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# Characterization and trend detection of meteorological drought for a semi-arid area of Parbhani district of Indian state of Maharashtra

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**सार** – सूखा, विशेष रूप से शुष्क और अर्ध-शुष्क क्षेत्रों में जल संसाधन प्रबंधन के संबंध में प्रतिकूल प्राकृतिक खतरों में से एक है। वैश्विक उष्णन (ग्लोबल वार्मिंग) और जलवायु परिवर्तन की स्थितियों के कारण, शुष्क तथा अर्द्ध शुष्क क्षेत्रों में सूखे की गंभीरता तथा इसकी प्रवृत्ति का पता लगाना अत्यंत महत्त्वपूर्ण है। इसलिए, इस अध्ययन में, भारतीय राज्य महाराष्ट्र के परभणी जिले के अर्ध शुष्क क्षेत्र के लिए मानकीकृत वर्षण सूचकांक (SPI) और मानकीकृत आवीक्षण सूखा सूचकांक ($RDI_{std}$) जैसे विभिन्न मौसम संबंधी सूखे सूचकांकों का उपयोग करके सूखे की प्रचंड गंभीरता का आकलन किया गया। परिणामों से पता चला कि SPI और $RDI_{std}$ समान रूप से व्यवहार करते हैं ताकि सूखे की गंभीरता का पता लगाया जा सके। 37 वर्षों (1983 से 2019) में, SPI में 1 प्रचंड सूखा वर्ष, 6 मध्यम सूखे वर्ष, 22 सामान्य वर्ष, 4 मध्यम आर्द्र वर्ष, 3 अत्यंत आर्द्र वर्ष तथा 1 प्रचंड आर्द्र वर्ष दर्शाए गए जबकि $RDI_{std}$ में 1 प्रचंड सूखा वर्ष, 5 मध्यम सूखे वर्ष, 23 सामान्य वर्ष, 4 मध्यम आर्द्र वर्ष, 3 अत्यंत आर्द्र वर्ष तथा 1 प्रचंड आर्द्र वर्ष दर्शाए गए। SPI और $RDI_{std}$ दोनों सूचकांकों के आधार पर एक प्रचंड सूखा वर्ष देखा गया। साप्ताहिक आँकड़ा विश्लेषण के आधार पर, सूखे, सामान्य और आर्द्र सप्ताह की आवृत्ति क्रमशः 70.58, 15.90 तथा 13.51% पाई गई। अल्पकालिक साप्ताहिक वर्षा विश्लेषण से अध्ययन क्षेत्र में सूखे की लगातार घटनाओं की स्पष्ट तस्वीर का पता चला जो दीर्घावधि पैमाने (मासिक या वार्षिक) की तुलना में अधिक है। सांख्यिकीय रूप से महत्वपूर्ण प्रवृत्ति की पहचान करने के लिए, एक गैर प्राचलिक परीक्षण (Mann-Kendall) और प्राचलिक परीक्षण (Linear regression) का उपयोग किया गया। वार्षिक पैमाने पर, PET और तापमान को छोड़कर वर्षा, SPI, $RDI_{std}$ के मामले में महत्वपूर्ण वृद्धि या कमी की प्रवृत्ति नहीं पाई गई। दोनों परीक्षणों में 0.1 स्तर ($\alpha$) में PET की सांख्यिकीय रूप से कमी की महत्वपूर्ण प्रवृत्ति को दिखाया गया जो वाष्पीकरण के माध्यम से जल की कमी और सूखे की गंभीरता को कम करेगा। मासिक समय मान पर, $\alpha = 0.01, 0.05$ तथा 0.1 में दोनों परीक्षणों में SPI के मामले में जून महीने के लिए सांख्यिकीय रूप से कम होने का संकेत मिला (अर्थात बढ़ते हुए सूखे की गंभीरता) जो मॉनसून की आरंभिक अवधि में वर्षा की कमी में वृद्धि का संकेत देता है और खरीफ ऋतु की फसलों की आरंभिक बुवाई में देरी को बढ़ाता है। नवंबर माह के लिए, दोनों परीक्षणों में, $\alpha = 0.1$ में SPI और $RDI_{std}$ की वृद्धि की प्रवृत्ति (अर्थात सूखे की गंभीरता में कमी) दिखाई दी। PET के मामले में, दोनों परीक्षणों में किसी भी माह में कोई सांख्यिकीय महत्वपूर्ण प्रवृत्ति नहीं दिखाई दी।

**ABSTRACT.** Drought is one of the adverse natural hazards especially in arid and semi-arid regions regarding water resources management. Under the conditions of global warming and climate change, the investigation of drought severity and its trend in arid and semi-arid regions is of primary importance. Therefore, in this study, drought severity assessment and trend detection were carried out using different meteorological drought indices like Standardized Precipitation Index (SPI) and Standardized Reconnaissance Drought Index (RDIstd) for a semi-arid area of Parbhani district of the Indian state of Maharashtra. The results showed that SPI and RDIstd behave similarly to detect drought severity except for some slight deviation in detecting moderate and normal drought severity. Out of 37 years (1983 to 2019), SPI showed 1 severe drought year, 6 moderate drought years, 22 normal years, 4 moderate wet years, 3 very wet years and 1 extremely wet year while RDIstd showed 1 severe drought year, 5 moderate drought years, 23 normal years, 4 moderate wet years, 3 very wet years and 1 extremely wet year. One severe drought year was observed on the basis of both SPI and RDIstd indices. On the basis of weekly data analysis, the frequency of drought, normal and wet week was found to be 70.58, 15.90 and 13.51 per cent, respectively. It is revealed that the short term weekly rainfall analysis provides clear picture of frequent occurrences of drought episodes at the study area as compared to longer (monthly or annual) time scale. For identifying a statistically significant trend, a non-parametric test (Mann-Kendall) and parametric test (Linear regression) were used. At an annual scale, no significant either increasing or decreasing trend was found in the case of precipitation, SPI, RDIstd except potential evapotranspiration (PET) and temperature. Both the tests showed a statistically significant decreasing trend of PET at 0.1 level of significance ($\alpha$) which would reduce water loss through evapotranspiration and minimize drought severity. At monthly time scale, both the tests indicated statistically decreasing trend for June month in the case of SPI (*i.e.*, increasing drought severity) at α = 0.01, 0.05 and 0.1 which indicated increment in shortage of precipitation at early monsoon period and hence, increase in delay of early sowing of Kharif seasonal crops. For November month, both the tests showed an increasing trend of SPI and RDIstd (*i.e.*, decreasing drought severity) at α = 0.1. In the case of PET, both the tests did not show any statistically significant trend at any month.

**Key words** – Drought, SPI, RDIstd, Mann-Kendall test, Linear regression test.

## 1. Introduction

Drought is a recurrent, multi-dimensional natural hazard that affects human life adversely. It occurs because of a shortage of precipitation, a high rate of evapotranspiration and overuse of available surface and groundwater resources (Bhelawe *et al.*, 2015; Zarei *et al.*, 2016). Since past few decades, the severity and frequency of occurrence of drought have been increased considerably due to the effects of climate change and global warming (Al-Qinna *et al.*, 2011; Edossa *et al.*, 2010; Liu *et al.*, 2012; Paulo *et al.*, 2016; Shen *et al.*, 2017; Surendran *et al.*, 2017). Drought is responsible to cause enormous impacts on ecology, environment, hydrology and agriculture. Drought is defined as the deficiency of precipitation for an extended duration that severely affects agricultural production; it causes a shortage of water for human or livestock even for consumption and influences the ecological balance (Singh *et al.*, 2014). Different specialist describes the drought in different ways; for instance, according to agriculturist's drought indicate a deficiency of moisture in the top layer of soil which relate drought to moisture shortage in topsoil up to root zone which influences the crops adversely, meteorologists relate it to when deficiency of precipitation occurs for a longer duration, according to hydrologist low runoff or low stream flow denote drought event (Zarei *et al.*, 2016). Over the last few decades, more people are affected due to increased frequency of drought as a natural hazard (Dhar *et al.*, 1979; Ray *et al.*, 1987; Kumar and Kumar, 1989; Dabral, 1996; Marathe *et al.*, 2001; Shrivastava *et al.*, 2008; Lala *et al.*, 2012; Lala *et al.*, 2014). Drought is a complex phenomenon which can be identified by its characteristics like duration, severity and areal extent. Monitoring and forecasting of drought is a research challenge (Rahmat *et al.*, 2015). There are four different types of drought as Meteorological, Agricultural, Hydrological and Socio-economic drought (Zarch *et al.*, 2011). For realizing the drought and its severity, different indices are being used. The severity of drought, it's spatial and temporal extent can be estimated using these indices (Zarei *et al.*, 2016). These indices help to analyze historical drought occurrences and to estimate recurrence probability. It helps to analyze this climatic anomaly in terms of their frequency, duration, intensity and spatial extent. Adverse effects of droughts like socioeconomic, agricultural and environmental impacts can be reduced by assessment as well as forecasting of drought behaviour (Singh and Sharma, 2003; Tiwari *et al.*, 2007; Manikandan and Tamilmani, 2011; Tigkas *et al.*, 2015). It has been proved that different drought indices are the key element for drought monitoring and the management of water resource. In order to assess the drought severity, different meteorological drought indices like the Standardized Precipitation Index (SPI) and Standardized Reconnaissance Drought Index ($RDI_{std}$) are widely used. The output obtained from these indices helps the academics, researchers, administrators and policy makers for decision making in water conservation and drought mitigation planning purposes. Drought indices can be calculated manually, it can also be calculated using tools or softwares designed for this purpose. The SPI makes the use of precipitation only while $RDI_{std}$ makes the use of precipitation as well as the potential evapotranspiration (PET) simultaneously. Different meteorological parameters like temperature, wind velocity, relative humidity and sunshine duration can also affect the drought magnitude in terms of PET. By keeping all these things in mind, this study was carried out with following objectives: (*i*) to assess the drought severity using different meteorological drought indices (*ii*) to develop linear regression equation in between SPI and $RDI_{std}$ meteorological indices and (*iii*) to detect the trend of drought severity using parametric and non-parametric tests for semi-arid Parbhani district of Maharashtra state of India.

## 2. Data sets and methodology

### 2.1. *Study area*

The Parbhani district of Maharashtra state comes under semi-arid climatic conditions. Parbhaniis situated at 19° 16′ N latitude and 76° 47′ E longitude and located at an altitude of 409 m above mean sea level. It comes under moderate to moderately high precipitation zone with an average annual precipitation of 955 mm. The mean maximum and minimum temperature of the study area is 44.6 °C and 21.8 °C, respectively. The mean relative humidity varies from 30 to 98 per cent. May is the hottest month while December is the coldest month of the year. April and May are dryer (low relative humidity) months of the year. The location of the study area is shown in Fig. 1. Agriculture is the main occupation of people lives in the study area.

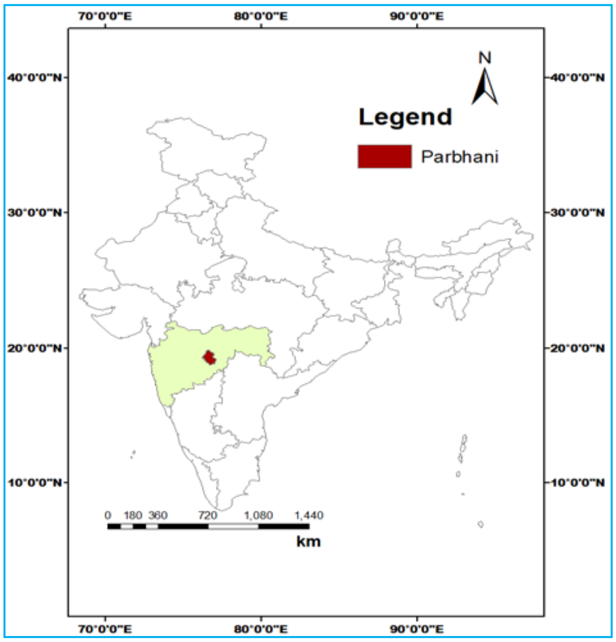


**Fig. 1.** Location map of the study area

2.2. *Precipitation and PET data*

Precipitation and other meteorological data (maximum temperature, minimum temperature, wind velocity, relative humidity and bright sunshine hours) from the year 1983 to 2019 were collected from India Meteorological Department (IMD) recognized observatory located in Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra. The monthly variation of rainfall and PET is shown in Fig. 2. Overall, rainfall is maximum in monsoon than summer and winter season. PET of the study area has been calculated using the Hargreaves method. In this study, DrinC (Drought index calculator) software was used for calculating the drought SPI and $RDI_{std}$ indices (Tigkas *et al.*, 2014). The daily rainfall data series were divided in to annual, monthly and weekly rainfall data series for determination of drought severity. In case of weekly data analysis, the last day of every year is counted in the $52^{nd}$ meteorological week while in case of leap year $29^{th}$ day of February is counted in the $9^{th}$ meteorological month.

2.3. *Drought indices*

2.3.1. *SPI*

McKee *et al.* (1993) invented SPI at Colorado State University to estimate the precipitation deficit at multiple time scales. The SPI is the transformation of the precipitation time series into a standardized normal distribution. The computation of SPI consists of fitting cumulative probability distribution function (PDF) on aggregated monthly (k) precipitation series and transforming the cumulative distribution function (CDF) to the CDF of the standard normal distribution with zero mean and unit variance. The gamma PDF [$g(x)$] is defined as:

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

where, $\beta$ is a scale parameter, $\alpha$ is a shape parameter, $x$ is the precipitation amount and $\Gamma(\alpha)$ is the gamma function at α. Scale and shape factors can be estimated using a method of maximum likelihood. The estimated parameters can be used to find the cumulative PDF of observed precipitation events for the given month and particular time scale. The CDF is obtained by integrating Eqn. (1) as:

$$G(x) = \int_0^x g(x)dx = \int_0^x \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} dx \tag{2}$$

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

$$\beta = \frac{\bar{x}}{\alpha} \tag{4}$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \tag{5}$$

$n$ is the number of precipitation observations and $\bar{x}$ refers to the sample mean of the data. Transformation of the CDF to the CDF of the standard normal distribution with zero mean and unit variance, gives SPI as:

$$\text{SPI} = \varphi^{-1}[G(x)] \tag{6}$$

This transformed probability is the SPI. A positive value of SPI indicates that precipitation is above average and a negative value denotes below average precipitation. Severe drought can be represented by a continuous negative value of SPI reaching to -1.0 or less.

2.3.2. *RDI*

Tsakiris & Vangelis (2005) invented RDI which represents the water balance deficit between input precipitation and an output PET. The initial value ($\alpha_k$) of

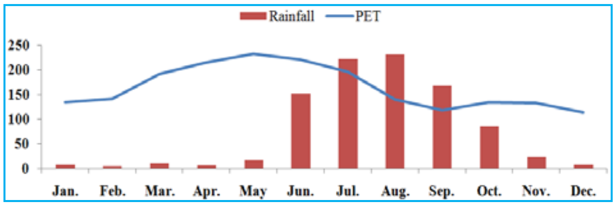


**Fig. 2.** Mean monthly rainfall (cm) and PET (cm) of the study area

RDI for a certain period, indicated by a certain month ($k$) during a year, is defined as:

$$\alpha_k = \frac{\sum_{j=1}^{j=k} \mathrm{P}_j}{\sum_{j=1}^{j=k} \mathrm{PET}_j} \tag{7}$$

where, $\mathrm{P}_j$ and $\mathrm{PET}_j$ are the precipitation and PET of the $j^{\mathrm{th}}$ month of the year. The RDI can be expressed as normalized RDI ($\mathrm{RDI}_n$) and Standardized RDI ($\mathrm{RDI}_{\mathrm{std}}$). The $\mathrm{RDI}_{\mathrm{n}}$ is computed using the following equation as:

$$\mathrm{RDI}_n(k) = \frac{\alpha_k}{\bar{\alpha}_k} - 1 \tag{8}$$

The $\mathrm{RDI}_{\mathrm{std}}$ is computed using a similar procedure which is used for SPI estimation. The equation is as follows:

$$\mathrm{RDI}_{std}(k) = \frac{y_k - \bar{y}_k}{\sigma_k} \tag{9}$$

where, $y_k$ is $\ln\alpha_k^{\mathrm{i}}$, $\bar{y}_k$ is the arithmetic mean, $\sigma_k$ is the standard deviation.

In this study, the initial values of RDI are fitted to a gamma PDF similar to the one used for SPI. Therefore, the $\mathrm{RDI}_{\mathrm{std}}$ could be computed following a similar procedure described for SPI and the values compared to the same threshold values as used for SPI drought categorization (Table 1).

### 2.4. *Statistical methods for trend detection*

Many statistical techniques (parametric or non-parametric) have been developed to detect trends within time series such as linear regression, Spearman's Rho test, Mann-Kendall test, Sen's slope estimator and Bayesian procedure, etc. Various parametric and non-parametric tests can be used for identifying trends in hydro-meteorological time series. In this study, the Mann-Kendall non-parametric and linear regression parametric tests were used to analyze the trend of drought severity.

**TABLE 1**

**Classifications scale of SPI and $\mathrm{RDI}_{\mathrm{std}}$ values**

| SPI/ $\mathrm{RDI}_{\mathrm{std}}$ values | Category |
|---|---|
| 2.00 or more | Extremely wet |
| 1.50 - 1.99 | Very wet |
| 1.00 - 1.49 | Moderately wet |
| 0.99 to -0.99 | Near normal |
| - 1.0 to -1.49 | Moderate drought |
| - 1.5 to -1.99 | Severe drought |
| -2 and less | Extreme drought |

#### 2.4.1. *Mann-Kendall trend detection test*

It is a non-parametric distribution free trend detection test. This type of test is the most useful because most of the hydro-meteorological time series data are not normally distributed. The Mann-Kendall test statistic $S$ is defined as:

$$s = \sum_{1=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(X_j - X_i) \tag{10}$$

where, $n$ is a number of data points, $X_i$ and $X_j$ are the data values in time series $i$ and $j$ ($j > i$), respectively and sgn ($X_j - X_i$) is the sign function given as:

$$\mathrm{sgn}(X_j - X_i) = \begin{bmatrix} +1 \text{ if } (x_j - x_i) > 0 \\ 0 \text{ if } (x_j - x_i) = 0 \\ -1 \text{ if } (x_j - x_i) < 0 \end{bmatrix} \tag{11}$$

where, the null hypothesis ($H_{\mathrm{o}}$) is that there is no trend in the data. If $H_{\mathrm{o}}$ is true, then s is approximately normally distributed with zero mean (μ) and variance ($\sigma^2$) is given as:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \tag{12}$$

The $z$-statistic (critical test statistic values for various level of significance can be obtained from normal probability tables) is given as:

$$z = \begin{bmatrix} (S-1)/\sigma \text{ if } \; S > 0 \\ 0 \qquad\qquad \text{if } \; S = 0 \\ (S+1)/\sigma \text{ if } \; S < 0 \end{bmatrix} \tag{13}$$

A positive value of s indicates an increasing trend and *vice versa*. Here, the detection of the trend was carried out at a specific level of significance (α). In this research, α = 0.01, 0.05 and 0.1 were used.

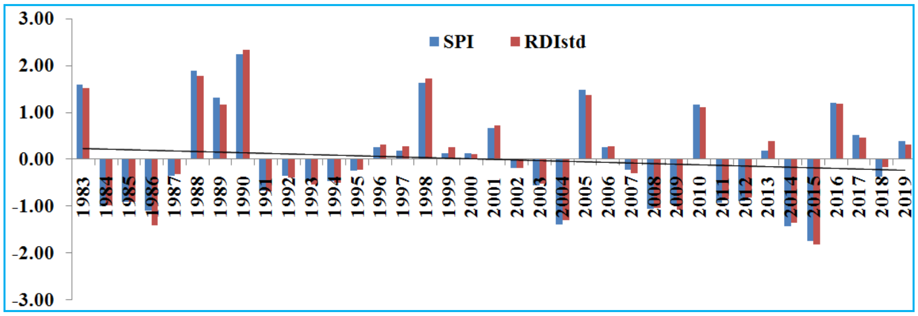


**Fig. 3.** Historical time series variation of annual SPI and $RDI_{std}$

2.4.2. *Linear regression trend detection test*

It is a parametric test that assumes that data are normally distributed. It tests the presence of a linear trend by identifying the relationship between time (*x*) and the variable of interest (*y*). The regression gradient (b) can be estimated as:

$$b = \frac{\sum_{i=1}^{n}\left(Xi-\bar{x}\right)\left(yi-\bar{y}\right)}{\sum_{i=1}^{n}\left(Xi-\bar{x}\right)\left(Xi-y\bar{x}\right)} \tag{14}$$

where, $X_i$ is the time, $Y_i$ is the variable of interest, $\bar{x}$ and $\bar{y}$ are the ranks. The intercept could be estimated as:

$$a = \bar{y} - b.\bar{x} \tag{15}$$

The test statistic *z* can be estimated as:

$$z = \frac{b}{\sigma} \tag{16}$$

$$\text{where, } \sigma = \sqrt{\frac{12\sum_{i=1}^{n}\left(Yi-a-bXi\right)}{n\left(n-2\right)\left(n^2-1\right)}} \tag{17}$$

The test statistic *z* follows a Student - *t* distribution with *n*-2 degrees of freedom under the $H_o$ (critical test statistic values for different α can be obtained from Student's *t* statistic tables).

## 3. Results and discussion

In this study, the correlation between SPI and $RDI_{std}$ was determined at different time scales. The correlation coefficients were observed to be very high at different time scale for a given semi-arid region as presented in Table 2.

**TABLE 2**

**Correlation coefficient of the SPI and $RDI_{std}$ at different time scales**

| Time scales | 1 month | 3 month | 6 month | 12 month |
|---|---|---|---|---|
| Correlation coefficient | 0.99408 | 0.9963 | 0.9965 | 0.9951 |

The SPI and $RDI_{std}$ indices showed similar behaviour to detect the severity of drought years, except a slight deviation for the year 1986 as shown in Fig. 3. Out of 37 years, SPI showed 1 severe drought year, 6 moderate drought years, 22 normal years, 4 moderate wet years, 3 very wet years and 1 extremely wet year while $RDI_{std}$ showed 1 severe drought year, 5 moderate drought years, 23 normal years, 4 moderate wet years, 3 very wet years and 1 extremely wet year. $RDI_{std}$ and SPI indices showed a nearly equal number of drought event with a slight deviation in their magnitude. The trend line shows the increased drought frequency and magnitude from the year 1983 to 2019 as shown in Fig. 3. Paired *t*-test indicated that SPI and $RDI_{std}$ values do not differ significantly with a *p*-value of 0.9861.

The occurrence of the number of drought episodes and their severity for the past 37 years is shown in Fig. 4 for different months. While assessing the drought severity at monthly time scale, for the month of February, June, July, August, October and December, the trend line showed increased drought severity as shown in Fig. 4. The monsoon season including June, July, August, September and October experienced moderate, severe and extreme drought episodes on the basis of monthly time scale. It indicated an abrupt deviation of rainfall from mean rainfall is more in monsoon season which is responsible for the occurrence of number drought episodes in the monsoon within the study area.

3.1. *Monthly linear regression in between SPI and $RDI_{std}$ values*

Monthly linear regression relationship between SPI and $RDI_{std}$ indices are shown in Fig. 5. The low

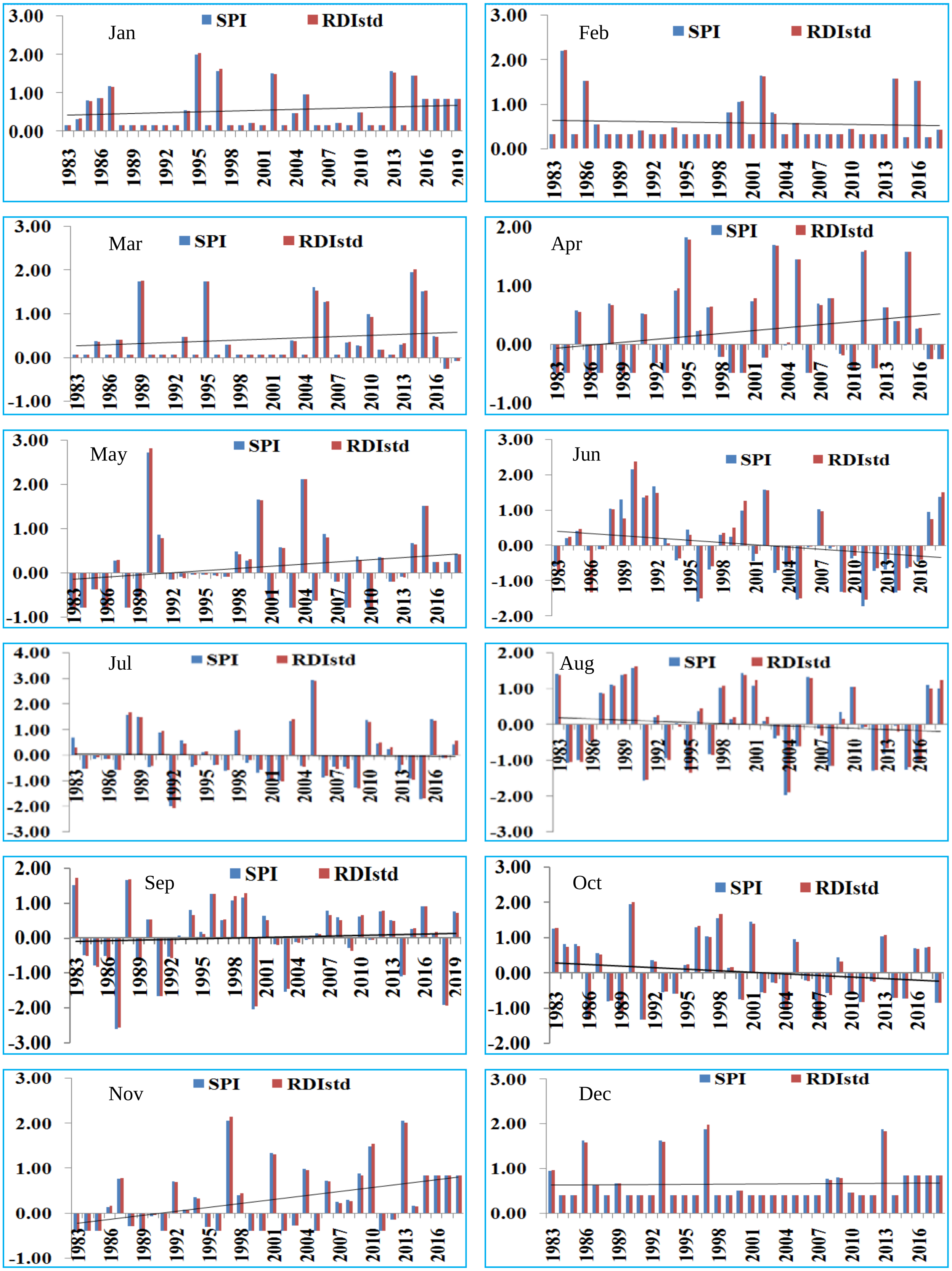


**Fig. 4.** SPI and $RDI_{std}$ of different months for past historical data

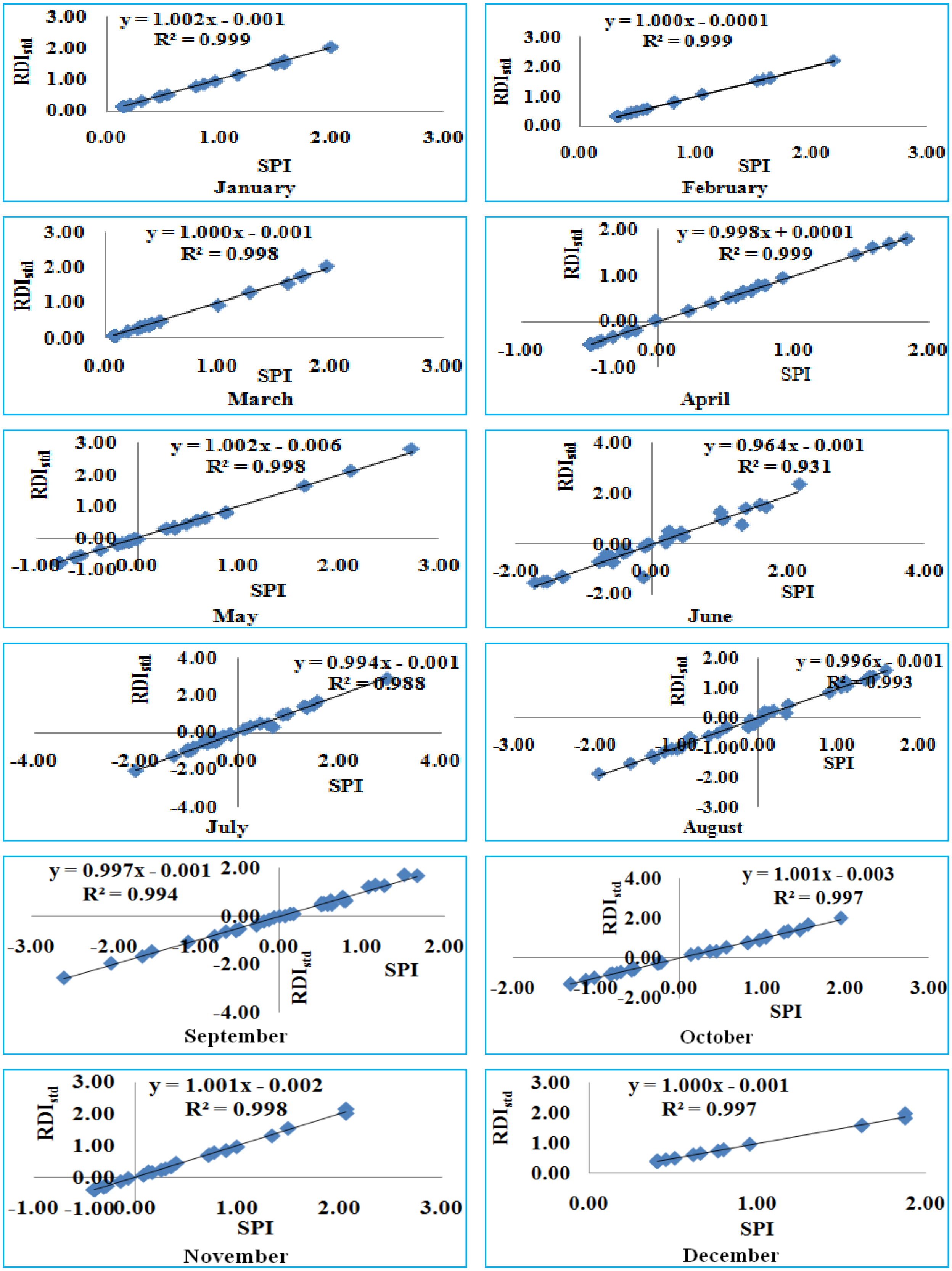


**Fig. 5.** Monthly linear regression between SPI and $RDI_{std}$ for Parbhani district

**TABLE 3**

**Mann-Kendall non parametric test for trend detection**

| Time scale | Variable | Test statistic (Z) | Critical values | | | Total S score | Result |
|---|---|---|---|---|---|---|---|
| | | | α = 0.1 | α = 0.05 | α = 0.01 | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Annual | Precipitation | -0.811 | 1.645 | 1.96 | 2.576 | -51 | NS |
| | Temperature | -1.314 | 1.645 | 1.96 | 2.576 | -82 | NS |
| | PET | -1.768 | 1.645 | 1.96 | 2.576 | -110 | S (0.1) |
| | SPI | -0.811 | 1.645 | 1.96 | 2.576 | -51 | NS |
| | $RDI_{std}$ | -0.762 | 1.645 | 1.96 | 2.576 | -48 | NS |
| January | Precipitation | -0.227 | 1.645 | 1.96 | 2.576 | -15 | NS |
| | Temperature | -1.184 | 1.645 | 1.96 | 2.576 | -74 | NS |
| | PET | 0.341 | 1.645 | 1.96 | 2.576 | 22 | NS |
| | SPI | -0.227 | 1.645 | 1.96 | 2.576 | -15 | NS |
| | $RDI_{std}$ | -0.243 | 1.645 | 1.96 | 2.576 | -16 | NS |
| February | Precipitation | -0.308 | 1.645 | 1.96 | 2.576 | -20 | NS |
| | Temperature | 0.811 | 1.645 | 1.96 | 2.576 | 51 | NS |
| | PET | -0.243 | 1.645 | 1.96 | 2.576 | -16 | NS |
| | SPI | -0.308 | 1.645 | 1.96 | 2.576 | -20 | NS |
| | $RDI_{std}$ | -0.308 | 1.645 | 1.96 | 2.576 | -20 | NS |
| March | Precipitation | 1.265 | 1.645 | 1.96 | 2.576 | 79 | NS |
| | Temperature | -1.314 | 1.645 | 1.96 | 2.576 | -82 | NS |
| | PET | -0.243 | 1.645 | 1.96 | 2.576 | -16 | NS |
| | SPI | 1.265 | 1.645 | 1.96 | 2.576 | 79 | NS |
| | $RDI_{std}$ | 1.297 | 1.645 | 1.96 | 2.576 | 81 | NS |
| April | Precipitation | 1.881 | 1.645 | 1.96 | 2.576 | 117 | S(0.1) |
| | Temperature | -0.519 | 1.645 | 1.96 | 2.576 | -33 | NS |
| | PET | -0.778 | 1.645 | 1.96 | 2.576 | -49 | NS |
| | SPI | 1.881 | 1.645 | 1.96 | 2.576 | 117 | S(0.1) |
| | $RDI_{std}$ | 1.865 | 1.645 | 1.96 | 2.576 | 116 | S(0.1) |
| May | Precipitation | 1.249 | 1.645 | 1.96 | 2.576 | 78 | NS |
| | Temperature | -1.184 | 1.645 | 1.96 | 2.576 | -74 | NS |
| | PET | 0 | 1.645 | 1.96 | 2.576 | -1 | NS |
| | SPI | 1.249 | 1.645 | 1.96 | 2.576 | 78 | NS |
| | $RDI_{std}$ | 1.314 | 1.645 | 1.96 | 2.576 | 82 | NS |
| June | Precipitation | -2.578 | 1.645 | 1.96 | 2.576 | -160 | S(0.01) |
| | Temperature | -0.697 | 1.645 | 1.96 | 2.576 | -44 | NS |
| | PET | -1.103 | 1.645 | 1.96 | 2.576 | -69 | NS |
| | SPI | -2.578 | 1.645 | 1.96 | 2.576 | -160 | S(0.01) |
| | $RDI_{std}$ | -1.946 | 1.645 | 1.96 | 2.576 | -121 | S(0.1) |
| July | Precipitation | -1.151 | 1.645 | 1.96 | 2.576 | -72 | NS |
| | Temperature | -0.243 | 1.645 | 1.96 | 2.576 | -16 | NS |
| | PET | -0.422 | 1.645 | 1.96 | 2.576 | -27 | NS |
| | SPI | -1.151 | 1.645 | 1.96 | 2.576 | -72 | NS |
| | $RDI_{std}$ | -0.989 | 1.645 | 1.96 | 2.576 | -62 | NS |
| August | Precipitation | -0.778 | 1.645 | 1.96 | 2.576 | -49 | NS |
| | Temperature | -1.362 | 1.645 | 1.96 | 2.576 | -85 | NS |
| | PET | 0.243 | 1.645 | 1.96 | 2.576 | 16 | NS |
| | SPI | -0.778 | 1.645 | 1.96 | 2.576 | -49 | NS |
| | $RDI_{std}$ | -0.876 | 1.645 | 1.96 | 2.576 | -55 | NS |

**TABLE 3 (*Contd.*)**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|
| September | Precipitation | 0.486 | 1.645 | 1.96 | 2.576 | 31 | NS |
| | Temperature | -2.027 | 1.645 | 1.96 | 2.576 | -126 | S(0.05) |
| | PET | -1.265 | 1.645 | 1.96 | 2.576 | -79 | NS |
| | SPI | 0.486 | 1.645 | 1.96 | 2.576 | 31 | NS |
| | $RDI_{std}$ | 0.519 | 1.645 | 1.96 | 2.576 | 33 | NS |
| October | Precipitation | -0.876 | 1.645 | 1.96 | 2.576 | -55 | NS |
| | Temperature | 0.243 | 1.645 | 1.96 | 2.576 | 16 | NS |
| | PET | 1.119 | 1.645 | 1.96 | 2.576 | 70 | NS |
| | SPI | -0.876 | 1.645 | 1.96 | 2.576 | -55 | NS |
| | $RDI_{std}$ | -0.843 | 1.645 | 1.96 | 2.576 | -53 | NS |
| November | Precipitation | 1.897 | 1.645 | 1.96 | 2.576 | 118 | S(0.1) |
| | Temperature | 1.476 | 1.645 | 1.96 | 2.576 | 92 | NS |
| | PET | 0.486 | 1.645 | 1.96 | 2.576 | 31 | NS |
| | SPI | 1.897 | 1.645 | 1.96 | 2.576 | 118 | S(0.1) |
| | $RDI_{std}$ | 1.849 | 1.645 | 1.96 | 2.576 | 111 | S(0.1) |
| December | Precipitation | -0.276 | 1.645 | 1.96 | 2.576 | -18 | NS |
| | Temperature | 0.081 | 1.645 | 1.96 | 2.576 | 6 | NS |
| | PET | 1.557 | 1.645 | 1.96 | 2.576 | 97 | NS |
| | SPI | -0.276 | 1.645 | 1.96 | 2.576 | -18 | NS |
| | $RDI_{std}$ | -0.276 | 1.645 | 1.96 | 2.576 | -18 | NS |

determination coefficient ($R^2$) in June was found to be about 0.931 because of abrupt variation of different meteorological parameters in this month. These linear regression equations can be useful to estimate the $RDI_{std}$ drought index with the availability of only rainfall data (SPI) because $RDI_{std}$ drought index actually represents agricultural drought as it depends on PET.

### 3.2. *Distribution of weekly rainfall*

Weekly data are more useful for proper planning and management of agricultural activities as compared to monthly, seasonal and annual rainfall data (Bhelawe *et al.*, 2015). The daily rainfall data series were converted in to weekly rainfall data for determination of drought severity. The weekly rainfall was classified as drought, normal and wet weeks. A week which receives rainfall less than or equal to half of the average weekly rainfall is called a dry week while a week which receives rainfall twice the average weekly rainfall is called a wet week and a week which receives rainfall between the limits of weekly rainfall corresponding to dry and wet week is called a normal week (Ramdas and Mallik, 1948; Ray *et al.*, 2016). The average values of weekly rainfall and corresponding values of drought, normal and wet week's rainfall ranges are presented in Table 5. The weekly rainfall distribution shows a better understanding about severity of drought and practices to be followed for short term planning and management of cropping pattern. The total numbers of dry, normal and wet weeks corresponding to different meteorological weeks considering 37 years rainfall data are presented in Table 5. The analysis of average weekly rainfall indicated that the maximum average weekly rainfall was observed during $32^{nd}$ week having magnitude of 60.08 mm followed by $34^{th}$, $35^{th}$, $31^{st}$ meteorological week while the lowest rainfall was received in $51^{st}$ meteorological week with average weekly value of 0.04 mm. The weekly analysis indicated that $51^{st}$ standard meteorological week showed maximum number of drought weeks with frequency of 36 out of 37 followed by $4^{th}$, $5^{th}$, $7^{th}$, $11^{th}$, $48^{th}$ and $49^{th}$ standard meteorological weeks. The minimum numbers of drought weeks were observed during $24^{th}$ standard meteorological week which receives 13 drought weeks, 18 normal weeks and 6 wet weeks out of 37 meteorological weeks. The analysis reveals that the frequency of drought, normal and wet week was found to be 70.58, 15.90 and 13.51 per cent, respectively. The analysis indicated that the maximum frequency of drought weeks was observed in winter and summer season as compared to monsoon season. Hence, it indicated the need of supplemental irrigation during this water deficit periods. Hence, short term weekly rainfall analysis provides clear picture of frequent occurrences of drought episodes at the study area as compared to longer (monthly or annual) time scale.

**TABLE 4**

**Linear regression parametric test for trend detection**

| Time scale | Variable | Test statistic (Z) | Critical values | | | σ | Result |
|---|---|---|---|---|---|---|---|
| | | | α = 0.1 | α = 0.05 | α = 0.01 | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Annual | Precipitation | -1.367 | 1.697 | 2.042 | 2.75 | 5.897 | NS |
| | Temperature | -1.84 | 1.697 | 2.042 | 2.75 | 0.013 | S(0.1) |
| | PET | -1.706 | 1.697 | 2.042 | 2.75 | 1.359 | S(0.1) |
| | SPI | -1.322 | 1.697 | 2.042 | 2.75 | 0.019 | NS |
| | $RDI_{std}$ | -1.118 | 1.697 | 2.042 | 2.75 | 0.019 | NS |
| January | Precipitation | -0.187 | 1.697 | 2.042 | 2.75 | 0.01 | NS |
| | Temperature | -1.645 | 1.697 | 2.042 | 2.75 | 0.036 | NS |
| | PET | -0.026 | 1.697 | 2.042 | 2.75 | 0.097 | NS |
| | SPI | -0.187 | 1.697 | 2.042 | 2.75 | 0.01 | NS |
| | $RDI_{std}$ | -0.212 | 1.697 | 2.042 | 2.75 | 0.01 | NS |
| February | Precipitation | -0.599 | 1.697 | 2.042 | 2.75 | 0.009 | NS |
| | Temperature | 0.463 | 1.697 | 2.042 | 2.75 | 0.019 | NS |
| | PET | 0.027 | 1.697 | 2.042 | 2.75 | 0.123 | NS |
| | SPI | -0.599 | 1.697 | 2.042 | 2.75 | 0.009 | NS |
| | $RDI_{std}$ | -0.624 | 1.697 | 2.042 | 2.75 | 0.009 | NS |
| March | Precipitation | 1.248 | 1.697 | 2.042 | 2.75 | 0.011 | NS |
| | Temperature | -1.2 | 1.697 | 2.042 | 2.75 | 0.023 | NS |
| | PET | -0.883 | 1.697 | 2.042 | 2.75 | 0.229 | NS |
| | SPI | 1.248 | 1.697 | 2.042 | 2.75 | 0.011 | NS |
| | $RDI_{std}$ | 1.243 | 1.697 | 2.042 | 2.75 | 0.011 | NS |
| April | Precipitation | 1.551 | 1.697 | 2.042 | 2.75 | 0.014 | NS |
| | Temperature | -0.397 | 1.697 | 2.042 | 2.75 | 0.018 | NS |
| | PET | -0.169 | 1.697 | 2.042 | 2.75 | 0.169 | NS |
| | SPI | 1.551 | 1.697 | 2.042 | 2.75 | 0.014 | NS |
| | $RDI_{std}$ | 1.577 | 1.697 | 2.042 | 2.75 | 0.014 | NS |
| May | Precipitation | 0.693 | 1.697 | 2.042 | 2.75 | 0.017 | NS |
| | Temperature | -1.286 | 1.697 | 2.042 | 2.75 | 0.022 | NS |
| | PET | 0.296 | 1.697 | 2.042 | 2.75 | 0.236 | NS |
| | SPI | 0.693 | 1.697 | 2.042 | 2.75 | 0.017 | NS |
| | $RDI_{std}$ | 0.637 | 1.697 | 2.042 | 2.75 | 0.017 | NS |
| June | Precipitation | -2.9 | 1.697 | 2.042 | 2.75 | 0.017 | S(0.01) |
| | Temperature | -1.453 | 1.697 | 2.042 | 2.75 | 0.12 | NS |
| | PET | -1.676 | 1.697 | 2.042 | 2.75 | 1.076 | NS |
| | SPI | -2.9 | 1.697 | 2.042 | 2.75 | 0.017 | S(0.01) |
| | $RDI_{std}$ | -2.105 | 1.697 | 2.042 | 2.75 | 0.018 | S(0.05) |
| July | Precipitation | -0.445 | 1.697 | 2.042 | 2.75 | 0.02 | NS |
| | Temperature | -0.088 | 1.697 | 2.042 | 2.75 | 0.015 | NS |
| | PET | -1.048 | 1.697 | 2.042 | 2.75 | 0.227 | NS |
| | SPI | -0.445 | 1.697 | 2.042 | 2.75 | 0.02 | NS |
| | $RDI_{std}$ | -0.316 | 1.697 | 2.042 | 2.75 | 0.02 | NS |
| August | Precipitation | -0.837 | 1.697 | 2.042 | 2.75 | 0.02 | NS |
| | Temperature | -1.482 | 1.697 | 2.042 | 2.75 | 0.012 | NS |
| | PET | 0.276 | 1.697 | 2.042 | 2.75 | 0.198 | NS |
| | SPI | -0.837 | 1.697 | 2.042 | 2.75 | 0.02 | NS |
| | $RDI_{std}$ | -0.843 | 1.697 | 2.042 | 2.75 | 0.02 | NS |

**TABLE 4 (*Contd.*)**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|
| September | Precipitation | 0.551 | 1.697 | 2.042 | 2.75 | 0.02 | NS |
| | Temperature | -2.426 | 1.697 | 2.042 | 2.75 | 0.015 | S(0.05) |
| | PET | -0.89 | 1.697 | 2.042 | 2.75 | 0.193 | NS |
| | SPI | 0.551 | 1.697 | 2.042 | 2.75 | 0.02 | NS |
| | $RDI_{std}$ | 0.511 | 1.697 | 2.042 | 2.75 | 0.02 | NS |
| October | Precipitation | -1.052 | 1.697 | 2.042 | 2.75 | 0.018 | NS |
| | Temperature | 0.75 | 1.697 | 2.042 | 2.75 | 0.02 | NS |
| | PET | 1.146 | 1.697 | 2.042 | 2.75 | 0.206 | NS |
| | SPI | -1.052 | 1.697 | 2.042 | 2.75 | 0.018 | NS |
| | $RDI_{std}$ | -1.052 | 1.697 | 2.042 | 2.75 | 0.018 | NS |
| November | Precipitation | 2.029 | 1.697 | 2.042 | 2.75 | 0.013 | S(0.1) |
| | Temperature | 1.319 | 1.697 | 2.042 | 2.75 | 0.023 | NS |
| | PET | 0.695 | 1.697 | 2.042 | 2.75 | 0.166 | NS |
| | SPI | 2.029 | 1.697 | 2.042 | 2.75 | 0.013 | S(0.1) |
| | $RDI_{std}$ | 1.958 | 1.697 | 2.042 | 2.75 | 0.013 | S(0.1) |
| December | Precipitation | -0.328 | 1.697 | 2.042 | 2.75 | 0.009 | NS |
| | Temperature | 0.218 | 1.697 | 2.042 | 2.75 | 0.022 | NS |
| | PET | 1.535 | 1.697 | 2.042 | 2.75 | 0.111 | NS |
| | SPI | -0.328 | 1.697 | 2.042 | 2.75 | 0.009 | NS |
| | $RDI_{std}$ | -0.357 | 1.697 | 2.042 | 2.75 | 0.009 | NS |

### 3.3. *Trend detection*

#### 3.3.1. *Mann-Kendall non-parametric test*

The non-significant (NS) or significant (S) trend of different variables at annual and monthly time scale was detected using a Mann-Kendall non-parametric test which is presented in Table 3. At annual scale, no significant trend was found for precipitation, temperature, SPI, $RDI_{std}$ except PET. PET shows a negative trend for $\alpha = 0.1$ at an annual scale. At a monthly time scale, a significant positive trend was observed in April for precipitation, SPI and $RDI_{std}$ at $\alpha = 0.1$. A significant decrease in precipitation and SPI was observed in June at all $\alpha = 0.1$, 0.05 and 0.01, respectively. A significant decrease in $RDI_{std}$ was observed in June at $\alpha = 0.1$. A significant decrease in temperature was observed in September at $\alpha = 0.1$ and 0.05. The positive increase in precipitation, SPI and $RDI_{std}$ were observed in November at $\alpha = 0.1$. The significant negative trend in precipitation, SPI and $RDI_{std}$ would cause reduction of water availability in the respective month. A positive trend of temperature and negative trend of precipitation, SPI and $RDI_{std}$ would cause water shortage in the respective month.

#### 3.3.2. *Linear regression parametric test*

The non-significant (NS) and significant (S) trend of different variables at annual and monthly time scale was detected using linear regression parametric test which is presented in Table 4. At annual time scale, temperature and PET indicated a decreasing trend at $\alpha = 0.1$. In June, precipitation and SPI indicated a decreasing trend at all $\alpha = 0.1$, 0.05 and 0.01while $RDI_{std}$ indicated a decreasing trend at $\alpha = 0.1$ and 0.05. In September, temperature indicated a decreasing trend at $\alpha = 0.1$ and 0.05. Precipitation, SPI and $RDI_{std}$ indicated increasing in November month at $\alpha = 0.1$.

#### 3.3.3. *Comparison of Mann-Kendall non-parametric and linear regression parametric test*

At an annual time scale, Mann-Kendall non-parametric test and linear regression parametric test showed a statistically significant decreasing trend of PET at $\alpha = 0.1$ which would reduce water loss through evapotranspiration and minimizes drought severity. At an annual time scale, only a linear regression test showed a statistically significant decreasing trend for the temperature at $\alpha = 0.1$ which would reduce drought severity. At a monthly time scale, for April month, Mann-Kendall non-parametric test showed an increasing trend for SPI and $RDI_{std}$ (*i.e.*, decreasing drought severity) at $\alpha = 0.1$ but linear regression parametric test did not show any significant trend for this month. Both the tests showed a decreasing trend of SPI in June (*i.e.*, increasing drought severity) at $\alpha = 0.01$, 0.05 and 0.1 which indicated a shortage of precipitation in this month. Both the tests

**TABLE 5**

**Analysis of weakly rainfall for drought detection at Parbhani**

| Meteorological week | Average rainfall (mm) | Rainfall value (mm) | | | Total number of weeks | | |
|---|---|---|---|---|---|---|---|
| | | Drought (less than) | Normal (in between) | Wet (more than) | Drought | Normal | Wet |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| 1 | 1.48 | 0.74 | 0.74-2.97 | 2.97 | 32 | 1 | 4 |
| 2 | 4.17 | 2.09 | 2.09-8.34 | 8.34 | 33 | 0 | 4 |
| 3 | 1.16 | 0.58 | 0.58-2.33 | 2.33 | 33 | 1 | 3 |
| 4 | 1.06 | 0.53 | 0.53-2.13 | 2.13 | 35 | 0 | 2 |
| 5 | 0.55 | 0.27 | 0.27-1.09 | 1.09 | 35 | 0 | 2 |
| 6 | 2.45 | 1.23 | 1.23-4.91 | 4.91 | 31 | 1 | 5 |
| 7 | 1.16 | 0.58 | 0.58-2.31 | 2.31 | 34 | 1 | 2 |
| 8 | 0.95 | 0.48 | 0.48-1.90 | 1.90 | 33 | 0 | 4 |
| 9 | 1.34 | 0.67 | 0.67-2.68 | 2.68 | 31 | 2 | 4 |
| 10 | 6.09 | 3.04 | 3.04-12.18 | 12.18 | 30 | 2 | 5 |
| 11 | 2.53 | 1.27 | 1.27-5.06 | 5.06 | 34 | 0 | 3 |
| 12 | 0.73 | 0.36 | 0.36-1.46 | 1.46 | 31 | 1 | 5 |
| 13 | 1.44 | 0.72 | 0.72-2.88 | 2.88 | 32 | 0 | 5 |
| 14 | 1.19 | 0.60 | 0.60-2.68 | 2.68 | 29 | 4 | 4 |
| 15 | 2.5 | 1.25 | 1.25-5.01 | 5.01 | 29 | 3 | 5 |
| 16 | 1.05 | 0.53 | 0.53-2.11 | 2.11 | 29 | 1 | 7 |
| 17 | 0.98 | 0.49 | 0.49-1.96 | 1.96 | 27 | 2 | 8 |
| 18 | 2.11 | 1.06 | 1.06-4.22 | 4.22 | 28 | 2 | 7 |
| 19 | 1.11 | 0.55 | 0.55-2.22 | 2.22 | 27 | 5 | 5 |
| 20 | 4.9 | 2.45 | 2.45-9.81 | 9.81 | 29 | 3 | 5 |
| 21 | 6.66 | 3.33 | 3.33-13.32 | 13.32 | 27 | 5 | 5 |
| 22 | 8.53 | 4.27 | 4.27-17.07 | 17.07 | 26 | 7 | 4 |
| 23 | 28.65 | 14.33 | 14.33-57.30 | 57.30 | 18 | 13 | 6 |
| 24 | 41.98 | 20.99 | 20.99-83.95 | 83.95 | 13 | 18 | 6 |
| 25 | 43.03 | 21.52 | 21.52-86.06 | 86.06 | 14 | 19 | 4 |
| 26 | 40.31 | 20.15 | 20.15 - 80.60 | 80.60 | 19 | 14 | 4 |
| 27 | 37.83 | 18.91 | 18.91-75.66 | 75.66 | 18 | 15 | 4 |
| 28 | 21.07 | 21.07 | 21.07-84.29 | 84.29 | 16 | 16 | 5 |
| 29 | 43.45 | 21.73 | 21.73-86.91 | 86.91 | 18 | 12 | 7 |
| 30 | 37.64 | 37.64 | 37.64-150.54 | 150.54 | 19 | 15 | 3 |
| 31 | 50.0 | 25.01 | 25.01-100.04 | 100.04 | 19 | 12 | 6 |
| 32 | 60.08 | 30.04 | 30.04-120.16 | 120.16 | 25 | 4 | 8 |
| 33 | 43.58 | 21.79 | 21.79-87.17 | 87.17 | 17 | 12 | 8 |
| 34 | 59.76 | 29.88 | 29.88-119.51 | 119.51 | 16 | 17 | 4 |
| 35 | 56.07 | 28.03 | 28.03-112.13 | 112.13 | 15 | 16 | 6 |
| 36 | 46.84 | 23.42 | 23.42-93.68 | 93.68 | 17 | 12 | 8 |
| 37 | 31.04 | 15.52 | 15.52-62.08 | 62.08 | 18 | 10 | 9 |
| 38 | 41.68 | 20.84 | 20.84-83.37 | 83.37 | 15 | 15 | 7 |
| 39 | 30.58 | 15.29 | 15.29-61.15 | 61.15 | 21 | 10 | 6 |
| 40 | 33.60 | 16.80 | 16.80-67.19 | 67.19 | 22 | 8 | 7 |
| 41 | 22.17 | 11.08 | 11.08-44.33 | 44.33 | 24 | 5 | 8 |
| 42 | 17.17 | 8.58 | 8.58-34.33 | 34.33 | 26 | 6 | 5 |
| 43 | 11.29 | 5.65 | 5.65-22.58 | 22.58 | 29 | 2 | 6 |
| 44 | 3.91 | 1.95 | 1.95-7.82 | 7.82 | 29 | 3 | 5 |

**TABLE 5 (*Contd.*)**

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|
| 45 | 5.28 | 2.64 | 2.64-10.56 | 10.56 | 29 | 3 | 5 |
| 46 | 4.27 | 2.13 | 2.13-8.54 | 8.54 | 29 | 2 | 6 |
| 47 | 7.68 | 3.84 | 3.84-15.37 | 15.37 | 29 | 2 | 6 |
| 48 | 7.03 | 3.51 | 3.51-14.05 | 14.05 | 34 | 1 | 2 |
| 49 | 4.07 | 2.04 | 2.04-8.14 | 8.14 | 34 | 0 | 3 |
| 50 | 2.05 | 1.02 | 1.02-4.09 | 4.09 | 33 | 1 | 3 |
| 51 | 0.04 | 0.02 | 0.02-0.08 | 0.08 | 36 | 0 | 1 |
| 52 | 2.48 | 1.24 | 1.24-4.96 | 4.96 | 31 | 2 | 4 |
| | | Total | | | 1358 | 306 | 260 |

showed an increasing trend for SPI and $RDI_{std}$ in November (*i.e.*, decreasing drought severity) at $\alpha = 0.1$. In the case of PET, both the tests did not show any significant trend in any month. Both the tests showed a significant decreasing trend of temperature in September at $\alpha = 0.1$ and 0.05 which would help to reduce the loss of water through evapotranspiration and minimize adverse effects on crop growth due to water shortage.

## 4. Conclusions

In this study, meteorological drought indices like SPI and $RDI_{std}$ were used to assess the drought severity of the semi-arid Parbhani district of the Indian state of Maharashtra. Here, it was observed that SPI and $RDI_{std}$ behave similarly for detecting the drought severity class except for some slight deviation in detecting moderate and normal drought years. One severe drought year was observed in based on both SPI and $RDI_{std}$ indices. The developed linear regression equations can also be useful to estimate the $RDI_{std}$ drought index with the availability of only rainfall data (SPI) because $RDI_{std}$ drought index actually represents agricultural drought as it depends on PET. On the basis of weekly rainfall analysis, winter and summer seasons were found to be more prone to drought hazards as compared to monsoon season. Hence, it indicated the need of supplemental irrigation during this water deficit periods. Here, it was observed that short term weekly rainfall analysis provides clear picture of frequent occurrences of drought episodes as compared to longer (monthly or annual) time scale. Hence, weekly rainfall data analysis is more useful for short term strategic planning in agriculture. Both the Mann-Kendall non-parametric and linear regression parametric tests showed a statistically significant decreasing trend of SPI in June (*i.e.*, increasing drought severity) at all $\alpha = 0.01$, 0.05 and 0.1 which indicated an increase in shortage of precipitation at the initiation of the monsoon season. The reduction of precipitation at the initiation of monsoon would be responsible for delaying the sowing of Kharif seasonal crops which may affect the crop yield. Both the tests showed an increasing trend of SPI and $RDI_{std}$ in November (*i.e.*, decreasing drought severity) at $\alpha = 0.1$ which would be beneficial for growing of winter seasonal crops. As the drought episodes are more frequent in arid and semi-arid regions, hence future study can be focused with combined drought index using remote sensing data like Normalized Difference Vegetation Index (NDVI) etc.

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