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Assessment of Meteorological Drought using Standard Precipitation Index (SPI) in Western Maharashtra, India

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Abstract

The crop production in rainy season in rainfed areas is dependent on vagaries of monsoon and is adversely influenced. The knowledge of different rainfall characteristics such as onset and withdrawal of monsoon, dry spell and drought would enable the optimal crop planning and implementation of protective irrigation strategies, thus mitigating the adverse impact of uncertainties of rainfall. The assessment of drought is one of the most important steps in risk management of drought analysis. The basis of drought indices is often based on measuring the deviation of precipitation values from long-term mean, during a specific period of time. The standard precipitation index (SPI) can be used for indicating the associated temporal and spatial variations. The aim of this research is the assessment of the characteristics such as intensity of meteorological drought using SPI with 12 months time scales in Western Maharashtra, India. The index has been computed in with 12 months time scales for 105 stations with 30 years record period in the study area and evaluated for the recent drought during 1983-2012. The results indicate that the rainfall pattern of Western Maharashtra exhibits non-uniform, irregular and erratic pattern of rainfall, as evidenced from SPI values. The meteorological drought shifted one step towards severity of drought condition for the time scales (month 1-12) i.e. from extremely wet to very wet; very wet to moderately wet; moderately wet to near normal; near normal to moderately dry; moderately dry to severely dry and severely dry to extremely dry condition.

Key words : Meteorological Drought; Standardized Precipitation Index; crop production.

Water is limited resource and its efficient use is important, especially in view of ever increasing population. The basic source of water is the precipitation in the form of rainfall or snowfall and is the most critical and key variable of hydrological cycle. The human activities such as rapid urbanization, ever increasing population and deforestation have interrupted the natural hydrological cycle. This ecological imbalance resulted in non-uniform distribution and erratic variation of rainfall pattern. The present world has to meet the challenges of increasing water demand, the depleting water resources along with non uniform distribution of water. In the country like India, there are huge and abrupt variations in rainfall characteristics (Venkateswaralu, 2011) including rainfall amount and its distribution, onset and withdrawal of monsoon and occurrence of dry spells both temporally and spatially. Hence the crop planning and water resource management in the rainfed area is difficult and complex. Therefore the study is focused on the analysis of drought and western Maharashtra has been chosen as the study area because 70 percent area of western Maharashtra is rainfed. There are several indices to know meteorological drought. Zargar et al. (2011) extensively reviewed different indices. However Standard Precipitation Index (SPI) that is solely based on rainfall data has been widely used in literature (Kazem and Zareiee, 2011). Hence in this study, it was proposed to investigate the drought characterization in terms of meteorological drought using SPI.

Materials and Methods

Data collection : The rainfall data of approximately 30 (1983-2012) years and more for 105 rainfall stations in the region of Western Maharashtra were collected from Indian Meteorological Department, Pune.

Meteorological Drought : Meteorological drought was analysed by using Standard Precipitation Index (SPI) for 105 stations in Western Maharashtra. The procedure for determining SPI is given below.

Any drought including meteorological and agriculture is a result of deficient rainfall. The SPI has been used widely to quantify the deficit of

Fig. 1. Location map of the study area

precipitation. It could be computed at different time scales from less than 1 month to 48 months or more. The calculation time period depends on the user's application. Short-term SPI is used to detect agricultural drought, and long-term SPI can be used for water supply management. The SPI value is derived from the inverse value of the cumulative probability function of the observed precipitation distribution. Standardized precipitation index was calculated according to the following formula Edwards and McKee, (1997).

$$\mathrm{SPI} = \mathrm{Z\ score} = \frac{X_i - \overline{X}}{\sigma}$$

The SPI is equivalent to Z-score which is often used in statistics. i.e. SPI=Z-score

Where, X_i = Precipitation of the specified time scale for ith year (i.e. for annual SPI is the precipitation of ith year; for monthly SPI, it is the precipitation of particular month in ith year; and for two month time scale, it is the sum of the precipitation of the particular month and the month preceding to this particular month), $\overline{X}$ = Long-term average precipitation of the specified time scale, σ = Standard deviation of the precipitation of the specified time scale.

To adjust for this empirical fact, the precipitation data is transformed to a more normal or Gaussian symmetrical distribution by applying the gamma function. After the precipitation data have been transformed, the SPI is calculated in a manner that mirrors the Z-score formula Edwards and Mckee, (1997). Procedure and formulae adopted for computation of SPI is;

I. The transformation of the precipitation value in to standardized precipitation index (SPI) with the purpose of:

   a) Transforming the mean of the precipitation value adjusted to 0;

   b) Standard deviation of the precipitation is adjusted to 1.0; and

   c) Skewness of the existing data is readjusted to 0.

   When these goals are achieved the standardized precipitation index is interpreted as mean 0 and standard deviation of 1.0.

II. The precipitation needs to convert to lognormal values and the statistics, U shape and β scale parameters of gamma distribution are computed as:

$$\log \text{mean} = \overline{X}_{\ln} = \ln(\overline{X})$$

$$U = \overline{X}_{\ln} - \frac{\sum \ln(X)}{N}$$

$$\text{Shape parameter} = \beta = \frac{1+\sqrt{1+\frac{4U}{3}}}{4U}$$

$$\text{Scale factor} = \alpha = \frac{\overline{X}}{\beta}$$

The resulting parameters are then used to find the cumulative probability of an observed precipitation event. The cumulative probability is given by:

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

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

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

Where, q = the probability of zero.

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 Edwards and McKee, (1997). Abramowitz and Stegun, (1965) provide the approximate conversion as an alternative:

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

$$Z = SPI = +\left(t - \frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right) \quad 0.5 < H(x) \le 1$$

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

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

Where, C_0= 2.515517, C_1= 0.802583, C_2= 0.010328, d_1= 1.432788, d_2= 0.189269 and d_3= 0.001308

The values of c_0, c_1, c_2, d_1, d_2 and d_3 given in equation are constants widely employed for SPI computation Edwards and McKee, (1997).

According to the SPI method the severity of a drought is determined. The negative value from zero shows the severity of dryness. The positive value of SPI shows the degree of wetness. The SPI value normally ranges from (-2) - (+ 2). An index of (+2) indicates extremely wet; (1.5) - (1.99) very wet; (1.0) - (1.49) moderately wet; (0.99) - (- 0.99) near normal;

(-1.0) - (1.49) moderately dry; (-1.5) - (-1.99) severely dry; (-2.0) or (less) extremely dry McKee et al. (1993). In this study SPI value were computed for 12 months time scale. The software SPI_SL_6.exe Svoboda et al. (2012) was used.

Drought Characteristics Maps by using GIS Technique : A methodology was developed using a Geographic Information System (GIS) to develop the maps. The maps were developed in Arc-GIS 9.3 by using Inverse Difference Weighted (IDW) technique of interpolation in spatial analysis tool. Inverse distance weighted interpolation (IDW) was one of the simplest and most readily available methods. It is based on an assumption that the value at an unsampled point can be approximated as a weighted average of values at points within a certain cut-off distance, or from a given number of the closest points. Weights are usually inversely proportional to a power of distance which, at an unsampled location r, leads to an estimator. The spatial distribution of SPI values is useful to evaluate the drought situation of area and to plan the cropping pattern for maximizing the value of the agriculture returns.

Results and Discussion

The SPI values were found to be more negative from 1983 to 2012 for all the stations of Western Maharashtra. This is due to the non-uniform, irregular and erratic pattern of rainfall. The comparison between SPI values at 12 months time scale of year 1983 with corresponding values of SPI with same time scale of year 2012 showed that a SPI values become more negative from years 1983 to 2012. It means that, meteorological drought shifted one step towards severity of drought condition. Similarly shifting of drought condition one step towards severe dry condition was observed for all the time scales for all the stations (105 stations) in different districts of Western Maharashtra (i.e. from extremely wet to very wet; very wet to moderately wet; moderately wet to near normal; near normal to moderately dry; moderately dry to severely dry and severely dry to extremely dry condition).

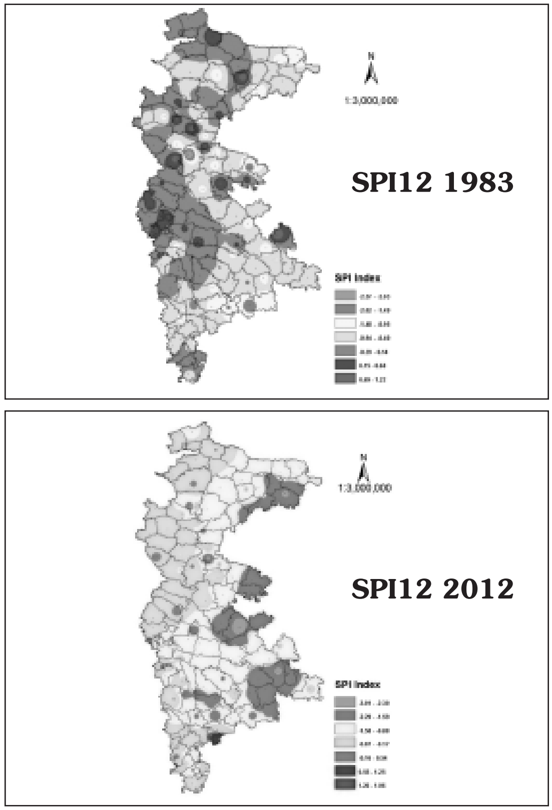

Fig. 2. Spatial distribution maps of 12 months time scales for the years 1983 and 2012 for the Western Maharashtra

Conclusion

The rainfall pattern of Western Maharashtra exhibits non-uniform, irregular and erratic pattern of rainfall. As evidenced from SPI value becoming more negative from 1983 to 2012 for 12 month time scale. This is an alert for region of Western Maharashtra to manage the water resources and to make crop planning according to changing drought pattern for sustainable development of agriculture and increase crop production. The SPI values revealed many interesting results on the variability in the occurrence of meteorological drought in Western Maharashtra. Comparison of drought indices of different years was found extremely useful for understanding historic drought patterns and assessment of future risk. Increased drought frequency in the recent years observed in the study facilitates better preparedness and coping mechanisms. The spatial maps of SPI that were prepared in this study are useful to understand drought situation, so we can make the plans of supplemental and protective irrigations for different crops of Western Maharashtra.

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