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# Comparison and evaluation of drought indices using Analytical Hierarchy Process (AHP) over Raichur district, Karnataka

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**सार** – कर्नाटक में रायचूर जिले को सूखा प्रवण क्षेत्र माना जाता है। इस अध्ययन में छहशुष्क सूचकांक क्षेत्रों के प्रदर्शन की तुलना और मूल्यांकन करने के लिए मानकीकृत वर्षा सूचकांक (SPI), मानकीकृत वर्षा वाष्पीकरण सूचकांक (SPEI), चीन जेड इंडेक्स (CZI), दशमकों, सामान्य वर्षा का प्रतिशत (PN) और वर्षा विसंगति सूचकांक (RAI) का अध्ययन किया गया है। आयत चित्र (Histogram) और विश्लेषणात्मक पदानुक्रम प्रक्रिया (AHP) का उपयोग करके छहशुष्क सूचकांकों के एक समय श्रंखला की तुलना और मूल्यांकन किया गया। छह शुष्क सूचकांकों के आयत चित्र से पता चला है कि पीएन, डेसील्स और आरएआई ने अत्यधिक सूखे की घटनाओं की उच्च आवृत्ति दिखाई है जो विश्लेषण में भ्रामक मानी जाती है। सूचकांकों के मूल्यांकन के दौरान सूचकांकों के बीच कोई पूर्वाग्रह नहीं किया गया एसपीआई और सीजेडआई मुख्य रूप से अपनी प्रकृति में दृढ़ता और कृत्रिमता के कारण शीर्षरैंक पर चले गए। जबकि, पीएन दूसरे स्थान पर चला गया क्योंकि 18.49 (SPI), 18.10 (PN) और 17.99 (CZI) स्कोर वाले अन्यसूचकांकों की तुलना में इसकी स्पष्टता अधिक थी। एसपीईआई को दृढ़ता और कृत्रिमता में उच्च स्कोर प्राप्त हुआ, ट्रैक्टेबिलिटी की कमी और पारदर्शिता के कारण इसमें कमी देखी गई। इसके अलावा, पारदर्शिता और सुवाह्यता के मामले में RAI और दशमक जैसे सूचकांकों को अच्छी श्रेणी हासिल करते देखा गया। पीएन को मजबूती में सबसे कम देखा गया, यद्यपि पीएन ने दूसरा स्थान हासिल किया है, फिर भी अत्यधिक सूखे पर अनुचित रूप से हावी होने के कारण अध्ययन के लिए अनुकूल होने के लिए इसकी अनुशंसा नहीं की जाती है। सभी सूचकांकों के पक्ष और विपक्ष को देखते हुए एसपीआई का मूल्यांकन चयनित अध्ययन क्षेत्र के लिए एक आदर्श सूचकांक के रूप में किया गया।

**ABSTRACT.** The Raichur district is considered as a drought prone area in Karnataka. The study was carried out to compare and evaluate the performance of six drought indices in the study area namely Standardized precipitation index (SPI), Standardized precipitation evapotranspiration index (SPEI), China Z index (CZI), Deciles, Percent Normal (PN) and Rainfall anamoly index (RAI). A time series of six drought indices were compared and evaluated using histogram and analytical hierarchy process (AHP). The histogram of six drought indices showed that PN, Deciles and RAI showed higher frequency of extreme drought events which is considered as misleading in analysis. During the evaluation of the indices no bias was done between the indices, SPI and CZI moved to the top rank mainly due to their robustness and sophistication in nature. Whereas, PN moved to the second position mainly because of its higher simplicity compared to other indices with a score of 18.49 (SPI), 18.10 (PN) and 17.99 (CZI). The SPEI was observed to score higher in robustness and sophistication, due to lack of tractability and transparency was observed to be lagged. Furthermore, indices like RAI and deciles were observed to score very good ranks under transparency and tractability. PN was observed to least in robust, thought the PN has scored 2nd position, it is highly not recommended for adaptation for the studies due to its unreasonably capturing of extreme droughts. Looking over all pros and cons of all indices SPI was evaluated as a perfect index for the selected study area.

**Key words –** CZI, Deciles, RAI, PN, SPI and SPEI.

## 1. Introduction

Among the many extreme events on earth, drought is considered as one of the most devastating extremities on the earth (Rahul *et al*., 2020). Drought is a complex natural hazard that affects global security through water stress, making the agri-food sector one of the most affected by the drought (Gortlapalli *et al.*, 2022). It is considered as the most widespread and slow-developing hazard which in turn affects for longer duration, natural resources, agriculture and socioeconomic life of human being. Furthermore, it also witnesses to the changes in the temporal and spatial patterns of precipitation around the globe, which leads to an impact on many agricultural and ecosystem problems. The worldwide land surface temperature is anticipated to rise from 1-3 percent in the current condition to 30% by the 2090s as a result of the drought (IPCC, 2012).

Assessment of drought is considered as a major topic in planning and management of fresh water. This requires the knowledge of the historical patterns of drought and their frequency over a time period. The understanding of drought over a region is characterized in many ways, like lack of rainfall, flow in the stream, reduced water level in the reservoir, soil moisture status and drought indices. Of these, drought indices (DI) are most the used these days in drought monitoring and modelling.

DI is a function of a number of hydro meteorological variables (*e.g*., rainfall and stream flow) and expresses with a numeric number which is more functional than raw data (rainfall) during decision-making. However, defining an appropriate DI is not always an easy task, the researchers and professionals face challenges for developing a suitable DI. Therefore, the selection of an appropriate DI for defining drought conditions is the first task in this work.

## 2. Location

Raichur district region is situated in the North Eastern part of the Karnataka state with a latitude and longitude of 16° 12' 2.9844" N and 77° 21' 44.2404" E. The historical data of precipitation and temperature from 1961-2017 was collected on a monthly basis from department of Statistics and Economics, MS. building, Bangalore, Karnataka, India.

## 3. Materials and method

Numerous methodologies for drought characterization and modelling exist. However, using drought indices are prevalent. Drought indices were estimated by incorporating the drought indictors (ex : rainfall, potential evapotranspiration and temperature) into a single physical based on numerical values. The drought indices provided us a broad view for the drought analysis and also helps in decision-making as compared to the raw data of the drought indicators (Hayes, 2006). Nowadays, more than 150 indices have been developed worldwide and still counting (Cai *et al*., 2011).

### 3.1. *Drought indices (DIs)*

The drought indices, namely Percent of Normal (PN), Deciles, Standardized precipitation index (SPI), Standardized precipitation evapotranspiration index (SPEI), China Z index (CZI) and Rainfall anomaly index (RAI) have been selected for particular study due to the availability of data, as these indices demand rainfall as a only input. Whereas, SPEI requires rainfall and temperature as input.

#### 3.1.1. *Percent of Normal (PN)*

Percent of Normal (PN) is defined as the ratio of actual rainfall of a particular month to the normal rainfall (30-year average) of that particular month rainfall (Hayes, 2003; Morid *et al.*, 2006). Percent normal can be calculated at different time scales.

#### 3.1.2. *Deciles*

In this method, the rainfall data collected for a longer duration is arranged in an ascending order and the dataset is divided into 10 equal parts (decile) (Gibbs and Maher, 1967). The first part is the rainfall, not exceeded by the lower 10 per cent of the data in the total record. The second decile is between the lower ten to twenty per cent etc. (Table 1). This index is widely used in Australia for drought analysis (Coughlan, 1987).

#### 3.1.3. *Standardized Precipitation Index*

The Standardized Precipitation Index (SPI) is one of the most widely used drought index (Hayes *et al.*, 1999;

**TABLE 1**

**Categorization of SPI, SPEI, Deciles, CZI, PN and RAI values into classes**

| S. No. | Drought indices (DIs) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Class | SPI | SPEI | Deciles | CZI | PN | RAI |
| 1. | Extreme wet | ≥ 2.0 | ≥ 2.0 | ≥ 90 | ≥ 2.0 | | ≥3.00 |
| 2. | Severe wet | 1.50 to 1.99 | 1.50 to 1.99 | 80 to 90 | 1.50 to 1.99 | ≥ 110 | 2.00 to 2.99 |
| 3. | Moderate wet | 1.0 to 1.49 | 1.0 to 1.49 | 70 to 80 | 1.0 to 1.49 | | 1.00 to 1.99 |
| 4. | Normal | 0.99 to -0.99 | 0.99 to -0.99 | 30 to 70 | 0.99 to -0.99 | 80 to 110 | 0.99 to 0.99 |
| 5. | Moderate dry | -1.0 to -1.49 | -1.0 to -1.49 | 20 to 30 | -1.0 to -1.49 | 55 to 80 | -1.00 to -1.99 |
| 6. | Severe dry | -1.50 to -1.99 | -1.50 to -1.99 | 10 to 20 | -1.50 to -1.99 | 40 to 55 | -2.00 to -2.99 |
| 7. | Extreme dry | ≤-2.0 | ≤ -2.0 | ≤ 10 | ≤ -2.0 | ≤ 40 | ≤ -3.00 |

Deo, 2011).The estimation of SPI procedure is as per (McKee *et al.*, 1993).

3.1.4. *Standardize Precipitation Evapotranspiration Index (SPEI)*

The Standardized Precipitation Evapotranspiration Index (SPEI) is quite familiar for calculation of SPI but the major change in this index is that it takes potential evapotranspiration into account compared to SPI. The indicators of this index are total monthly precipitation (P) and monthly potential evapotranspiration Evapotranspiration (PET). Monthly PET was estimated using the Thornthwaite method (Thornthwaite, 1948; Patil *et al*., 2022). The details of the SPEI estimation more systematically explained by Vicente-Serrano *et al*., 2010.

3.1.5. *China Z index (CZI)*

The China Z index is related to the Wilson-Hilferty cube-root transformation (Kendall and Stuart 1977). The china Z index assumes that under consideration follows Pearson Type III distribution and more details are explained in Vicente-Serrano *et al.* (2010).

3.1.6. *Rainfall Anamoly Index (RAI)*

Van Rooy, 1965 developed the Rainfall Anomaly Index (RAI) and incorporated a ranking method to assign magnitudes to positive and negative precipitation anomalies. The threshold range for RAI is presented in Table 1.

$$\text{RAI} = \pm 3 \frac{P - \overline{P}}{\overline{E} - \overline{P}} \quad (1)$$

where, $P$ = measured precipitation, $\overline{P}$ = average precipitation and $\overline{E}$ = average of 10 extrema.

3.2. *Comparison of drought indices*

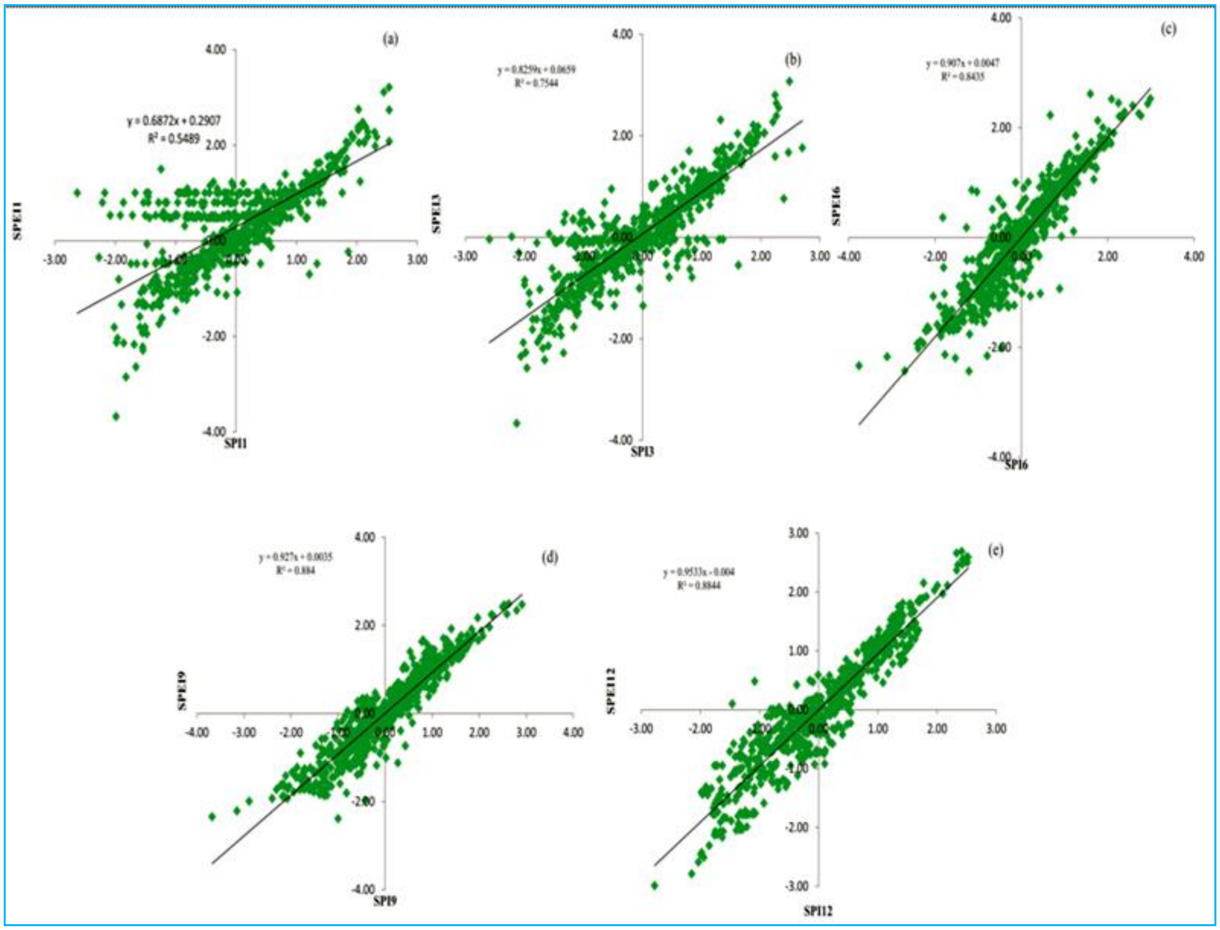
The comparison of drought indices, was carried out using scattered plot and histogram for different indices**.** The indices namely SPI, SPEI and CZI almost have a similar kind of severity range for drought categorization so they are able to compare among themselves using scattered plot and Pearson correlation. However, as mentioned above, the severity ranges of PN, Deciles and RAI are different from the SPI, SPEI and CZI. To make them comparable with the SPI classes, the Deciles, PN and RAI values were categorized into similar classes (Table 1).

3.3. *Evaluation of drought indices*

Taking into consideration that each index is estimated in different methods as compared to the other indices. It is quite important to evaluate drought indicesfor any particular region in order to select the appropriate indices for that study area.

3.3.1. *Criteria for evaluation*

The evaluation of drought indices was carried out using an analytical hierarchy process using six qualitative



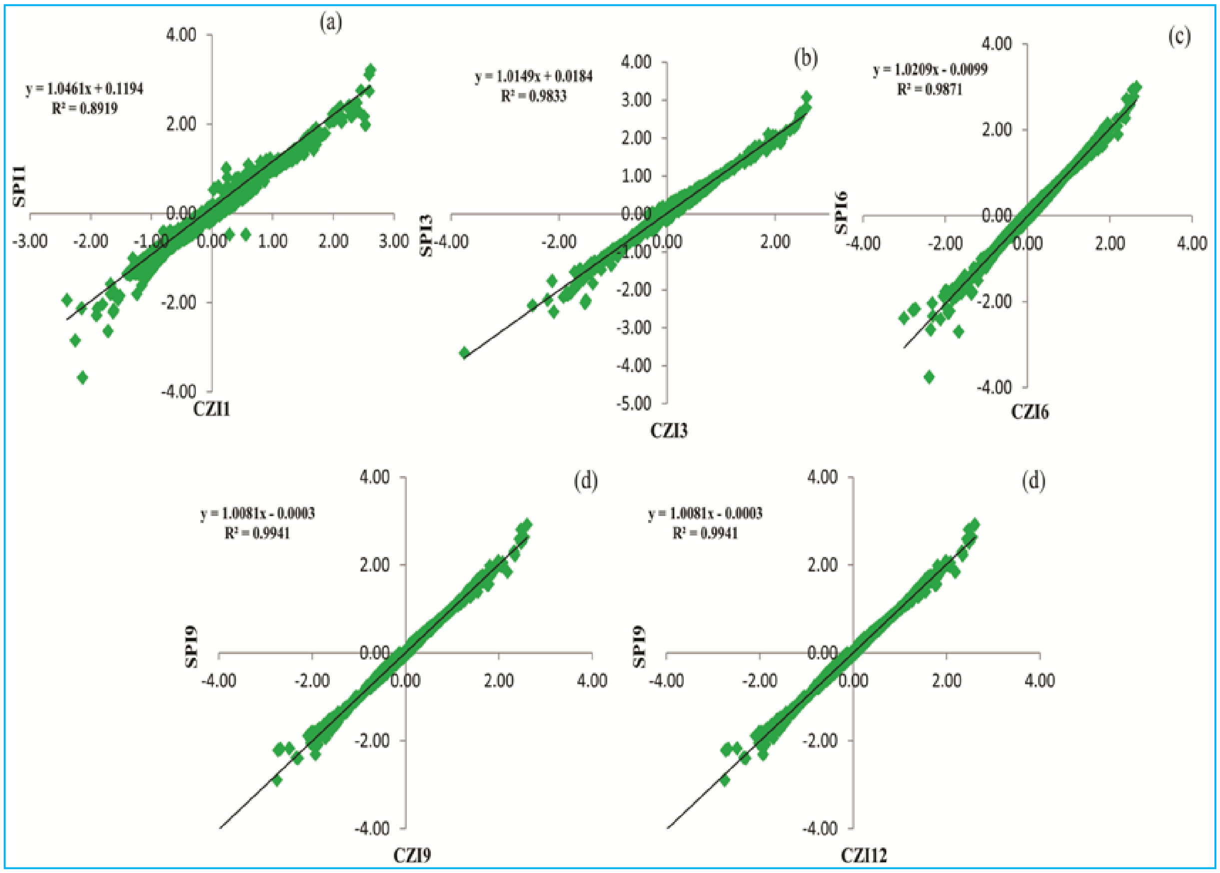

**Figs. 1(a-e).** Scattered plots for (a-e) SPI and SPEI at 1, 3, 6, 9 and 12 months time scales

criteria namely (1) robustness (2) tractability (3) transparency (4) sophistication (5) extendibility (6) dimensionality. To account for the relative importance of each decision criterion, a set of weights called relative importance factors were used (Keyantash and Dracup, 2002). The relative importance (weights) provides for each criterion's robustness (28), tractability (21), transparency (17), sophistication (17), extendibility (10) and dimensionality (7).

### 3.4. *The Analytic Hierarchy Process (AHP) Method*

The AHP is a technique for structuring, measuring and synthesizing and is generally focused on the well-defined mathematical structure of consistent matrices and the ability of their related right-eigenvector to generate accurate or approximate weights (Saaty 1980). In essence, the AHP method structures a complex problem by dividing the problem into target (problem definition), decision criteria and/or alternatives, then comparing the criteria or alternatives in a natural, pairwise mode with respect to a criterion. To this end, the AHP uses a basic scale of absolute numbers (1 - 9), which has been proved in practice and confirmed by studies on physical and decision issue (Forman and Gass, 2001). According to Saaty's scale, the pair-wise comparison values are set members: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}. These scale numbers show how many times more significant or superior one element is compared to another element in relation to the given criteria or property they are being compared with (Saaty 2008). Several established literatures were carefully reviewed in the present work before assigning ranks and weights to obtain an appropriate understanding of the ranking of variables under distinct environmental circumstances and in different regions. The AHP gathers the probability of uncertainty in the evaluation through the key Eigen value and the consistency index (Saaty, 2008).

The consistency index is known to provide a measure of departure from the consistency, that is, the difference between the maximum eigen value ($\lambda$ max) of




**Figs. 2(a-e).** Scattered plots for SPI and CZI at 1, 3, 6, 9 and 12 months time scale

the pairwise comparison matrix and the eigen value ($n$) of a perfectly consistent matrix. This is expressed as below:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1} \qquad (2)$$

where, $\lambda_{max}$ is the maximum of the eigen values (*i.e.*, the average value of the consistency vector) and n is the number of evaluation criteria parameters (drought indices). The RI value is read from a statistical table that is proposed by Saaty (1980).

Consistency ratio (CR) defined as the measure of consistency between pairwise comparison matrix (Saaty, 1980) is calculated. It is estimated as a ratio of consistency index (CI) to the random inconsistency index (RI). The consistency value should be less than 0.10 (Saaty, 1980). Otherwise, the scoring process needs to change.

### 3.5. *The computation of the final index scores*

A few mathematical operations are needed to calculate the weightings of the parameters. The summation of the values of each column of the pairwise comparison matrix and normalization each matrix value, followed by averaging the elements of each row to form the required weights. These averages are also referred to as eigenvectors. Furthermore, the weighted average is estimated with the help of different criteria (robustness, tractability, transparency, sophistication, extendibility and dimensionality) to obtain a final score.

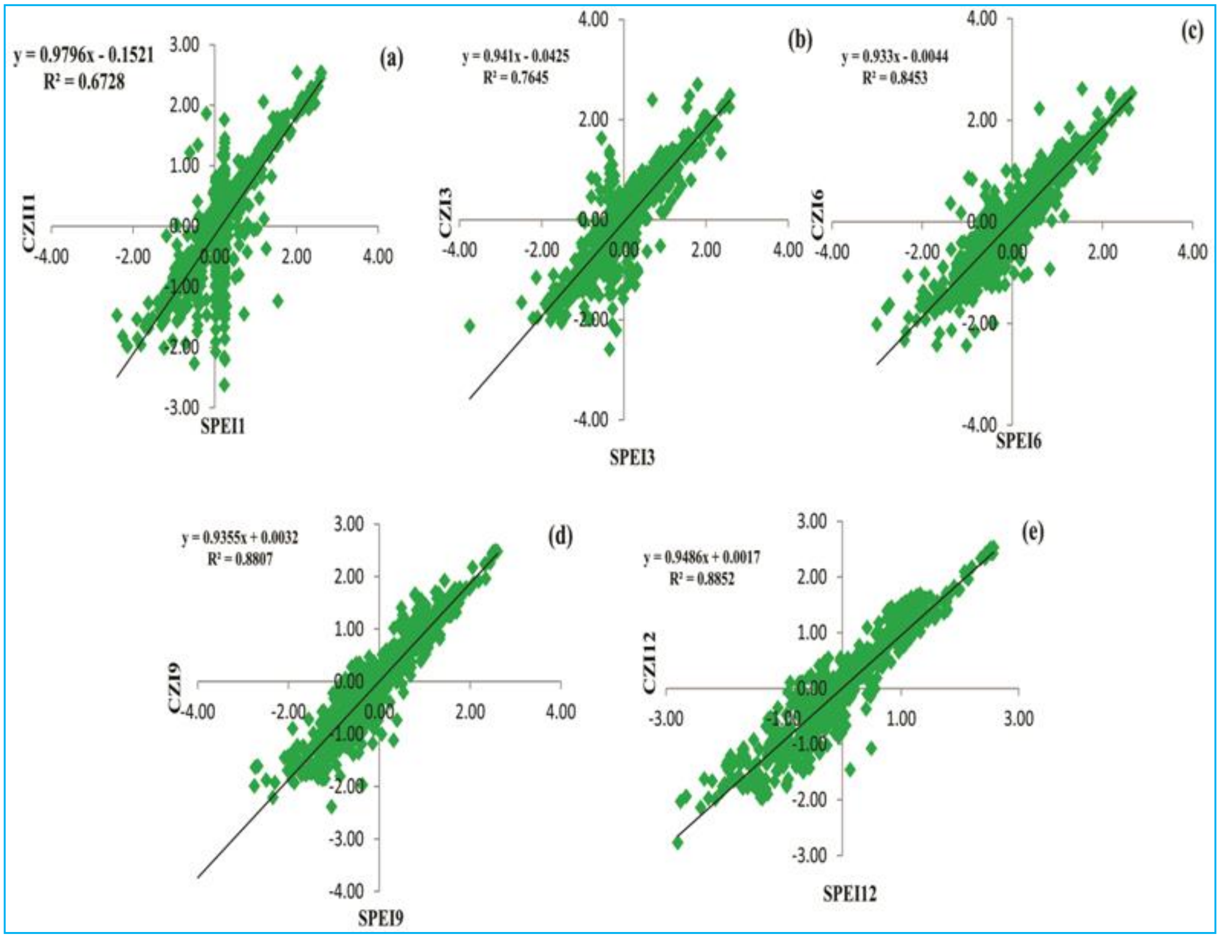
## 4. Results and discussion

### 4.1. *Comparison of drought indices*

The evaluation study was carried out in order to select appropriate indices for a study area to characterize and model a drought. Drought indices evaluation was carried out for Raichur station, evaluation part mainly consists of comparison between different indices namely SPI, SPEI, CZI, PN, Deciles and RAI.

#### 4.1.1. *Comparison of the SPI and SPEI*

The SPI index uses only rainfall as input, whereas the SPEI utilises rainfall and potential evapotranspiration




**Figs. 3(a-e).** Scattered plots for SPI and CZI at 1, 3, 6, 9 and 12 months time scales

as input was compared with the help of a scattered plot and bar graph at different timescales of 1, 3, 6, 9 and 12 months are presented in Figs. 1(a-e), 4 and Table A (Appendix I). The correlation of determination ($R^2$) between SPI and SPEI observed was 0.54, 0.75, 0.84, 0.88 and 0.88 at a timescale of 1, 3, 6, 9 and 12 months. For higher accurate comparison, relative frequencies of the dry classes identified by the two indices were compared for the 57-year long period (1961-2017).

The histogram of wet and dry classes is shown in Fig. 4. Both indices have a bell-shaped normally distributed histogram, but the 'normal class' of the SPI is larger than that of the SPEI. On the contrary, other classes of dryness in the SPEI are quite more compared to the SPI. Moreover, the correlation between SPI and SPEI compared over different months for different timescales, the results reveal that the correlation was high between indices during monsoon months, whereas during summer and winter conditions it was observed to be low (Table A) (Appendix I).

In comparison, both indices identified the temporal variability of droughts and were able to identify different types of droughts as indicated by the different timescales. SPEI could capture more extreme events as compared to SPI over different timescales. Correlation analysis between SPI and SPEI clearly indicates that precipitation is the major driver of drought. The lower correlation observed between SPI and SPEI during the summer and winter months is mainly due to a higher rate of evapotranspiration and lack of rainfall, which leads to sense different signature from SPEI, which may mislead information. During the summer and winter seasons the rainfall in the study area is quite negligible.

4.1.2. *Comparison of SPI and CZI*

Comparison between SPI and CZI was carried out at different timescales of 1, 3, 6, 9 and 12 months with the help of scattered plots, correlation and drought frequency at different classes which are presented in Figs. 2(a-e), 4 and Table A (Appendix I). Results reveals that correlation

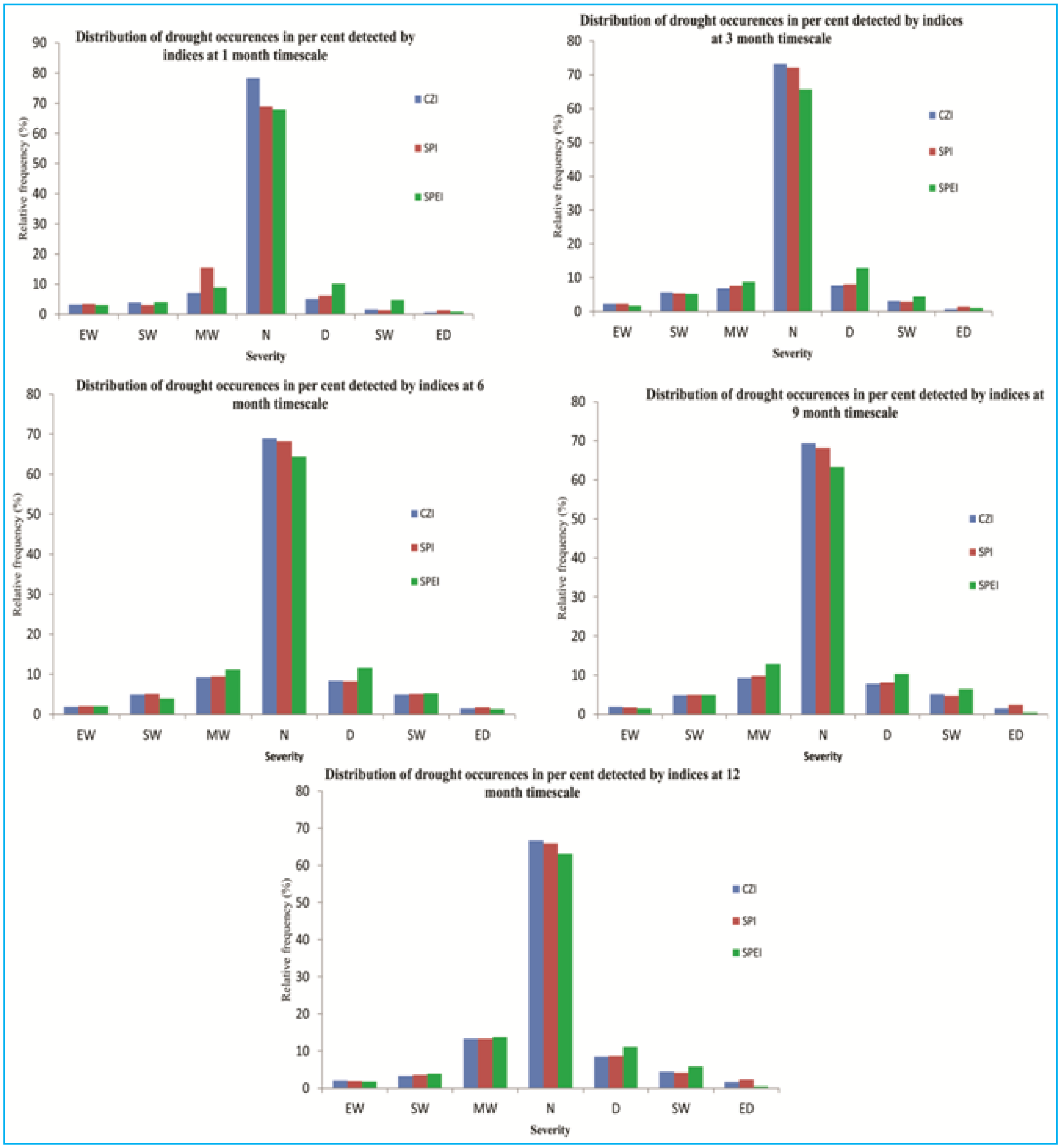



**Fig. 4.** Typical distributions of the drought event identified by SPEI, CZI and SPI indices at 1, 3 6, 9 and 12-month timescale

between CZI and SPI was observed to be very stronger with a value of 0.89, 0.98, 0.98, 0.99 and 0.99 on a time scale of 1, 3, 6, 9 and 12 months respectively. A view at the results also illustrate that the correlation coefficient increases with an increase on the timescales. Relative frequencies of the dry classes identified by the two indices were observed in the range of 5.11 to 8.46 (D) and 6.20 to 8.61(D), 1.61 to 5.17(SD) and 1.31 to 5.15(SD) and 0.58 to 1.63(ED) and 1.31 to 2.37 (ED) for CZI and SPI at different timescale respectively.

The histogram of both indices observed to follow a bell shape with higher frequency accounted for normal conditions followed by wet and dries (Fig. 4).

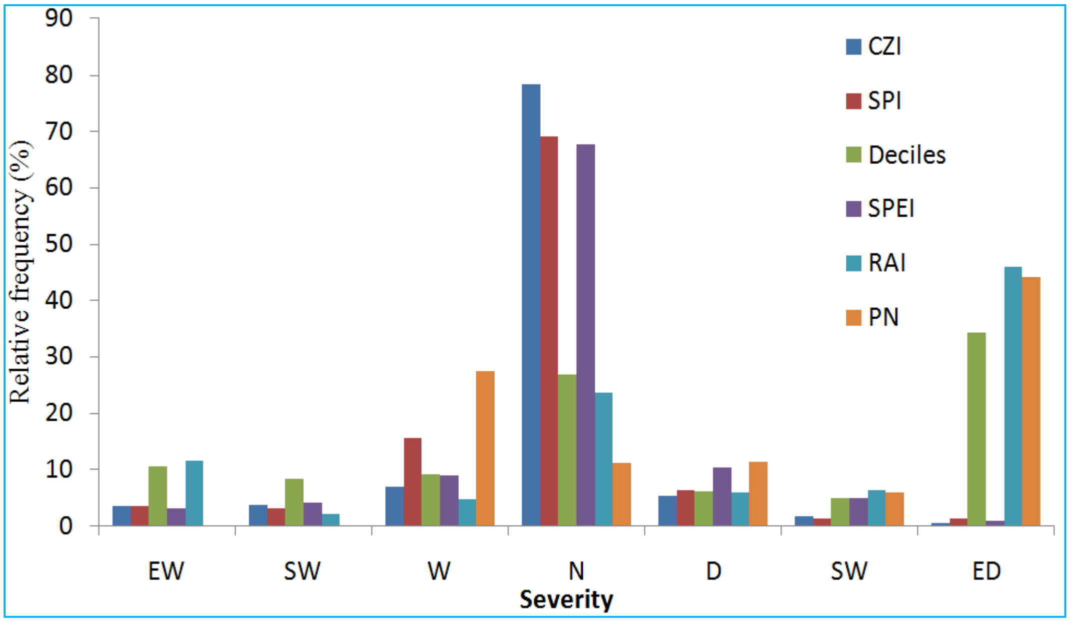



**Fig. 5.** Typical distributions of the drought event identified by SPEI, CZI, SPI, Deciles, RAI and PN indices at 1-month timescale for Raichur station

Furthermore, correlation between SPI and CZI compared over each month and also at different timescales, the results reveal that correlation is high between indices during all months for January to December (Table A) (Appendix I).

The correlation between the two indices was quite strong at all-time scales, particularly during wet and normal months. Discrepancies increased during drier months, as SPI observed higher negative values as compared to the CZI index. This point is more related during 1 and 3-month time scales. Similarly, Morid *et al.*, 2006 observed higher negative values of SPI compared to the CZI at Meharabad and Abali station.

4.1.3. *Comparison of SPEI and CZI*

Correlation and drought frequency analysis were used to compare SPEI and CZI at 1, 3, 6, 9 and 12 months and the results are presented in Figs. 3(a-e), 4 and Table A (Appendix I). Results show that the correlation of determination ($R^2$) between SPEI and CZI was observed to be 0.67, 0.76, 0.84, 0.88 and 0.88 over a timescale of 1, 3, 6, 9 and 12 months respectively. Relative frequencies of the dry classes identified by the two indices (Fig. 4) were observed in the range of 5.11 to 8.46 (D) and 10.23-12.90 (D), 1.61 to 5.17(SD) and 4.54 to 6.5 (SD) and 0.58 to 1.63(ED) and 0.87 to 1.32 (ED) for CZI and SPEI at different timescale respectively.

A view at the results shows that for all classes of dryness the frequency was observed to be more in the case of SPEI compared to CZI. Besides, the correlation between CZI and SPEI compared over each month for different timescales, the results reveal that correlation was high between indices during the monsoon months (June-Oct) whereas during summer (March-may) and winter (Nov-Feb) conditions was observed to be low (Table A) (Appendix I).

In comparison, both indices identified the temporal variability of droughts and were able to identify different types of droughts at different timescales. SPEI could capture more extreme events as compared to CZI over different timescales. The majority of excess drought captured by the SPEI were from the winter and summer months. The lower correlation was observed between CZI and SPEI during the summer and winter months which can be attributed to higher rate of evapotranspiration and lack of rainfall which leads to capture different signature from SPEI. Whereas, higher correlation was observed during the monsoon season.

4.1.4. *Comparison of SPI and Deciles*

The comparison between SPI and Decile was carried out by frequency analysis using histogram, as the severity range for both the indices was quite different for each other so no correlation process was carried out, the results are presented in Fig. 5. The results reveal that the frequencies of wet and dry months observed by the two indices were 10.53(EW), 8.33(SW), 9.06(W), 26.90(N), 6.14(D), 4.82(SD) and 34.21(ED) for Decile and 3.51(EW), 3.07(SW), 15.50(W), 69.01(N), 6.29(D), 1.32(SD) and 1.32(ED) for SPI index in one month timescales. The frequency of dry and wet months captured by Deciles was different from SPI principally for normal classes. Furthermore, Deciles has captured a significantly a higher frequency of Extreme dry months. The histogram for Deciles was observed to be negatively skewed.

The capturing of higher amount of extreme drought months was mainly during the summer and winter seasons. For example, let us say the normal rainfall in January is 2 mm if the rainfall of any particular year say 1 mm, the Decile index considers it as an extreme drought conditions whereas, on the other the SPI, considers it as a normal class. This indicates a higher sensitivity on the part of Deciles for rates of precipitation when compared to the SPI. (Morid *et al*., 2006) observed that the decile shows lower normal status as compared to SPI.

4.1.5. *Comparison of SPI and PN*

To compare SPI and the PN, all wet classes have been added up and then compared with the PN. Fig. 5 shows the histogram of the relative frequency of dry and wet classes. The frequencies of wet and dry months observed by PN were 27.49(W), 11.11(N), 11.40(D), 5.85(SD) and 44.15(ED). Conversely, with the indices namely SPI, SPEI and CZI, Extreme drought is much higher than the 'normal' class in the PN.

The histogram of PN is observed to be negatively skewed. Morid *et al*., 2006 found that Extreme droughts captured by the PN were much more compared to SPI. The capturing of higher amount of extreme drought months was mainly during the summer and winter seasons.

4.1.6. *Comparison of SPI and RAI*

The comparison between SPI and RAI was carried out using a frequency analysis as presented in Fig. 5. The results reveal that a histogram of the RAI was observed to be negatively skewed with a higher frequency of extreme drought condition as compared to SPI which was normally distributed. Furthermore, the frequencies of dry months observed by RAI were 23.68(N), 5.85(D), 6.29(SD) and 45.91(ED).

The results reveal that a histogram of the RAI was observed to be negatively skewed with a higher frequency of extreme drought condition as common compared to SPI which was normally distributed. The RAI was found to be more sensitive, which was observed to be unreasonable.

The detailed comparisons between indices are explained in the above sections. Despite different underlying statistical distributions, the SPI, CZI and SPEI have performed in a similar manner except SPEI in the winter and summer. On the other hand, the indices, namely PN, RAI and Deciles have performed in a different pattern by capturing much more extreme drought as compared to SPI, CZI and SPEI. The PN, RAI and Deciles should not be recommended for drought monitoring in the study area since they have been found to declare 'extreme drought' conditions unreasonably frequently. Given the similarity in the performance of several indices, the choice of an index may partially be based on criteria such as input information requirements, simplicity of calculations and current level of acceptance in operational practice in the world.

4.2. *Evaluation of drought indices using the Analytical hierarchy process*

The performance of each of the six indices SPI, SPEI, Deciles, CZI, PN and RAI were carried out using Saaty's Analytic Hierarchy Process (AHP) approach and the results are explained in the below sections.

4.2.1. *Robustness*

The robustness refers to the effectiveness of drought indices over a large variety of conditions. It also refers to the capacity of the drought indices to be spatially and temporally comparable (Narasimhan and Srinivasan 2005). The scores related to different indices are presented in Table B (Appendix I). The score obtained for different indices as per AHP under robustness criteria (Table 2) were 0.28 each for the SPI, SPEI and CZI, 0.06, 0.06 and 0.05 for deciles, RAI and PN respectively.

4.2.2. *Tractability*

Tractability is the term chosen to represent the practical aspects of calculating drought indices (Keyantash and Dracup, 2002). Since the purpose of the study is to recommend the most appropriate tools for measuring/monitoring drought in Study region, it is extremely important that the recommended indices are easy to calculate using readily available data. The ranks related to different indices are presented in Table B (Appendix I). Under tractability criteria, the scores obtained for each index were 0.34, 0.21, 0.21, 0.10, 0.08 and 0.05 for PN, RAI, Deciles, SPI, CZI and SPEI, which are presented in Table 2.

**TABLE 2**

**The eigenvectors obtained for SPI, SPEI, Deciles, CZI, PN and RAI for each of the decision criteria**

| Indices/ Criteria | Robustness | Tractability | Transparency | Sophistication | Extendibility | Dimensionality | Weighting | Ranking |
|---|---|---|---|---|---|---|---|---|
| SPI | 0.28 | 0.10 | 0.11 | 0.22 | 0.19 | 0.17 | 18.49 | 1 |
| SPEI | 0.28 | 0.05 | 0.06 | 0.35 | 0.06 | 0.17 | 17.77 | 4 |
| Deciles | 0.06 | 0.21 | 0.19 | 0.08 | 0.19 | 0.17 | 14.10 | 5 |
| CZI | 0.28 | 0.08 | 0.11 | 0.22 | 0.19 | 0.17 | 17.99 | 3 |
| PN | 0.05 | 0.34 | 0.33 | 0.05 | 0.19 | 0.17 | 18.10 | 2 |
| RAI | 0.06 | 0.21 | 0.19 | 0.08 | 0.19 | 0.17 | 14.10 | 6 |
| CR | 0.01 | 0.019 | 0.006 | 0.01 | 0 | 0 | | |
| CI | 0.0124 | 0.023 | 0.007 | 0.0124 | 0 | 0 | | |

4.2.3. *Transparency*

A good drought index is one that is readily reasonable to decision-makers and the user community. The ranks related to different indices are presented in Table B (Appendix I). The scores under transparency for different indices (Table 2) were 0.33, 0.19, 0.19, 0.11, 0.11 and 0.06 for PN, Deciles, RAI, SPI, CZI and SPEI respectively.

4.2.4. *Sophistication*

Although sophistication is somewhat counter to transparency it is nonetheless, an important characteristic of a good drought index (Keyantash and Dracup, 2002). A sophisticated drought index is one that has conceptual (scientific) merit. Therefore, even if a drought index is not easy to understand, it may still be valuable if it accurately represents important physical aspects of drought. The ranks related to different indices are presented in Table B (Appendix I). As mentioned in Table 2, the scores for indices under sophistication criteria are 0.35, 0.22, 0.22, 0.08, 0.08 and 0.05 for SPEI, SPI, CZI, deciles, RAI and PN respectively.

4.2.5. *Extendibility*

Extendibility refers to whether an index that can be extended back in time. For example, an index that only relies on precipitation data can be applied to measure drought all the way back to the start of the instrumental record (100+ years), while an index that utilizes satellite or radar data is limited to the last few decades (Keyantash and Dracup, 2002). The ranks related to different indices are presented in Table B (Appendix I). As per Table 2, the scores obtained for indices under extendibility criteria are 0.19 for SPI, CZI, deciles, PN and RAI and 0.06 for SPEI.

4.2.6. *Dimensionality*

Dimensionality refers to the relation between the drought index values and the actual world conditions (Keyantash and Dracup, 2002). The ranks related to different indices are presented in Table B (Appendix I). As per Table 2, the scores obtained for indices under dimensionality criteria were 0.17 for SPEI, SPI, CZI, Deciles, RAI and PN.

4.3. *Comparison of drought indices over different criteria*

The SPI, SPEI and CZI were observed to be more robust as compared to the other indices. Three of these indices have the ability to measure drought over a wide range of conditions and they can be calculated for any period of interest (month, season, year) and they are spatially and temporally comparable. One of the major disadvantage of deciles, PN and RAI is that they unnecessarily capture higher frequency of drought under extreme class, which makes these indices less useful. In terms of tractability PN, RAI and Deciles have an advantage over the other indices (SPI, SPEI and CZI). The calculation of PN is quite easy as compared to that of the all other indices so it was ranked in the first position. The SPEI was ranked at 6th position as it need two indicators (Precipitation and Temperature) and moreover, for calculation of SPEI we need to estimate PET which is quite laborious and time-consuming over other indices. Though the calculation part of the CZI is almost the same as that of SPI, in SPI Gamma distribution is used, whereas in the CZI Log Pearson III distribution is used. The major drawback of the CZI is that no open source is available to estimate the time series of the CZI. Manual calculation for larger datasets is difficult in such a situation. In terms of transparency PN, RAI and Deciles have an advantage over the SPI, SPEI and CZI because, even though SPI, CZI and SPEI values are easy to understand (*e.g.*, higher positive values indicate the wet conditions than normal and higher negative values indicate that conditions is drier than normal) the method used to calculate these values are not as easy to grasp. Moreover, the SPEI indices, uses Log-logistic distribution which is not familiar to many users compared to Gamma and log Pearson III which are used for SPI and CZI respectively. This does give the SPEI, SPI and CZI an edge with regard to sophistication, because they use a probability density function (*e.g.*, Log-logestic, Gamma and Pearson) that is more appropriate for characterizing precipitation variability than the empirical distribution (*e.g.*, percentiles). Moreover, SPEI considers PET, which is one of the more important components of the hydrologic cycle, which helps to capture drought in a better way compared to the other indices. When it comes to extendibility, as all indices utilize only precipitation data but SPEI utilises temperature, which may be difficult to obtain in developing and undeveloped countries. Moreover, in order to estimate PET for SPEI using advanced methods such as Penman Monteith, more indicators need to be available. So SPEI lacks score in extendibility criteria.

Under the evaluation process in general SPI, PN and CZI grabbed the top position followed by SPEI, RAI and Deciles as shown in Table 2. During the evaluation of the indices, no bias was done between the indices. SPI and CZI moved to the top rank mainly due to their robustness and sophistication in nature. Whereas, PN moved to the second position mainly because of its higher simplicity compared to others with a score of 18.49 (SPI), 18.10 (PN) and 17.99 (CZI). The SPEI was observed to score higher in robustness and sophistication, due to lack of tractability and transparency was found to be lagged. Furthermore, indices like RAI and deciles were observed to score very good rank under transparency and tractability. PN was observed to least in robust, as percent normal cannot be used to compare drought conditions spatially and temporally. This limitation with using percent normal (or departures from normal) is one of the main reasons that so many drought indices have been created. Thought the PN has scored the 2nd position it is highly not recommended for adaptation for the studies due to its unreasonably capturing of extreme droughts.

Even though SPEI and CZI were used in many studies but during evaluation the score under criteria of tractability and transparency, they observe to be difficult to understand for a normal public and likewise the CZI do not have an open source program to estimate. Moreover, the results of SPI and CZI are quite similar, in the future if availability of any program we can use CZI as an alternative to SPI. Looking over all the pros and cons of all indices SPI was evaluated as the perfect index for the selected study area. To date, SPI is found to have more application in SW Asia than other indices due to its limited input data requirement, flexibility and simplicity in calculation. SPI is selected by the World meteorological organization (WMO) as the reference drought index for more effective drought monitoring and climate risk management (Hayes *et al*., 2011)

## 5. Conclusions

Drought indices evaluations have been a kind of challenging task for the researchers over time. In order to tackle the problem of evaluation, analytical hierarchy process has been used for evaluation of the drought indices, without any bias. Five different evaluation criteria have been used for evaluation namely robustness, tractability, transparency, sophistication, extendibility and dimensionality. The comparison of DIs showed that PN, RAI and Deciles sensed a higher drought month as compared to other indices namely SPI, SPEI and CZI. Whereas, comparison of SPI and SPEI showed higher correlation during the monsoon months and lower during the summer and a winter which is mainly due to the incorporation of PET in SPEI. Similar results were found during the comparison of SPEI and CZI. The evaluation of DIs showed that SPI is the most ranked meteorological drought index for Raichur region with a priority weight of 18.49. Furthermore, advanced evaluating criteria can be used to improve the evaluation accuracy in the future days.

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**Appendix I**

**TABLE A**

**Pearson correlation between SPEI, CZI and SPI at different months and timescales (1, 3, 6, 9 and 12 months)**

| Months | Cases | 1 Month | 3 Month | 6 Month | 9 Month | 12 Month |
|---|---|---|---|---|---|---|
| January | SPEI *vs* SPI | 0.53 | 0.73 | 0.98 | 0.96 | 0.95 |
| | SPEI *vs* CZI | 0.51 | 0.72 | 0.97 | 0.96 | 0.95 |
| | SPI *vs* CZI | 0.96 | 1.00 | 1.00 | 1.00 | 0.99 |
| February | SPEI *vs* SPI | 0.49 | 0.52 | 0.93 | 0.93 | 0.94 |
| | SPEI *vs* CZI | 0.48 | 0.52 | 0.95 | 0.93 | 0.94 |
| | SPI *vs* CZI | 0.98 | 1.00 | 0.98 | 1.00 | 1.00 |
| March | SPEI *vs* SPI | 0.72 | 0.68 | 0.94 | 0.93 | 0.95 |
| | SPEI *vs* CZI | 0.72 | 0.69 | 0.94 | 0.92 | 0.95 |
| | SPI *vs* CZI | 1.00 | 1.00 | 1.00 | 0.99 | 0.99 |
| April | SPEI *vs* SPI | 0.87 | 0.81 | 0.69 | 0.96 | 0.94 |
| | SPEI *vs* CZI | 0.87 | 0.82 | 0.70 | 0.96 | 0.94 |
| | SPI *vs* CZI | 1.00 | 0.99 | 1.00 | 1.00 | 0.99 |
| May | SPEI *vs* SPI | 0.92 | 0.89 | 0.84 | 0.90 | 0.90 |
| | SPEI *vs* CZI | 0.92 | 0.89 | 0.83 | 0.90 | 0.91 |
| | SPI *vs* CZI | 1.00 | 0.98 | 0.99 | 1.00 | 1.00 |
| June | SPEI *vs* SPI | 0.98 | 0.94 | 0.91 | 0.92 | 0.91 |
| | SPEI *vs* CZI | 0.97 | 0.94 | 0.90 | 0.92 | 0.91 |
| | SPI *vs* CZI | 0.99 | 1.00 | 1.00 | 1.00 | 0.99 |
| July | SPEI *vs* SPI | 0.91 | 0.97 | 0.94 | 0.91 | 0.94 |
| | SPEI *vs* CZI | 0.91 | 0.97 | 0.95 | 0.91 | 0.94 |
| | SPI *vs* CZI | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| August | SPEI *vs* SPI | 0.96 | 0.98 | 0.96 | 0.94 | 0.94 |
| | SPEI *vs* CZI | 0.99 | 0.98 | 0.96 | 0.94 | 0.94 |
| | SPI *vs* CZI | 0.97 | 1.00 | 1.00 | 1.00 | 1.00 |
| September | SPEI *vs* SPI | 0.94 | 0.95 | 0.95 | 0.95 | 0.95 |
| | SPEI *vs* CZI | 0.98 | 0.96 | 0.97 | 0.96 | 0.95 |
| | SPI *vs* CZI | 0.97 | 0.99 | 0.99 | 0.99 | 1.00 |
| October | SPEI *vs* SPI | 0.99 | 0.99 | 0.97 | 0.96 | 0.95 |
| | SPEI *vs* CZI | 0.99 | 0.99 | 0.97 | 0.96 | 0.95 |
| | SPI *vs* CZI | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 |
| November | SPEI *vs* SPI | 0.80 | 0.95 | 0.95 | 0.96 | 0.95 |
| | SPEI *vs* CZI | 0.80 | 0.95 | 0.95 | 0.96 | 0.95 |
| | SPI *vs* CZI | 0.96 | 1.00 | 1.00 | 1.00 | 1.00 |
| December | SPEI *vs* SPI | 0.67 | 0.97 | 0.95 | 0.96 | 0.95 |
| | SPEI *vs* CZI | 0.67 | 0.97 | 0.93 | 0.96 | 0.95 |
| | SPI *vs* CZI | 1.00 | 0.99 | 0.99 | 1.00 | 1.00 |

**TABLE B**

**Pairwise comparison matrix generated for Robustness, Tractability, Transperency, Sophistication, Extendibility and Dimensionality**

| Indices | SPI | SPEI | Deciles | CZI | PN | RAI |
|---|---|---|---|---|---|---|
| | | | **Robustness** | | | |
| SPI | 1.00 | 1.00 | 4.00 | 1.00 | 6.00 | 4.00 |
| SPEI | 1.00 | 1.00 | 4.00 | 1.00 | 6.00 | 4.00 |
| Deciles | 0.25 | 0.25 | 1.00 | 0.25 | 1.00 | 1.00 |
| CZI | 1.00 | 1.00 | 4.00 | 1.00 | 6.00 | 4.00 |
| PN | 0.17 | 0.17 | 1.00 | 0.17 | 1.00 | 1.00 |
| RAI | 0.25 | 0.25 | 1.00 | 0.25 | 1.00 | 1.00 |
| Total | 3.67 | 3.67 | 15.00 | 3.67 | 21.00 | 15.00 |
| | | | **Tractability** | | | |
| SPI | 1.00 | 2.00 | 0.33 | 2.00 | 0.25 | 0.33 |
| SPEI | 0.50 | 1.00 | 0.25 | 0.50 | 0.20 | 0.25 |
| Deciles | 3.00 | 4.00 | 1.00 | 3.00 | 0.50 | 1.00 |
| CZI | 0.50 | 2.00 | 0.33 | 1.00 | 0.25 | 0.33 |
| PN | 4.00 | 5.00 | 2.00 | 4.00 | 1.00 | 2.00 |
| RAI | 3.00 | 4.00 | 1.00 | 3.00 | 0.50 | 1.00 |
| Total | 12.01 | 18.00 | 4.92 | 13.53 | 2.70 | 4.91 |
| | | | **Transparency** | | | |
| SPI | 1.00 | 2.00 | 0.50 | 1.00 | 0.33 | 0.50 |
| SPEI | 0.50 | 1.00 | 0.33 | 0.50 | 0.25 | 0.33 |
| Deciles | 2.00 | 3.00 | 1.00 | 2.00 | 0.50 | 1.00 |
| CZI | 1.00 | 2.00 | 0.50 | 1.00 | 0.33 | 0.50 |
| PN | 3.00 | 4.00 | 2.00 | 3.00 | 1.00 | 2.00 |
| RAI | 2.00 | 3.00 | 1.00 | 2.00 | 0.50 | 1.00 |
| Total | 9.53 | 15.06 | 5.33 | 9.53 | 2.91 | 5.33 |
| | | | **Sophistication** | | | |
| SPI | 1.00 | 0.50 | 3.00 | 1.00 | 4.00 | 3.00 |
| SPEI | 2.00 | 1.00 | 4.00 | 2.00 | 5.00 | 4.00 |
| Deciles | 0.33 | 0.25 | 1.00 | 0.33 | 2.00 | 1.00 |
| CZI | 1.00 | 0.50 | 3.00 | 1.00 | 4.00 | 3.00 |
| PN | 0.25 | 0.20 | 0.50 | 0.25 | 1.00 | 0.50 |
| RAI | 0.33 | 0.25 | 1.00 | 0.33 | 2.00 | 1.00 |
| Total | 4.92 | 2.70 | 12.50 | 4.92 | 18.00 | 12.50 |
| | | | **Extendibility** | | | |
| SPI | 1.00 | 3.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SPEI | 0.33 | 1.00 | 0.33 | 0.33 | 0.33 | 0.33 |
| Deciles | 1.00 | 3.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CZI | 1.00 | 3.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| PN | 1.00 | 3.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| RAI | 1.00 | 3.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total | 5.33 | 16.12 | 5.33 | 5.33 | 5.33 | 5.33 |
| | | | **Dimensionality** | | | |
| SPI | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SPEI | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Deciles | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| CZI | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| PN | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| RAI | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Total | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |