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Multi-temporal SPI and RDI Based on the Modified Meteorological Draught and Hydrological Drought of Marathwada Region of Maharashtra, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The meteorological and hydrological drought indices are mostly applying as a tool for observing changes in drought situations. In the present research work, evaluated the performance of two modified meteorological drought indices *i.e.* modified standardized precipitation index (SPI_e) and

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modified recoinnaissance drought index (RDI_e) and hydrological drought indices *i.e* stream-flow drought index (SDI)**.** The effective precipitation was used instead of precipitation for modification of meteorological drought indices. The assessment of drought trends at multi-temporal such as 1, 3, 6 and 12 months was done by using popular Mann-Kendall test and the probability and return period of occurrence of severe and extreme drought condition of the meteorological and hydrological drought events. Finally results were non-significant trend (either positive or negative) at 95% confidence limit and the 43 years reoccurrence interval of extreme meteorological drought for Latur and Parabhani districts, the 10.75, 21.5 and 14.33 years return period of severe meteorological drought for Latur, Nanded and Parabhani districts. Also, the 18, 18 and 43 years reoccurrence interval of severe hydrological drought for Latur, Nanded and Parabhani districts was calculated.

Keywords: SPI_e; RDI_e; SDI; mann-kendall test; probability; return period.

1. INTRODUCTION

"The meteorological and hydrological drought is a periodic natural hazard and difficult to provide an accurate and universally accepted description of drought due to its changing characteristics and effects across different regions such as rainfall patterns, water availability, human response and resilience etc. Drought happens as a result of several variables acting on multiple time scales and varies with spatial location and temporal season; thus, drought can have impacts on various sectors especially on agriculture and ecosystems" Heim Jr., [1]; Hao and Singh, [2]. Due to its compound nature and extensive occurrence, it is challenging to describe drought and to classify its characteristics. A meteorological drought in the beginning happens when there is an insufficiency of precipitation for a continued period and it may even lead to further shortage of runoff and steam discharge depending on multi-time scales convert into hydrological drought [3,4]. Consequently, the assessment of meteorological drought can be applied for planning of crop management, water management and soil moisture and hydrological drought assessment is used for planning of water storage structures such as pond, check dam and dam for reducing the effect of water deficit on social and agricultural activity [5,6]. Thus, the classifications of droughts may vary depending on viewpoints and stakeholders [7]. The Ministry of agriculture is the chief Ministry in veneration of watching and handling drought situations and droughts are categorized into meteorological droughts, hydrological droughts and agricultural droughts in India [8,9]. The meteorological drought is categorized based on rainfall deficiency with respect to elongated term average 25% or less is normal, 26-50% is moderate and more than 50% is severe. The hydrological drought is best defined as insufficiencies in surface and sub-surface water deliveries important to a lack of water for normal and precise requirements [10-12]. Such conditions arise even in times of average (or above average) precipitation when increased usage of water diminishes the reserves. Ji and Peters [13] suggested the monthly SPI redirects short-term situations and its used can be associated closely to soil moisture, the three month SPI be responsible for a periodic assessment of precipitation, six and nine month SPI designates medium term movements in rainfall patterns. Although it is quite a recent index, the SPI, RDI, and SDI have been used (Nalbantis and Tsakiris [14]; Ch et al. [15]; Tabari et al. [16]; Ma et al. [17]; Davida and Davidovaa [1] Satpute et al. (2016) and Tigkasa et al. [18]. The present investigation has been undertake with following objectives (a) to determine the long term trend in meteorological and hydrological drought of selected stations. (b) to compute indices of meteorological and hydrological drought for different time scales. (c) to assess the probability and return period of the meteorological and hydrological drought events.

2. MATERIALS AND METHODS

2.1 Study Area and Data

Latur, Nanded and Parabhani districts lies in the eastern portion of Marathwada region of Maharashtra state and which is falling under the Godavari river basin (Fig. 1). The meteorological data of Latur, Nanded and Parabhani districts were acquired form Indian meteorological deviation (IMD) and hydrological data was acquire from Central Water Commission (CWC) site Bhatkhedda, Yelli and Dholegon of Godavari river basin (Table 1).

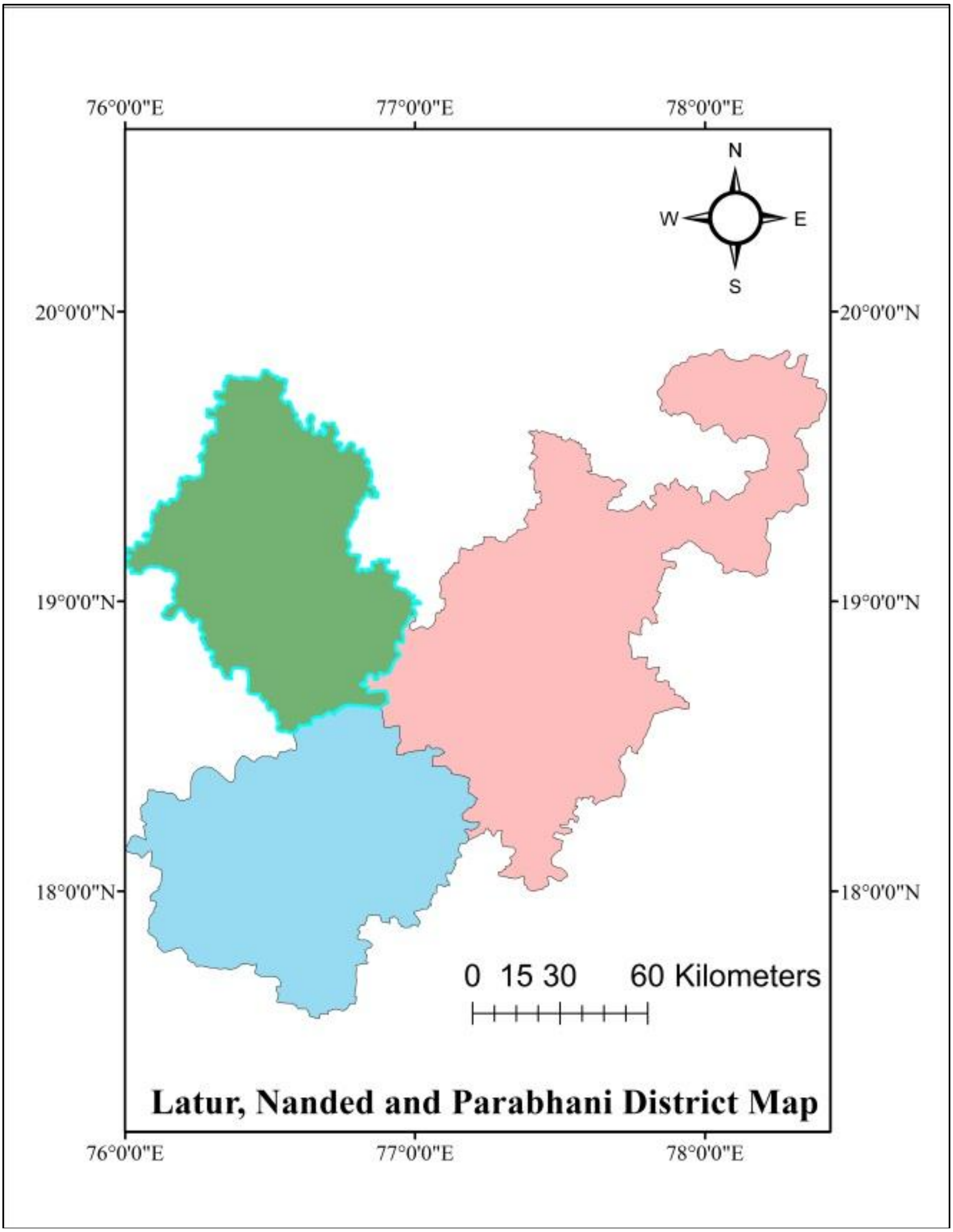

Fig. 1. Study area map

Table 1. Data set used for study area

Station	Latur	Parabhani	Nanded
Meteorological	1971-2012	1971-2012	1971-2012
Hydrological	1969-2003	1971-2012	1979-2013

2.2 Effective Precipitation

The effective precipitation was estimated with help of U.S. Bureau of Reclamation (USBR) method, which is generally suggested for semi-arid or arid regions. The USBR method is used for classes of the total monthly precipitation (Table 2), in direction to define the analogous percentage for the estimation of effective precipitation (P_e) (Stamm 1967). Alternatively, the following equation may be used (Smith (1988) and Patwardhan et al. (1990)):

$$P_e = \frac{P \times (125 - 0.2 \times P)}{125} \quad for\ P \leq 250\ mm \tag{1}$$

$$P_e = 0.1 \times P + 125 \quad for\ P > 250\ mm \tag{2}$$

2.3 Modified Standardized Precipitation Index

McKee et al. [19] was developed a new drought index the standardized precipitation index (SPI) by a group of scientists at Colorado State University. The standardized precipitation index is the inclusive studies presented that is highly correlated with precipitation at certain time scales (almost always 1-, 3-, 6-, 9-, and 12-months etc.), and therefore, temperature added little supplementary information. “Although based on precipitation alone the SPI was designed to address many of the weaknesses associated with the PDSI and intended to provide a direct answer to the questions most commonly posed by water managers. The different time scales are designed to reflect the impacts of precipitation deficits on different water resources. For instance, soil moisture conditions respond to precipitation anomalies on a relatively short scale, whereas groundwater, stream flow, and reservoir storage reflect longer-term precipitation anomalies. The main advantage is its standardization so that the values represent the same probability of occurrence, regardless of time period, location, and climate. Equal categorical intervals have differing occurrence probabilities” [20]. “Different time scales reflect the convenience of water resources to drought conditions. Soil moisture conditions respond relatively to short-term precipitation anomalies. According to the time average duration, SPI value provides the deviation of the precipitation, Pi, amount at time instant, i, from the long term average, $\bar{P}$, and the division of this difference to the standard deviation. This is the same procedure in the statistics literature for the standardization of a given time series, which is here the precipitation measurements as P_1, P_2, …, Pn, where n is the number of data. The SPI, which is shown as pi, is defined according to Equation for simple drought interpretations” [20].

Thom (1958) found that the gamma distribution fits the rainfall data more appropriately. The probability density function for the gamma distribution is defined as follows: SPI may be estimated by fitting a Gamma probability density function (x_e) to a given times of effective rainfall, whose probability density function is defined by:

$$g(x_e) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \beta^{\alpha-1} e^{-\frac{-x}{\beta}} \tag{3}$$

Where α is a shape factor, $\alpha > 0$; β is a scale factor, X_e is the amount of effective rainfall, $X_e>0$; $\Gamma(\alpha)$ is the gamma function of $\Gamma\alpha$, expressed as:

$$\Gamma(\propto) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \tag{4}$$

Fitting the gamma distribution to the effective rainfall data requires estimating α and β.

Thom (1958) for maximum likelihood to obtain

$$\Gamma\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + (4A)/3}\right) \tag{5}$$

$$\beta = \frac{\bar{\mathrm{x}}}{\alpha}$$

Where

$$A = \ln(\bar{\mathrm{x}}) - \frac{\sum \ln(\mathrm{x})}{\mathrm{n}} \tag{6}$$

n is number of rainfall measurements, and $\bar{\mathrm{x}}$ is the mean of x.

The estimate of the parameters can be further improved by using the interactive approach suggested in Wilks (1995). After estimating coefficients α and β, the density of probability function $g(x_e)$ is integrated with respect to x and we obtain an expression for cumulative probability $G(x_e)$ that a certain amount of rain has been observed for a given month and for a specific time scale.

$$G(x_e) = \int_0^x g(x)dx = \int_0^x \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} dx \tag{7}$$

Table 2. Effective precipitation based on total monthly precipitation classes (USBR method)

Total monthly precipitation class (mm)	Effective precipitation (%)
0.0 - 25.4	90 – 100
25.4 - 50.8	85 – 95
50.8 - 76.2	75 – 90
76.2 - 101.6	50 – 80
101.6 - 127.0	30 – 60
127.0 - 152.4	10 – 40
> 152.4	0 – 10

Substituting t = x/β, the last Eq. is reduced to:

$$G(x_e) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1}\ e^{-1} dt \qquad (8)$$

It is possible to have several zero values in a sample set. In order to account for zero value probability, since the gamma distribution is undefined for x=0, the cumulative probability function for gamma distribution is modified as:

where q is the probability of zero effective precipitation.

$$H(x_e) = q + (1-q)g(x) \qquad (9)$$

$$Z = SPI = -\left(t - \frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 + d_2 t^2 + d_3 t^3}\right) \qquad (10)$$

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

$$Z = SPI = +\left(t - \frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 + d_2 t^2 + d_3 t^3}\right) \qquad (11)$$

$$t = \sqrt{ln\left(\frac{1}{1-(H(x))^2}\right)} \qquad \text{for } 0.5 < H(x) < 1$$

C_0 = 2:515517; C_1=0:802853; C_2 = 0:010328
d_1 = 1:432788; d_2 = 0:189269; d_3 = 0:001308

Table 3. SPI values classification

Class SPI value	SPI
Extreme wet	>2.0
Very wet	1.5 to 1.99
Moderate wet	1.0 to 1.49
Near normal	0.99 to −0.99
Moderate drought	−1.0 to −1.49
Severe drought	−1.5 to −1.99
Extreme drought	<−2.0

2.4 Modified Recoinnaissance Drought Index

The RDI can be expressed in three forms. The initial form of the index (α) within a year for a reference period of k months is calculated as

$$\alpha_k = \frac{\sum_{j=1}^{j=k} P_j}{\sum_{j=1}^{j=k} PET_j} \qquad (12)$$

The second form is a normalized expression of the index (RDIn), calculated by the following equation:

$$RDI_n(k) = \frac{a_k}{\bar{a}_k} - 1 \qquad (13)$$

in which $\bar{a}_k$ is the long term average of a_k.

Assuming that the values of k follow the log-normal distribution, the standardized form of the index (RDIst) is calculated as

$$RDI_{st}(k) = \frac{y_k - \bar{y}_k}{\sigma_k} \qquad (14)$$

in which y_k is equal to the lnσ_k, while $\bar{y}_k$ is its average and σ_k is its standard deviation, respectively.

Previous studies have shown that RDI can be successfully used for the assessment of drought effects on crop yield, especially in rainfed agriculture. However, as already mentioned, the P_e is expected to better represent the amount of water that is used beneficially by the crops. Therefore, a modified version of RDI, RDI_e, was modified by replacing the total precipitation by the P_e. The modified initial form of the index (a_e) is calculated as:

$$\alpha_{ek} = \frac{\sum_{j=1}^{j=k} P_{ej}}{\sum_{j=1}^{j=k} PET_j} \qquad (15)$$

$$RDIe_n(k) = \frac{a_{ek}}{\bar{a}_{ek}} - 1 \qquad (16)$$

$$RDI_{est}(k) = \frac{y_{ek} - \overline{ye}_k}{\sigma_{ek}} \qquad (17)$$

2.5 Stream-flow Drought Index (SDI)

It is assumed that a time series of monthly stream-flow volumes Qij is available where i denotes the hydrological year and j the month within that hydrological year (j=1 for October and j=12 for September). Based on this series we obtain:

$$V_{i,k} = \sum_{j=1}^{k} Q_{i,j} \qquad (18)$$

i= 1, 2, …….12, k = 1, 3, 6, 12

where *Vi,k* is the cumulative stream-flow volume for the i-the hydrological year and k-the reference period *k*=1 for October-December, *k*=2 for October-March, *k*=3 for October-June, *k*=4 for October – September. Based on cumulative stream-flow volumes *Vi,k* the Stream-flow Drought Index

(SDI) is defined for each reference period k of the i-th hydrological year as follows:

$$SDI_{i,k} = \frac{V_{i,k}-\bar{V}_k}{s_k} \tag{19}$$

Where *Vk* and *Sk* are respectively the mean and the standard deviation of cumulative stream-flow volumes of reference period k as these are estimated over a long period of time. In this definition, the truncation level is set to *Vk* although other values could be used.

2.6 Trend Analysis

2.6.1 Mann-kendall test

The Mann-Kendall tend test is a rank correlated test between the rank of observation and there time order. This method has been widely used to test randomness against trend detection in a time series Mann and Kendall, [19]. It is the null hypothesis (H_0) of no trend, *i.e.*, the observation is randomly ordered in time, against the alternative hypothesis, (H_i) where there is increasing or decreasing monotonic trend detection. The Mann-Kendall test statistic S is calculated by given formula:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{20}$$

Where Xi is the time series ranked from i=1,2,….n. Each of the data Xi is taken as reference point which is compared with the rest of the data point's Xj.

$$sgn = \begin{Bmatrix} 1 & x_j < x_i \\ 0 & x_j = x_i \\ 1 & x_j > x_i \end{Bmatrix} \tag{21}$$

It has been documented that when $n \geq 8$, the statistic S is approximately normally distributed with the mean zero and a variance is

$$Z = \begin{Bmatrix} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 \quad if & S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{Bmatrix} \tag{22}$$

Z follows the standard normal distribution. The null hypothesis H_0 represents that no significant trend is present, is accepted if the test statistic Z is not statically significant.

3. RESULTS AND DISCUSSION

3.1 Meteorological Drought

The Modified Standardized precipitation index (SPI_e) was used to compute meteorological drought on multi-temporal such as monthly (SPI_e-1), three months (SPI_e-3), six months (SPI_e-6) and Annual SPI_e -12 time-steps for Latur, Nanded and Parabhani districts under the study (Table 4). The SPI_e values corresponding to SPI_e-1, SPI_e-3, SPI_e-6 and SPI_e -12 time-steps were computed. The positive values indicate wet condition and negative values indicate dry condition. The total drought events SPI_e-1 (249), SPI_e-3 (65), SPI_e-6 (33) and SPI_e-12 (19) were estimated for Latur district. The extreme drought events were computed time-steps SPI_e-1 (1976-Oct, 1982-July, 1983- July, 1991-Oct, 1995-May, 1996-Sep and 2012 July, SPI_e-3 (1976-(Oct-Dec), 1983-(July-Sep), 1991-(Oct-Dec), 1995-(April-Jun) and 1996-(July-Sep)), SPI_e-6, 1976-(Oct-March), 1983-(April-Sep) and 1995-(April-Sep), SPI_e-12, (1983). Similarly total drought events of RDI_e were computed, the total drought event RDI_e-1 (249), RDI_e-3 (65), RDI_e-6 (33) and RDI_e-12 (19) was computed for Latur district. The extreme drought events were computed time-steps RDI_e-1 (1976-Oct, 1982-July, 1983- July, 1991-Oct, 1995-May, 1996-Sep and 2012 July, RDI_e-3 (1976-(Oct-Dec), 1983-(July-Sep), 1991-(Oct-Dec), 1995-(April-Jun) and 1996-(July-Sep)), RDI_e-6 , 1976-(Oct-March), 1983-(April-Sep) and 1995-(April-Sep), RDI_e-12, (1983). In case of Nanded district, the total drought events SPI_e-1 (242), SPI_e-3 (78), SPI_e-6 (34) and SPI_e-12 (20) were computed. The extreme drought events were found at multi-time step SPI_e-1, 1979-Aug, 1982-July, 1984-May, 1994-April, 1995-Jun, 2001-April and 2012-July and SPI_e-3, 1981- Oct-Dec, 1983- Jan-March and July-Sep, 1995-April-Jun and 2009-April-Jun, SPI_e-6, 1976-Oct-March,1981-Oct-March, 1983-April-Sep and 1995-April-Sep and SPI_e-12, 1983 and 1995. Also RDI_e computed the total drought events RDI_e-1 (242), RDI_e-3 (78), RDI_e-6 (34) and RDI_e-

12 (20) were computed. The extreme drought events were found at multi-time step RDI_e-1, 1979-Aug, 1982-July, 1984-May, 1994-April, 1995-Jun, 2001-April and 2012-July and RDI_e-3, 1981- Oct-Dec, 1983- Jan-March and July-Sep, 1995-April-Jun and 2009-April-Jun, RDI_e-6, 1976-Oct-March,1981-Oct-March, 1983-April-Sep and 1995-April-Sep and RDI_e-12, 1983 and 1995. After analyzing the results of Parabhani district at multi-temporal steps were found that the total number of drought SPI_e-1 (262), SPI_e-3 (77), SPI_e-6 (35) and SPI_e-12 (18). The extreme events were calculated at different time steps SPI_e-1, 1979-May and Aug, 1982-July, 1983-Oct, 1991-Oct, 1995- May and Jun and 2012-July, SPI_e-3, 1983-July-Sep and 1995-April-Jun, SPI_e-6, April-Sep and 1994- April-Sep, SPI_e-12, 1983. Moreover, RDI_e at multi-temporal steps were computed, the total number of drought RDI_e-1 (262), RDI_e-3 (77), RDI_e-6 (35) and RDI_e-12 (18). The extreme events were calculated at different time steps RDI_e-1, 1979-May and Aug, 1982-July, 1983-Oct, 1991-Oct, 1995- May and Jun and 2012-July, RDI_e-3, 1983-July-Sep and 1995-April-Jun, RDI_e-6, April-Sep and 1994- April-Sep, RDI_e-12, 1983.

3.2 Hydrological Drought

The multi-temporal hydrological drought was calculated using SDI_e for Latur, Nanded and Parabhani districts under the studies. The multi-temporal SDI_e such as monthly (SDI_e-1), three months (SDI_e-3), six months (SDI_e-6) and Annual SDI_e-12 time-steps were computed with help of Drink C software. The total drought condition at different time steps were compute SDI_e-1 (249), SDI_e-3 (80), SDI_e-6 (36) and SDI_e-12 (15) for Latur district. The extreme events were estimated at multi-temporal steps SDI_e-1, 1998-March, April and May, SDI_e-3, 1998-Jan-Marrch and April-Jun, and SDI_e-6, 1998-April-Sep. Also, the total drought condition at different time steps were computed SDI_e-1 (233), SDI_e-3 (76), SDI_e-6 (34) and SDI_e-12 (17) for Nanded district. The extreme drought events were computed at multi-time steps SDI_e-1, 1994- May, 1995-May and Jun and 2009-Dec, SDI_e-3, 1994- April-Jun and 1995-April-Jun, SDI_e-6, 1995-April-Sep. Similarly, total numbers of drought events were calculate SDI_e-1 (297), SDI_e-3 (98), SDI_e-6 (49) and SDI_e-12 (26) for Parabhani district but not converted into extreme drought events.

3.3 Trend Analysis

The Mann-Kendall test statistics were presented in Table 5. The table shows that Monthly, 3-month, 6-month and the annual SPI_e, RDI_e and SDI_e of Latur, Nanded and Parabhani stations have a significant negative trend in 95% confidence limit. After analyzing trend result, monthly, 3-month, 6-month and the annual SPI_e, RDI_e and SDI_e of Latur Nanded and Parabhani stations have a non-significant trend (either positive or negative) in 95% confidence limit.

3.4 Probability and Return Period

The probability and return period of extreme and severe yearly drought for Latur, Nanded and Parabhani districts were presented in Table 6. After analyzing the result of Lutur district, it was concluded that both SPI_e and RDI_e having the extreme drought event in 1983 with probability and return period 0.023 and 43 years. Also, result of severe drought was estimated probability and return period in (1991), 0.046 and 21.5 year, (1976) 0.070, 14.33 years and (1995), 0.093 and 10.75 years of both SPI_e and RDI_e. The extreme meteorological and hydrological drought was not found in Nanded district but severe drought in term of SPI_e and RDI_e was found in 1983 and 1995 and SDI_e was estimated severe drought in 1991 and 2008. Moreover, extreme meteorological drought was found in 1983 in of term of SPI_e and RDI_e with probability 0.023and return period 43 years for Parabhani districts. Finally, conclusion was that the 43 years reoccurrence interval of extreme meteorological drought for Latur and Parabhani district, the 10.75, 21.5 and 14.33 years return period of severe meteorological drought for Latur, Nanded and Parabhani districts was estimated. Also, the 18, 18 and 43 years reoccurrence interval of severe hydrological drought for Latur, Nanded and Parabhani districts was calculated.

Table 4. Results of modified meteorological drought and hydrological drought indices

No. of Event		**SPI_e**				**RDI_e**				**SDI**			
		SPI_e-1	**SPI_e -3**	**SPI_e -6**	**SPI_e -12**	**RDI_e -1**	**RDI_e -3**	**RDI_e -6**	**RDI_e -12**	**SDI-1**	**SDI -3**	**SDI -6**	**SDI -12**
Latur	Total wet	255	103	51	23	255	103	51	23	171	60	34	20
	Total drought	249	65	33	19	249	65	33	19	249	80	36	15
	Severe drought	16	6	3	3	16	6	3		18	5	1	2
	Extreme drought	8	5	3	1	8	5	3	1	4	2	1	0
Nanded	Total wet	257	91	50	22	257	91	50	22	187	64	36	18
	Total drought	242	78	34	20	247	77	34	20	233	76	34	17
	Severe drought	18	10	4	0	18	10	4	0	16	5	1	2
	Extreme drought	7	5	4	2	7	5	4	2	4	2	1	0
Parabhani	Total wet	247	90	49	24	262	90	49	24	207	70	35	16
	Total drought	262	77	35	18	242	78	35	18	297	98	49	26
	Severe drought	13	8	6	2	13	8	6	2	16	5	1	1
	Extreme drought	8	2	2	1	8	2	2	1	0	0	0	0

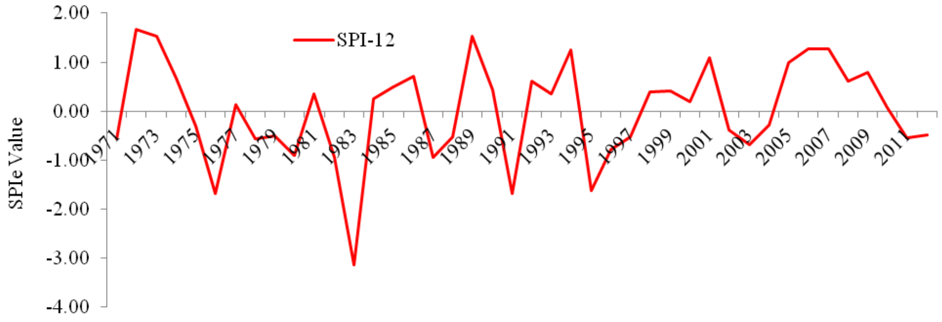

Fig. 2. Yearly based graph of SPI at Latur district

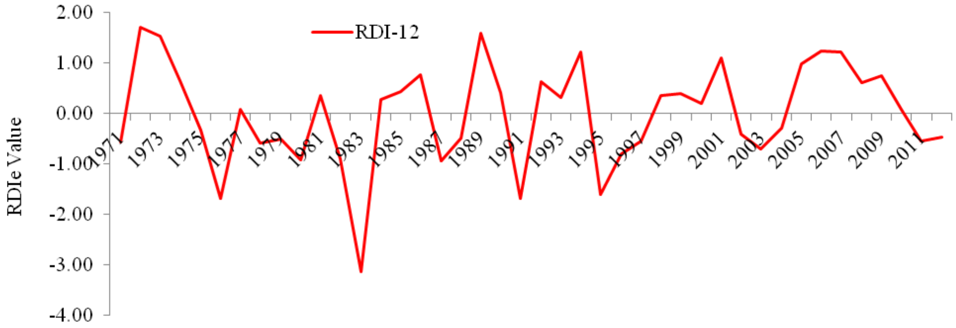

Fig. 3. Yearly based graph of RDI at Latur district

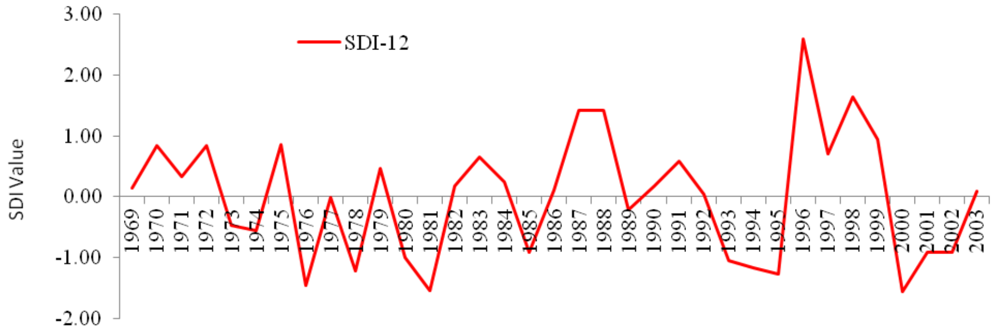

Fig. 4. Yearly based graph of SDI at Latur district

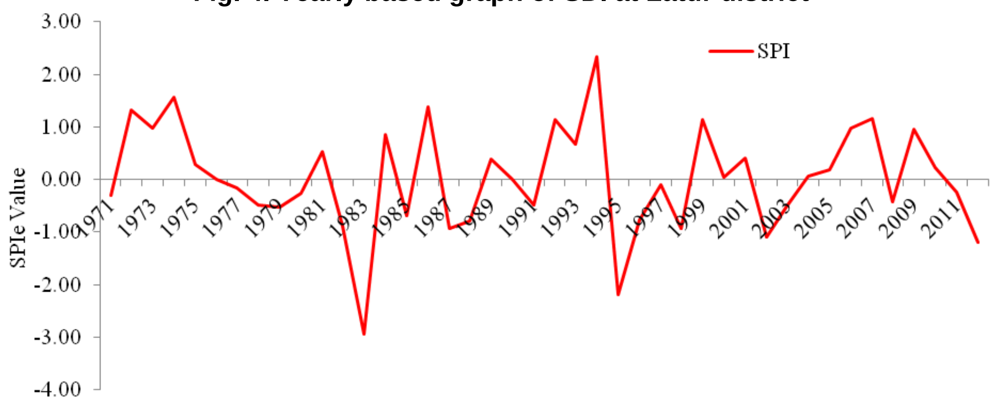

Fig. 5. Yearly based graph of SPI_e at Nanded district

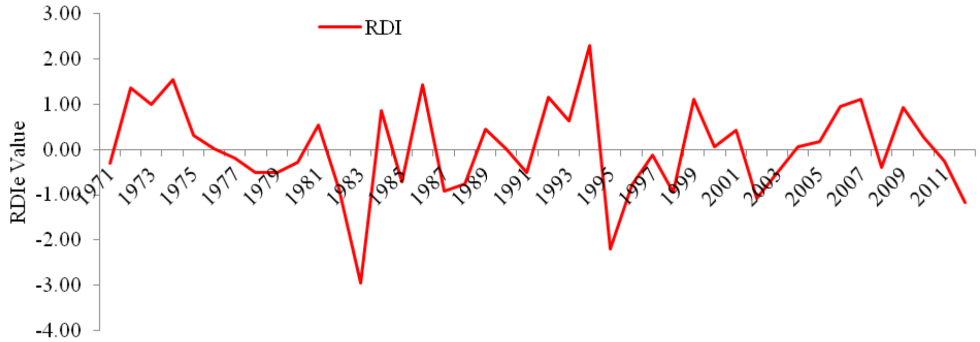

Fig. 6. Yearly based graph of RDI_e at Nanded district

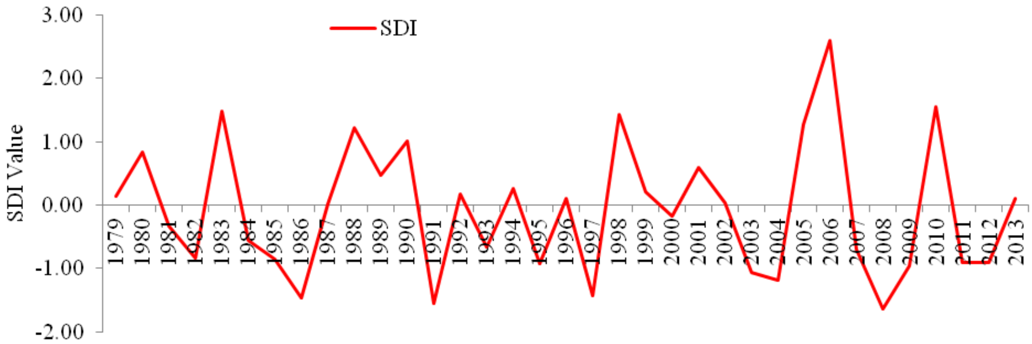

Fig. 7. Yearly based graph of SDI at Nanded district

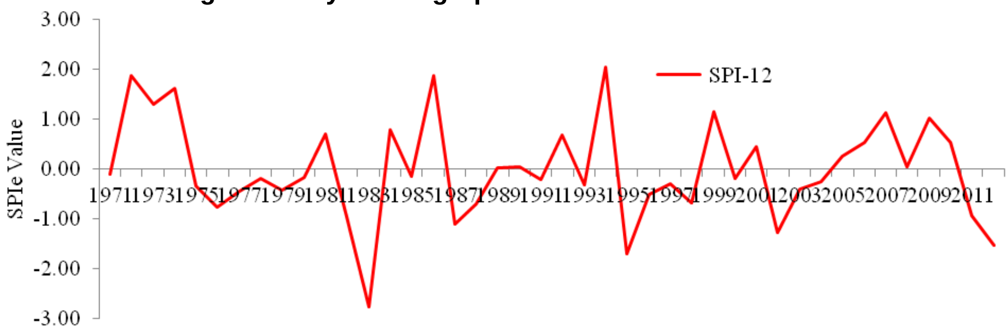

Fig. 8. Yearly based graph of SPI_e at Parabhani district

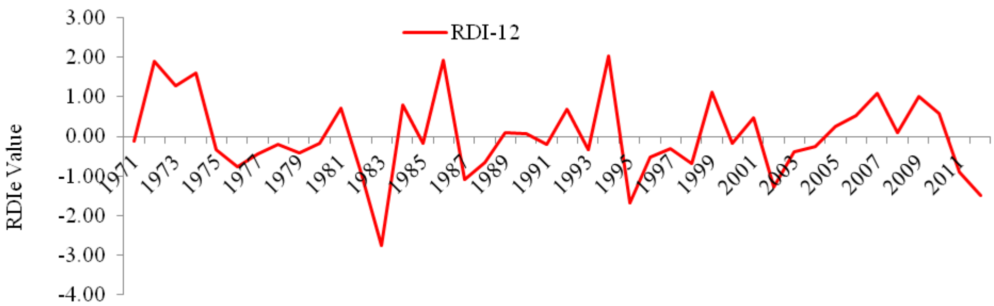

Fig. 9. Yearly based graph of $_{RDIe}$ at Parabhani district

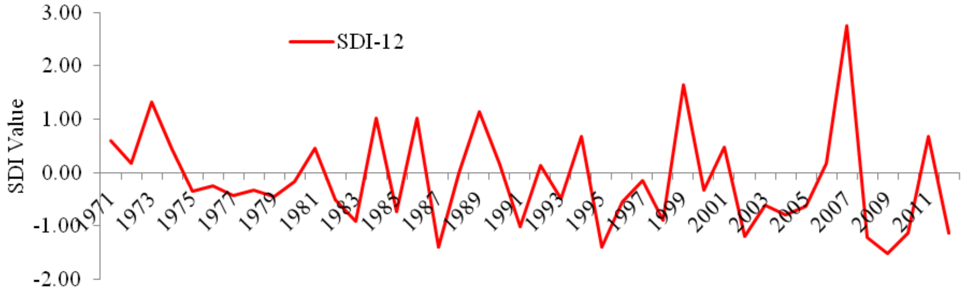

Fig. 10. Yearly based graph of SDI at Parabhani district

Table 5. Trend analysis result based on Mann-Kendall test of multi-temporal drought

Station	Time	SPI_e		RDI_e		SDI	
		Z_{st}	Trend	Z_{st}	Trend	Z_{st}	Trend
Latur	Annual	0.867	No	0.834	No	-0.256	No
	6-Month	1.141	No	1.392	No	-1.207	No
	3-Month	1.409	No	1.891	No	1.162	No
	Monthly	-0.592	No	-0.585	No	-0.241	No
Nanded	Annual	0.889	No	-0.236	No	-0.236	No
	6-Month	1.242	No	-1.197	No	-1.197	No
	3-Month	1.112	No	1.175	No	1.175	No
	Monthly	-0.492	No	-0.241	No	-0.241	No
Parabhani	Annual	-0.236	No	-0.215	No	-0.211	No
	6-Month	-1.199	No	-1.179	No	-1.16	No
	3-Month	1.189	No	1.168	No	1.154	No
	Monthly	-0.234	No	-0.211	No	-0.221	No

Table 6. Probability and return period of extreme and severe drought

Site	Event	SPI_e				RDI_e			SDI_e			
Latur		Year	Value	P	T	Value	P	T	Year	Value	P	T
	Extreme drought	1983	-3.14	0.023	43	-3.14	0.023	43	-	-	-	-
	Severe drought	1991	-1.68	0.046	21.5	-1.68	0.046	21.5	1981	-1.55	0.055	18
		1976	-1.68	0.070	14.33	-1.68	0.070	14.33	2000	-1.56	0.027	36
		1995	-1.60	0.093	10.75	-1.60	0.093	10.75				
Nanded	Extreme drought	-	-	-	-	-	-	-	-	-	-	-
	Severe drought	1983	-2.95	0.023	43	-2.95	0.023	43	1991	-1.55	0.055	18
		1995	-2.19	0.046	21.5	-2.19	0.046	21.5	2008	-1.64	0.027	36
Parabhani	Extreme drought	1983	-2.75	0.023	43	-2.75	0.023	43	-	-	-	
	Severe drought	1995	-1.69	0.046	21.5	-1.69	0.046	21.5	2009	-1.51	0.023	43
		2012	-1.52	0.070	14.33	-1.52	0.070	14.33				

4. CONCLUSION

In this study, the very popular meteorological drought Standardized Precipitation Index (SPI) and Reconnaissance drought Index (RDI) have been modified using effective rainfall instead of rainfall and the studied in present work in using gamma distribution probability instead of the normal and log-normal to describe effective rainfall data series. The monthly meteorological data and hydrological data were used from 1971-2012 and 1969-2003 of Latur, 1971-2012 and 1971-2012 of Prabhani, and 1971-2012 and 1979-2013 of Nanded and tested for various time scales (1, 3, 6 and 12 months). After analyzing trend result, monthly, 3-month, 6-month and the annual SPI_e, RDI_e, and SDI_e of Latur Nanded and Parabhani stations have a non-significant trend (either positive or negative) in 95% confidence limit. The only one meteorological extreme drought year was occurring in 1983 and hydrological extreme drought year was not found in Latur district. Analyzing the result of Nanded district, the meteorological and hydrological extreme drought year was not found. At Parabhani district, the meteorological extreme drought year was occurring in 1983 and hydrological extreme drought was not occurring.

Finally, the conclusion was the 43 years reoccurrence interval of extreme meteorological drought for Latur and Parabhani districts, the 10.75, 21.5 and 14.33 years return period of severe meteorological drought for Latur, Nanded and Parabhani districts. Also, the 18, 18 and 43 years reoccurrence interval of severe hydrological drought for Latur, Nanded and Parabhani districts was calculated. The forecasting model will be develop for forecasting of drought using soft computing techniques Singh, et al. [21], Kumar et al. [22] in future.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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