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Spatio-Temporal Drought Assessment of Marathwada Region

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Abstract Drought is a prolonged shortage in the water supply and considered to be the most complex but least understood of all-natural hazards. The current study utilizes 47 years of data for drought assessment to understand drought patterns and severity. All drought-prone districts in the study area experience famine that is still slow-onset, creeping, and a recurrent occurrence. The spatio-temporal behavior of meteorological drought was investigated by calculating the Standard Precipitation Index (SPI) and spatial distribution of droughts by ArcGIS software. The SPI index is useful for the determination of drought conditions at diverse time scales and monitoring different types of drought. This index captured the collected deficit (SPI< 0) or extra (SPI> 0) of precipitation over a specified period. In the current investigation, 1972, 2000, and 2014 chosen as representative drought years based on negative SPI trends. The spatial pattern shows the area of agricultural drought increased during the kharif crop season (June - Oct). Based on the acquired result it is reveals that the SPI is an indicative parameter for assessment of agricultural drought in the Marathwada region. It also provides useful information to create a decision support system for agricultural drought or arid condition avoidance, mitigation, along with irrigation management improvement.

Keywords: *agriculture drought assessment, precipitation, SPI, spatial-temporal analysis and meteorological drought*

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1. Introduction

The Maharashtra state of India experienced recurring severe droughts and its influence on agricultural production affecting thousands of villages, lakhs of cattle, and several peoples. The worst drought in Maharashtra has made water supply instate a scary issue. As the agriculture sector is badly affected, people had to migrate from their native places for water, livelihood, and fodder for cattle. The increase in farmer suicide is a serious concern due to the loss of food crops, cattle, and other livestock. "From the year 1995 to 2004" farmer suicide in Maharashtra increased from 11,866 to 14,729 [1]. Among the various region of Maharashtra, the Marathwada region is the worst-hit area that the media has referred to as "Graveyard of Farmers" [2].

Recurring drought over Marathwada had a threatening impact over surface water (reservoirs) as well as groundwater storage. Major dams in the Marathwada region like Jaikwadi at Paithan and Kornool at Tuljapur; do not reach their full capacity because of scanty of rainfall. Hence, it is a priority to release water for drinking purposes, then for irrigation. As a result, these farmers begin digging wells to support agricultural activities that have sequentially led to the depletion of groundwater levels.

Many drought indices were framed in past by assimilating weather variables like precipitation, evapotranspiration, degree of hotness (temperature). The Palmer drought severity index (PDSI) and the moisture anomaly index (Z-index) are most commonly used drought indices [3], Percent Normal, Deciles [4], the standardized precipitation index (SPI) [5,6] and aridity index [7]. In general drought, indices are enabled to detect the onset of drought events, and to measure their severity, it allows an evaluation of the spatial and temporal features of drought as well as comparative assessment between different regions [8]. The majority of drought indices like PDSI have longer time-scale about nine-months [9], which enables to permit the identification of drought at shorter 3 or 6 months scales. Standardized precipitation index (SPI) is intended in such a way that it is capable to notice drought over different stages at multiple time scales. The SPI is designed based on calculation methods that fitting gamma distribution to interpreted values of annual rainfall for various time stages and it transmuting reverse to the normal distribution with an average zero and variance of one.

For example, SPI of 1 month for december signifies standard deviation in rainfall of december only; SPI for 3 months of december represents the standard deviation of precipitation totals of december and the earlier two months. The positive and negatives values of SPI show that the higher than average precipitation and lesser than the average precipitation respectively. SPI is calculated by standardizing the possibility of measured precipitation for any period. In context to the agricultural interests, the SPI index (weekly or monthly) is applicable whereas, a longer period SPI is water management purpose [10]. The significance of calculating one-month SPI in the application of soil moisture measurement, three months for cyclical estimation of rainfall, and six and nine-months SPI for understanding the trend of precipitation [11]. Even though it is very relative drought assessment index, the SPI has been used in Turkey [12], Argentina [13], Canada [14], Spain [15], Europe [16] and India [17] for real-time monitoring or retrospective analysis of droughts.

SPI calculation is based on meteorological variable parameters, which are often called as meteorological indices to assess meteorological drought. Although the meteorological indices can emulate the features of drought at approximate level, the agricultural drought often has a time-scale of 3-6 months after meteorological drought [18]. Analyzing the spatio-temporal pattern of meteorological drought and its impact on agricultural production could provide a better understanding of effective characteristics of drought in Marathwada region. The SPI has probable to detect and depict drought episodes worldwide, the present study was focused on studying the usefulness of the SPI in the assessment of drought events in eight districts of Marathwada region, Maharashtra, India.

2. Study Area

The study was carried out in Marathwada (Semi-Arid region) of Maharashtra State, located in western India, lies to the west of the Vidarbha and east of Khandesh regions of Maharashtra between 17°35” to 20°30” N latitude and 74°00” to 79°12” E longitude (Figure 1). It comprises 8 districts with a total geographical area of 64,590 km2. Marathwada is affected by frequent anomalies in precipitation during the Monsoon season, which accounts for almost 80 percent of the annual precipitation. The annual precipitation of the study area is 882 mm [19]. Nearly three-quarters area of the study region is used for agricultural purposes hence natural calamities like drought are having a significant impact on the farmer's livelihood. According to government records, 422 farmers in Marathwada committed suicide in 2014 [20,21]. This was because of their inability to bear crop losses and a financial quandary made acute by water scarcity and an agrarian crisis. Among 422 suicides the 252 cases were due to unable to repay the agricultural loans because of uncertainty and unseasonal rainfall in the study area. There have been more than 117 farmer suicides in the first two months of 2017 [22]. According to a study by IIT Bombay, severe or extreme droughts have regularly occurred in major portions of Marathwada, in the last few decades. [23]. The majority part of the study area falls under the Godawari and Krishna river basin. The study area comes under the rain shadow region having 700mm annual mean rainfall, whereas, like a Beed district is reported 600 mm rainfall. Apart from the Godavari, no major river originates or flow through Marathwada except rivers like Purna, Shiva, Dudhna, Velganga, Sindhphana, Bindusara, etc. These are modest rivers, which carry little water as the harsh summer approaches.

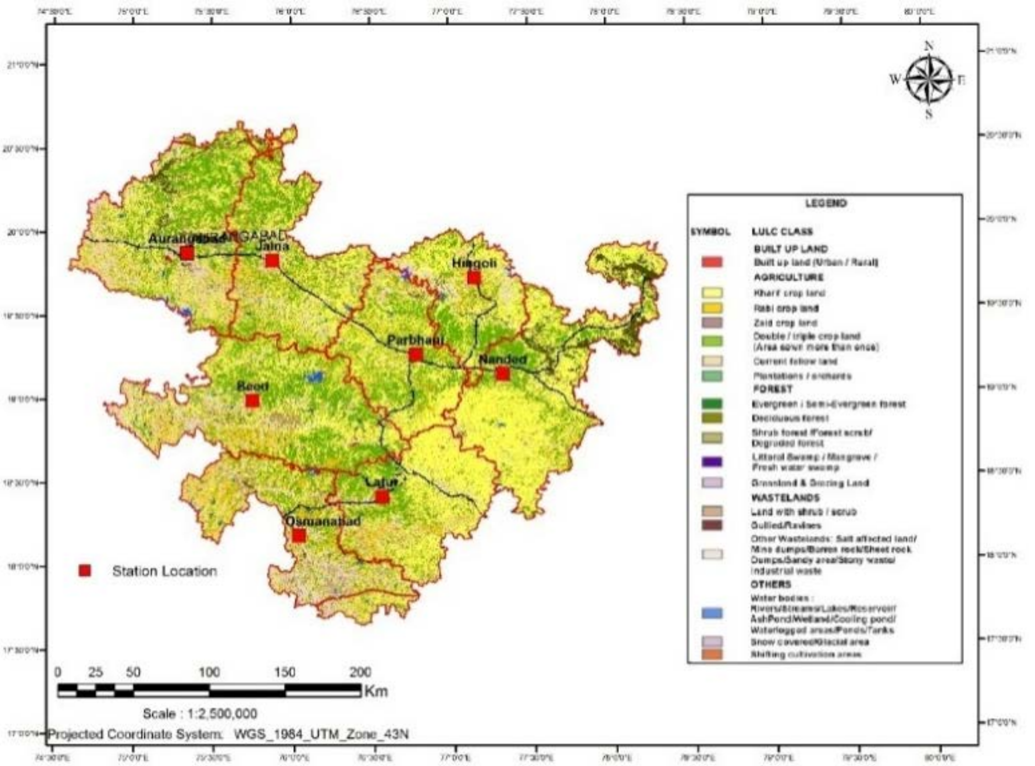

Figure 1. Land use and District Location map of Study Area

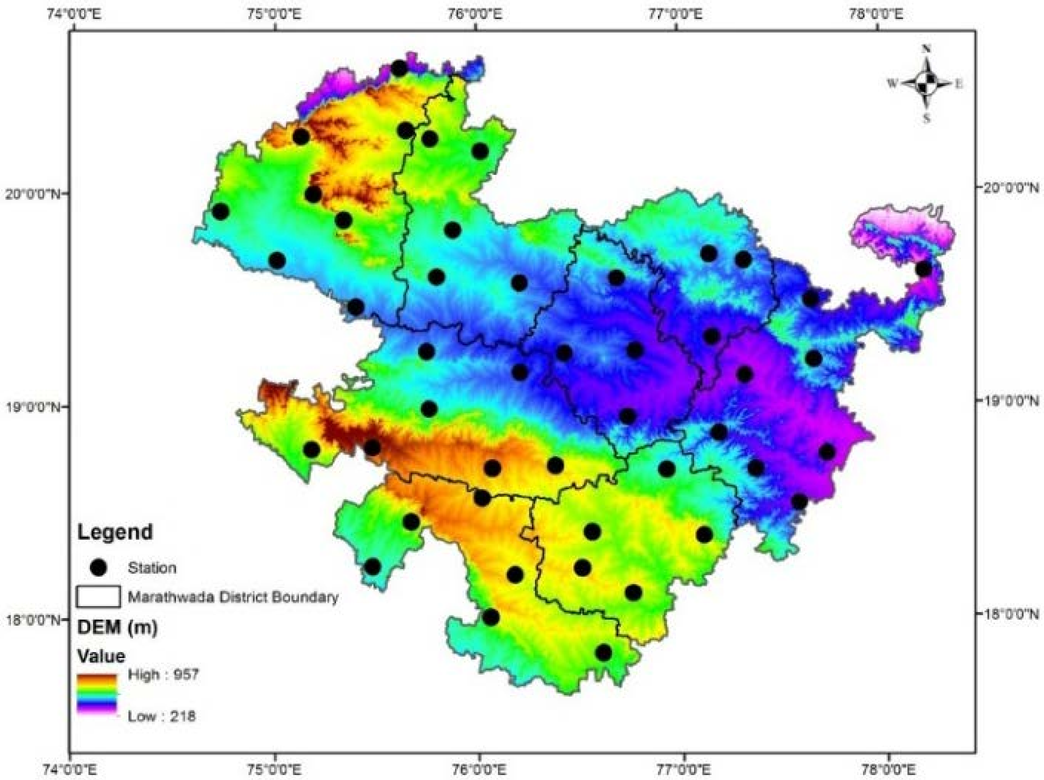

Figure 2. Digital elevation model (DEM) and location of meteorological gauging station in Marathwada

3. Materials and Methods

3.1. Data Description

3.1.1. Precipitation and Agriculture Production Statistics

Rainfall data were derived from monthly rainfall measurements for a period of 45 years (since 1970). These monthly rainfall data were used to compute the SPI for each station of Marathwada. The rainfall data were collected and compiled from various sources such as the Open Government Data Platform [24], India Meteorological Department [25], and Agro-Meteorological Department, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. The geographical coordinates of these stations were used to create a map of rain gauge stations using ERDAS Imagine software (Figure 2).

The historical crop statistics for cereals and pulses grown during crop season was obtained from the Department of Agriculture, Government of Maharashtra [26]. These statistics were used to compute the crop production of the crop season for 1970-2015.

3.1.2. Agriculture Production Data

The major crops (Tur,bajra, cotton-lint, green gram, soybean, urad, wheat, sunflower) of three cropping seasons viz. Kharif, Rabi, and zaid data are collected from [24] and State Agriculture Department [26]. The unit of production data is measured in a ton in this study. In addition to that, The Area (Hector unit) for all eight districts (Aurangabad, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad and Parbhani) of semi-arid Marathwada region, Maharashtra.

3.2. Methodology

3.2.1. SPI algorithm and Interpretation

The meteorological analysis consisted of computing the SPI, which was based on the long-term monthly precipitation record (1970-2017). The SPI is a dimensionless index, where negative (-) values represent dry conditions and positive (+) values indicate wet conditions.

Conceptually, SPI is equivalent to the Z-score used in statistics and is formulated as,

$$SPI = \frac{X_{ij} - \mu_{ij}}{\sigma_{ij}} \quad (1)$$

Where, SPIij is the SPI of the i^{th} month at j^{th} time-scale; X^{ij} is rainfall total for the i^{th} month at j^{th} time-scale $\mu^{ij}$and σ ij are long-term mean and standard deviation allied with an i^{th} month at the j^{th} time-scale. Since precipitation has a skewed distribution, the precipitation data are first transformed to a more normal or Gaussian distribution, and then calculated in a manner as demonstrated in Equation 1. Calculation of SPI normally based on the typical length of time (1, 2, 3, 6, 9, 12, 24 and 48 months of total precipitation) and directs how precipitation for an exact period compares with the complete record (possibly 25 or 50 or 100 years) at a given station. SPI at different time scales (1 or 3 months SPI) of a particular month represents a deviation in precipitation totals for the same month and current plus previous two months respectively. Based on SPI values a drought event occurs when index moving towards the intensity of -1.0 or lower. While positive SPI intensity value indicating the ending of the drought event. Continuity and progress of each drought event will be governed by the intensity of every month that the event continues.

Drought magnitude is the positive sum of the SPI for each month during the drought event [27]. The SPI can monitor drought on multiple time-scales. It is usually figured with five successively time scales, i.e. 1-, 3-, 6-, 9-, and 12-months, but the index is flexible concerning the period chosen. Which depends on the amount of information needed by the researcher. Moreover, being a standardized index, the SPI is particularly suited to compare drought conditions among different periods and regions with different climatic conditions. Monthly rainfall is not usually distributed, so the transformation is done by the derived SPI values that follow the normal distribution. The standard deviation of observed values of SPI would diverge from the long-term mean, for a normally distributed random variable [28]. One interpretation of the resultant values is presented in Table 1.

Table 1. Classification of drought conditions according to the SPI

SPI Values	Classification
2.0+	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
-2.0 and Less	Extremely Dry

3.2.2. Precipitation Data Processing

The 3-months SPI was calculated for rainfall stations of the study area using monthly rainfall data of the Kharif crop-growing season (June-October) from 1970 to 2017. The threshold for indicating the severity of meteorological drought based on SPI has been adopted from Table 1. The different classes used for the reclassification of the SPI maps.

Previously, the SPI values were interpolated by kriging considering grid size of 8 km. The kriging method provides optimal spatial evaluation both for drought and flood [29]. In the present work, an interpolation by ordinary kriging did not give appropriate results. So, no particular semi-variogram model parameters could be recognized due to least number of rainfall measure stations.

Therefore, the most commonly used method, inverse distance weighted (IDW) was chosen to interpolate the SPI values. The IDW assumes that things are close to one another are more similar than those farther apart. It means rainfall or its derived amount at any desired location is interpolated from the given data using weights that are based on the distance from each rainfall gauge and the desired location [30].

This approach produces a smooth surface of rainfall and the interpolation of SPI datasets was performed by the IDW function in-built within ArcGIS 10.2 software.

The interpolated maps have been reclassified into different drought severity classes in Table 1. The 3-months precipitation SPI interpolated data during the 1970-2017 period were used for assessment of drought and the growth of agricultural production during the selected dry and wet year. For each of 45 years (1970-2017) the interpolated 3-months SPI of rainfall has been categorized into the different categories of drought. The resultant maps were added to obtain the frequency of drought occurrence over a period of 45 years (1970-2017). Three model years for drought (1972, 2000 and 2014) along with wet conditions (1983, 2005 and 2016) have been chosen to present the drought severity classes in these two different conditions.

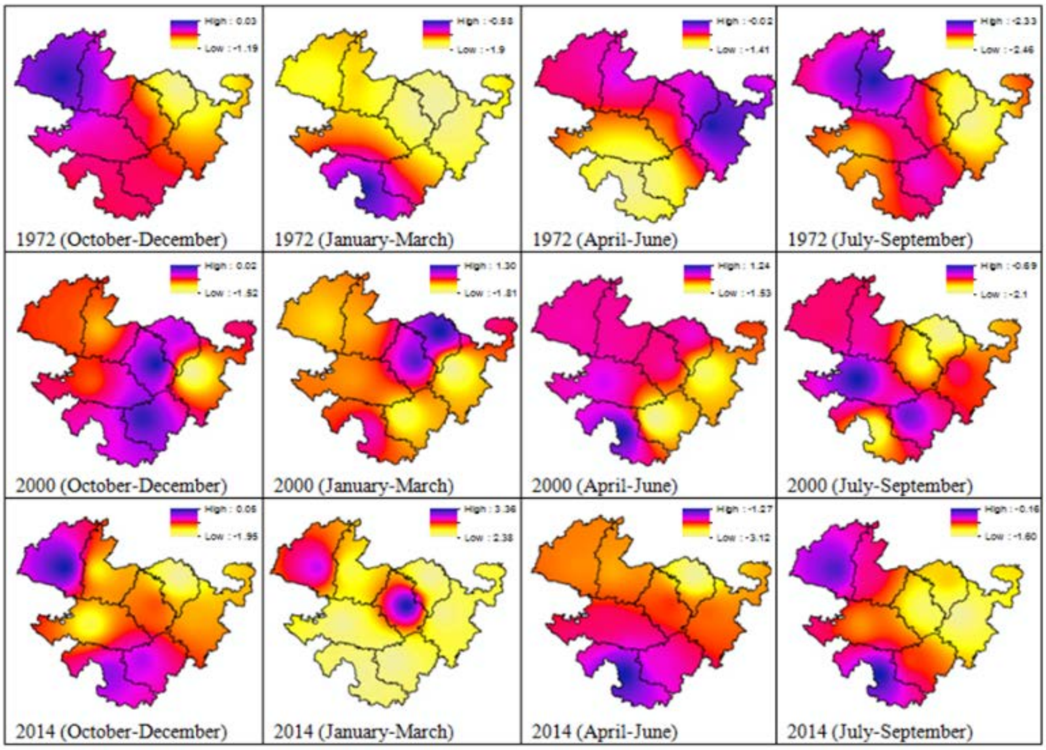

Figure 3. Spatial forms of 3-monthsSPI over 3 months during drought Year (1972, 2000 and 2014)

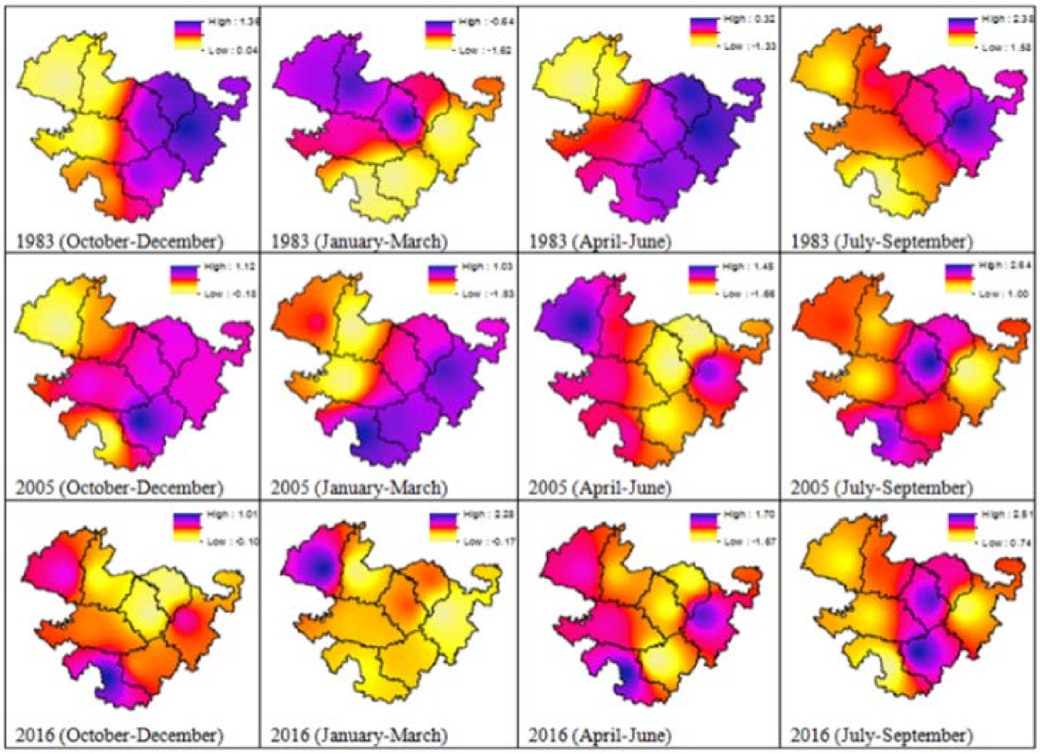

Figure 4. Spatial forms of 3-months SPI over 3 months during wet Year (1983, 2005 and 2016)

Table 2. Crop area and production assessment of the study area

Marathwada	2000		2005	
	Area (Ha)	Production (t/Ha)	Area (Ha)	Production (t/Ha)
Arhar/Tur	442200	196700	433800	320300
Bajra	507400	391400	431900	372800
Cotton(lint)	955000	464900	1079800	1186500
Moong (Green Gram)	278100	81000	179000	78000
Soybean	63300	65800	646000	766800
Urad	261400	87800	208100	95400
Gram	222400	109700	346700	226100
Wheat	243800	320900	298100	373600
Sunflower	129100	70700	175900	107600
Total	3102700	1788900	3799300	3527100

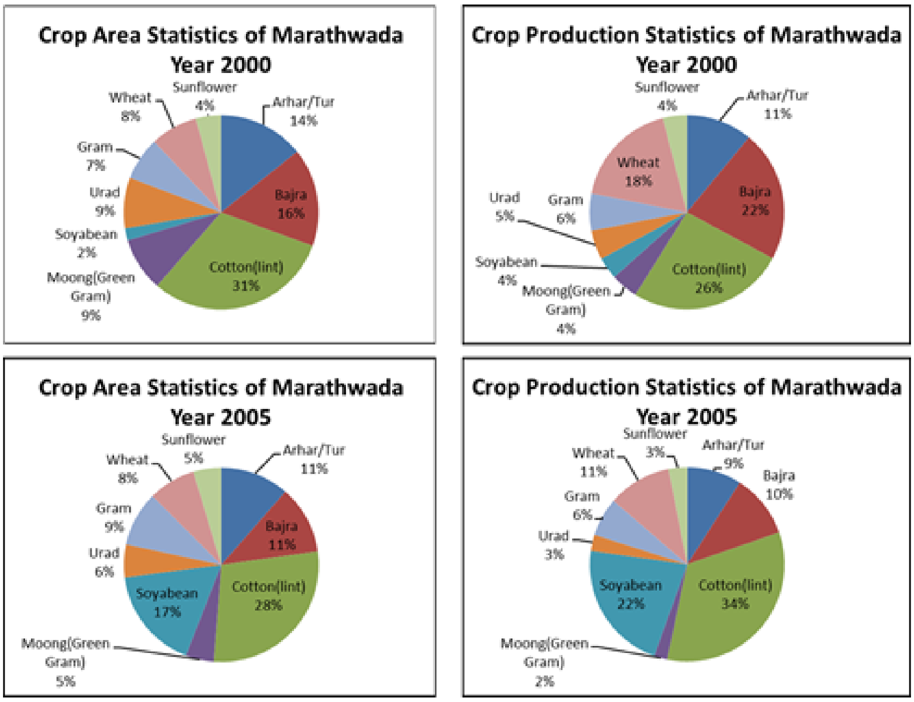

Figure 5. Crop area and production assessment

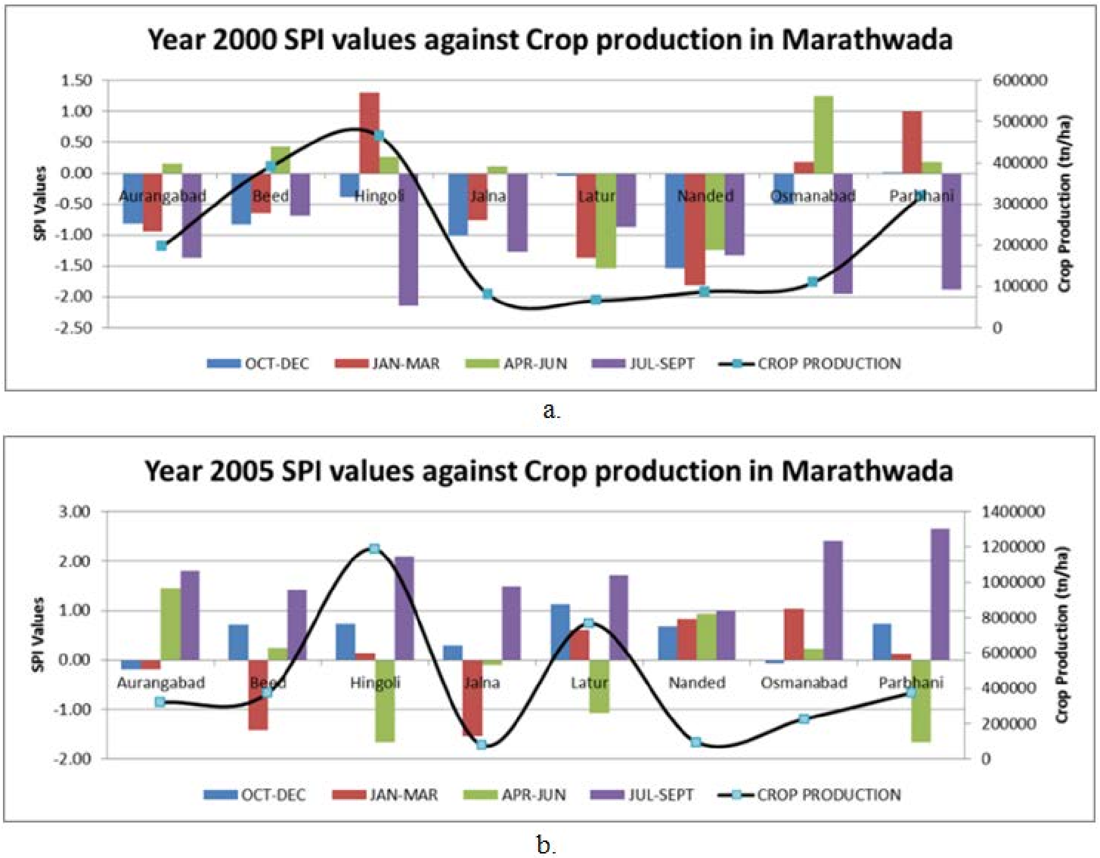

Figure 6. Crop production and SPI values (**a.** 2000 and **b.** 2005)

4. Results

4.1. Agriculture Production Data Assessment

Crop production statistics have been collected district-wise for the entire Marathwada region of two years i.e. 2000 and 2005. It is including all major crops like bajra, cotton, wheat, gram, soybean, green gram, urad, and sunflower. In addition to that, the area and production for all eight districts of semi-arid Marathwada region, Maharashtra calculated in percentile (Table 2 and Figure 5) [24,26]. The agricultural drought assessment based on the SPI values was used for exploring the spatial pattern of drought and also through the comparison of crop production data to the precipitation indexing values shown in (Figure 6). The spatial pattern of SPI for the dry year (1972, 2000, and 2014) shown in Figure 3, almost all areas of the Marathwada region experienced drought. The spatial pattern of SPI values in drought years 1972, 2000 and 2014 in the growing crop season i.e. June to September, shows that among the three-drought year, the year 1972 extremely dry and the SPI values vary in between -2.33 to -2.46 so the entire Marathwada region suffers from severe drought.

4.2. SPI and Drought Assessment

The interpolated maps of SPI, for drought (1972 and 2000) and wet (1983 and 2005) years have been presented to show the pattern of SPI during these years (Figure 3 and Figure 4).

In the last 4 years, the study region has been facing extremely cruel weather. In the monsoon season, which is the lifeline of the rainfed region has been playing truant. Last year, the region experienced the highest rainfall deficit in the past 10 years at -42%. In both districts (Beed and Parbhani in 2014), it was higher than 40%, leading to a severe water crisis. The 3-months (January to March) SPI value for the dry year 2014, shows the temporal dynamics of above-normal precipitation distribution in Marathwada. In addition to the dismal rainfall, Marathwada has been battered by unseasonal rainfall and hailstorms in 2014 months of February, March, and November. Destroying Rabi plantations and negative SPI values during the cropping season of the year indicate that there was rainfall shortfall in these areas during the southwest monsoon season, i.e. during June-September.

In 1972, 2000 and 2014, the spatial pattern of 3-months SPI across critical months for Kharif crops depicts negative SPI, with a majority of areas having an SPI value below or near to -2.0. Thus, the spatiotemporal evolution of the SPI indicates that during 1972, 2000 and 2014 was a severe drought year taking into account the degree, duration, and extent of a negative SPI.

Furthermore, the 3-months SPI patterns of September for rainfall stations in Marathwada, Maharashtra (Figure 7) reveal that in 1972 the SPI dropped as low as -2.77 and most of the stations had 3-months SPI below -1.5. These results further indicate, that 1972 was a most severe drought year and SPI of the last 10 years shows that receptivity of shortfall rainfall during the monsoon season is negative SPI values and unseasonal heavy rainfall so farmers crop production was affected not only during Kharif but also Rabi and Zaid crop season.

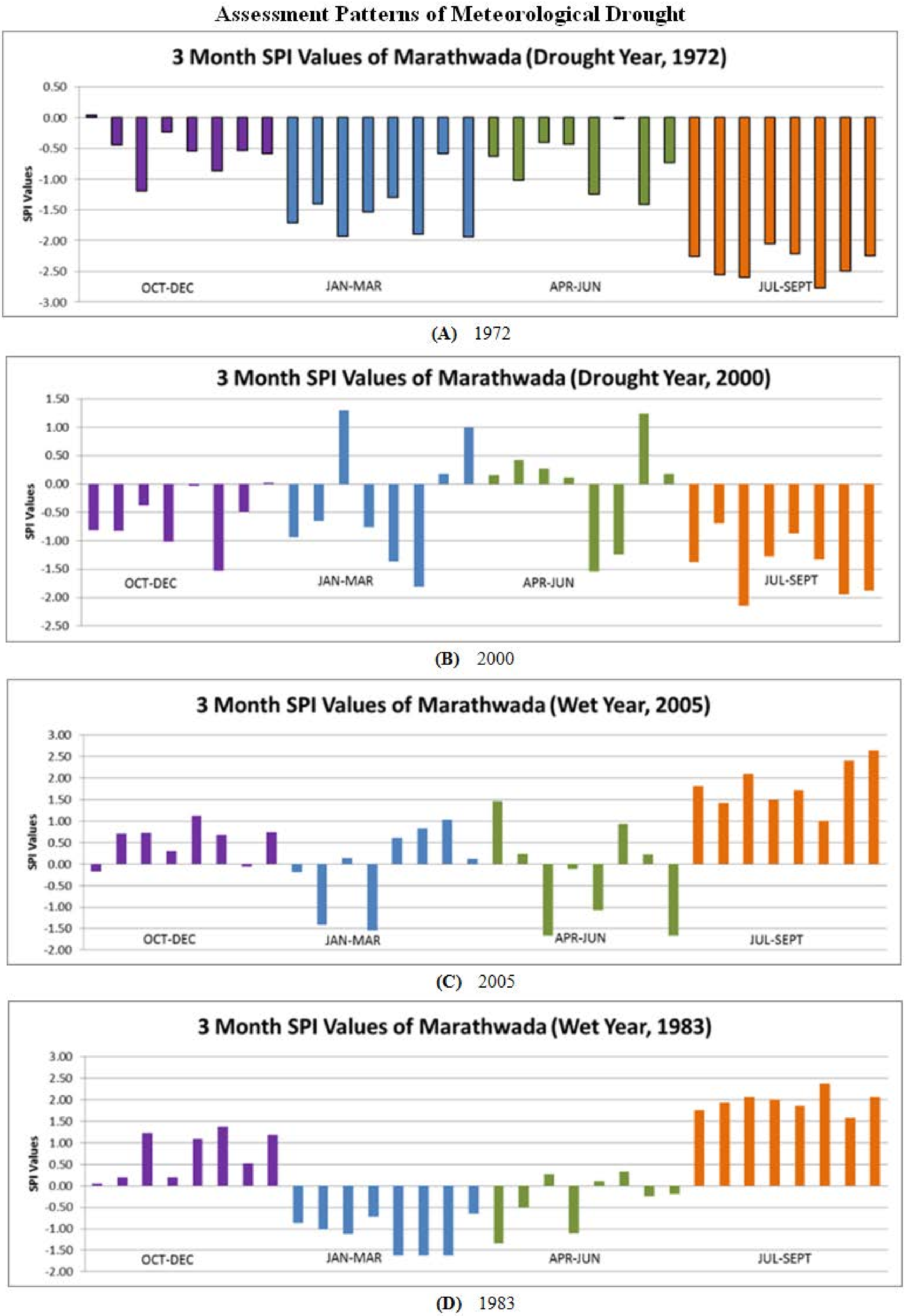

Figure 7. Three-months SPI for drought years **(A)** 1972 **(B)** 2000 and wet years **(C)** 2005 and **(D)** 1983

5. Discussion

The study carried out for drought assessment in the semi-arid region of Marathwada. The results reveal not only understand the behavior of meteorological and agricultural drought but also to analyze its impact on the socio-economic livelihood of the population and farmers of this region. Which is directly related to the life of the individual in the region, according to [20] the highest number (125) suicide was reported in drought-affected Beed district and lowest (42) suicide in the Hingoli district and also in another remaining district of Marathwada, which comes under rain shadow region and it receives approximate average 700mm rainfall.

Generally, the drought indices are permitted to detect and assess the onset of drought events and to understand the severity. Also, it allows an evaluation of spatial and temporal feature drought as well as comparative assessment between different regions [8].

According to [28], it can be considered as the first step for assessing regional drought. Needless to say, that it should be followed by a more comprehensive approach associated with predicted damages caused by drought events. Furthermore, the procedure may be used for assessing the drought potential of each unit area. The advantage of the proposed methodology of assessment of drought is its simplicity, transparency, and universality. It produces a quick result that requires low infrastructure, understandable, and compatible with the result of another region. Therefore, proposed methodology can be an initial basis for developing a drought assessment and evaluation system and also the estimation and management, it is the basis to make a Decision Support System (DSS) for adaptation and mitigation plan for drought events of government agencies and organizations.

6. Conclusion

In this study, the meteorological and agricultural drought in eight districts of Marathwada was assessed with precipitation data and SPI (3-months' time scale) values. The result of agricultural drought assessment compared and verified by crop production data.

The SPI is useful to present the Spatio-temporal assessment of meteorological drought at a seasonal level in eight districts. Based on SPI values, it is possible to categorize 1972, 2000, and 2014 drought years and years 1983, 2005, and 2016 are wettest years from 1970-2017 precipitation data of all stations. Whenever SPI values are showing below or equal to -1.0 indicating occurrence of drought. The collected negative values of SPI during crop growing season can be useful in the measurement of drought severity. Drought Assessment will be useful for developing drought preparedness plans and formulating drought mitigation strategies in the Marathwada region.

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