3.5% of rainfall to annual budget. CV of southwest monsoon is 40.1% which indicates the very high inter annual rainfall variability. Winter, pre-monsoon and post-monsoon seasons have comparatively higher CV value than Southwest monsoon (CV > 70%) showing extremely high inter annual variability of rainfall.

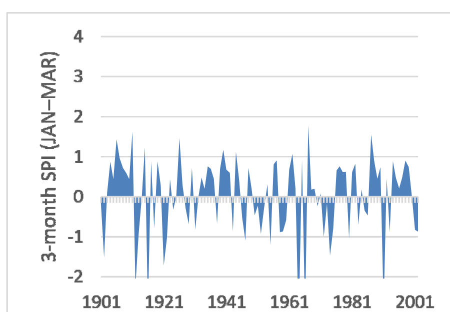
## 5.2 *Standardised precipitation index*

Three-month SPI for the month October–December, January–March, April–June, and July–September were considered for the calculation. Figure 2 shows the time series of three-month SPI for all four-time frames. SPI of all the years shows that total 70 drought events were found during all four-month time frames (October–December, January–March, April–June and July–September). Among all 70 years drought events 59 years are recorded with moderately dry, nine years with severely dry and eight years with extremely dry rainfall regime. Six-month and nine-month SPI were analysed for intermediate drought events. Six-month SPI for the month October–March and April–September were considered for the calculation. Figure 3 shows the time series of six-month SPI for two-time frames. According to classification of rainfall regime based on SPI (refer Table 1). Among all 49 years of drought events 23 years are recorded with moderately dry, 13 years with severely dry and 13 years with extremely dry rainfall regime. Calculation for nine-month SPI time frame of October–June nine months was considered as shown in Figure 4. According to classification of rainfall regime based on SPI (refer Table 1), among all 23 years of drought events 11 years are recorded with moderately dry, five years with severely dry and seven years with extremely dry rainfall regime. Temporal variation of long-term drought event for 12-month SPI (October–September) and its drought characteristics are given in Figures 5 and 6. As per classification (refer Table 1). Among all 19 drought events, eight years are recorded with moderately dry years, six years with severely dry and five years with extremely dry event.

**Figure 2** SPI of three-month step for (a) October–December, (b) January–March, (c) April–June and (d) July–September over Pali District (see online version for colours)

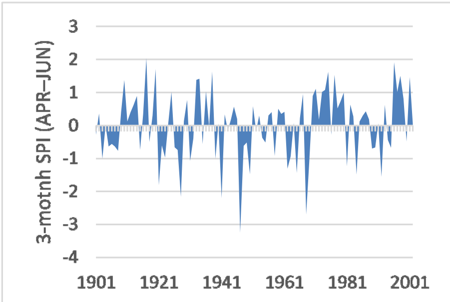



(a)

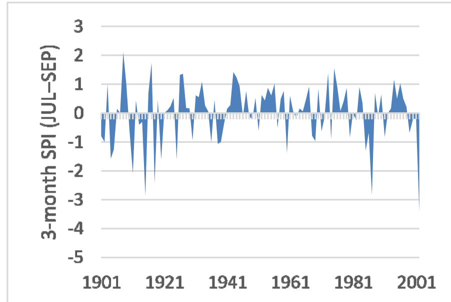



(b)

**Figure 2** SPI of three-month step for (a) October–December, (b) January–March, (c) April–June and (d) July–September over Pali District (continued) (see online version for colours)

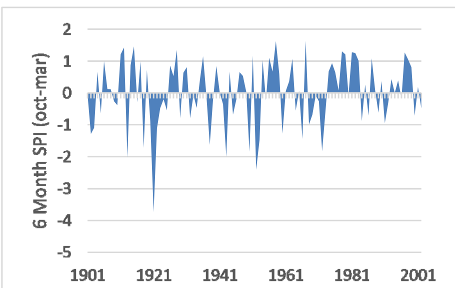



(c)

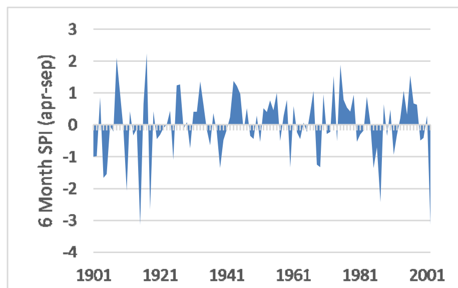



(d)

**Figure 3** SPI of six-month SPI for (a) October–March and (b) April–September over Pali District (see online version for colours)




(a)




(b)

**Figure 4** SPI for nine months (October–June) over Pali (see online version for colours)

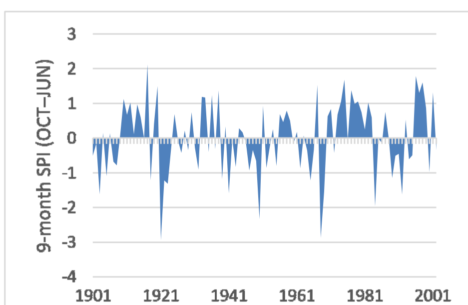
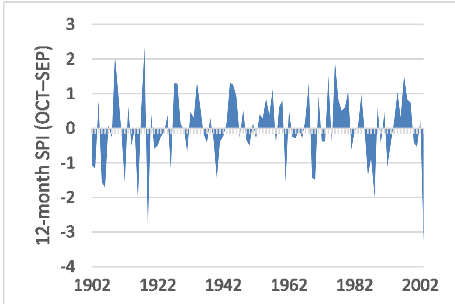


**Figure 5** SPI for 12 months (October–September) over Pali (see online version for colours)




## 6 Conclusions

This study assessed droughts observed in Pali District of Rajasthan state by using the SPI. It has been found for the given rainfall data that there is no long-term trend of drought, but only a seasonal variation pattern of time series component. The district had 14 years of drought out of the observed 30 years. There have been ten years of severe droughts, i.e., 1986, 1987, 1989, 1991, 1993, 1994, 1995, 1996, 1998 and 1999 with average annual rainfall being lower than the average by 79.1, 91.2, 73.2, 74.0, 59.6, 53.4, 68.1, 65.0, 77.5 and 62.8 respectively. The moderate drought years were 1988, 1990, 1997 and 2002 with average annual rainfall 30.7%, 43.7%, 40.1% and 45.4% below the average respectively. The conclusion derived from this study can be very useful in planning the suggested mitigation measures to minimise the drought impact. Identifying the local drought-prone villages and the changes required in water management strategies will help to fill the gap between availability, supply, and demand of water, and can help policy makers and local administrators to take appropriate drought relief measures.

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