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Comparison of SPI and SPEI indices for drought assessment in eastern part of Satara district of Maharashtra, India

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सार – सूखे की स्थिति का आकलन करने के लिए आमतौर पर सूखे सूचकांक का उपयोग एक उपकरण के रूप में किया जाता है। प्रस्तावित अध्ययन में, हमने भारत के महाराष्ट्र के सतारा जिले के पूर्वी भाग के लिए मानकीकृत वर्षा सूचकांक (एसपीआई) और मानकीकृत वर्षा वाष्पोत्सर्जन सूचकांक (एसपीईआई) का उपयोग करके मौसम संबंधी सूखे की स्थिति का आकलन किया है। इस जांच के लिए सोलह मौसम विज्ञान स्टेशनों के लिए 1979 से 2014 की अवधि के वर्षा और तापमान के आंकड़ों का उपयोग किया गया है। वही डेटा जलवायु पूर्वानुमान प्रणाली पुनर्विश्लेषण (सीएफएसआर) वेबसाइट से एकत्र किया गया था। परिणाम से पता चलता है कि, एसपीआई के अनुसार, गंभीर सूखे की स्थिति स्टेशन 2, 3, 8, 9, 11 और 12 पर अधिक प्रमुखता से देखी गई है। स्टेशन 1, 4 और 7 पर मध्यम सूखे की स्थिति देखी गई है। एसपीआई से पता चलता है कि उल्लेखनीय गंभीर सूखे की घटनाएं वर्ष 1983 से 1988, 1992, 2000 से 2004, 2007, 2008, 2012 और 2013 में पाई गई थीं। एसपीईआई के अनुसार, प्रत्येक स्टेशन ने सूखे और गीले दौर का अनुभव किया है। स्टेशन 2, 3, 5, 6, 8, 9, 11, 12, 15 और 16 पर अत्यधिक शुष्क स्थितियाँ देखी गई हैं। स्टेशन 1, 4 और 7 पर मध्यम शुष्क स्थितियाँ प्रमुखता से देखी गई हैं। एस.पी.ई.आई. से पता चलता है कि उल्लेखनीय अत्यधिक सूखे की घटनाएँ वर्ष 1985 से 1990, 1993, 2000 से 2007, 2009, 2013 और 2014 में पाई गई थीं। सहसंबंध विश्लेषण से पता चला कि एस.पी.आई. और एस.पी.ई.आई. मूल्यों के बीच एक मजबूत रैखिक संबंध है।

ABSTRACT. Drought indices are normally used as a tool to assess drought conditions. In the proposed study, we have assessed meteorological drought conditions using the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI)for the eastern part of the Satara district of Maharashtra, India. For this investigation, precipitation and temperature data have been used from the period of 1979 to 2014 for sixteen meteorological stations. The same data was collected from the Climate Forecast System Reanalysis (CFSR) website.The result reveals that, according to SPI, severe dry conditions are more prominently observed at stations 2, 3, 8, 9, 11 and 12. Moderate dry conditions are observed at stations 1, 4 and 7. The SPI reveals that notable severe drought events were found in the years 1983 to 1988, 1992, 2000 to 2004, 2007, 2008, 2012 and 2013. According to SPEI, every station has experienced a dry and wet period. Extreme dry conditions are notably observed at stations 2, 3, 5, 6, 8, 9, 11, 12, 15 and 16. Moderate dry conditions are prominently observed at stations 1, 4, and 7. The SPEI reveals that notable extreme drought events were found in the years 1985 to 1990, 1993, 2000 to 2007, 2009, 2013 and 2014. The correlation analysis revealed that there is a strong linear relationship between the SPI and SPEI values.

Key words – Drought Index, Standardized Precipitation Index (SPI), Standardized Precipitation Evaporation Index (SPEI).

1. Introduction

Drought is the most complex meteorological event that has societal and environmental consequences. (Wilhite 2007). It is one of the most costly, deadliest and widespread natural disasters among all natural disasters, which impacts on the economic and agricultural sectors, water resources, natural ecosystems and community activities (Mishra and Singh 2010). Because of its complex nature and extensive occurrence, it is challenging

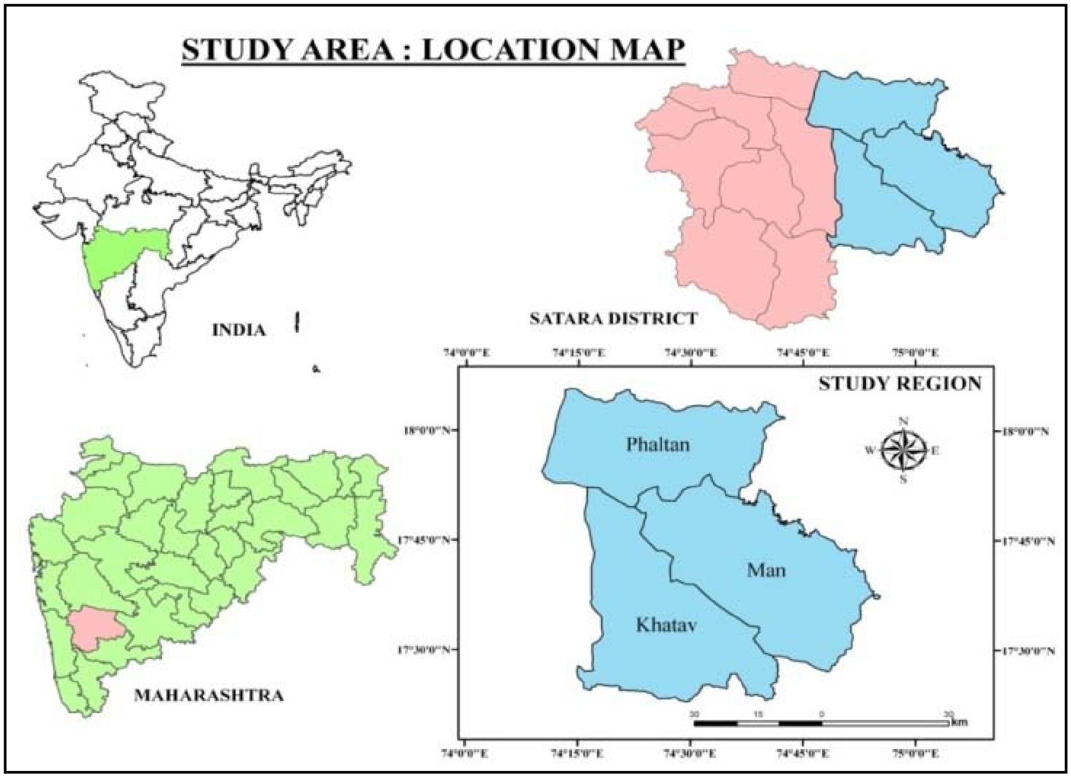

Fig. 1. Geographical Location of the Study Area

to define drought. Drought is usually defined as precipitation deficits during a specific period (Törnros T. and Menzel, L. 2014).

Drought indices are very useful for capturing a drought's physical features, such as its frequency, duration, severity and spatial extent (Wilhite and Glantz, 1985). These features are useful for objective and quantitative assessment of drought severity and are usually represented by the use of drought indices, which are based on different climatic and hydrological variables that may reflect different aspects of drought (Vicente-Serrano *et al.* 2012; Rajsekhar *et al.* 2015; Sahoo *etal.*2015). Scientists have put a lot of effort into developing different drought indices and their strengths and limitations have been widely discussed in recent years (Benitez 2014; Wang *et al.* 2015; Yan *et al*. 2014, Guttmann 1998). At present, there is no specific index that will be able to adequately characterize the drought conditions in every place and every time period (Svoboda *et al*., 2017), because, severity, spatial extent, speed, development and duration of drought are different in different regions.

The SPI (McKee *et al.* 1993) is a powerful, flexible index that is easy to calculate. Precipitation is the only required input parameter. Besides, analyzing dry periods is equally effective at analyzing moisture. The SPI has an intensity scale in which both positive and negative values are possible, which correlate directly to wet and dry events.Historical precipitation records for any location help develop a probability of precipitation that can be computed at any number of timescales, from 1 month to 48 months or longer. The SPEI was proposed by Vicente-Serrano *et al*. (Vicente-Serrano *et al*.2010. The SPEI is as flexible as SPI but includes the demand forPotential Evapotranspiration (PET), a key component of the water cycle (Oki and Kanae, 2006). There is still high uncertainty and a lot of disagreement over the global drought trend due to inconsistencies in techniques and the indicators used (Seneviratne *et al*., 2012). Therefore, much more research is needed to bridge this gap, especially at local levels.

This study focused on a comprehensive analysis of the meteorological drought conditions in the eastern part of the Satara district of Maharashtra state, India, during the period 1979 to 2013. The droughts are successively assessed based on the SPI and SPEI indices for various time lags, the multi-scale patterns, the trend, and the temporal extent, as well as the correlation analysis between SPI and SPEI.

This paper evaluates the SPI and SPEI on 3, 6, 9 and 12 month time scales, computed using a long time series (1979-2013) of monthly precipitation data at 16 stations in the study area.

2. Study area and its climatology

India is one of the most vulnerable and drought-prone countries in the world (Mishra and Singh 2010). Since the mid-1990s, India has experienced frequent drought conditions, particularly in western India. The present study is focused on the drought-prone area of the eastern Satara district of Maharashtra (Fig. 1). The entire study area is located in the southwestern part of Maharashtra. It extends between 17° 22' 57" to 18° 6' 03" North latitude and 74° 09' 38" to 74°55' 32" East longitude. The total area of the proposed study is 3894 km^2 and it comprises Man, Khatav and Phaltan tehsils of Satara district. The average height of the study area is about 713 meters. The maximum height is 1004 meters, which is observed towards the western part of the study area. The lowest elevation is observed towards the extreme easternpart, where the height is 423 meters.

Study area experience a semi-arid climate with distinct seasonal patterns in rainfall and wind. The monsoon season (June-September) provides most of the annual rainfall, though it is limited (400-600 mm) due to the leeward effect of the Western Ghats. Rainfall is often concentrated in short, intense spells. Post-monsoon (October-November) rainfall is minimal, ranging from 50-100 mm, while winter (December-February) and pre-monsoon (March-May) seasons are generally dry, with only occasional showers. During the monsoon, southwest winds dominate, averaging 10-20 km/h, influenced by monsoonal circulation. Post-monsoon winds shift to the northeast as the monsoon withdraws. Winter brings calm northeast winds, with speeds around 5-10 km/h, influenced by continental high-pressure systems. In the pre-monsoon season, winds turn hot and dry, blowing from the northwest, sometimes reaching 15-25 km/h as temperatures rise. Monsoon winds from the southwest dominate during the rainy season, followed by a retreat to north-easterly winds in the post-monsoon period. Winter winds remain calm and north-easterly, while pre-monsoon winds are dry and gusty due to localized low-pressure systems.

3. Materials and methods

3.1. *Database*

The daily weather datasets including precipitation, maximum and minimum temperatures, relative humidity, wind speed and solar radiation for the period 1979 to 2013 were obtained from global weather dataportal (https://www.uoguelph.ca/watershed/w3s/). This dataset is being used for Soil and WaterAssessment Tool (SWAT) (https://swat.tamu.edu/). The dataset is freely available online (https: globalweather.tamu.edu) in CSV format.

TABLE 1

Categorization of dryness/wetness grade by the SPI and SPEI

Categories	SPEI Values
Extreme drought	Less than −2.00
Severe drought	−1.99 to −1.50
Moderate drought	−1.49 to −1.00
Near normal	−0.99 to 0.99
Moderately wet	1.00 to 1.49
Severely wet	1.50 to 1.99
Extremely wet	More than 2.00

3.2. *Method*

3.2.1. *SPI*

The SPI (McKee *et al*., 1993) is based on the probability of long-term precipitation representing wet or dry conditions. The SPI index was developed to compute precipitation deficits for different time scales~~,~~ such as 3, 6, 9, 12, 24, or more of cumulative precipitation. The first step to quantifying the SPI is to fit a long-term time series of monthly precipitation measurements to determine the cumulative probability density function (PDF). Consequently, the PDF distribution of the observed precipitation is converted to a normal distribution with a mean of zero and standard deviation of one. The basic concept of SPI implements a two-parameter gamma distribution. The computation procedure for the SPI can be found in McKee *et al*. (1993), and some details are shown in equation (1):

$$g(x) = \frac{1}{\beta^{\alpha}\tau(\alpha)} X^{\alpha-1} e^{\frac{-X}{\beta}} \quad (1)$$

Here, β is a scale parameter, α is a shape parameter, $g(x)$ is the gamma probability density function, e is Euler's number for exponentiation and $\tau(\alpha)$ is the ordinary gamma function of α. The estimation of β and α can be found in more detail in McKee *et al*. (1993).

3.2.2. *SPEI*

The SPEI has been designed to assess drought conditions (Vicente- Serrano *et al*., 2010). The procedure

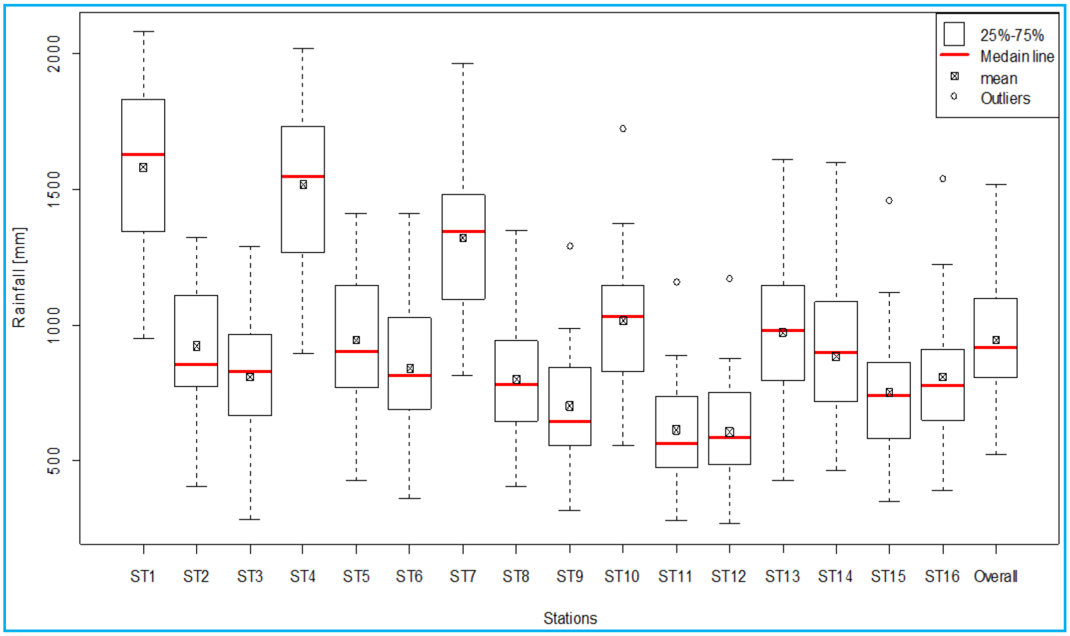

Fig. 2. Box plot of annual rainfall variability for every station and overall study area (1979-2013)

TABLE 2

Descriptive statistics of annual rainfall at various stations in the study area

Station	No. of years	Minimum	Maximum	Range	Mean	Median	Kurtosis	Skewness	Standard Deviation
1	35	948.89	2079.75	1130.86	1582.23	1627.48	-0.97	-0.18	307.06
2	35	406.68	1323.52	916.84	922.70	854.43	-0.65	-0.22	224.08
3	35	287.04	1292.47	1005.43	807.52	831.80	0.06	-0.13	212.50
4	35	895.35	2021.07	1125.71	1519.07	1548.77	-0.67	-0.25	288.83
5	35	425.48	1412.58	987.11	943.59	900.79	-0.69	-0.06	241.28
6	35	359.57	1412.61	1053.04	839.32	815.95	-0.08	0.23	229.57
7	35	812.43	1965.32	1152.89	1319.81	1342.42	-0.25	0.07	268.20
8	35	405.74	1348.91	943.18	801.51	783.76	-0.31	0.33	219.92
9	35	318.86	1289.90	971.04	701.79	646.21	0.61	0.60	201.72
10	35	559.32	1724.33	1165.01	1016.48	1029.02	0.83	0.46	241.67
11	35	281.82	1157.77	875.94	613.79	561.31	0.73	0.67	184.14
12	35	267.13	1172.92	905.79	606.04	585.10	1.12	0.77	185.31
13	35	546.32	1621.32	1057	630.43	665.32	0.93	0.35	210.32
14	35	590.45	1273.32	682.87	690.21	734.32	-0.54	0.63	190.45
15	35	490.32	1334.30	843.98	756.32	843.45	-0.21	0.85	231.65
16	35	545.75	1672.63	1126.88	890.23	921.32	0.45	0.26	211.23

for calculating SPEI depends on the original SPI calculation but uses the monthly difference between precipitation (P) and PET. The authors selected the L-moment parameter estimation and the log-logistic distribution as the ones that best fit the cumulated P-ET for 3 to 12 month time scales. The difference P-PET is

TABLE 3

Classification of months in different drought conditions based on SPI values (Mckee *et al.* 1993)

SPI Time Scale		SPI Classification						
		2.0 and more (Extreme wet)	1.5 to 1.99 (Severe wet)	1.0 to 1.49 (Moderate wet)	-0.99 to -0.99 (Near normal)	-1.49 to -1.0 (Moderate Drought)	-1.99 to -1.5 (Severe Drought)	-2.0 and less (Extreme Drought)
SPI-3	Month	10	13	39	292	64	0	0
	%	2.39	3.11	9.33	69.86	15.31	0	0
SPI-6	Month	11	12	42	280	70	0	0
	%	2.65	2.89	10.12	67.47	16.87	0	0
SPI-9	Month	8	11	48	277	68	0	0
	%	1.94	2.67	11.65	67.23	16.50	0	0
SPI-12	Month	11	8	40	283	67	0	0
	%	2.69	1.96	9.78	69.19	16.38	0	0

referred to as a climatic water balance, where monthly PET was computed with the Thornthwaite equation (Thornthwaite, 1948, Van der Schrier *et al*. 2011).The dry and wet conditions in the study area have been classified based on McKee *et al*. (1993), which are defined in Table 1. The SPEI is a slightly superior index than the SPI index for examining characteristics of drought variation in a study area because it considers both precipitation and evapotranspiration data.

4. Result and discussion

4.1. *Distribution of annual rainfall*

The average annual distribution of rainfall for the sixteen stations in the study area is shown in Fig. 2. The box plot represents annual average rainfall variability in the rainfall stations over the period 1979-2013 to describe the behavior of annual rainfall in the study area. Each box includes the middle 50% of the data. The median values are displayed as a line and the mean value is displayed with symbol. The top and bottom of the box represent the inter-quartile ranges (25-50% and 50-75%). The lines extended above and below in the box mark the maximum and minimum values that fall within an acceptable range respectively (Jemai *et al*. 2018). The mean annual rainfall ranges from 267mm to 2089mm at stations 12 and 1 respectively. The high and irregular variability in the distribution of rainfall is depicted by alternating wet and dry periods over the entire study area (Fig. 2). The descriptive statistics of annual rainfall at various stations are analyzed in the study area as per Table 2. The highest average precipitation observed at station 1, which is 1582.23mm, as well as the minimum, maximum, range,

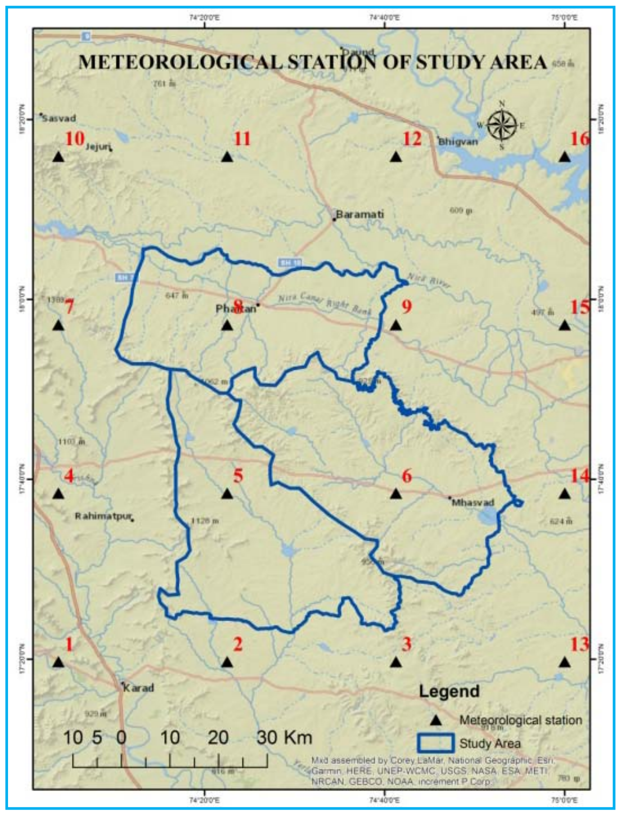

Fig. 3. Location of the Meteorological Station

median, Kurtosis, Skewness, and standard deviation of station 1 are 948.89, 2089.57, 1130.86, 1627.48, -0.97, -0.18 and 307 respectively (Table 2). The location of the meteorological station is shown in Fig. 3. The result also

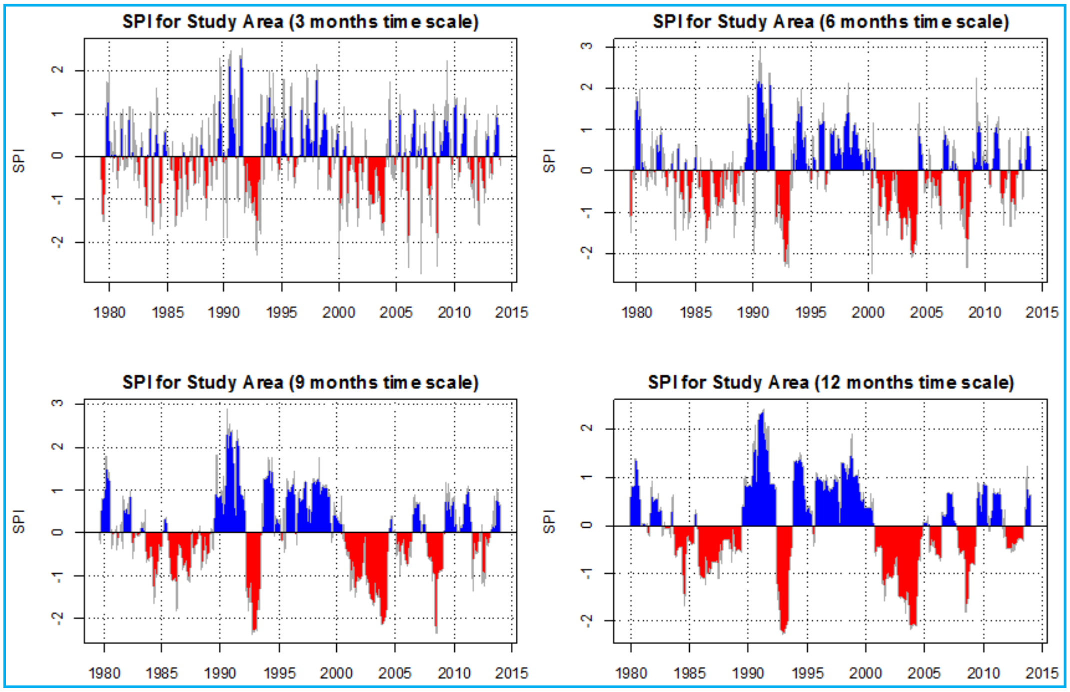

Fig. 4. Temporal variation of SPI at short (SPI-3 months), medium (SPI-6 and 9 months), and long term (SPI-12 months) for the study area (1979-2014)

illustrates that a significant amount of precipitation falls in the hilly region of the western part of the study area.

4.2. *Analysis of SPI 3, 6, 9 and 12 months*

As precipitation is the dominant driving force in the process of drought, SPI has been proven to be a very good indicator of meteorological drought (Keyantash and Dracup 2002). Fig. 4 illustrates the temporal variation of SPI in the short term (SPI-3 months), medium-term (SPI-6 and 9 months) and long term (SPI-12 months) for the year form 1979-2014 of the study area. Fig. 4 represents some differences in drought events with regard to intensity, severity, and duration of drought in the study area. The positive index value represents wet conditions or no drought and the negative index value indicates dry or drought conditions. SPI-3 months presents a high occurrence of alternated dry/wet episodes. According to SPI-3 and SPI-6, month's time scale dry and wet episodes often fluctuate frequently over the study area. With an increased time scale of SPI-9 and SPI-12 months, the frequency of variation in the dry and wet spells is lower for a longer duration. The SPI-9 and SPI-12 months' time scale results show a heterogeneous distribution in the historical series. Each station found a dry period. However, some years seem exceptionally dry or wet throughout the study area. In general, annual rainfall analysis reveals similar trends (increasing and decreasing) at different stations but with different magnitudes during the study period. Alternating periods of excess and deficit precipitation are well defined in all studied stations. Severe dry conditions are more prominently observed at stations 2, 3, 8, 9, 11 and 12. Moderate dry conditions are observed at stations 1, 4 and 7. The SPI reveals that notable severe drought events were found in the years 1983 to 1988, 1992, 2000 to 2004, 2007, 2008, 2012 and 2013. The SPI-12 month time scale was found to be a useful tool for detecting dry period recurrence in the dry region. The SPI 12 month time scale was chosen because it proved to be the most suitable for water resource management and the most suitable for identifying the persistence of dry periods (Milanovic *et al*. 2014).

The classification of temporal variation of SPI at short (SPI-3 months), medium (SPI-6 and 9 months) and long term (SPI-12 months) for the study area has been prepared for all 420 months in different dry and wet conditions as described in Table 3. The positive SPI index value represents wet conditions whereas the negative value denotes dry conditions as per McKee, 1993. The SPI value of near normal dry conditions ranged from-0.99 to-0.99. According to SPI-3, SPI-6, SPI-9 and SPI-12 month time scale prominently months under near normal dry conditions, which are 292, 280, 277 and 283 months respectively. The moderately dry conditions ranged from-1.49 to-1.0. As per SPI-3, SPI-6, SPI-9, and SPI-12 month

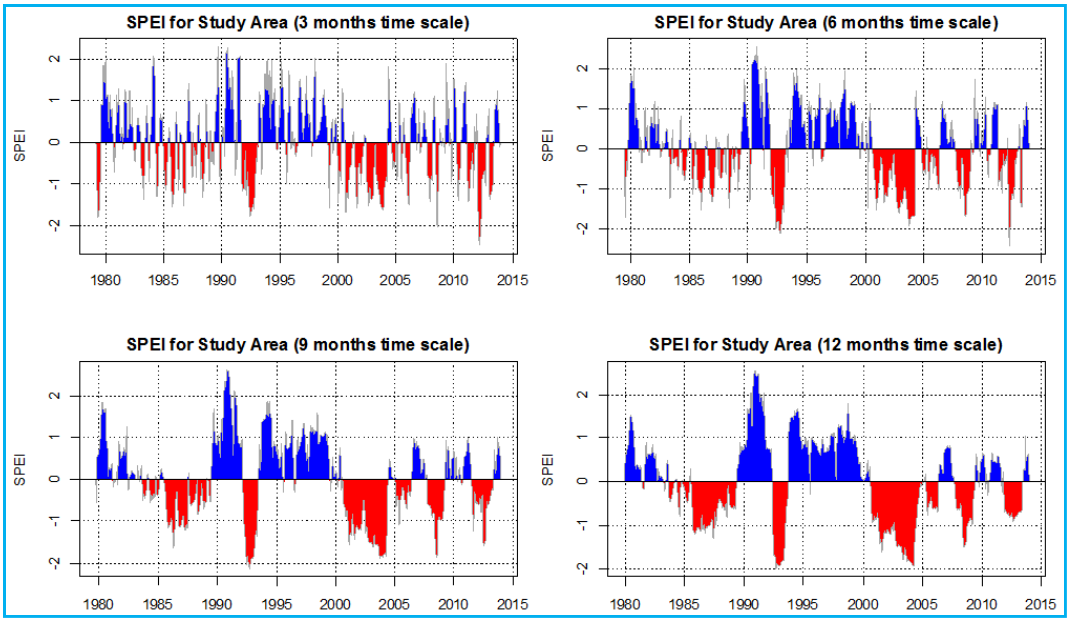

Fig. 5. Temporal variation of SPEI at short (SPI-3 months), medium (SPI-6 and 9 months), and long term (SPI-12 months) for the study area (1979-2014)

TABLE 4

Classification of months in different drought conditions based on SPEI values

SPEI Time Scale		SPEI Classification						
		2.0 and more (Extreme wet)	1.5 to 1.99 (Severe wet)	1.0 to 1.49 (Moderate wet)	-0.99 to -0.99 (Near normal)	-1.49 to -1.0 (Moderate Drought)	-1.99 to -1.5 (Severe Drought)	-2.0 and less (Extreme Drought)
SPEI-3	Month	10	18	41	278	71	0	0
	%	2.39	4.31	9.81	66.51	16.99	0.00	0.00
SPEI-6	Month	9	15	47	265	79	0	0
	%	2.17	3.61	11.33	63.86	19.04	0.00	0.00
SPEI-9	Month	8	16	37	278	73	0	0
	%	1.94	3.88	8.98	67.48	17.72	0.00	0.00
SPEI-12	Month	9	15	35	278	72	0	0
	%	2.20	3.67	8.56	67.97	17.60	0.00	0.00

time scale, nearly about 64, 70, 68 and 67 months suffered from moderate drought.

4.3. *Analysis of SPEI 3, 6, 9 and 12 months*

The duration of the drought events at sixteen stations for each year as per SPEI is calculated. The duration is expressed in the number of months. Further, the durations for all stations each year were averaged to reflect the overall temporal extent of the drought on a regional scale. SPEI is more appropriate than SPI, because SPEI explicitly takes the effects of more meteorological variables (*i.e.*, both precipitation and temperature) as compared to the spatial and temporal patterns of drought severity change implicated by SPI and SPEI are basically alike. Fig. 5 represents the temporal variation of SPEI in the short term (SPEI-3 months), medium term (SPEI-6 and 9 months) and long term (SPEI-12 months) for the year from 1979-2014 ofthe study area.

The dry years significantly increased from 2000 to 2014. The different time scales of SPEI can represent

TABLE 5

Classification of all months according to SPI and SPEI indices 3 months time scale for the study area

		SPEI 3					
		Extremely wet	Severely wet	Moderately wet	Near normal	Moderate drought	Total
SPI 3	Extremely wet	9	1				10
	Severely wet	1	11	5	1		18
	Moderately wet		1	23	17		41
	Near normal			11	250	17	278
	Moderate drought				24	47	71
	Total	10	13	39	292	64	418

TABLE 6

Classification of all months according to SPI and SPEI indices 6 months time scale for the study area

		SPEI 6					
		Extremely wet	Severely wet	Moderately wet	Near normal	Moderate drought	Total
SPI 6	Extremely wet	7	2				9
	Severely wet	4	9	2			15
	Moderately wet		1	32	14		47
	Near normal			8	245	12	265
	Moderate drought				21	58	79
	Total	11	12	42	280	70	415

TABLE 7

Classification of all months according to SPI and SPEI indices 9 months time scale for the study area

		SPEI 9					
		Extremely wet	Severely wet	Moderately wet	Near normal	Moderate drought	Total
SPI 9	Extremely wet	6	2				8
	Severely wet	2	9	5			16
	Moderately wet			35	2		37
	Near normal			8	265	5	278
	Moderate drought				10	63	73
	Total	8	11	48	277	68	412

different aspects of drought conditions. The SPEI with a one month time scale indicates meteorological drought. At the 3 to 6 month time scales, it denotes the drought with respect to agriculture, and at the 6 to 12-month time scales, it represents hydrological drought conditions, useful for assessing surface water resources (Potop v. 2014). The meteorological and agricultural droughts were slightly more severe than the hydrological drought. The most extensive drought was observed from 2000 to 2005. SPI-3 months represents a high frequency of dry

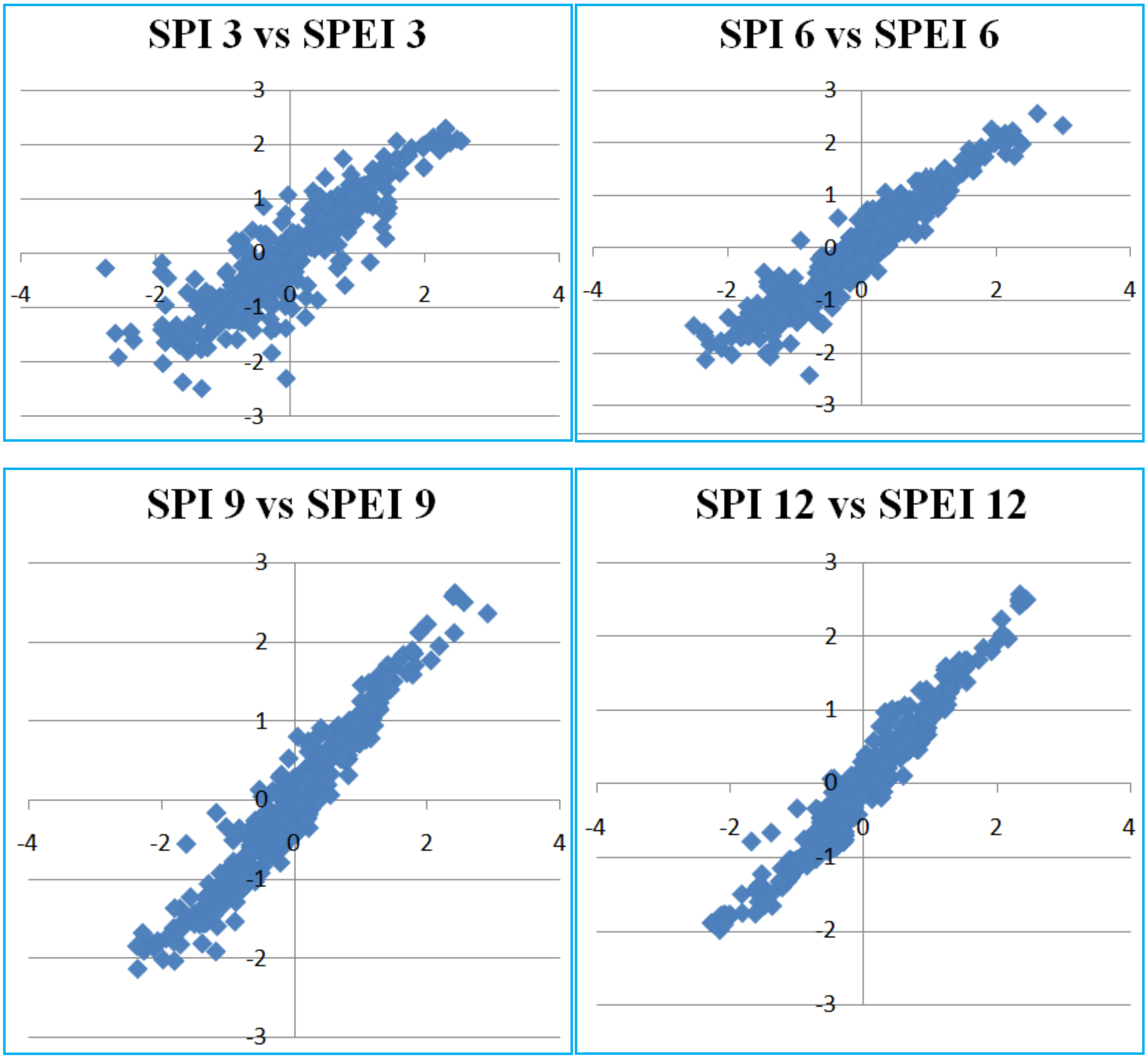

Fig. 6. Scatter plot of the SPI and SPEI values computed based on 3, 6, 9, 12 months' time scale for the study area

TABLE 8

Classification of all months according to SPI and SPEI indices 12 months time scale for the study area

		SPEI 12					
		Extremely wet	Severely wet	Moderately wet	Near normal	Moderate drought	Total
	Extremely wet	9					9
	Severely wet	2	7	6			15
	Moderately wet		1	27	7		35
	Near normal			7	268	3	278
SPI 12	Moderate drought				8	64	72
	Total	11	8	40	283	67	409

and wet conditions. According to the SPEI-3 and SPEI-6 month time scale, dry and wet spells fluctuate frequently over the study area. The increased time scale as per SPEI-9 and SPEI-12 months reveals the frequency of variation in the dry and wet spells is lower in longer duration. SPEI-12 months time scale; results displayed a varied distribution in the historical series. Every station has experienced a dry and wet period. Extreme dry conditions are notably observed at stations 2, 3, 5, 6, 8, 9, 11, 12, 15 and 16. Moderate dry conditions are prominently observed at stations 1, 4 and 7. The SPEI reveals that notable extreme drought events were found in the years 1985 to 1990, 1993, 2000 to 2007, 2009, 2013 and 2014.

The classification of temporal variation of SPEI at short (SPEI-3 months), medium (SPEI-6 and 9 months), and long term (SPEI-12 months) for the study area has been prepared for all 420 months in different dry and wet conditions as described in Table 4. The positive SPEI index value represents wet conditions whereas the negative value denotes dry conditions as per McKee, 1993. The SPEI value of near normal dry conditions ranged from-0.99 to-0.99. According to SPEI-3, SPEI-6, SPEI-9 and SPEI-12 month time scale, the months under near normal dry conditions are 278, 265, 278 and 278 respectively. The moderately dry conditions ranged from-1.49 to-1.0. As per the SPEI-3, SPEI-6, SPEI-9, and SPEI-12 month time scale, about 41, 47, 37 and 35 months, the study area is suffering from moderate drought.

4.4. *Comparison and Correlation*

For every month, we compute the SPI and SPEI index values for the study area and classify the drought condition of that month into various drought conditions as discussed earlier. Tables 5-8 shows the classification of months into various drought conditions according to SPI and SPEI indices of 3 months, 6 months, 9 months, and 12 months' time scale respectively. In the case of indices based on a 3 month time scale, about 81% of the months are classified in the same class by both the indices. This percentage is about 85%, 92% and 92% for indices based on 6 months, 9 months and 12 months respectively. This higher percentage of classifications in the same class by both the indices indicates that the classification of the months by two indices in various drought conditions is equivalent.

The scatter plots between the SPI and SPEI values are shown in Fig. 6. These plots suggest that there is strong linear relation in the SPI and SPEI values. The correlation in the SPI and SPEI indices for the study area based on 3 months' time scale is relatively weak than the correlation in the SPI and SPEI indices based on 12 months.

5. Conclusion

The present investigation attempts to identify and assess the severity of drought in the eastern part of the Satara district by using the SPI and SPEI indices. The distribution of rainfall shows that 1992 and 2003 had an average rainfall of about 918mm and 709mm respectively. The rainfall stations 1, 4 and 7 have the highest annual average rainfall, whereas the lowest annual average rainfall dominates at 11 and 12 stations in the study area. SPI 3 month's time scale 69.86 percent month (292 months), SPI 6 month time scale 67.47 percent month (280 months), SPI 9 month time scale 67.23 percent month (277 months), and SPI 12 month time scale 69.19 percent month (283 months) denote near-normal drought conditions, whereas SPI 3 month's time scale 15.31 percent month (64 months), SPI 6 month time scale 16.87 percent month (70), SPI 9 month time scale 16.50 percent month (68 months), and SPI 12 month time scale 16.38 percent month (67 months) denote moderate dry conditions. SPEI 3 month's time scale 66.51 percent (278 months), SPEI 6 month time scale 63.86 percent (265 months), SPEI 9 month time scale 67.48 percent (278 months), and SPEI 12 month time scale 67.97 percent (278 months) denote near-normal drought conditions, whereas SPEI 3 month's time scale 16.99 percent (71 months), SPEI 6 month time scale 19.04 percent (79 months), SPEI 9 month time scale 17.72 percent (73 months), and SPEI 12 month time scale 17.60 percent (72 months) denote moderate dry conditions in the study area over the period from 1979 to 2014. The correlation analysis shows that there is a strong linear relation in the SPI and SPEI values. The correlation between the SPI and SPEI indices for the study area based on a 3 month time scale is relatively weaker than the correlation between the SPI and SPEI indices based on 12 months. The overall investigation reveals that the eastern and southern parts of the study area are prone to moderate drought conditions. The present study will be helpful in identifying potential sites of drought and be useful for planning and mitigation purposes.

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References

Benitez, J. B. and Domecq, R. M., 2014, "Analysis of meteorological drought episodes in Paraguay", *Climatic Change*, **127**, 1, 15-25.

Guttman, N. B., 1998, "Comparing the palmer drought index and the standardized precipitation index 1", *JAWRA Journal of the American Water Resources Association*, **34**, 1, 113-121.

Jemai, S., Kallel, A. and Abida, H., 2018, "Drought distribution using the standardized precipitation index: case of Gabes Basin, South Tunisia", Arabian *Journal of Geosciences*, **11**, 23, 1-10.

Jensen, M. E., Burman, R. D. and Allen, R. G., 1990, "Evapotranspiration and irrigation water requirements", ASCE Manuals and Reports on Engineering Practice no. 70. Am. Soc. Civil Eng., New York. Evapotranspiration and irrigation water requirements. ASCE Manuals and Reports on Engineering Practice No. 70. Am. Soc. of Civil Engineers, New York.

Keyantash, J. and Dracup, J. A., 2002, "The quantification of drought: an evaluation of drought indices", *Bulletin of the American Meteorological Society*, **83**, 8, 1167-1180.

McKee, T. B., Doesken, N. J. and Kleist, J., 1993, January, "The relationship of drought frequency and duration to time scales", In *Proceedings of the 8th Conference on Applied Climatology* (**17**, 22, 179-183).

Milanovic, M., Gocic, M. L. and Trajkovic, S., 2015, "Analysis of meteorological and agricultural droughts in Serbia", Facta Universitatis. Series : *Architecture and Civil Engineering*, 253-264.

Mishra, A. K. and Singh, V. P., 2010, "A review of drought concepts", *Journal of hydrology*, **391**, 1-2, 202-216.

Mo, K. C., 2008, "Model-based drought indices over the United States", *Journal of Hydrometeorology*, **9**, 6, 1212-1230.

Oki, T. and Kanae, S., 2006, "Global hydrological cycles and world water resources", *Science*, **313**, 5790, 1068-1072.

Potop, V., Boroneanţ, C., Možný, M., Štěpánek, P. and Skalák, P., 2014, "Observed spatiotemporal characteristics of drought on various time scales over the Czech Republic", *Theoretical and applied climatology*, **115**, 3, 563-581.

Rajsekhar, D., Singh, V. P. and Mishra, A. K., 2015, "Multivariate drought index: An information theory based approach for integrated drought assessment", *Journal of Hydrology*, 526, 164-182.

Sahoo, A. K., Sheffield, J., Pan, M. and Wood, E. F., 2015, "Evaluation of the tropical rainfall measuring mission multi-satellite precipitation analysis (TMPA) for assessment of large-scale meteorological drought", *Remote Sensing of Environment*, 159,181-193.

Seneviratne, S., Nicholls, N., Easterling, D., Goodess, C., Kanae, S., Kossin, J., ... & Zwiers, F. W., 2012, "Changes in climate extremes and their impacts on the natural physical environment".

Svoboda, M. D. and Fuchs, B. A., 2016, Handbook of drought indicators and indices (pp. 1-44). Geneva, Switzerland: World Meteorological Organization.

Thornthwaite, C. W., 1948, "An approach toward a rational classification of climate", *Geographical review*, **38**, 1, 55-94.

Törnros, T. and Menzel, L., 2014, "Addressing drought conditions under current and future climates in the Jordan River region", *Hydrology and Earth System Sciences*, **18**, 1, 305-318.

Van der Schrier, G., Jones, P. D. and Briffa, K. R., 2011, "The sensitivity of the PDSI to the Thornthwaite and Penman-Monteith parameterizations for potential evapotranspiration", *Journal of Geophysical Research: Atmospheres*, 116(D3).

Vicente-Serrano, S. M., Beguería, S.and López-Moreno, J. I., 2010, "A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index", *Journal of climate*, **23**, 7, 1696-1718.

Vicente-Serrano, S. M., Beguería, S., Lorenzo-Lacruz, J., Camarero, J. J., López-Moreno, J. I., Azorin-Molina, C., ... & Sanchez-Lorenzo, A., 2012, "Performance of drought indices for ecological, agricultural and hydrological applications", *Earth Interactions*, **16**, 10, 1-27.

Wang, Q., Shi, P., Lei, T., Geng, G., Liu, J., Mo, X., ... & Wu, J., 2015, "The alleviating trend of drought in the Huang-Huai-Hai Plain of China based on the daily SPEI", *International Journal of Climatology*, **35**, 13, 3760-3769.

Wilhite, D. A. and Glantz, M. H., 1985, "Understanding: the drought phenomenon: the role of definitions", *Water international*, **10**, 3, 111-120.

Wilhite, D. A., Svoboda, M. D. and Hayes, M. J., 2007, "Understanding the complex impacts of drought : A key to enhancing drought mitigation and preparedness", *Water resources management*, **21**, 5, 763-774.

Yan, H., Wang, S. Q., Lu, H. Q., Yu, Q., Zhu, Z. C., Myneni, R. B., ... & Shugart, H. H., 2014, "Development of a remotely sensing seasonal vegetation-based Palmer drought severity index and its application of global drought monitoring over 1982-2011", *Journal of Geophysical Research: Atmospheres*, **119**, 15, 9419-9440.

APPENDIX

- CFSR = Climate Forecast System Reanalysis
- CSV = Comma-Separated Values)
- NCEP = National Centers for Environmental Prediction
- P = Precipitation
- PDF = Probability Density Function
- PET = Potential Evapotranspiration
- SPEI = Standardized Precipitation Evaporation Index
- SPI = Standardized Precipitation Index

Research highlights

The present research work focused on assessing meteorological drought conditions using SPI and SPE indices in the eastern part of Satara district at meteorological station level. The SPI and SPEI were computed at 3, 6, 9, and 12 month time scales. This study also highlights comparisons between SPI and SPEI.