



INTERNATIONAL CONFERENCE ON WATER RESOURCES, COASTAL AND OCEAN
ENGINEERING (ICWRCOE 2015)

Drought Index Computation Using Standardized Precipitation Index (SPI) Method For Surat District, Gujarat

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Abstract

By definition drought is a long period of unusually low rainfall, especially one that badly affects growing or living conditions. Rainfall is to be believed as a normal, wet and dry condition of the climate. It is one of the most important water associated hazards. It has great impact on agricultural, hydrological, economic, environmental and social systems. Understanding these impacts is crucial for drought planning, mitigation, and response. It also helps decision makers identify and reduce vulnerability to drought. A drought index value is a single number, far more valuable than raw numbers for result making. The standardized precipitation index (SPI) has several characteristics that are an upgrading over other indices, with its simplicity and flexibility. The standardized precipitation index (SPI) method is used for observing and describing drought based on forty (40) year precipitation data of Surat district. Finding drought index with twelve month time scale basis and compare with the actual drought of the station. Positive SPI values point to normal condition to wet condition and negative values indicate normal condition to dry condition. SPI method resulted in showing as 50% variation of normal to wet and normal to dry condition respectively.

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Peer-review under responsibility of organizing committee of ICWRCOE 2015

Keywords: Standardized precipitation index; Drought; Drought index; Precipitation.

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1. Introduction

Drought is not only a physical occurrence that can be defined by the weather conditions. A drought is defined as an extended period of unusually dry weather that causes water shortages and crop damage. Over the past century an increase of the Earth's average surface temperature of about $+0.76^{\circ}\text{C}$ as per Intergovernmental Panel on Climate Change, 2007 (Change,2007). The IPCC, in its 2007 report, predicts that temperature will rise by $2.7\text{-}4.3^{\circ}\text{C}$ over India by the 2080s. The panel also predicated an increase in rainfall over India is 6-8% and the sea level would rise by 88 cm by 2100. The Irrigation Commission of India defines drought as a situation occurring in any area where the annual rainfall is less than 75% of normal rainfall. In general there are three types of droughts based on relevance, duration and time of occurrence.

The feature of a drought is reducing of water availability in a particular era over an exacting region. The study of drought on the basis of "Drought aridity index" for carried for the central part of Andhra Pradesh, the aridity which is an index of drought is observed significantly influenced by rainfall where as in other part of the state, the aridity does not appear to be significantly influenced by the rainfall alone (Rakhecha and Dhar, 1976). The value of Palmer Drought Severity Index (PDSI) was found based on limited comparison and was weakly justified on a physical or statistical basis and observed the value of PDSI were very sensitive to the criteria for ending an establish drought (Alley,1984). The comparative study between these two methods carried out show that the spectral characteristics of the PDI vary from site to site, while those of the SPI do not vary from site to site throughout the U.S. and the Palmer Drought Index (PDI) has a complex structure than SPI (Guttman, 1998). In one of the study carried out which compared the characteristics of the SPI computed over time scales of 3 to 24 months with the PDSI and show SPI12 (Yearly SPI) exhibits a close correspondence to the PDSI (Lloyd-Hughes and Saunders, 2002). The Reconnaissance Drought Index (RDI) is more sensitive than the SPI to climatic conditions and so cannot neglect the role of evapotranspiration in the drought assessments. The comparative study carried out between SPI and RDI methods of indices for their sensitivity towards climatic conditions found that both indices behave in the same manner under similar climatic condition, but RDI due to the inclusiveness of potential evapotranspiration found more sensitive (Jamshidi et. al., 2011).

The droughts are broadly divided in three classes as (a) Meteorological drought (b) Hydrological drought (c) Agricultural drought. Meteorological drought is defined as a condition, where the annual precipitation is less than the normal over an area for prolonged period (month, season or year). Hydrological drought is drought connected with the effects of periods of precipitation shortages on water supply and Agricultural drought mostly effects food production. Agricultural drought and precipitation shortages carry soil water deficits.

Drought is having certain characteristics such as they usually take an elliptic profile. Being of slow start it is difficult to determine the beginning and end of the drought event. The duration may vary from months to years and the core area or epicenter changes over time. The impacts are non-structural and not easy to compute. It is a creeping phenomenon. The impacts of drought are increasing and the effects expand when events continue from one season or year to the next. It does not have a sharp ending.

2. Study Area and Data Collection

Surat district is located in the state of Gujarat, India. Geographical location of Surat district is $21^{\circ} 00' \text{ N}$ to $21^{\circ} 23' \text{ N}$ (Latitude) and $72^{\circ} 38' \text{ E}$ to $74^{\circ} 23' \text{ E}$ (Longitude). Location map of the study area is shown in Fig.1. The monthly average maximum and minimum temperature are 33.4°C and 22.0°C of forty years data respectively and monthly average rainfall of forty years data is 97.1 mm. Forty years precipitation data has been collected from Indian Meteorological Department (IMD) for this study from 1971 to 2010. Variations in the yearly precipitation for forty years from 1971 to 2010 is shown in Fig. 2.

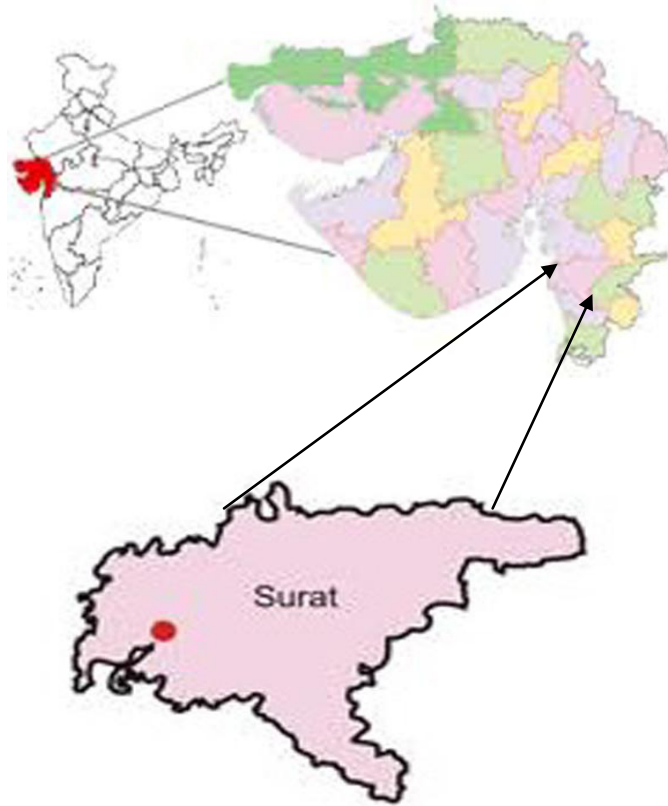


Fig. 1. Location of the study area

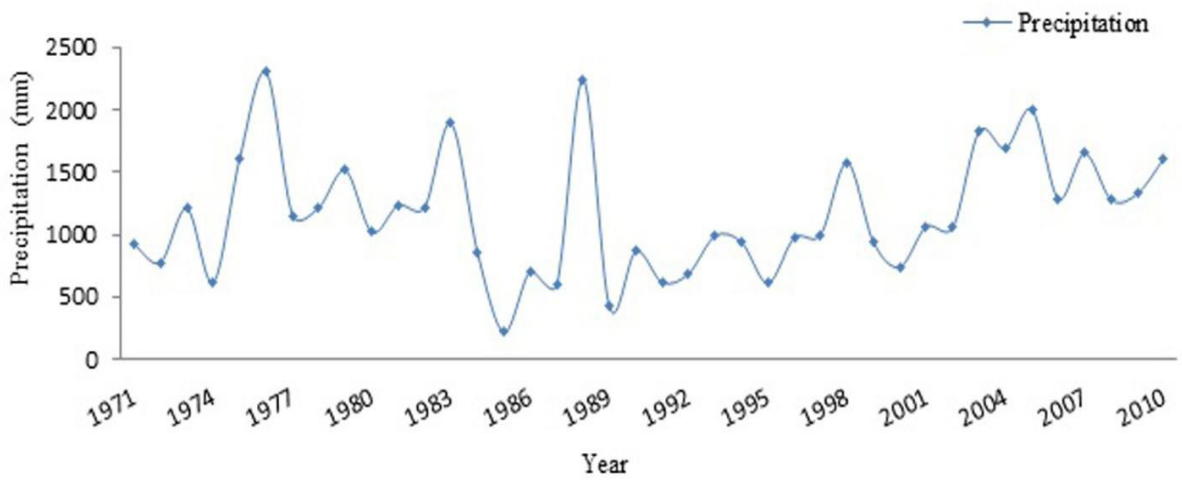


Fig. 2. Yearly precipitation(mm) from 1971 to 2010 for Surat region

3. Methodology

McKee et al. (1993) developed the Standardized Precipitation Index (SPI) for the purpose of monitoring drought. Thom (1966) found the gamma distribution to fit climatological precipitation time series well. The gamma distribution is defined by its frequency or probability density function:

$$G(x) = \frac{1}{\beta^{\alpha} \tau^{\alpha}} x^{\alpha-1} e^{-x/\beta} \quad (1)$$

Where, $\alpha > 0$, α is a shape factor, $\beta > 0$, β is a scale factor.

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} \quad (2)$$

Where, $\Gamma(\alpha)$ is the gamma function.

Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation total for a station. From Thom (1966), the maximum likelihood solutions are used to optimally estimate α and β

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

$$\hat{\beta} = \frac{\bar{x}}{\alpha} \quad (4)$$

$$A = \ln \bar{x} - \frac{\sum \ln(x)}{n} \quad (5)$$

Where, n = number of precipitation observations.

The cumulative probability is given by:

$$G(x) = \int_0^x g(x) dx = \frac{1}{\beta^{\alpha} \tau^{\alpha}} \int_0^x x^{\alpha-1} e^{-x/\beta} \quad (6)$$

Letting $t = x/\beta$

$$G(x) = \frac{1}{\tau^{\alpha}} \int_0^x t^{\alpha-1} e^{-t} dt \quad (7)$$

The gamma function is undefined for $x=0$ and a precipitation distribution may contain zeros, the cumulative probability becomes

$$H(x) = q + (1 - q)G(x) \quad (8)$$

where q is the probability of a zero. If m is the number of zeros in a precipitation time series, Thom (1966) states that q can be estimated by m/n . The cumulative probability, $H(x)$, is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI. SPI is categorized based on their range values is shown in table 1.

Table 1. Category of Standardized Precipitation Index (SPI) based on range values

SPI Range	Category
+ 2 to more	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 to less	Extremely dry

4. Results and Discussion

The results for Surat district were evaluated and found that the results of SPI and actual climatic condition have quite similar results as per their respective categories. For example (-1 to -2) categories indicates (Moderately dry to extremely dry) drought years include 1974, 1985, 1987, 1989, 1991 and 1995. The second category (+1 to +2) indicates (Moderately wet to extremely wet) wet years include 1976, 1983, 1988, 2003, 2004, 2005, and 2007. The third category (-0.99 to +0.99) indicate normal condition years include remaining years for Surat district. The actual drought in percentage was available for the year 1972, 1974, 1985, 1986, 1987, 1989, 1990, 1991, 1992, 1995 and 2000 for Surat district. Fig. 3 shows graphical representation of SPI 12 (SPI at the end of each year) derived on excel sheet of formulae of SPI 12 discussed in methodology.

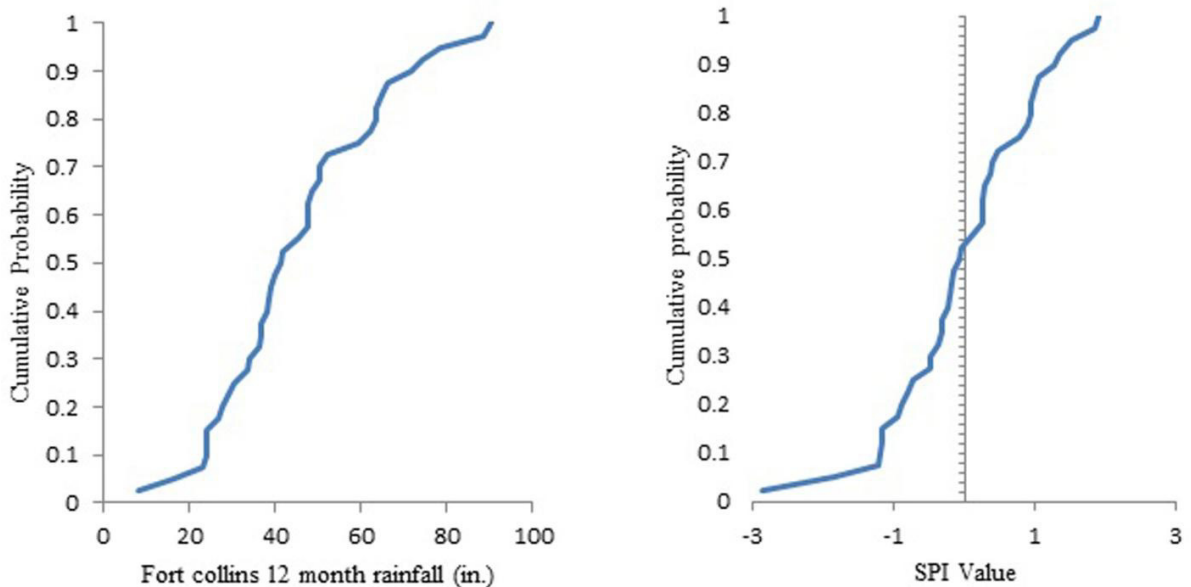


Fig. 3. Results of probability transformation from fitted gamma distribution to the standard normal distribution.

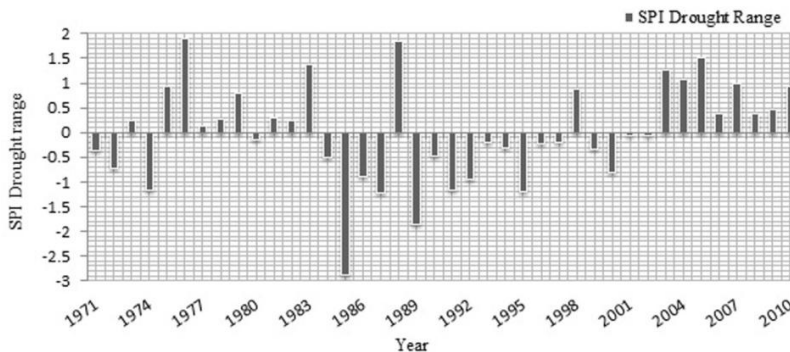


Fig. 4. 12-month time scale basis drought results using SPI method

Fig. 4 represents SPI derived at the end of each year (known as SPI 12) and explained in drought range. The results obtained from SPI method was brought on to the common conversation in percentage. The comparison between actual drought and estimated drought for Surat district is shown in Table 2 and graphically in Fig. 4. From the comparison, it is observed that for the year 1985 result obtained for SPI shows over estimation of drought index as compared to actual one. The reason for showing over estimates is because of low precipitation occurred in these years. The reason for higher estimation of drought particularly in 1972, 1974, 1987 and 1990 is the index based on the probability of precipitation for any time scale.

Table 2. Comparison between actual drought and SPI results

Year	Actual drought in %	SPI in %
1972	36.18	41.89
1974	44.89	45.22
1985	78.90	143.50
1986	50.13	52.36
1987	46.40	47.54
1989	66.37	66.41
1990	26.63	28.50
1991	45.74	44.84
1992	48.56	55.85
1995	45.49	46.00
2000	46.28	47.12

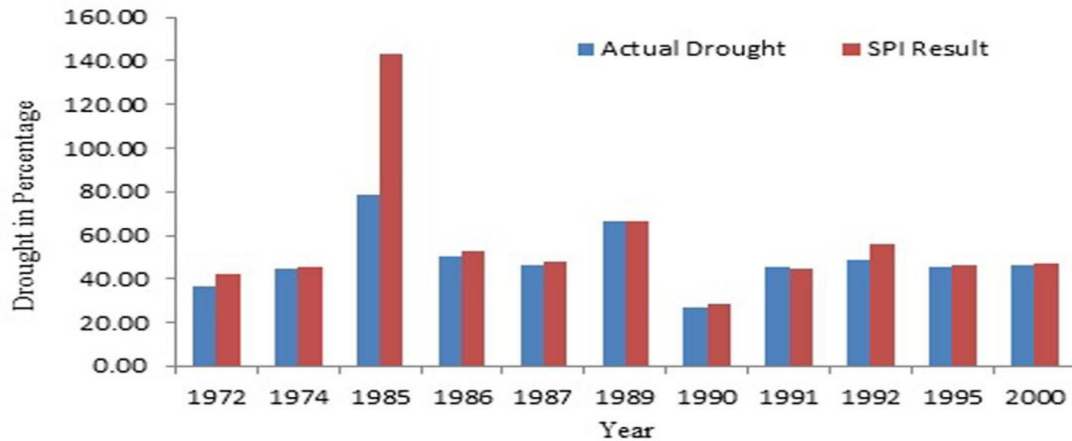


Fig. 5. Comparison between actual drought and SPI results

5. Conclusion

The SPI method gives best result without other climatic parameters like minimum and maximum temperature, humidity, potential evapotranspiration (ET_0) and sun hours as it uses only precipitation data and gives accurate result. Results derived by SPI method are similar to actual drought situation except that in extremely severe drought condition. This method is better for agricultural applications since it is simple and effective.

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