Drought Scenario Assessment using Standardized Precipitation Index (SPI)

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Abstract *:* Drought is a normal feature of climate, however, it is also one of the most common and severe natural disasters. It is characterized by the deficient supply of moisture resulting either from sub-normal, erratic rainfall distribution, higher water need or a combination of all these factors. Persisting over months or years, it can affect large areas and periods of droughts have significant environmental, agricultural, health, economic and social consequences. Indian agriculture is heavily dependent on the monsoon as a source of water. In some parts of India, the failure of monsoons result in water shortages, resulting in drought and subsequent below-average crop yields. For example, Adhala village in Akole Taluka, Ahmednagar district of Maharashtra, being located in precipitation scarcity zone, is known to face water scarcity and periodic occurrence of drought. A systematic analysis of the drought pattern in such areas would help in identifying drought scenario and will be considered as an aid to drought management. By carrying out drought analysis, a drought plan so as to mitigate environmental, social and costly economic impacts could be developed. In this paper, drought scenario and periodicity in Adhala village is analyzed using the Standardized Precipitation Index (SPI). Monthly time series rainfall data during the period 1976 to 2009, obtained from environmental agencies, is used to derive the SPI. Temporal pattern of meteorological drought and its severity during typical drought and wet years is interpreted based on a three-month seasonal SPI. It is observed that the most severe drought was experienced during the year 1985. Accumulated magnitude of the negative values of the SPI shows that prolonged drought is observed from 1990 to 1993. Also, in this study, the overall meteorological drought vulnerability Adhala village has been assessed by reconstructing historical occurrences of droughts at varying time steps, i.e., at 1, 3, 6, 9 and 12 month time steps. The analysis reveals that Adhala village experienced moderate drought during 77% of the time, severe drought during 14% of the time, and extreme drought during 5% of the time. By applying the SPI approach, the obtained results indicated that the drought events occur at an approximate interval of 8-10 years in Adhala village.

Key words : SPI, drought, meteorological data, precipitation.

INTRODUCTION

Drought is a normal, recurring feature of climate, it occurs in virtually all climatic regimes. It is the consequence of natural reduction in the amount of precipitation received over an extended period of time, usually a season or more in length, although other climatic factors (such as high temperatures, high winds, and low relative humidity) are often associated with it and can significantly aggravate the severity of the event. Globally, drought is the second- most geographically extensive hazard after floods of the earth's land area.

Long-term annual rainfall data over 60 or more years show that more than 13% of India experiences drought once in 2.3 years. More than 50% of the dry tropical region is affected by droughts about once in 4 years.[1]. The resultant of acute water shortage due to lack of rains over extended periods of time affects various human activities and lead to problems like widespread crop failure, un-replinshed ground water resources, depletion in lakes/reservoirs levels, shortage of drinking water, reduced fodder availability etc. Often a region adopts itself to a certain level of water shortage based on the long-term climatic conditions experienced by it. Any negative departure from these levels creates conditions of drought, depending on the intensity and duration of this deficit. Thus drought conditions differ from region to region. Drought has different meanings to different class of experts. To a meteorologist, it is the absence of rain while to the agriculturist it is the deficiency of soil moisture in the crop root zone to support crop growth and productivity. To the hydrologist, it is the lowering of water levels in lakes, reservoirs, etc., while for the city management , it may mean the shortage of drinking water availability. Thus, it is difficult to expect a universal definition of drought applicable to all the fields of activity[2] .However, Wilhite and Glantz[3] have categorized drought into meteorological (lack of precipitation); hydrological (drying of surface water shortage); agricultural (lack of root zone soil moisture) and socio-economic (lack of water supply for socio-economic purpose)

Drought differs from other natural hazards in several important ways. First of all, drought is a slow-onset natural hazard, often referred to as a creeping phenomenon. Because of the creeping nature of drought, its effects accumulate slowly over a substantial period of time. Therefore, the onset and end of drought are difficult to determine and scientists and policy makers often disagree on the bases(ie.crtiteria) for declaring an end to drought[1]

Drought is one of the most common and severe natural disaster. In most regions the economic damages caused by droughts are greater than those caused by any other events such as earthquakes and volcanic eruptions. Persisting over months or years, it can affect large areas and may have serious environmental, social and economic impacts . In some parts of India, the failure of monsoons result in water shortages, resulting in drought and subsequent below-average crop yields. For example, Adhala is a village in Akole Taluka, Ahmednagar district of Maharashtra, being located in precipitation scarcity zone, is known to face water scarcity and periodic occurrence of drought. A systematic analysis of the drought pattern in such areas would help in identifying drought scenario and will be considered as an aid to drought management. By carrying out drought analysis, a drought plan so as to mitigate environmental, social and costly economic impacts could be developed.

In this paper, it is attempted to investigate the pattern and periodicity of drought in Adhala village using the Standardized Precipitation Index (SPI) applied to the monthly time series rainfall data during the period 1976 to 2009. The rainfall data is collected from Water Resource Department, Hydrology Project, Nashik. Temporal pattern of meteorological drought and its severity during typical drought and wet years is interpreted based on a three-month seasonal SPI as well as varying time steps SPI.

STANDARDIZED PRECIPITATION INDEX

Many drought indices which integrate hydrological and meteorological parameters like Rainfall, evapotranspiration, soil moisture, run off, temperature and other water supply indicators into a single number, are available to provide a comprehensive picture of drought scenario for a decision making. In general, the drought index is a prime variable for assessing the effect of a drought and defining different drought parameters, which include intensity, duration, severity and spatial extent. The most commonly used among such indices include the Palmer Drought Severity Index (PDSI), the Standardized Precipitation Index (SPI) [4] and Percent Normal Deciles. The majority of drought indices adopt a fixed time-scale. For example, the PDSI has a time-scale of about 9 months [5], which does not allow identification of droughts at shorter time scales, as in the case of agricultural drought. However, SPI is designed in such a way that it can detect drought over different periods at multiple time scales.

The standardized Precipitation Index (SPI) was developed for the purpose of defining and monitoring drought [4]. The SPI is an index normally calculated on the basis of selected periods of time and indicates how the precipitation for a specified period compares with the complete record. It is a probability index that was developed to give a better representation of abnormal wetness and dryness. Standard Precipitation Index for any location is calculated, based on the long-term precipitation for a desired period. This long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero [4,5]. SPI can be computed for various time scales.1-month SPI reflects short-term conditions and its application can be related closely to soil moisture; the 3-month SPI provides a seasonal estimation of precipitation; 6- and 9-month SPI indicates medium term trends in precipitation patterns [6].

A.Calculation of SPI

SPI is computed based on fitting of a distribution to precipitation series [7,8]. In most cases, the distribution that best models observational precipitation data is the Gamma distribution. The density probability function for the Gamma distribution is given by

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}}; \qquad x > 0 \tag{1}$$

where α > 0 is the shape parameter, β > 0 is the scale parameter, and x>0 is the amount of precipitation. Γ(α) is the value taken by the standard mathematical function known as the Gamma function defined by the integral

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

The Gamma function is evaluated either numerically or using the values tabulated depending on the value taken by parameter α.

In order to model the data observed with a gamma distributed density function, it is necessary to estimate appropriately parameters α and β. Different methods have been suggested in literature for the estimate of these parameters. For example, in Edwards and McKee, the Thom approximation is used for the maximum probability

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

$$\hat{\beta} = \frac{x}{\hat{\alpha}} \tag{3}$$

where for n observations,

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

After estimating coefficients α and β the density of probability function g(x) is integrated with respect to x and we obtain an expression for cumulative probability G(x) that a certain amount of rain has been observed for a given month and for a specific time scale.

$$G(x) = \int_0^x g(x)dx \tag{4}$$

The Gamma function is not defined by x=0 and since there may be no precipitation the cumulative probability becomes

$$H(x) = q + (1-q)G(x) \tag{5}$$

where q is the probability of no precipitation. The cumulative probability is then transformed into a normal standardized distribution with null average and unit variance from which we obtain the SPI index.

The above approach, however, is neither practical nor numerically simple to use if there are many grid points or many stations on which to calculate the SPI index. In this case, an alternative method can be described in using the technique of approximate conversion developed that converts the cumulative probability into a standard variable Z [7,8]. The SPI index is then defined as

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_0 + d_1 t + d_2 t^2 + d_3 t^3}\right); 0 < H(x) < 0.5$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_0 + d_1 t + d_2 t^2 + d_3 t^3}\right); 0.5 < H(x) < 1$$

where

$$t = \sqrt{\ln \frac{1}{(H(x))^2}}; 0 < H(x) < 0.5$$

$$t = \sqrt{\ln \frac{1}{(1 - H(x))^2}}; 0.5 < H(x) < 1$$

where x is precipitation, H(x) is the cumulative probability of precipitation observed and c0, c1,c2, d1,d2,d3 are constants with the following values:

c0=2.515517; c1=0.802853; c2=0.010328; d0=1.432788; d1=0.189269; d2= 0.001308.

If the value of parameter α is very high, the Gamma distribution tends towards a normal distribution and, therefore, it may be more effective, at the computational level, to estimate the SPI index using Normal distribution with average μ and standard deviation σ, for both the values estimated by the sample used. Then, the SPI index will be defined by [8]

$$Z = SPI = \frac{(x - \hat{\mu})}{\hat{\sigma}} \qquad (6)$$

Having computed the SPI, severity of the drought is categorized as shown in Table I.

Table I: Drought Severity Classification [6]

Category	Description	SPI
D0	No drought	>-0.5
D1	Abnormally dry	-0.5 to -0.7
D2	Moderate drought	-0.8 to -1.2
D3	Severe drought	-1.3 to -1.5
D4	Extreme drought	-1.6 to -1.9
D5	Exceptional drought	-2 or less

The major advantage of SPI is its simplicity. The SPI is based only on precipitation. Second, the SPI is versatile: it can be calculated on any timescale, which gives the SPI the capability to monitor conditions important for both agricultural and hydrological applications. The versatility is also critical for monitoring the temporal dynamics of a drought, including its development and decline. The third advantage of the SPI is that, because of its normal distribution, the frequencies of the extreme and severe drought classifications for any location and any time scale are consistent [9].

RESULTS AND DISCUSSION

Fig. 1 shows the 3-month SPI calculated for Adhala using monthly rainfall data of the southwest monsoon season (July-August-September). It can be observed that moderate drought was experienced during the years 1984, 1985, 1991, 1994,1996, 2002 . However, during the years of 1979, 1993, 2006 and 2008 to 2007, the SPI values are positive, and maximum reached an intensity of 1.7 in 2007, which shows that these years were wet years.

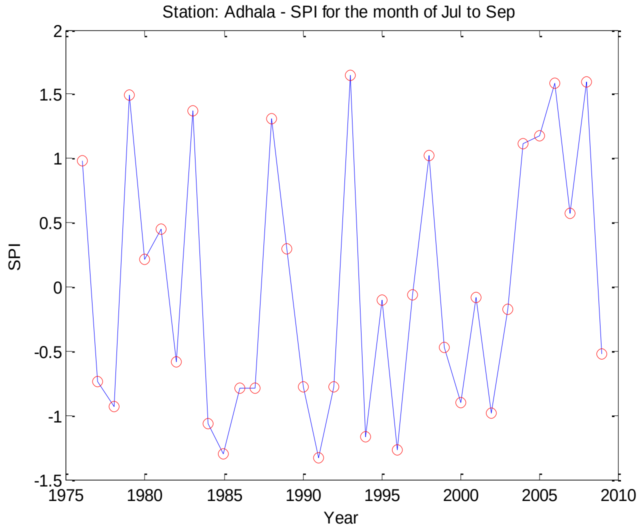

Fig 1: Seasonal 3-month SPI of September

Figure 2 shows the rainfall deviation from the mean rainfall. It can be observed that rainfall is very low during the year 1985 and maximum during the year 2007, which denotes a similar behavior as obtained from 3-month SPI of September.

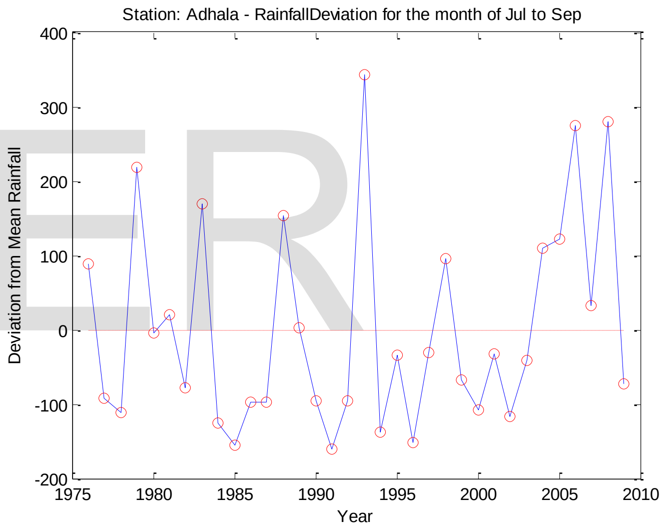

Fig 2: Rainfall deviation from the mean

A.SPI at multiple time intervals

The overall meteorological drought vulnerability in Adhala village has been assessed by reconstructing historical occurrences of droughts at varying time steps and drought categories with the SPI approach. The occurrences in varying drought categories at 1, 3, 6, 9 and 12 month time steps has been analyzed. The SPI values have been calculated for the total period and also for a specific month. From the analysis it can be observed that Adhala experienced moderate drought during 77% of the time , severe drought during 14% of the time, and extreme drought during 8% of the time. Drought occurrence expressed at multiple time steps for varying drought severity categories.

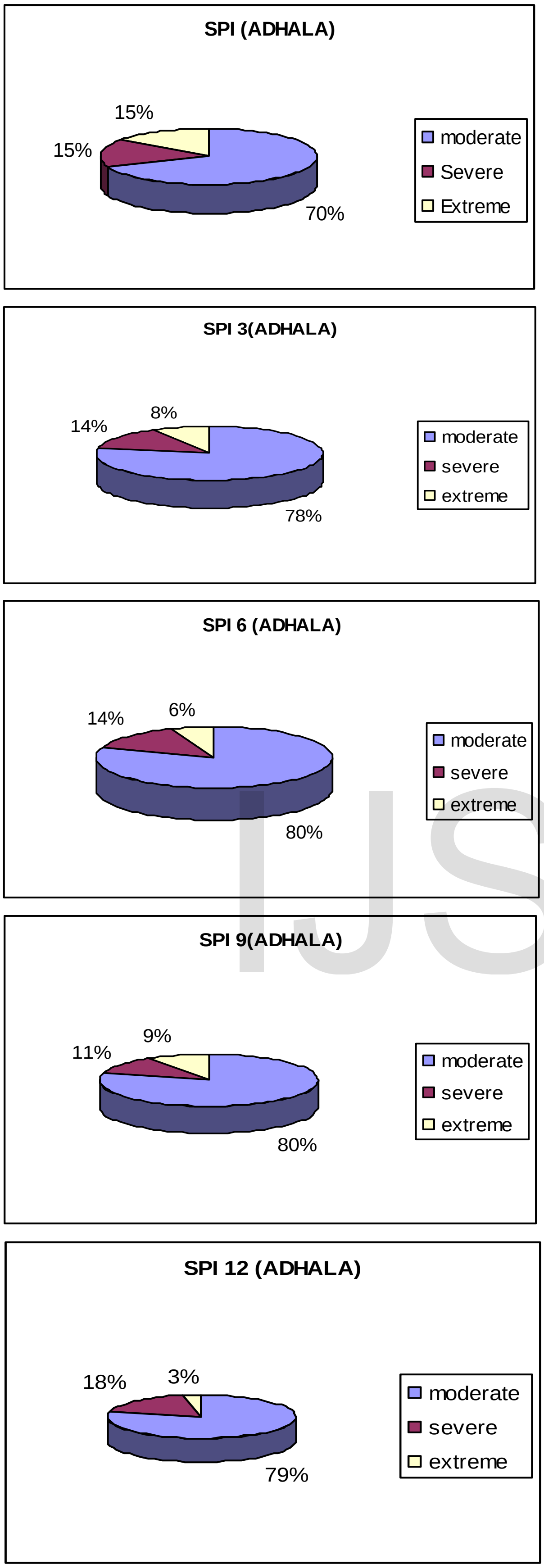

Fig 3: Drought occurrences at different categories and time steps

Fig: 4 shows the accumulated magnitude of the negative values of the station Adhala. This figure can be used as a guide for the selection of driest years and to compare also between different droughts. It can be seen that prolonged drought is observed from 1990 to 1993.

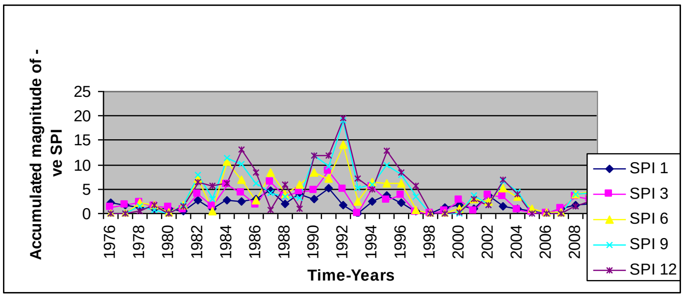

Fig 4: Accumulated magnitude of the negative values of the station Adhala

Table II shows the number of drought incidences along with their duration

Table II : DROUGHT PROPERTIES OF SPI SERIES (ADHALA)

SPI Series	No of Drought Months(SPI <-1) 1976-2009)	No of Drought Incidence	Duration of drought in months		
			Minimum	Maximum	Average
SPI 1	27	24	1	3	1.125
SPI 3	37	22	1	4	1.68
SPI 6	51	24	1	7	2.125
SPI 9	67	20	1	9	3.35
SPI 12	67	14	1	20	4.785

It is found that for the station Adhala the number of drought incidences for SPI-1 is 24 with maximum duration of 3 month. The number of drought incidences for SPI-3 is 22 with the maximum duration of 4 month. The number of drought incidences for SPI 6 is 24 with a maximum duration of 7 month. The number of drought incidences for SPI 9 is 20 with maximum duration of 9 month. The number of drought incidences for SPI 12 is 14 with maximum duration of 20 month which was occurred in 1992's. Based on the average duration of drought (which is calculated by dividing total number of drought months with the total number of drought incidences for a particular series.), the droughts are classified as short-term drought, medium –term drought and long-term drought. The average duration of drought for SPI and SPI 3 are 1.25 and 1.68 month respectively, which are termed as short-term drought. Similarly, the average duration of drought for SPI 6 and SPI 9 are 2.125 and 3.35 month respectively, which are termed as medium term drought. When the drought due to SPI 12 occurs, it persists for a longer duration and the average duration is 4.785 month. So SPI 12 is considered as long term drought.

CONCLUSION

Drought monitoring is an important part of planning and preparedness at national, regional and local levels. Monitoring can help the policy makers with a unique perspective (across political boundaries) for determining the allocation of resources. In this study, a methodology for drought monitoring is demonstrated at a small location using available in-situ data. The proposed methodology is found effective in capturing temporal drought pattern in Adhala village. It is observed that the prolonged drought is observed from 1991 to 1993.Overall meteorological vulnerability in

Adhala by reconstructing historical occurrences of drought at various time steps and drought categories with the SPI approach shows Adhala village received severely and extremely drought events during the period 1976-2009. It can also be observed that the drought events occur at an approximate interval of 8-10 years.

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