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Drought Characterization using Standardized Precipitation Index for Ajmer, Rajasthan, India

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Long-term drought predictions can provide valuable figures which helps to mitigate some of the magnitudes of drought. For prediction of any natural hazard previous observation and tools are required. Similarly for preparedness of natural hazard i.e. drought, rainfall data and SPI tool is required to analyze drought at different time scales accurately. The present study targets to identify drought using Standardized Precipitation Index (SPI) for Ajmer district of Rajasthan using rainfall data collected from Rajasthan Water Resource Department. Result from the analysis shows that the year 1987 was the year of severe drought for 1m- and extreme drought for 3m-, 6m- time scales.

Introduction

Drought is the most complex and natural phenomenon that has momentous influences on economic, social, water resources, agriculture production and environment. It develops gradually, and its impacts may persist for years after termination of the event (Umran Komuscu, 1999; Tan *et al.*, 2015). It is differentiated from other natural disasters because its implications lack structure and disperse in vast geographical regions (Καραμπατάκης, 2017). Drought can be defined in a number of ways. According to the India Meteorological Department (IMD), an area or region is considered to be under drought, if it receives total seasonal rainfall less than 75% of its normal value. In general terms, drought is a “prolonged absence or marked deficiency of rainfall”, a “deficiency” that results in water shortage for some activity. There are many ways in the form of indices to quantify drought. Standardized precipitation index (SPI) is largely used to evaluate meteorological drought quantitatively due to its simplicity and capability of calculating drought at different timescale. But, for precise result long term rainfall data is required (Thakur *et al.,* 2019).

Materials and Methods

Ajmer a district of Rajasthan in India lies between 25°38' to 26°58'N latitude and 73°54' to 75°22'E longitude (Fig. 1). It is positioned more or less in the mid of Rajasthan. Ajmer is covered with the Nagaur district to the north, the Jaipur and Tonk districts to the east, the Bhilwara district to the south, and the Pali district to the west. To the north of Ajmer city is a large artificial lake called Anasagar, which is decorated with a marble structure called Baradari. The Ajmer District has an area of 8,481 km^2.

Standardized Precipitation Index (SPI)

The SPI method was introduced by McKee *et al.,* in 1993 in University of Colorado. This effort was accomplished by quantifying the rainfall deficit at multiple time scales. More specifically, McKee *et al.,* (1993) estimated the SPI for the time scales of 1, 3, 6, 12, 24, and 48 months. Drought at time scales 1-, 3-, and 6-month is relevant for agriculture, 12-month for hydrology and 24-month for socioeconomic impact. In addition, the 1-month SPI reflects a short-term condition; the 3-month SPI provides a seasonal estimation of precipitation; the 12-month SPI also reflects medium-term trends in precipitation patterns and may provide an annual estimation of water condition. Therefore, this study used the SPI values at 1-, 3- and 6-month scales to discover the drought discrepancy (Tan *et al.,* 2015). Therefore, this multi-temporal approach of SPI provides “a macroscopic insight of the impacts of drought on the availability of water resources” (Angelidis *et al.,* 2012; Καραμπατάκης, Θ. M.2017). The advantage of SPI is, it needed only precipitation data and can be used for both dry and rainy seasons while some indices using specific data as per designed. It can describe drought conditions that are important for a range of meteorological, agricultural, and hydrological applications. Studies have shown that the SPI is suitable for quantifying most types of drought events (Guenang and Kamga, 2014).

The computation of standardized precipitation index consists of following steps:

(1) Calculation of the mean for the normalized precipitation values of the log-normal (L_n) rainfall series and computation of the shape and scale parameters β and α respectively by the equation given here under,

Log mean $$\overline{X}_{\ln} = \frac{\sum \ln X}{N} \quad \ldots \text{(i)}$$

Shape parameter $$\beta = \frac{1}{4U}\left[1+\sqrt{\frac{4U}{3}}\right] \quad \ldots \text{(ii)}$$

Scale parameter $$\alpha = \frac{\overline{X}}{\beta} \quad \ldots \text{(iii)}$$

Here, U is the constant $U = \ln\left(\overline{X}\right) - \overline{X}_{\ln}$

(2) The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in equation. The cumulative probability as given by gamma distribution is as follows:

$$G(x) = \frac{1}{\alpha^{\beta}\Gamma\beta}\int_0^x x^{\beta-1} e^{\frac{-x}{\alpha}} dx \quad \ldots \text{(iv)}$$

Letting $t = \frac{-x}{\alpha}$, this equation becomes the incomplete gamma function;

$$G(x)=\frac{1}{\Gamma\beta}\int_{0}^{t\alpha} t^{\beta-1}e^{-t}dt \quad \ldots \text{(v)}$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zero, the cumulative probability becomes

$$H(x)=q+(1-q)G(x)$$

Where, q is the probability of a zero.

Thom (1966) states that q can be estimated by m/N where m is the number of zero in a precipitation time series. He used the table of the incomplete gamma function to determine the cumulative probability G(x). McKee *et al.*, (1993) used an analytic method to determine the cumulative probability.

The cumulative probability H(x) is then transformed to the standard normal random variable Z with mean zero and variance one, which is the value of the SPI.

The Z or SPI value can be easily obtained computationally using an approximation provided by Abramowitz and Stegun (1965) that convert cumulative probability to the standard normal random variable Z.

$$Z = SPI = -\left[t-\frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2d_3t^3}\right] for\, 0<H(x)\le 0.5 \quad \ldots \text{(vi)}$$

$$Z = SPI = +\left[t-\frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2d_3t^3}\right] for\, 0.5<H(x)\le 1.0 \quad \ldots \text{(vii)}$$

Where,

$$t = \sqrt{\ln\left\{\frac{1}{(H(x))^2}\right\}}\, for\, 0<H(x)\le 0.5 \quad \ldots \text{(viii)}$$

$$t = \sqrt{\ln\left\{\frac{1}{(1-H(x))^2}\right\}}\, for\, 0.5<H(x)\le 1.0 \quad \ldots \text{(ix)}$$

c_0 = 2.515517, c_1 = 0.802853 and c_2 = 0.010328

d_1 = 1.432788, d_2 = 0.189269 and d_3 = 0.001308

Negative value of SPI shows the drought occurrence anytime until it becomes positive. In order to evaluate the drought severity in different areas using SPI, one of the most commonly used classifications presented by (Hayes *et al.*, 1999) is given in table 1.

Results and Discussion

The analysis shows the drought severity at 1, 3 and 6 month time scale for Ajmer district of Rajasthan, India. For the present study the last month of Indian summer monsoon i.e. September month was selected for calculating SPI for above monthly time as negative SPI values in the wet season will indicate drought throughout the year (Palchaudhuri and Biswas, 2013).

1m SPI

1m SPI results shown in figure 2 reveals that for the study area 23 years were normal years that means the rainfall received during these years did not deviate much from normal annual rainfall. Over the study period both moderate dry and severe dry conditions occurred two times while moderate wet and very wet both conditions happens two times with maximum positive SPI value of 1.96 in 2006. For severe dry conditions the maximum value was -1.92 for the year 1987.

3m SPI

Figure 3 shows 3m SPI value from for the studied period of 31 years. The result shows that 21 years comes under normal category whereas 2 years i.e. 1987 and 2003 were under extremely dry condition.

Two years which are 1993 and 2009 were affected by moderate drought. Six years i.e. 1996, 1997, 2010, 2011, 2012 and 2014 were under moderate wet condition according to classification with SPI value ranging from 1.01 to 1.33.

6m SPI

As per 6m SPI two years were affected by extreme drought and one year was affected by moderate drought. The years 1996 and 1997 were under very wet condition although 2011 and 2012 were under moderate wet condition. For the study period of 31 years 6m SPI value as shown in figure 4, shows that 24 years had normal precipitation.

Table.1 Standard ranges of SPI values and their classification

S. No.	SPI	Classification
1.	≥ 2.0	Extremely wet
2.	1.5 to1.99	Very wet
3.	1.0 to 1.49	Moderately wet
4.	-0.99 to 0.99	Near normal
7.	-1.0 to -1.49	Moderate dry
8.	-1.5 to -1.99	Severe dry
9.	≤ -2.0	Extreme dry

Fig.1

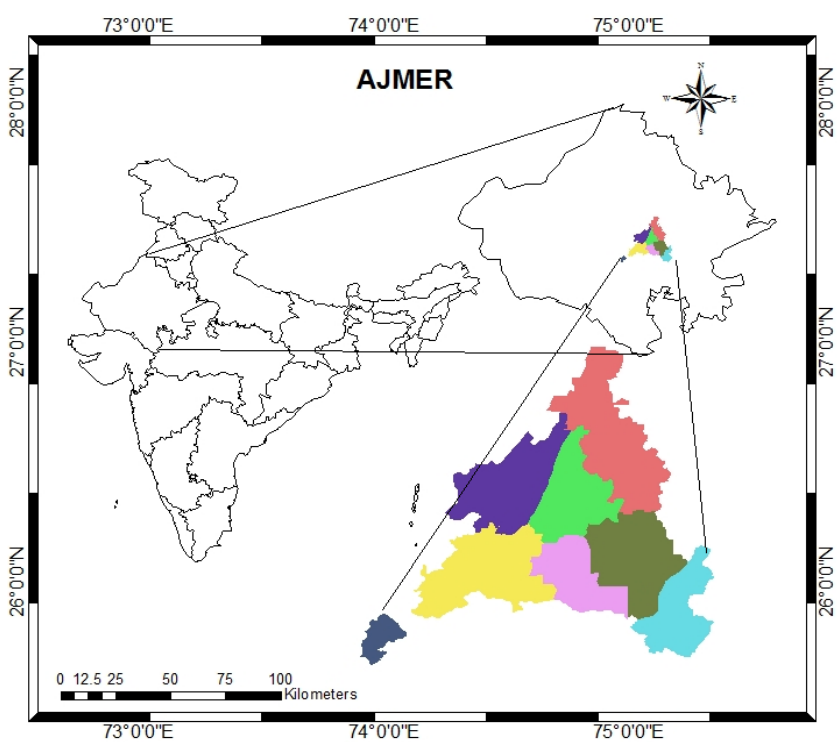


Fig.2

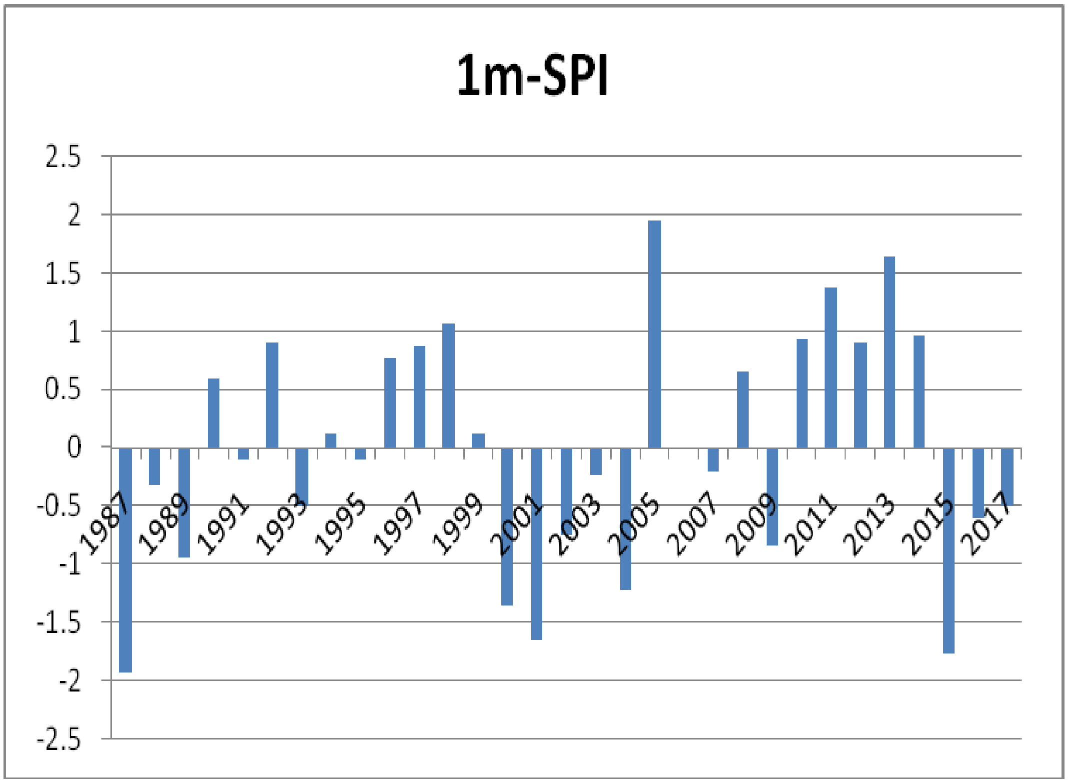

1m-SPI
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017

Fig.3

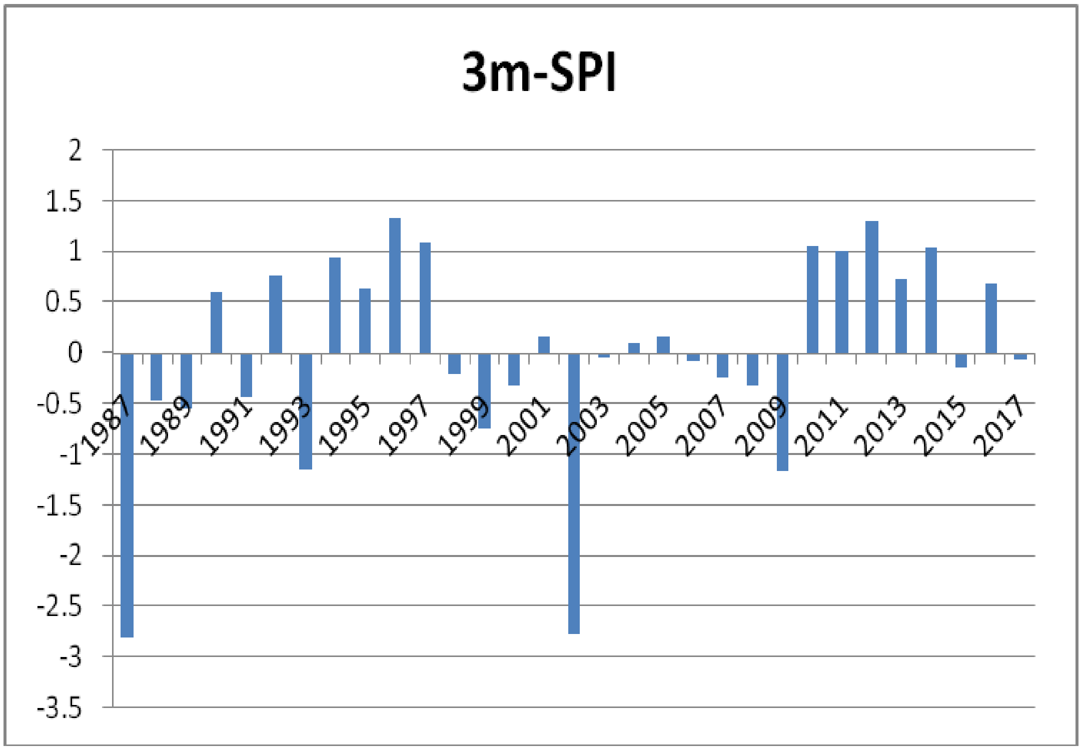
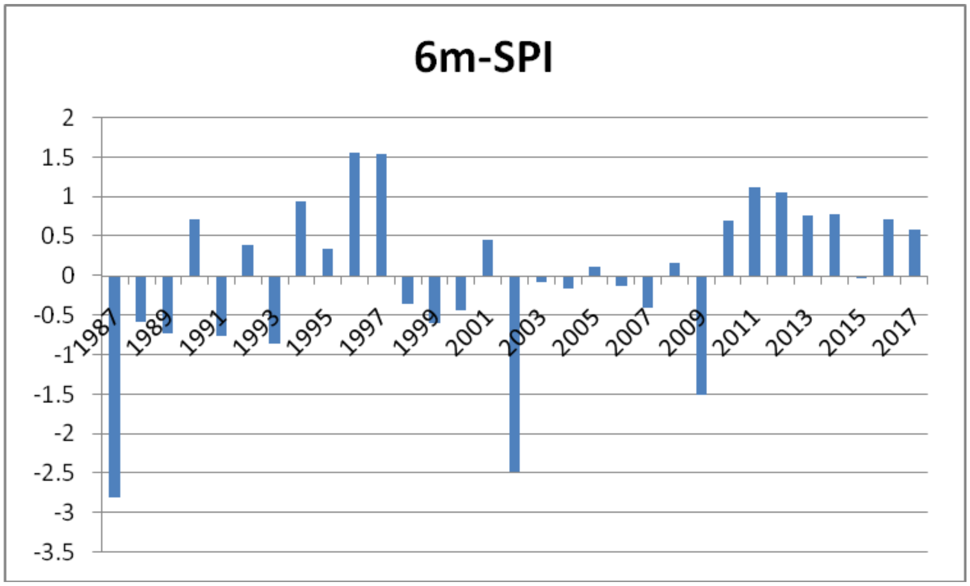

3m-SPI
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017

Fig.4



This study concluded that for each time scale more than 21 years have normal rainfall over entire study period while each time scale for the year 1987 shows the occurrence of drought event either severely or extremely. The result of 1m SPI shows that there is both wet as well as dry condition occurred while in 23 there were normal years. The results of 3m SPI expressed the more number of moderate wet spell years while only two years were extremely dry years over the study period. 6m SPI shows all type of spell occurred approximately equal in other than normal years.

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