



## Drought monitoring using multi-time-scale Standardized Precipitation Index

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### ABSTRACT

Drought is a natural hazard that affects almost all regions. In recent years, it has become more intense and frequent causing adverse impacts on the socio-economic conditions of the country. The primary cause of drought development is the deficiency in precipitation impacting crop production during *kharif* with a follow-up effect also in crops grown during *rabi*. The present study was carried out over one of the most drought-prone regions of India, i.e. Marathwada region, Maharashtra to characterize meteorological drought through the Standardized Precipitation Index (SPI) during both *kharif* and *rabi* crop growing seasons. SPI was computed at different time scales (1, 3, 6, 9 and 12-month) using *in-situ* precipitation data for 35 years (1980–2014). Drought area observed by multi-time-scale SPI was correlated with drought declared by the Government and foodgrain production for 15 years (2000–14). It was observed that none of the time scales of SPI had a significant correlation with declared drought. However, correlation analysis of multiscale SPI with foodgrain production showed that 3-month SPI had a significant correlation ( $r = -0.72$ ) during *kharif*, while a low correlation was observed between multiscale SPI and foodgrain production for *rabi* season. Therefore, information observed by SPI would be useful if it could be combined with other biophysical conditions and drought indices to increase its accuracy and reliability for effective drought characterization and monitoring.

**Keyword:** Marathwada, Meteorological drought, Standardized Precipitation Index (SPI), Time-scale

About 16% of the total area of India is under different degrees of water stress and about 50 million people are affected by drought annually (Dutta *et al.* 2015), which has a huge adverse impact on socio-economic conditions mainly on the rainfed region. India has a monsoon climate and receives the majority of precipitation (about 75%) from the South-West monsoon during the period June to September which supports water demand for crops. A delay or failure in the monsoon causes dry spells or drought in the region that affects crop growth and development leads to a decline in crop production during *kharif* crop growing season. The *rabi* crop growing season follows the *kharif* and is characterized by limited rainfall, cooler average temperature and shorter days, resulting in lower potential crop evapotranspiration (Kholová *et al.* 2013). If sufficient precipitation occurs in the rainy season, the soil profile gets fully charged with moisture which supports the crops to be grown under *rabi* season. However, if the antecedent season (*kharif*) does not get sufficient rainfall or has dry spells, the soil profile would not be recharged sufficiently and hence water stress situation could be experienced in *rabi* crops

as well. Generally, less attention was paid to quantify and monitor the pattern of drought across seasons.

Information of onset, progression and areal extent could be contributing to proper planning and management of water resources. Many indices and methods have been developed and are used to determine the intensity of meteorological drought. However, Standardized Precipitation Index (SPI) is comparatively better than other indices for its simplicity in terms of computation and data requirement (Bordi and Sutera 2008, Angelidis *et al.* 2012). It is also effective during the winter months and not adversely affected by topography (Hayes *et al.* 1999). In this present study, meteorological droughts for both *kharif* and *rabi* crop growing seasons were characterized through SPI. The main objective of this study is to identify the time scale of SPI which is more suitable to observe the drought events in this region during both *kharif* and *rabi* crop growing seasons.

### MATERIALS AND METHODS

**Study area:** The study area comprises nine districts of Maharashtra, India covering 9.4 Mha areas namely Ahmednagar, Aurangabad, Beed, Jalna, Latur, Osmanabad, Sangli, Satara and Solapur. Geographically, the region is located between 16°42'35.72"N to 20°39'11.99"N latitude and 73°32'39.10"E to 77°17'43.49"E longitude and is characterized by a hot semi-arid climate with dry summer and cool winter. The Marathwada region of Maharashtra comes under the drought-prone areas and has historically

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faced many drought events of varying magnitudes. Topographically, it receives less precipitation compared to the rest of Maharashtra, thereby leading to frequent dry spells and drought conditions. It receives an average annual rainfall of about 550 mm, which mainly occurs during the monsoon period (June to September).

#### Data used

The daily time series data of precipitation for 35 years (1980–2014) from 17 rain-gauge stations was obtained from the Department of Hydrology, Nashik, Maharashtra, India.

Crop production statistics of major foodgrain crops grown in these districts were collected from the Department of Agriculture, Government of Maharashtra for 15 years (2000–2014) to validate multiscale SPI during both *kharif* and *rabi* crop growing season.

Drought years declared by the State Government during 2000–2014 were obtained from the Department of Agriculture & Cooperation and Farmers Welfare (DAC&FW), Ministry of Agriculture and Farmers Welfare (MoA&FW), Government of India.

*Computation of Standardized Precipitation Index:* Standardized Precipitation Index (SPI) was used as an indicator of meteorological drought. It was developed by McKee *et al.* (1993, 1995) for estimating wet or dry conditions based on precipitation variables. The SPI calculation procedure was adopted from WMO, SPI user guide (Svoboda *et al.* 2012). The SPI program (SPI\_SL\_6.exe) is available on <http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx> used for computation.

Daily time series data of precipitation for 35 years of 17 rain-gauge stations of the study region were arranged into monthly precipitation and input file were prepared as per the desired format of the program to compute SPI. SPI was calculated for multi-time-scale, i.e. 1-month (June), 3-month (June– August), 6-month (June–November), 9-month (June–February) and 12-month (June–May) for *kharif* crop growing season and 1-month (November), 3-month (November–January), 6-month (November–April), 9-month (November–July) and 12-month (November–October) for *rabi* crop growing season. The drought classification used in this study was adopted from Hayes *et al.* (1999) (Table 1).

The spatial mapping of meteorological droughts was obtained by interpolating SPI values using the spline interpolation technique (Bhuiyan *et al.* 2006, Vicente-Serrano 2007) in ArcGIS 10.5 and the area under each drought category was computed.

*Drought severity based on drought-affected areas:* The severity of a drought year was classified based on India Meteorological Department (IMD) guidelines. IMD specifies that when the spatial coverage of drought is more than 40% it will be called as “All India severe drought year” and if the area under drought is found to be in the range of 20–40%, then, it could be considered as moderate drought (Attri and Tyagi 2010). Hence, the year, when the area under drought observed by drought index (SPI) was found to be more than 40%, was designated as a severe drought year, 20–40% as

Table 1 Drought classification scheme (Hayes *et al.* 1999)

SPI	Classification
$\geq 2.0$	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
$\leq -2.0$	Extremely dry

moderate drought year and less than 20% as considered as normal year in the region.

*Validation of Standardized Precipitation Index (SPI):* The ground observations of the magnitude of drought events are not available. Therefore, to evaluate the drought monitoring potential of SPI, indirect observations/ approaches like impacts on crop production and drought years declarations for the study region were used in the present study.

*Correlation with foodgrain production:* To identify the appropriate time-scale of SPI for characterizing and monitoring meteorological drought in the region, a correlation analysis between multi-time-scale SPI and foodgrain production was carried out. Foodgrain production for 15 years (2000–2014) during *kharif* and *rabi* in the study region was used for analysis.

*Comparison with the Government drought declaration:* The drought declared by the Government for the study region was compared with the drought observed by multi-time-scale SPI. Year-wise drought areas affected for the Government drought declaration were computed and classified based on IMD guidelines. As Government drought declaration data was available only for *kharif* season thus, this comparison was carried out for *kharif* season using 15 years (2000–2014) dataset.

## RESULTS AND DISCUSSION

Meteorological drought events in the study area were analysed using the Standardized Precipitation Index (SPI). SPI value was calculated for the period of 35 years (1980–2014) for different time scales 1, 3, 6, 9 and 12 months for both *kharif* and *rabi* crop growing season. The drought events for 15 years (2000–2014) were validated against crop production and drought areas declared by the Government.

*Assessing kharif-drought monitoring potential of SPI:* Multi-time scales (1, 3, 6, 9 and 12-month) of SPI were used to characterize meteorological drought events during *kharif* season. Each time-scale observed different degrees of drought severity and drought coverage. The drought area (%) observed by multiscale SPI from the year 2000–14 was shown in Fig 1. One-month SPI identified 2005, 2008 and 2011 as drought years where more than 40% area was found to be drought-affected. Three-month SPI observed about 54% area under drought in the year 2008. Six-month

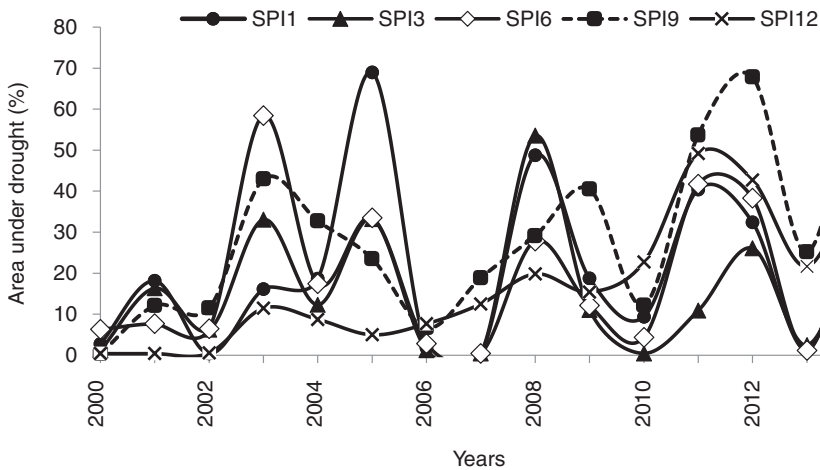


Fig 1 Area under drought (%) observed by multiscale SPI during *kharif* crop growing season.

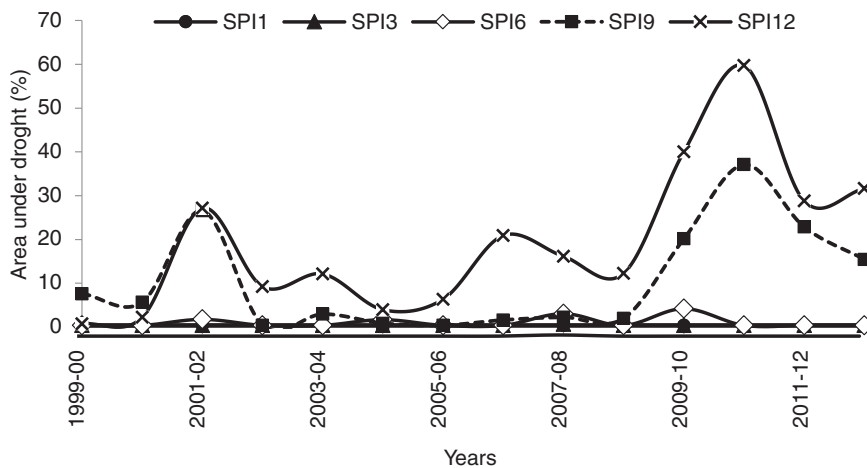


Fig 2 Area under drought (%) observed by multiscale SPI during *rabi* crop growing season.

SPI observed drought area more than 41% in the years 2003 and 2011. Nine-month SPI observed the years 2003, 2009, 2011, 2012 and 2014 having more than 40% area under drought. Twelve-month SPI also observed drought in years 2011, 2012 and 2014 having area under drought was more than 40% (Fig 1).

*Assessing rabi-drought monitoring potential of SPI:* Like *kharif*, 5-time scales (1, 3, 6, 9 and 12-month) of SPI were also used for *rabi* crop growing season to study the drought dynamics in the region. One, three and six-month SPI could not observe any drought event during the period from 1999-2000 to 2013-14. However, 9-month SPI observed drought events in the year 2011-12, 2012-13 2002-03 and 2010-11 was having a magnitude of 37%, 23%, 26% and 20% respectively. Whereas, 12-month SPI observed drought during the year 2011-12, 2010-11, 2013-14, 2012-13 and 2002-03 with a varying magnitude of droughts 60%, 40%, 30%, 28% and 27%, respectively (Fig 2). This indicated that SPI of a shorter time scale could not observe drought events during *rabi* crop growing season. However, the response by medium-term SPI (9, 12-month) was found to be better than the shorter time scale of SPI.

*Validating drought monitoring potential of SPI:* Drought monitoring potential of multi-time-scale SPI was validated using foodgrain production and declared drought by Government for the study region.

*SPI vs. foodgrain production for kharif season:* The drought area (%) observed by multiscale SPI during *kharif* season was correlated with foodgrain production. The correlation analysis showed that 3-month SPI had a significant correlation ( $r = -0.72$ ) with foodgrain production (Table 2) (at 0.01 level of significance) followed 6-month SPI which has a significant relationship (at 0.05 level of significance). The negative sign indicates that foodgrain production is inversely proportional to drought. These analyses indicated that the 3-month time-scale was found to be more closely related to foodgrain production. Several studies reported that a multi-temporal analysis of SPI showed that a shorter time-scale of SPI captures drought events more often than a longer time scale (Morán-Tejeda *et al.* 2013, Thavorntam *et al.* 2015). Zuo *et al.* (2019) reported that the  $R^2$  value at the 3-month scale was greater than that at 6-month in their study in Northeast China. Portela *et al.* (2015) used 3-month SPI for drought analysis in Slovakia. Dodamani *et al.* (2015) found that 3-month SPI showed better

results for the drought sensitivity in Maharashtra. Zambrano *et al.* (2016) also showed that the 3-month SPI has a better correlation with VCI (Vegetation Condition Index) with an overall correlation of 0.63. Sahoo *et al.* (2015) also found that 3-month SPI has a good correlation with VCI for the Mewat region, India. The 3-month time scale of SPI (June to August) could be able to capture drought conditions better than other time scales because these three months (June, July and August) are the most important period for plant growth and development and sufficient availability of soil moisture during this time lead to having good crop production. The South-West monsoonal precipitation takes place during the month June-September hence, this period supplies crop water demand, especially in the rainfed regions and ensuring good crop production. Shortage of water supply cause dry spells that may impact crop production in this region. Therefore, the 3-month time scale of SPI was more suitable to observe the drought situation in the region.

*SPI vs. foodgrain production for rabi:* The drought area (%) observed by multi-time-scale SPI during *rabi* crop growing season was correlated with *rabi* foodgrain production. Correlation analysis observed a low correlation

Table 2 Correlation coefficient (r) of multi-time-scale SPI with foodgrain production and drought area declared during *kharif* and *rabi*.

SPI (Time-scale)	<i>Kharif</i>		<i>Rabi</i>	
	Foodgrain production	Declared Drought	Foodgrain production	Declared Drought
1-month	-0.47	-0.07	ND	-
3-month	-0.72**	0.02	0.28	-
6-month	-0.60*	0.35	0.38	-
9-month	-0.49	0.36	-0.30	-
12-month	-0.13	0.06	-0.02	-

\*Significant at 0.05 level and \*\* significant at 0.01 level; ND: 'r' cannot be defined

between all the scales of SPI and foodgrain production. Out of these time scales, 9-month SPI showed maximum correlation ( $r = -0.30$ ) (Table 2). This is because the fact that the production during *rabi* was not only dependent on *rabi* season precipitation but also had the impact of antecedent *kharif*. Thus, short-term SPI could not be able to observe drought events while 9-month SPI could able to capture drought in the region. Contreras and Hunink (2015) also reported the highest correlations between 9-month SPI and productivity of vineyards because antecedent rainfall accumulated on a longer time scale. Hence, crops grown during *rabi* season could be reflected better by the medium-term time scale compared to a short-term time scale of SPI.

*SPI vs. Government drought declaration(s)*: For comparing the drought monitoring potential of multi-time-scale SPI with the government drought declaration, the government-declared drought data for *kharif* season for 15 years (2000-2014) was collected and analysed for percent drought-affected areas in the study region. The analysis revealed that severe drought years during 2000, 2001, 2002, 2003, 2004, 2009, 2011 2012 and 2014 while normal years were observed during 2005, 2006, 2007, 2008, 2010 and 2013 in the study area.

The so computed year-wise percent drought-affected areas declared by the government were compared with the SPI-based percent drought-affected areas. The correlation analysis showed that none of the time scales of SPI were strongly correlated with government-declared drought-affected areas. The correlation coefficient (r) ranged from -0.07 (1-month SPI) to 0.36 (9-month SPI) (Table 2). The preliminary reason for low correlation could be the difference in the technique of estimation of drought-affected areas. SPI observed drought was spatio-temporal in nature, whereas drought declared by government was a lumped approach, e.g. the entire district (100% area of the district) was under drought in the case of drought declaration while nil area under drought in the case drought was not declared. It was also observed that droughts were not declared by the government in the years 2005 and 2008, whereas SPI (1, 3, 6 and 9-month) observed more than 23% area under drought

in the region for those years. It means based on SPI these two years (2005, 2008) could have been drought years. This indicated that SPI with different time-scale solely cannot be used for drought characterization and monitoring rather it should be combined with other bio-physical drought indicators as well.

Meteorological drought is more prominent during *kharif* than *rabi* especially in the rainfed region where crop production mainly depends on rainfall. Also, water for irrigation available in reservoirs and canals relies on the amount of rainfall, whereas crops of *rabi* depend on precipitation as well as residual soil moisture of antecedent season. Multi-time-scale SPI was used to quantify the quantum of drought in the study area and it was observed that short-term SPI (3-month) was found suitable to observe the impact of droughts on foodgrain production for *kharif*. However, foodgrain production during the *rabi* was more related to medium-term (9-month) SPI. As SPI monitors drought dynamics only based on precipitation, therefore, biophysical parameters and remote sensing indicators could be used together to present better pictures and perceptions of drought for effective characterization and monitoring.

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