Development and application of SPI generator using open source for analyzing drought at a varying time scale

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ABSTRACT

The Standardized Precipitation Index (SPI) is a probability index that gives a better representation of abnormal wetness and dryness than any other drought indices. The primary objective of the current study is to develop a comprehensive tool to compute SPI on a spatial basis and analyze spatiotemporal variability of drought in North West Indian region during 1951–2007 using APHRODITE water resource data at 0.25-degree resolution. This tool was developed using the python programming language, and the site-packages such as Numpy, Scipy, Matplotlib, NetCDF, PyQt were used. The result showed that the SPI time series showed significant inter-annual and multi-decadal variations. In the whole data period, three consecutive droughts have occurred only once, 1999–2002. This prolonged drought hurt the agricultural and water resources sectors over the study area. The computed SPI for the year 2002 showed an extreme dry spell over the study area signifying the major drought over India in the same year with a 56% deficit of rainfall in July. The computed 12-month SPI for the year 1996 shows a wet period over the northwestern part of India, especially over Haryana signifying medium to heavy rainfall, conforming 1996 flood. The developed SPI tool, portray a realistic picture of drought scenario over the Northwest region and improve the timely identification of emerging drought conditions that can trigger appropriate responses by the decision makers.

Keywords: SPI generator; drought; spatial; time series; rainfall; APHRODITE

Drought is considered to be one of the significant natural calamities that affect the environment, agriculture produce and socio-economic condition of the population of that area. Drought occurs for a longer duration through its slow developmental process and indefinite beginning and termination. It leaves an impact even after the phenomenon is over. Despite its devastating nature of drought, scientific declaration of drought has not received much attention particularly in developing countries (Wilhite *et al.*, 2000).

The Technical Committees on 'Drought Prone Area Program' and 'Desert Development Program,' constituted by Govt. of India have spotted about 120 million hectares of land, spanned across 13 drought-prone states (185 districts) (Anonymous, 1994). Barring certain pockets, the whole of India is drought prone. Of the ten drought years in the 19th Century, three of them, 1901, 1905 and 1918, were reported to be severe. In addition to this, in the late 20th Century, two severe droughts were reported in the years 1979 and 1987 (Kulshrestha, 1997). Two severe droughts were also reported in the year 2002 and 2009, thus causing considerable damage to the agricultural sector of India. In the past 210 years, six

drought years have been reported, i.e., 1877, 1899, 1918, 1972, 1987, 2002 and 2009. In these years, nearly 50 percent of the total cropped area in the country was affected by drought (Gore *et al.*, 2010).

Precise quantification of drought was considered daunting task in the past; however, development of drought indices has made drought characterization easier and more effective (Gibbs and Maher, 1967; Palmer, 1965; Shafer and Dezman, 1982; Heim, 2002; Zargar et al., 2011). Among different drought indices of the recent times, the Palmer drought severity index (PDSI) (Palmer, 1965) and standardized precipitation index (SPI) (McKee et al., 1993, 1995) are found efficient in monitoring drought and related agricultural applications (Chaudhary and Dadhwal, 2004; Patel et al., 2007). SPI is simple to calculate, easy to understand and interpret, spatially invariant or better spatial standardization, for any period of interest (Mishra and Singh, 2010). It is good indicator of wet and dry spell at varying timescales and period of drought events. Standardized Precipitation Index (SPI) which have been widely used in different the regions of the world (Lee and Dang, 2018;

Pradhan et al., 2011; Chaudhari and Dadhwal, 2004). As SPI is spatially invariant, it detects the onset of drought much earlier than PDSI (Sims *et al.*, 2002; Hayes *et al.*, 1999).

The computation of SPI is currently being done using the UNIX version of the SPI program developed by the Colorado Climate Center (http://ccc.atmos.colostate.edu). The program calculates SPI for rainfall totals of different periods for a single point at a time. However, the timescales cannot be modified because of their hard coding into the program. The research aims at developing a comprehensive tool to compute SPI spatially and investigate the spatiotemporal variability of incidence of drought in North West India region during 1951–2007 using APHRODITE water resource data at 0.25-degree resolution. The study is based on the proposal of McKee *et al.*, (1993) in which the study depends on the analysis of calculated space-time field of the SPI.

MATERIALS AND METHODS

The study area is comprised of three Indian states viz., Haryana, Punjab, and Himachal Pradesh. The data sets required for SPI computation were obtained from Asian Precipitation - Highly-Resolved Observational Data Integration towards Evaluation of Water Resources (APHRODITE) project (http://www.chikyu.ac. jp/precip). They include daily precipitation on a 0.25/0.5-degree grid for Asia using multiple rain-gauge stations from 1951 to 2007. In the present study, 0.25 degree-gridded precipitation data of APHRO_MA_V1101 (which pertains to the Monsoon Asia region) has been used over Asia from 1951 to 2001.

Calculation of SPI

The calculation of SPI is done based on the record of long-term precipitation, mainly longer than 30 years, for the desired location. The process involves a transformation from one to another frequency distribution for example, gamma to normal or Gaussian. Thus, at first, a particular probability distribution fitting to the long-term precipitation time scale is selected (for example, gamma or incomplete beta distribution (McKee et al., 1993, 1995), and Pearson III distribution (Guttman, 1998). The selection is made in such a way that it can conduct fitting to the selected distribution. Based on the requirements, gamma distribution has been the most used. In this case, fitting is achieved through the maximum likelihood estimation of the gamma distribution parameters. The percentile value obtained from the probability distribution is further transformed to the corresponding value in the new probability distribution. Then the probability of rainfall being

less or equal to any amount of rainfall will be same as the probability values stating that the new variate is less than or equal to the corresponding value of that rainfall amount. The normal distribution is used for the other transformation for maintaining the zero value for the mean and one value for SD of SPI for a particular region and over a long-term period (Edwards and McKee, 1997). If the value of SPI is positive, it indicates wetness, which is higher than median precipitation. Negative values indicate dryness, which is less than the median precipitation. Classification of SPI indices is given in Table 1. A detailed description of SPI calculation has been given by Lloyd-Hughes and Saunders (2002).

Development of SPI tool and subsequently generation of spatio-temporal SPI maps at different timescales were carried out using opensource programs and software libraries. Various steps involved in this study is mentioned in Fig. 2. The SPI generator tool was developed in open source environment, as python and other site packages were used for writing the code. Steps followed in developing SPI generator tool is explained as follows:

- Extraction of the area of interest for the study and converting them to daily precipitation into monthly precipitation.
- ii. Transformation of precipitation values into log-normal values
- iii. Estimation of U-statistics, shape and scale parameter
- iv. Calculation of cumulative probability of an observed rainfall event
- v. Transformation of cumulative probability into gamma probabilities by involving zero precipitation events.
- vi. Gamma probability transformation into standard normal distribution using equi-probability transformation techniques.

Table 1: SPI indices and its classification (McKee et al., 1993)

SPI indices	Classification
2.0+	Extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

- vii. The graphical user interface for the SPI generator tool was developed using PyQt module.
- viii. Spatiotemporal SPI map at various timescales were generated using python GDAL library and regional time series plots were generated using python matplotlib library.
- ix. GrADs and ArcGIS were used for the visualization of SPI Drought severity based on drought severity classification.

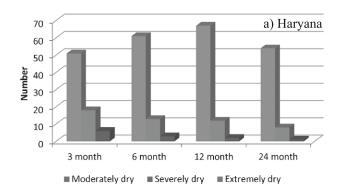
RESULTS AND DISCUSSION

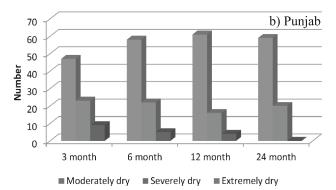
The SPI generator tool was developed as explained in the methodology and was used for computing the values of SPI for the APHRODITE data at varying time scales.

Observed variability of drought

The observed variability of droughts in monsoon season has been presented in this section based on various time scales. Fig. 1 shows frequency of drought period based on the SPI for 3,6,12 and 24 month drought occurrence in the categories of moderately dry. The data revealed the 3-month SPI depicts the seasonal pattern of drought or above normal rainfall conditions in conditions whereas 6 to 12-month SPI indicates inter-annual precipitation patterns. In addition, 12 month period data indicated that the frequency of drought occurrence under the category of severely dry is 1 in 4 years for Punjab, 1 in 3 years for Haryana and 1 in 9 years for Himachal Pradesh. In addition, the 3 month SPI value indicates, which season of a year is mostly affected and periodically, how that season is affected during long term, if we look at the time series data, since it is a continuous one and hence which have lot of practical applicability and based on that policy makers and farmers can plan their crop. If a particular season shows more frequent drought, then farmers can choose drought resistant crop. Similarly, this will assist in assessing the influence of drought on productivity of crops as reported by Deepa et al. (2019) that the monthly SPI and VCI values from July to October were highly correlated with productivity index (PI) of kharif rice.

The drought cases in India that occurred during 1999–2002, showed an adverse effect on the agricultural sector and water resources. The time series of SPI-12 and 24 exhibited significant inter-annual, decadal and long-term trends. If there is deficient rainfall during the southwest monsoon for consecutive 2-3 years, then the effect can be determined by SPI-12 & SPI 24. During 1951-2010, multi-year drought cases were observed in a time series of SPI-24.





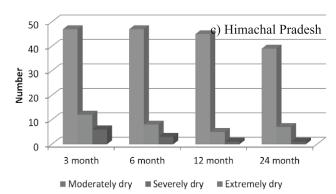
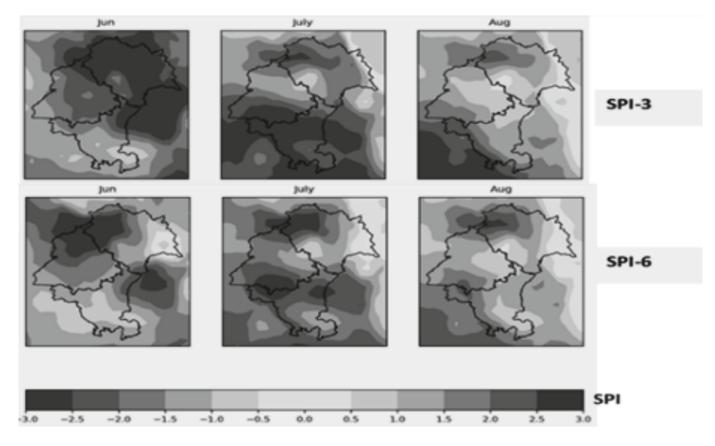


Fig. 1 : Frequency of drought period based on SPI for three states during different time period

Temporal and spatial analysis of drought

The temporal and spatial characteristics of droughts in Haryana, Punjab, and Himachal region were assessed by analyzing the SPI values of each pixel. The computed SPI values at varying time scales of highly gridded APHRODITE data for the period of analysis that ranges from 1951 to 2007 were analyzed and visualized using GrADS and ArcGIS.

SPI-3 offers comparison between the rate of precipitation over a 3-months period and from all the years included in the historical record. For example, SPI-3recorded during February end is compared with that of the December to February data in that particular year with the December-February precipitation data for all years. SPI-3 exhibits both short-term and medium-term moisture conditions by



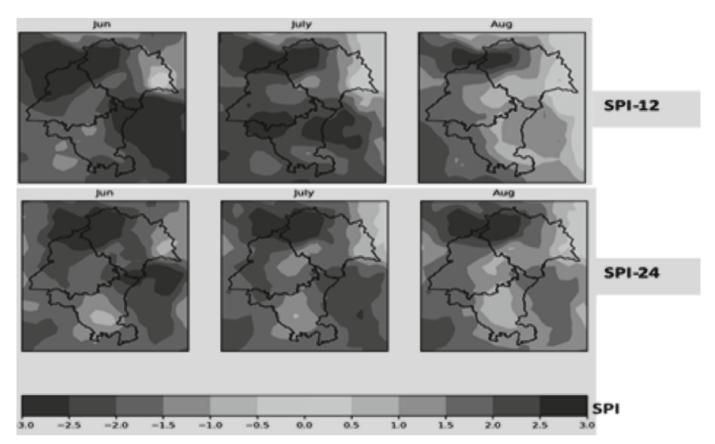


Fig. 2: SPI map of the study area at 3, 6, 12 & 24 month time scales for 2002

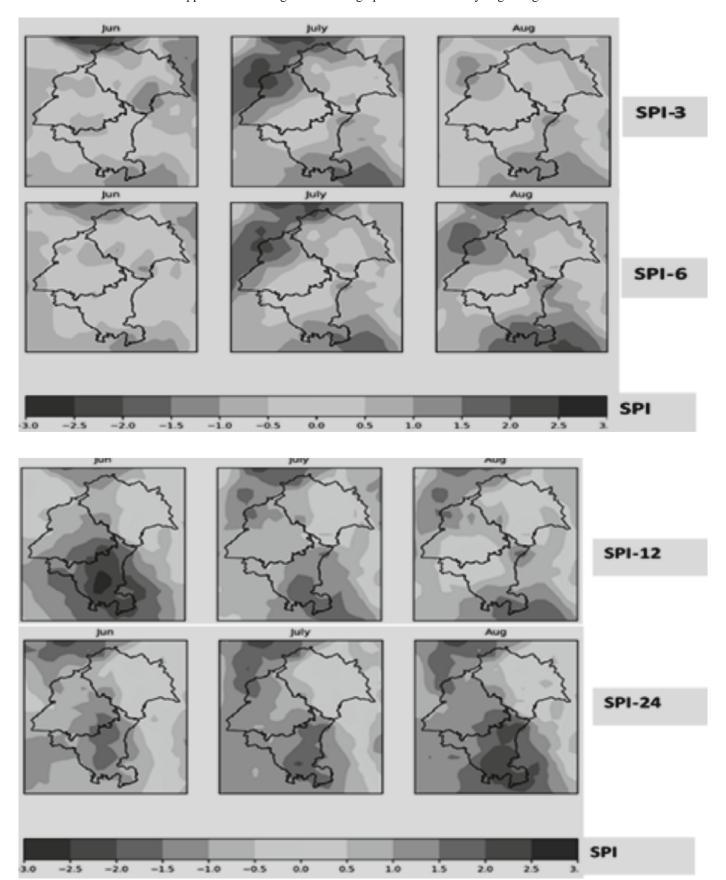


Fig.3 : SPI map of the study area at 3, 6, 9 & 12 month time scales for 1996

providing a seasonal estimation of precipitation. If we want to have the seasonal information for instance during south west monsoon, north east monsoon, summer and winter the occurrence of drought, which can be inferred from these 3-month SPI output. Even though the season is dry, the whole year might not fall under severely dry condition which is evident from 12 month or 24-month period data. However, this data can be very well utilized for planning of agricultural and reservoir operational plan to mitigate the effect of drought.

SPI-6 is highly sensitive to climatic conditions and showcases medium-term precipitation trends. It shows precipitation data over a specific season. For example, SPI-6 might begin with anomalous stream flow and reservoirs.

SPI-9 offers information on precipitation patterns in terms of medium scale. For this time scale, SPI values below - 1.5 provides good indication in support of fairly significant impacts that occurs in the agricultural sector.

SPI-12 involves study of precipitation pattern for a period of 1 year and the obtained data is compared with the same 12 months data of previous years, which exhibits long-term precipitation patterns. These time scales are cumulative result of shorter periods that may be above or below normal, the longer SPIs tend toward zero unless a specific trend is taking place. SPIs of these time scales are probably tied to stream flows, reservoir levels, and even groundwater levels at the longer time scales. The computed SPI for the year 2002 using APHRODITE data (Fig.2) showed an extreme dry spell over the north western part of India that signifies major drought cases that occurred in 2002 with a deficit of 21.5% in the seasonal rainfall and 56% deficit in the monsoon rainfall (Sikka, 2003).

The blue color in the map depicts the wet condition and the red color signifies the dry condition. (Fig.3) The computed 12 month SPI for the year 1996 shows a wet period over northwestern part of the India especially over Haryana signifies the medium to heavy rainfall, conforming 1996 flood (Saini and Kaushik, 2012). Thus, the SPI at varying scales in the year 1996 indicates the wet spells over the northern west parts of India.

CONCLUSION

The current work observed variability of droughts and its intensity in some of the Indian states by using a standardized index for determination of drought. SPI calculation was done for various time scales, such as at 3 months, followed by 6, 12 and 24 months, for a longer time period of 1951–2004 using high resolution gridded data on

monthly rainfall. The study outcomes showed that SPI had significant inter-annual, decadal and long-term trends. Based on the data, extreme drought conditions and extreme rainfall patterns were observed during 1996-2002, mainly in the regions of northwest India. A decrease in SPI was observed since 1951, thus showing increase in monsoon drought intensity in the study area.

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