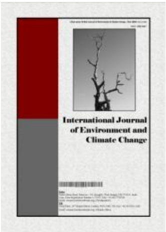


International Journal of Environment and Climate Change

12(10): 800-818, 2022; Article no.IJECC.86651
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

An Evaluation of the Performance of Five Meteorological Drought Monitoring Indices Over an Arid and Semi-Arid Region of Gujarat (India)

Bhukya Srinivas [a*], Mukesh Kumar Tiwari [a] and Gautam R. Patel [b]

[a] *College of Agricultural Engineering and Technology, AAU, Godhra, Gujarat, India.*
[b] *College of Agriculture, AAU, Vaso, Gujarat, India.*

Authors' contributions

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

Article Information

DOI: 10.9734/IJECC/2022/v12i1030865

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/86651

Original Research Article

Received 14 February 2022
Accepted 25 April 2022
Published 03 June 2022

ABSTRACT

Drought Monitoring plays an important role in drought risk assessment and management. Different meteorological drought indices are normally used to determine drought, which are essentially constant functions of rainfall and hydro-meteorological factors. A universal drought index cannot be used to evaluate the severity of drought in a specific region due to the essential difficulty of drought phenomena, hydro-climatic factors, and watershed characteristics. Classifying an appropriate drought index requires evaluating the performance of various drought indices. This study evaluated 5 meteorological drought indices for Gujarat, India utilizing a dataset from a total of 167 raingauge and climate stations having over 30 years (1986-2015 of the dataset). In various countries, several droughts indices have been introduced and utilized. This study evaluates the effectiveness of 5 meteorological drought monitoring indices in Gujarat. The following meteorological drought indexes were chosen based on data availability: Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Percent Departure from Normal (PDN), Effective Drought Index (EDI), and Reconnaissance Drought Index (RDI). The EDI is a time step independent drought indicator, with 1-, 3-, 6-, 9-, and 12-month time intervals defined for the four multi-time scale indices. This drought index was compared using several time scales of multi-time scale drought indices based on their association with the EDI. The evaluation of drought indices

**Corresponding author: E-mail: srinivascae28@gmail.com;*

during the historic drought was assessed based on the occurrence and response of drought indices within the specific drought severity classes. In the present study area, the 9-month scale is suitable for comparisons of drought indices. The SPEI-9 had the highest relative occurrence in the 'severe dry' class, and it was subtle to 9-monthly rainfall in most districts. As a result of the study, SPEI-9 is considered the best drought index.

Keywords: Standardized Precipitation Index (SPI); Standardized Precipitation Evapotranspiration Index (SPEI); Percent Departure from Normal (PDN); Effective Drought Index (EDI); Reconnaissance Drought Index (RDI).

1. INTRODUCTION

Drought is possibly the most complicated natural hazard. It is frequently defined as a short-term meteorological event caused by a lack of rainfall over an extended time in comparison to some long-term average condition (e.g., precipitation). On the other hand, droughts develop slowly, are difficult to detect, and have many facets in any given region. To successfully manage and mitigate drought, timely information about drought onset and progress is imperative. A drought index is commonly used for drought monitoring. Drought indices can inform drought-severity decision-makers and, if available, activate drought contingency plans [1,2]. Meteorological drought is a commonly used drought index, and it is defined as a period of decreased precipitation over a region [3]. Various meteorological drought indices have been established to calculate meteorological drought from various perspectives, with the majority of them focusing on precipitation as a major input [4,5]. “There are 4 types of droughts: meteorological, agricultural, hydrological, and socioeconomic. Meteorological drought is defined by a prolonged decrease in precipitation compared to the long-term average. Agricultural drought is categorized by deficits in total soil moistness and is caused primarily by more precipitation. The impact of a persistent lack of precipitation on the surface and/or subsurface water supply (i.e., streamflow, reservoir and lake levels, and groundwater) is referred to as hydrological drought. Socioeconomic drought is related to the impact of meteorological, agricultural, and hydrological droughts on the socioeconomic sectors” [3]. There are three types of drought indicators based on these physical datasets: meteorological drought indicators, agricultural drought indicators, and hydrological drought indicators. The most widely used meteorological drought indicators are Palmer Drought Severity Index (PDSI), Percent Departure from Normal (PDN), Deciles Index (DI), Effective Drought Index (EDI), Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI) and Reconnaissance Drought Index (RDI); agricultural drought indicators are Aridity Index (AI), Moisture Adequacy Index (MAI), Crop Moisture Index (CMI), Crop Water Stress Index (CWSI); and hydrological drought indicators are Standardized Water Level Index (SWLI), Surface Water Supply Index (SWSI), Streamflow Drought Index (SDI) and Standardized Hydrological Index (SHI). The most commonly used meteorological drought indicators are the Palmer Drought Severity Index (PDSI), Percent Departure from Normal (PDN), Deciles Index (DI), Effective Drought Index (EDI), Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI) and Reconnaissance Drought Index (RDI); Agricultural Drought Indicators include the Aridity Index (AI), Moisture Adequacy Index (MAI); and hydrological drought indicators are the Standardized Water Level Index (SWLI), Surface Water Supply Index (SWSI), [6], Streamflow Drought Index (SDI), and Standardized Hydrological Index (SHI). Among the most commonly used drought indices are the Standardized Precipitation Index (SPI) and Z-Score Index (ZSI) [7], Palmer Drought Severity Index (PDSI) [8], Standardized Precipitation Evapotranspiration Index (SPEI) [9], Moisture Anomaly Index (Z-index) [2], Surface Water Supply Index (SWSI). The rainfall anomaly index RAI [10], Deciles [11] & [12], EDI [13], RDDI [14], Perpendicular Drought Index (PDI) [12], SRI [15], CZI [16], SDVI [17,18], Alley [19], WLDI [20,21,1,4] and [14].

Although much research has been conducted on drought indices worldwide, very few studies have been performed in India [22,23, 18]. Consequently, it calls for an increase in studies in these areas in different agro-climatic zones of India. Also, earlier studies neglected to determine the effects of evapotranspiration on water resources in semi-arid and arid regions by using multiple time scales such as SPEI and

RDI. Due to these research gaps and increasing incidences of droughts in several parts of India. The purpose of this study was to better understand the propagation relationship between different types of drought monitoring indices in the semi-arid state of Gujarat (India). The present study has been conceptualized with the objectives to determine different meteorological drought indices, estimate meteorological drought using five different drought indices, and analyzing and validating a suitable drought index for the study area.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Drought affects 50 million people in India each year, affecting approximately one-third of the country (NCDM2010). Large parts of northwest India fall under arid and semi-arid regions, including the state of Gujarat, which witnesses droughts every 3 to 4 years. However, the trend over the last 35 years demonstrates that the drought phenomenon occurs almost every year, resulting in scarcity and semi-scarcity conditions in some parts of Gujarat. The state is located on the western coast of India between 20° 06′ N to 24° 42′ N and 68° 10′ E to 74° 28′ E (Fig. 1). Gujarat is composed of 3 physiographic regions: Central Highlands, Western Hills, and West Coast. The physiographic division shows the wide variations in topography across the state. Gujarat is located near the Thar Desert in the north, so the majority of the land is dry. Moreover, Gujarat's topography is characterized by small hilly tracts, particularly around the Rann of Kutch. Rainfall varies from 310 to 350 mm in Kutch to 620-700 mm in Saurashtra and north Gujarat to more than 1500 mm in south Gujarat. In nearly 99 blocks and 60% of the area, droughts are frequent.

2.2 Sources of Data Collection

To analyze the PDN, RDI, EDI, SPEI, and, SPI data from 167 meteorological stations in Gujarat over the period 1986 to 2015 was collected. The data included daily rainfall, Minimum/Maximum temperature, and relative humidity. This daily data collected from 167 stations over 30 years was converted into monthly rainfall. These meteorological observation data are collected from State Water Data Centre (SWDC), Gandhinagar, Gujarat.

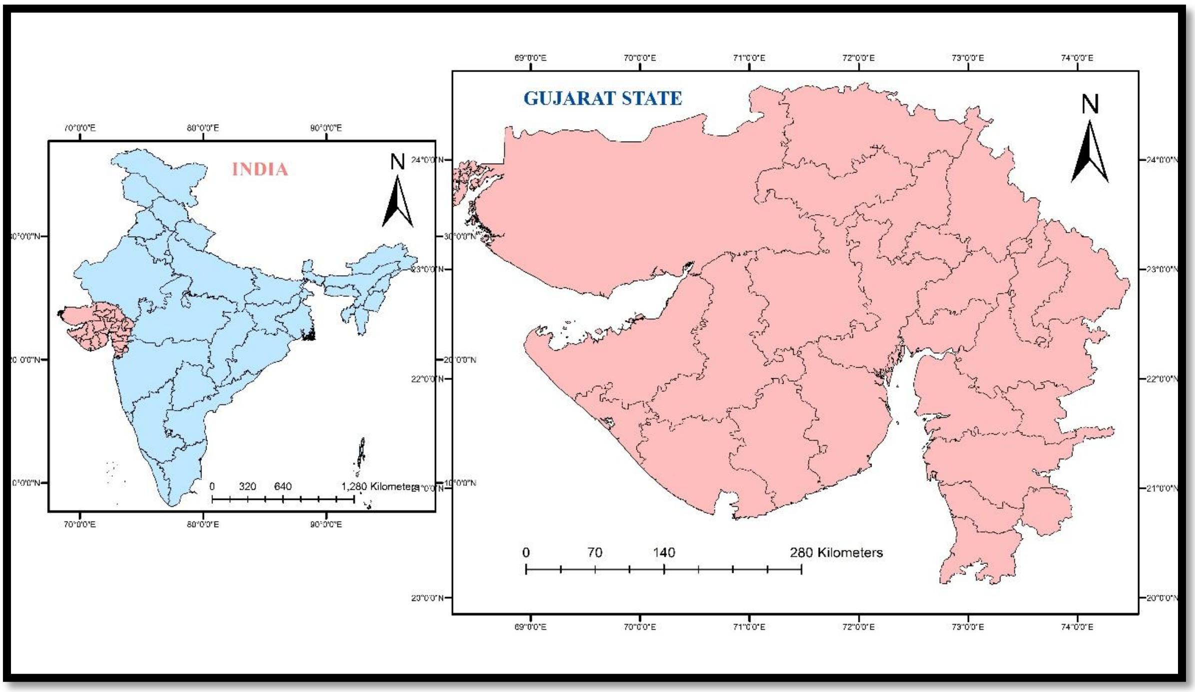


Fig. 1. Location map of study area Gujarat (India)

2.3 Meteorological Drought Monitoring Indices

2.3.1 Standardized Precipitation Index (SPI)

The SPI was developed by [7], for drought monitoring. Among the indices that can express rainfall over a given period, it is recommended by the (WMO) for worldwide use [24,25]. The gamma distribution was found to fit climatological precipitation time series well. The method used for this calculation was as follows:

$$SPI_{ij} \approx X_{ij} - \mu_{ij} \ \ \sigma_{ij} \quad (1)$$

Where SPI_{ij} is the SPI of the i^{th} month at j_{th} time-scale, X_{ij} is the precipitation total for the i^{th} month at j^{th} time-scale, μ_{ij} and σ_{ij} are the long-term mean and standard deviation related with the i^{th} month at j^{th} time-scale.

2.3.2 Standardized Precipitation Evapotranspiration Index (SPEI)

Vicente-Serrano [1], developed the Standardized Precipitation Evapotranspiration Index, (SPEI). SPEI can be calculated as standardized values of the monthly difference series probability distribution function. The log-logistic distribution can be used over multiple timescales, including 1, 3, 6, 9, and 12-months. Therefore, it is possible to analyze both short and medium-term droughts [26]. It is mathematically expressed as follows:

$$D_i = P_i - PET_i \quad (2)$$

The calculated 'D' values are aggregated at different time scales as:

$$D_n^k = \sum_{i=0}^{k=1} (P_{n-i} - PET_{n-i} \quad (3)$$

Where, k (months) denotes the timescale of the aggregation, and n denotes the calculation month. SPEI is calculated similarly to SPI. However, a three-parameter distribution is needed to standardize D-series as D-values can have negative values. Globally, the 3-parameter log-logistic distribution is a better fit for SPEI at all-time scales using the Kolmogorov-Smirnov, test [1]. The drought severity classification supported SPEI values is comparable to the SPI classification and it will be outlined at multiple scales.

2.3.3 Reconnaissance Drought Index (RDI)

Reconnaissance Drought Index (RDI) was developed by [10], to monitor the severity of meteorological droughts. RDI was categorized as a general meteorological index for the drought calculation. It is calculated using the ratio of cumulative precipitation and evapotranspiration values (PET). The RDI's initial value is calculated by computing a ratio 'a_k' between precipitation in a specific area and total potential evapotranspiration for each consecutive period of the k months in a year [18].

It is mathematically expressed as:

$$a_k = \frac{\sum_{j=1}^{j=k} Pij}{\sum_{j=1}^{j=k} PETij} \quad (4)$$

Where, P_{ij} and PET_{ij} represent precipitation and potential evapotranspiration for the jth month of the i^{th} year, respectively. In several locations, the values of '*ak*' have been found to follow either lognormal or Gamma distribution. This ratio is standardized using the same equations that were used to standardize SPI to get RDI values. It has an equivalent drought severity, classification as that of SPI and it may be outlined at multiple scales.

2.3.4 Effective Drought Index (EDI)

The effective drought index (EDI) was formulated by [27], which is an effectively non-parametric, index. Originally developed for daily time steps, it can also be used on a monthly scale [13]. It is based on the concept of effective precipitation (EP), which is a function of the current and previous day's rainfall, but with lower weights [Eq. (5)]. Eq. (5) shows that the EP, which is the most essential feature of EDI, is calculated using the concept of available water as a function of precipitation and time. According to EP, today's precipitation contributes 100% (weight of 1) to the available water, whereas the second day's contribution is less (weight of 0.85) and the next day's contribution is even less (weight of 0.77), and so on, with the contribution of precipitation from a year ago being the least (weight of 0.000423). This duration is either 365 days, a representative value of the total water resources available or stored for a longer period, or it can be 16 days, a representative of a short period. A similar decay of available water resources over time is also observed in rainfall-runoff models [28]. It is noteworthy that rainfall-runoff models exhibit a similar effect on EP in representing the decay of available water resources over time [28]. In this manner, drought risk can be robustly analyzed due to water scarcity conditions [29,30].

$$EP_i = \sum_{n=1}^{i}\left[\left(\sum_{m=1}^{n} P_m\right)/\,n\right]$$

$$= P1\left(1+\frac{1}{2}+\frac{1}{3}+\cdots+\frac{1}{365}\right) \quad (5)$$

$$+ \mathrm{P2}\left(1+\frac{1}{2}+\frac{1}{3}+\cdots+\frac{1}{365}\right)+\cdots+P365\left(\frac{1}{365}\right)$$

$\approx P_1 + 0{:}85P_2 + 0{:}77P_3 + \ldots + 0{:}000423P_{365}$

In addition, the following equations were used to create EDI:

$$DEP_i = EP_i – MEP \quad (6)$$

$$EDI_i = \frac{DEPi}{ST\ (\mathrm{DEPi})} \quad (7)$$

Where MEP is the mean EP, ST is the standard deviation derived for each day's deviation of EP (DEP), and 'i' is the particular day.

"EDI requires at least 30 years of data. Like other indices, EDI is a standardized index, which facilitates the comparison of severity between two regions despite different climates" [31]. It has also similar severity classes as those of SPI" [32].

2.3.5 Percent Departure from Normal (PDN)

Percent departure from normal (PDN) is a simple and easy-to-use indicator of dry/wet conditions over a specified area and time. This indicator is used by the India Meteorological Department (IMD) to declare drought on a weekly/monthly/ annual basis. PDN is calculated by estimating the deviation of rainfall from long-term averages. According to IMD, if the percent deviation of rainfall in a year from normal rainfall is 0 percent, 0-25 percent, 25-50 percent, or more than 50 percent, the drought is classified as 'No Drought,' 'Mild Drought,' 'Moderate Drought,' or 'Severe Drought.

2.4 Calculation of Drought Indices

In this study, five meteorological indices/ indicators, namely PDN (Percent Departure from Normal), EDI (Effective Drought Index), SPI (Standardized Precipitation Index), SPEI (Standardized Precipitation Evapotranspiration Index), and RDI (Reconnaissance Drought Index).

"To define the Reconnaissance Drought Index (RDI) [Eq. (4)] and Standardized Precipitation Evapotranspiration Index (SPEI) [Eq. (3)], the estimation of Potential Evapotranspiration (PET) is needed. It is worth mentioning that RDI is not dependent on the PET estimation method" [33]. "However, in the case of SPEI, the use of the Thornthwaite method proposed by [1] was later revisited by [34]". "They showed that on using different PET methods, there is a significant difference in the estimated SPEI series. Hence, primarily proposed Hargreaves method for the estimation of SPEI. The Hargreaves equation is expressed as" [35]:

PET = 0.0023Ru × (T_mean + 17.8) × (T_max - T_min)0.5 (8)

Where, PET = Potential Evapotranspiration, Ra = extraterrestrial radiation (mm/day), Tmax = maximum ambient temperature (°C), Tmin = minimum ambient temperature (°C). It is worth to mention that the concept of PET has been modified [19] and PET is replaced with Reference Evapotranspiration (ETo).

"For defining EDI, a dummy water deficit period of 365 days was selected as it represents the dominant precipitation cycle" [2]. For standardization, the remaining four indices, i.e., SPI, SPEI, RDI, need fitting of a probability distribution. The variables used for distribution fitting and the selected distributions for these indices are shown in Table 1. Software from the Spanish National Research Council website is available (http://digital.csic.es/handle/10261/10006;http://digital.csic.es/handle/10261/10002), and the Korean Daily Drought Monitoring website (available at http://atmos.pknu.ac.krintra) were used to calculate drought indices.

Table 1. Variables used for distribution fitting and probability distribution selected for SPI, RDI, SPEI, and SDI [18]

Drought Index	Variable	Probability Distribution Selected
Standardized Precipitation Index (SPI)	Rainfall	Gamma
Reconnaissance Drought Index (RDI)	The ratio of Rainfall to ET	Gamma
Standardized Precipitation Evapotranspiration Index (SPEI)	Difference between Rainfall and ET	Log-Logistic (3-parameter)

Table 2. Drought Severity Classification [18]

Class	Values of SPI, RDI, SPEI, and EDI	Value of PDN
Extremely Wet (EW)	≥2	≥ 1.75
Severe Wet (SW)	1.5 to 1.99	1.50 to 1.75
Moderately Wet (MW)	1 to 1.49	1.25 to 1.50
Normal (N)	0.99 to 0.99	0.75 to 1.25
Moderately Dry (MD)	-1 to -1.49	0.50 to 0.75
Severely Dry (SD)	-1.5 to -1.99	0.25 to .50
Extremely Dry (ED)	≤2	≤ 0.25

Similar to PDN, the drought indices SPI, RDI, and SPEI were also defined for 1, 3, 6, 9, and 12 months, whereas EDI, which is a time-step independent index, was calculated using a monthly time step.

2.5 Comparative Evaluation of Drought Indices

Following the selection of an appropriate scale, the meteorological indices were tested for their ability to model historical drought events. The ability of the drought indices was assessed based on their relative frequency in the drought-severity class and their response to rainfall variation. The term relative frequency' refers to the percentage of the drought index that remains in a specific drought-severity class for the duration of the study. Because drought indexes have different ranges for defining the severity of drought events, they are divided into wet and dry classes for comparison (Table 2). The table shows that the four indices, SPI, RDI, SPEI, and EDI, have the same severity classification. PDN, on the other hand, is only classified as drought or dry. To compare with other indices, the PDN classification was modified to include three wet classes. This was accomplished by adding 25% to each wet class, resulting in 'Moderately Wet,' 'Extremely Wet,' and 'Severely Wet' classes with 125 to 150 percent, 150 to 175 percent, and > 175 percent deviations from normal rainfall, respectively. The modified classes of PDN with their value of ranges in decimals are shown in the last column of Table 1.

2.6 Selection of Suitable Drought Index

“Although numerous drought indices have been developed, slight emphasis has been placed on their practical application in decision making because each index has its limitations” [36]. “As a result, drought indices used to assess drought conditions in the study area were evaluated using the desirable properties of a good drought index. In this region, the selection of a suitable drought index is vital for developing effective strategies for the mitigation of drought conditions. In this study, the performance of five meteorological drought indices, namely, SPI, RDI, SPEI, PDN, and EDI was examined to identify a suitable drought index for Gujarat, India” [37,2,23,18,38,3,39] & [23].

3. RESULTS AND DISCUSSION

"The SPI, RDI, and SPEI indices are multi-time scale indices, whereas the EDI is a time-step independent index. PDN can also be calculated for 1, 3, 6, 9, and 12 months, with the deviation from the corresponding multi-monthly long-term mean calculated. For example, in the case of 3-month rainfall, the sum of 3-months for a specific year is compared to the long-term mean, of the sum of 3-months in India, there is a lot of seasonal variation, from one month to the next. As a result, these multi-time scale indices were defined at time scales of 1, 3, 6, 9, and 12 months” [40,23,41,42,43,44] & [18].

“The correlation, of five-time scales (1, 3, 6, 9, and 12) of SPI, RDI, SPEI, and PDN with EDI was evaluated to select a suitable scale, for comparison” [45,2,23,46,18,34,3,47]. Thus, a correlation coefficient has calculated using OPOSTAT software for a five-time scale (1, 3, 6, 9, and 12) was calculated for all the 33 districts of Gujarat using the drought series. The correlation coefficient was calculated for all the 33 districts of Gujarat out of the 33 districts 7 districts has majorly affected by drought. Table 3 (bold values) shows the correlation coefficient is shown for all 7 districts (Ahmedabad, Bharuch, jamanager, Kucchh, Rajkot, Sabarkantha, Surendranagar, Valsad) of Gujarat. Except for similar time-scale indices, the values of the EDI's correlation coefficient, with other indices are generally higher than those of all-scale indices (orange color shading). In the multi-time scale indices calculated for a given month scale, the correlation between similar time scales is greater than the correlation between dissimilar scales. In comparison to other scale indices, SPI-1 has a correlation coefficient, (r) value of more than 0.54

with RDI-1, SPEI-1, and PDN-1. In addition, correlation coefficient, values for 3, 6, 9, and 12 months of SPI are greater than 0.82, 0.85, 0.93, and 0.95, respectively, when compared to dissimilar time scales. This implies that estimates, obtained from similar time scales are only comparable, to estimates obtained from similar time scales. The correlation, between SPI and RDI, is found to be very strong (r > 0.96) at all month timescales. Furthermore, the fact that both SPI and RDI follow the same Gamma distribution, implies that they have at least the same values outside of the monsoon season.

Fig. 2a-f show the correlation, of the EDI with other drought indices, for 1, 3, 6, 9, and 12-month periods for all seven districts of Gujarat (Ahmedabad, Bharuch, Jamanager, Kucchh, Rajkot, Sabarkantha, Surendranagar, Valsad). The correlation, with EDI, increases from 1 month to 9 months but decreases from 12 months. For 1-, 3-, and 6-month time scales, EDI varies between 0.4 and 0.5 and 0.6 to 0.7, respectively, but is greater than 0.7 for 6-, 9-, and 12-month time scales. PDN has the lowest correlation, between 1-, 3-, and 6-month time scales, implying that PDN is only comparable to EDI at higher time scales. This finding is similar to those of [29] and [18].

The average value of correlation of drought indices for a given time scale by different indices (excluding EDI) is shown in the last line of Table 3 (bold values). SPI-1 has a 0.53 average paired correlation, with RDI-1, SPEI-1, PDN-1, SPI-3, RDI-3, SPEI-3, PDN-3, SPI-6, RDI-6, SPEI-6, PDN-6, SPI-9, RDI-9, SPEI-9, PDN-9, SPI-12, RDI-12, SPEI-12, and PDN-12. Similarly, average paired correlation, values were found for all indices time scales and were plotted as shown in Fig. 3a-g. It is obvious from Fig. 3a-g that the value of average correlation, is higher for the 9-month scale. In addition, the mean average correlation coefficient, of all indices for a given scale is shown with a continuous line in Fig. 3a-g. As shown in the figure, the average correlation, is 0.53 in all 7 districts (last line of Table 3) over the 1-month period (SPI = 0.59, RDI = 0.52, SPEI = 0.54, PDN = 0.51) is 0.53. “It is clear from the figure that even excluding EDI, the maximum correlation value is for 9-month scales followed by 6 and 12-months. Hence, for the evaluation of drought indices, 9-month are selected, which is reasonable since a major part of India receives rainfall only after 9-months, once the monsoon is terminated in September [2,23,48,49,50,42,41,51,18] & [2] or early October and the same is true for the study area as well.”

3.1 Performance Evaluation of Drought Indices Concerning Historical Droughts

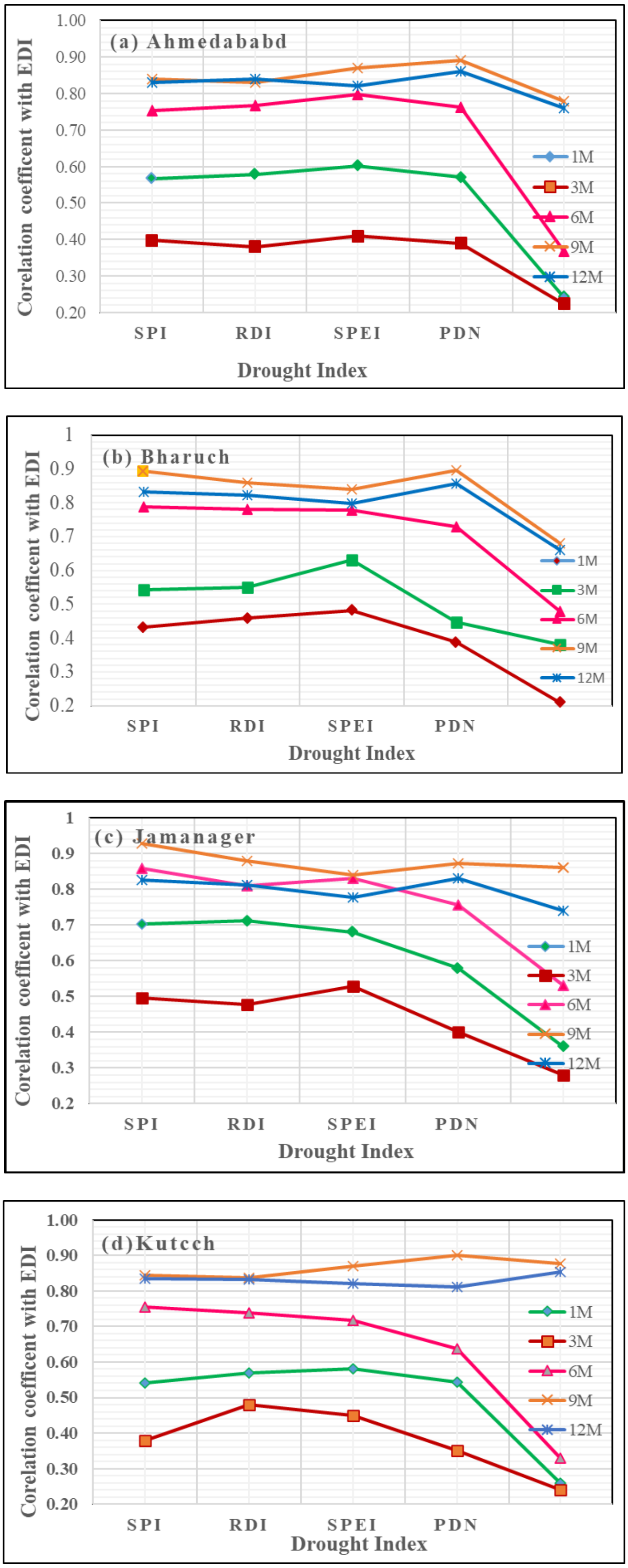
According to an EIS report from the Gujarat government (EIS 2010), the study area was affected by drought with seven districts experiencing acute water shortages at least once during the study period. Furthermore, the time series of 1986-2015 was used to evaluate the performance, of selected meteorological drought indices, (SPI, RDI, SPEI, and PDN at a 9-month scale, and EDI) regarding historical droughts. The relative frequencies, of these indices during this period for the monsoon months are shown in Fig. 4a-f. During a drought period, the relative frequency indicates the percentage of the drought index, that remains in the particular drought severity, class. Total wetness equals the sum of relative frequencies, of Extreme Wet (EW), Severe Wet (SW), and Moderate Wet (MW) classes, whereas total dryness equals the sum of relative frequencies, of Extreme Dry (ED), Severe Dry (SD), and Moderate Dry (MD) classes.

It can be seen from Fig. 4a-f that the SPI-9 has detected 45% (Jamanager district) to 85% (for Kutch district) of the months as a ‘Normal’ situation and a total of 10-55% in dry classes for the latter and former districts. EDI shows the least relative frequency, for total dry classes, ranging from 5% (Bharuch district) to 50% (Kutch district). On the other hand, the maximum total relative frequencies, for SPEI-9, RDI-9, and PDN-9 in dry classes, are found to be 65%, 70%, and 75%, respectively for the Kutch district.

The relative frequency, in the wet classes, is the main difference between these three indices. The wet classes frequency, identified by the PDN-9 varies from 0 to 25%, even though there was a dry spell, during this period (1986-2015). SPEI-9 shows the greatest relative frequency, of 'severe dry' classes in all seven districts (Fig. 4). The performance, of PDN-9, is the worst since most of its relative frequencies, during the 1986-2015 drought spell are in the ‘Normal’ class. As a result, SPEI-9 accurately detects dry spells, in the research area.

Table 3. Correlation coefficient for all scale drought indices for 33 districts of Gujarat

S. no	1M				3M				6M				9M				12M			
	SPI	RDI	SPEI	PDN	SPI	RDI	SPEI	PDN	SPI	RDI	SPEI	PDN	SPI	RDI	SPEI	PDN	SPI	RDI	SPEI	PDN
Ahmadabad	**0.54**	**0.58**	**0.60**	**0.57**	**0.40**	**0.38**	**0.41**	**0.39**	**0.38**	**0.36**	**0.39**	**0.32**	**0.33**	**0.38**	**0.43**	**0.31**	**0.26**	**0.28**	**0.31**	**0.27**
Amreli	0.65	0.74	0.42	0.52	0.69	0.37	0.39	0.60	0.69	0.54	0.42	0.78	1.00	0.71	0.80	0.85	0.92	0.87	0.66	0.74
Anand	0.40	0.36	0.31	0.37	0.90	0.80	0.69	0.91	0.36	0.44	0.42	0.38	0.92	0.86	0.73	0.85	0.96	0.92	0.75	0.85
Aravalli	0.62	0.67	0.67	0.63	0.41	0.33	0.31	0.43	0.38	0.55	0.34	0.54	0.80	0.74	0.83	0.79	0.75	0.59	0.81	0.89
Banaskantha	0.67	0.52	0.73	0.67	0.49	0.59	0.51	0.46	0.73	0.63	0.58	0.75	0.93	0.74	0.87	0.78	0.95	0.89	0.82	0.50
Bharuch	**0.43**	**0.46**	**0.48**	**0.39**	**0.54**	**0.55**	**0.61**	**0.45**	**0.42**	**0.38**	**0.39**	**0.23**	**0.35**	**0.46**	**0.34**	**0.30**	**0.23**	**0.34**	**0.43**	**0.52**
Bhavanager	0.69	0.50	0.41	0.67	0.50	0.69	0.52	0.60	0.60	0.51	0.79	0.50	0.93	0.74	0.75	0.73	1.00	0.90	0.89	0.70
Botaed	0.66	0.52	0.72	0.63	0.62	0.52	0.46	0.43	0.62	0.80	0.88	0.65	0.77	0.64	0.75	0.52	0.70	0.88	0.72	0.75
Chota Udaipur	0.70	0.48	0.58	0.71	0.38	0.31	0.35	0.43	0.83	0.65	0.61	0.88	0.92	0.65	0.87	0.84	0.95	0.93	1.00	0.73
Dahod	1.00	0.78	0.86	0.72	0.35	0.39	0.30	0.42	0.63	0.82	0.83	0.50	0.76	0.84	0.91	0.74	0.83	0.96	0.60	0.86
The Dangs	0.48	0.35	0.41	0.46	0.32	0.29	0.35	0.32	0.45	0.70	0.52	0.76	0.64	0.58	0.54	0.68	0.92	0.74	0.78	0.84
Devbhumi Dwraka	0.78	0.51	0.56	0.84	0.34	0.53	0.39	0.52	0.84	0.63	0.48	0.60	0.83	0.78	0.69	0.79	0.75	0.66	0.56	0.71
Gandhinagar	0.52	0.62	0.67	0.54	0.40	0.38	0.51	0.55	0.71	0.68	0.60	0.88	0.63	0.73	0.78	0.76	0.71	0.85	0.63	0.85
Gir Somnath	0.51	0.42	0.48	0.47	0.31	0.34	0.37	0.35	0.82	0.78	0.62	0.63	0.65	0.72	0.88	0.76	0.81	0.84	0.80	0.69
Jamanager	**0.47**	**0.42**	**0.52**	**0.43**	**0.32**	**0.48**	**0.53**	**0.40**	**0.46**	**0.48**	**0.38**	**0.37**	**0.93**	**0.88**	**0.84**	**0.87**	**0.83**	**0.81**	**0.78**	**0.83**
Junagadh	0.47	0.57	0.18	0.48	0.48	0.82	0.74	0.61	1.00	0.72	0.82	0.70	0.41	0.36	0.37	0.38	0.69	0.94	1.00	0.76
Kheda	0.52	0.39	0.37	0.52	0.51	0.39	0.38	0.48	0.71	0.69	0.66	0.73	0.53	0.65	0.58	0.69	0.60	0.83	0.67	0.54
Kutcch	**0.54**	**0.57**	**0.58**	**0.54**	**0.38**	**0.48**	**0.45**	**0.35**	**0.75**	**0.74**	**0.72**	**0.64**	**0.84**	**0.84**	**0.87**	**0.90**	**0.84**	**0.83**	**0.82**	**0.81**
Mahisager	0.49	0.43	0.32	0.56	0.46	0.34	0.60	0.62	0.75	0.63	0.68	0.62	0.72	0.51	0.55	0.66	0.89	1.00	0.93	0.87
Mehasana	0.73	0.52	0.68	0.72	0.54	0.32	0.28	0.37	0.62	0.72	0.68	0.74	0.91	0.76	0.66	1.00	1.00	0.86	0.68	0.75
Morbi	0.41	0.39	0.39	0.40	0.43	0.31	0.47	0.48	1.00	0.85	0.73	0.86	0.94	0.82	0.70	0.95	0.98	0.90	0.80	0.71
Narmada	0.74	0.61	0.54	0.68	0.84	0.63	0.82	0.74	0.87	0.76	0.79	0.87	0.85	0.68	0.76	0.78	0.96	1.00	0.97	0.93
Navsari	0.47	0.55	0.56	0.58	0.53	0.31	0.47	0.33	0.71	0.87	0.64	0.71	0.81	0.88	0.72	0.80	0.86	0.91	0.88	0.86
Panchmahal	0.74	0.63	0.62	0.75	0.34	0.33	0.38	0.46	0.73	0.61	0.88	0.68	0.63	0.51	0.62	0.64	0.65	0.86	0.72	0.66
Patan	0.52	0.43	0.36	0.50	0.56	0.52	0.58	0.38	0.68	0.49	0.40	0.58	0.93	0.73	0.83	0.75	0.73	0.67	0.44	0.45
Porbandar	0.73	0.53	0.74	0.74	0.36	0.64	0.59	0.49	0.50	0.67	0.63	0.72	0.66	0.75	0.77	0.68	0.93	0.88	0.86	1.00
Rajkot	**0.43**	**0.43**	**0.41**	**0.28**	**0.32**	**0.28**	**0.32**	**0.30**	**0.55**	**0.56**	**0.55**	**0.46**	**0.29**	**0.39**	**0.34**	**0.59**	**0.49**	**0.59**	**0.49**	**0.48**
Sabarkantha	0.70	0.53	0.66	0.73	0.49	0.37	0.41	0.42	0.61	0.73	0.81	0.68	0.91	0.98	0.75	0.77	0.94	0.80	0.86	1.00
Surat	0.49	0.71	0.45	0.57	0.54	0.64	0.34	0.45	0.79	0.75	0.87	0.73	0.90	0.74	0.65	0.69	0.94	0.84	0.94	0.74
Surendranagar	**0.55**	**0.56**	**0.62**	**0.43**	**0.45**	**0.46**	**0.48**	**0.27**	**0.38**	**0.47**	**0.47**	**0.37**	**0.39**	**0.49**	**0.39**	**0.39**	**0.24**	**0.28**	**0.38**	**0.49**
Tapi	0.74	0.38	0.54	0.68	0.49	0.42	0.38	0.41	0.83	0.94	0.99	0.80	0.73	0.65	0.77	0.75	0.60	0.53	0.65	0.62
Vadodara	0.77	0.36	0.66	0.73	0.46	0.34	0.32	0.36	0.84	0.58	0.71	0.74	0.59	0.52	0.51	0.53	0.72	0.78	0.42	0.38
Valsad	**0.36**	**0.51**	**0.54**	**0.59**	**0.30**	**0.32**	**0.37**	**0.36**	**0.48**	**0.38**	**0.38**	**0.47**	**0.38**	**0.48**	**0.38**	**0.49**	**0.59**	**0.48**	**0.38**	**0.49**
Avg correlation without EDI	**0.59**	**0.52**	**0.54**	**0.51**	**0.47**	**0.45**	**0.45**	**0.46**	**0.66**	**0.64**	**0.62**	**0.63**	**0.72**	**0.67**	**0.67**	**0.70**	**0.76**	**0.77**	**0.71**	**0.70**


(a) Ahmedababd
Corelation coefficent with EDI
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
SPI
RDI
SPEI
PDN
Drought Index
1M
3M
6M
9M
12M
(b) Bharuch
Corelation coefficent with EDI
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
SPI
RDI
SPEI
PDN
Drought Index
1M
3M
6M
9M
12M
(c) Jamanager
Corelation coefficent with EDI
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
SPI
RDI
SPEI
PDN
Drought Index
1M
3M
6M
9M
12M
(d)Kutcch
Corelation coefficent with EDI
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
SPI
RDI
SPEI
PDN
Drought Index
1M
3M
6M
9M
12M

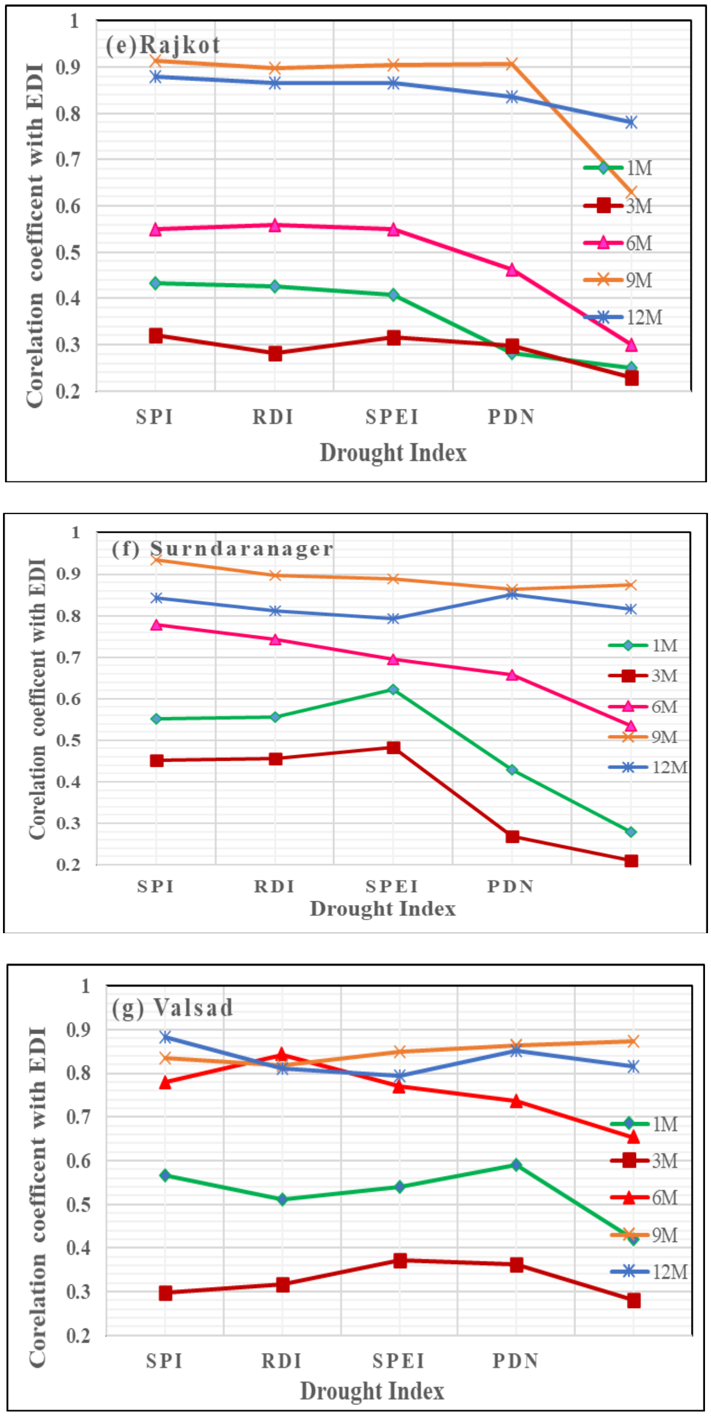
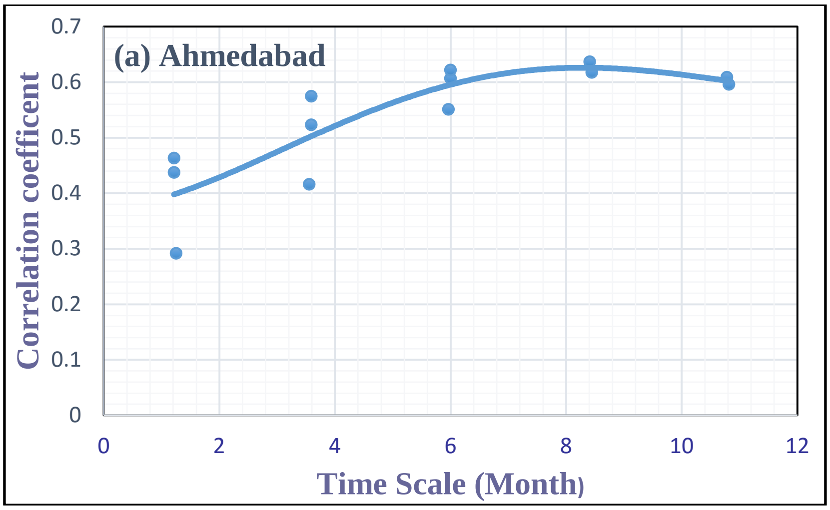
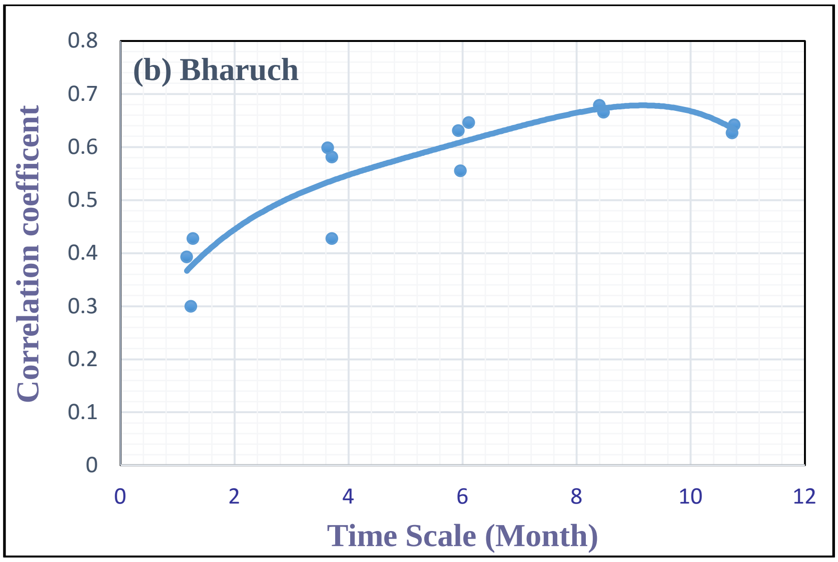
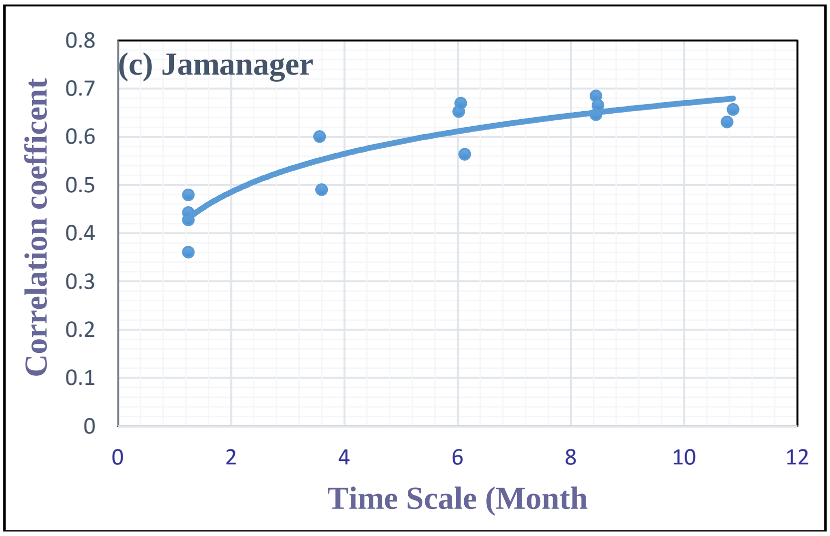
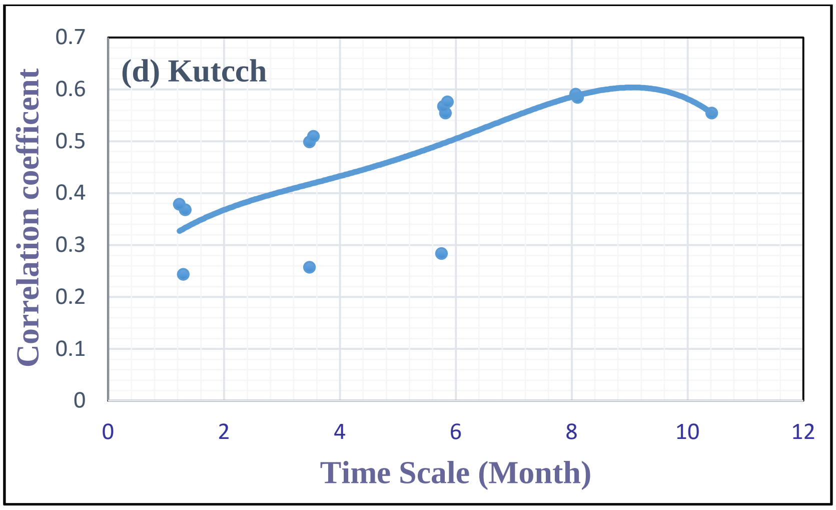


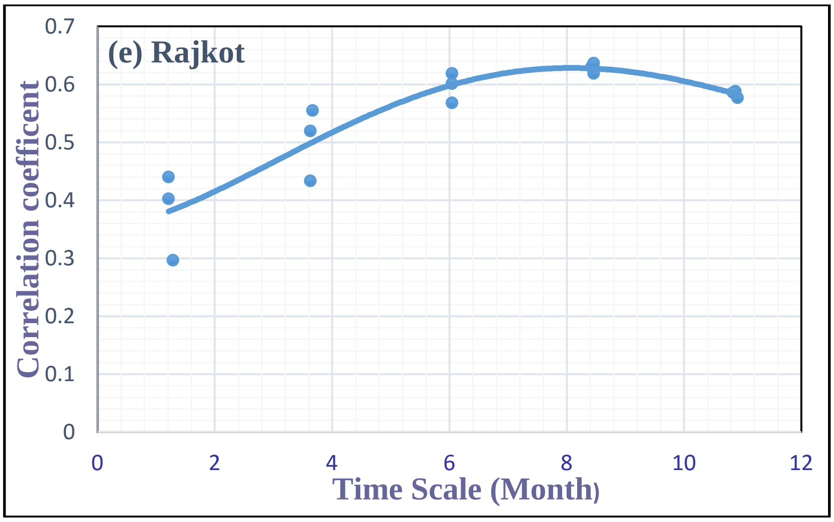
Fig. 2. Correlation, of EDI with four drought indices, for 1-month (green line), 3-month (red line), 6-month (pink line), 9-month (orange line), 12-month (blue line) at six stations: (a) Ahmedabad, (b) Bharuch, (c) Jamanager, (d) Kutcch, (e) Rajkot, (f) Surendranagar, and (g) Valsad Districts

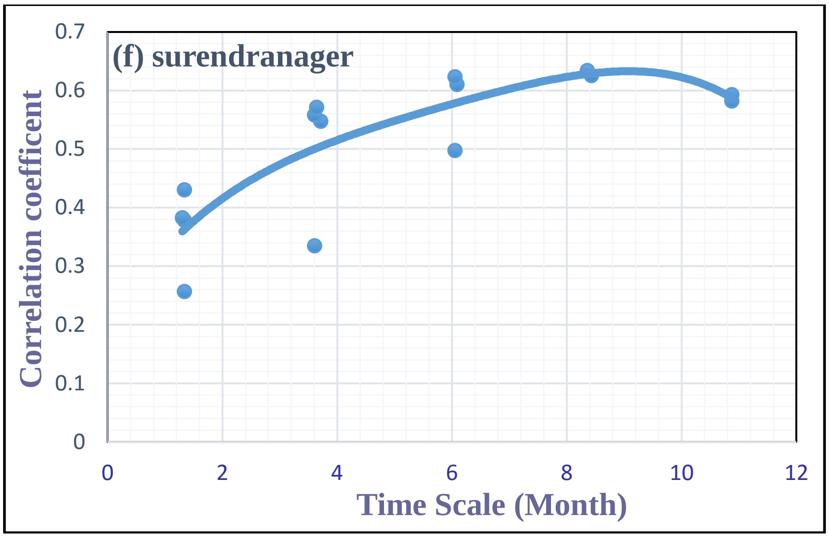

(a) Ahmedabad
Correlation coefficent
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
Time Scale (Month)


(b) Bharuch
Correlation coefficent
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
Time Scale (Month)


(c) Jamanager
Correlation coefficent
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
Time Scale (Month


(d) Kutcch
Correlation coefficent
Time Scale (Month)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12


(e) Rajkot
Correlation coefficent
Time Scale (Month)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12


(f) surendranager
Correlation coefficent
Time Scale (Month)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12

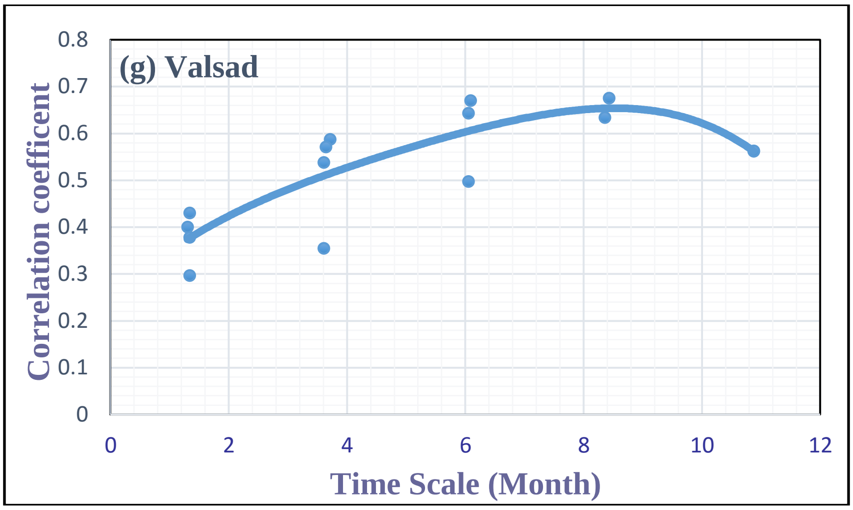
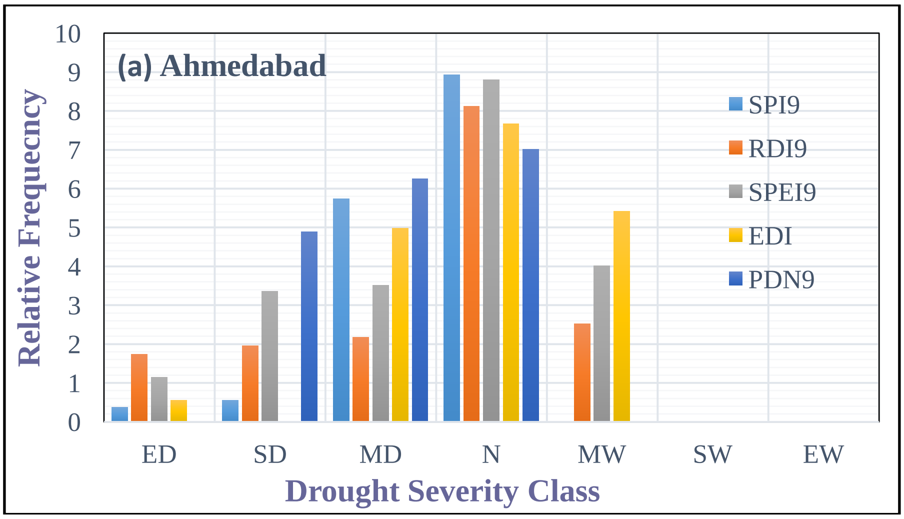
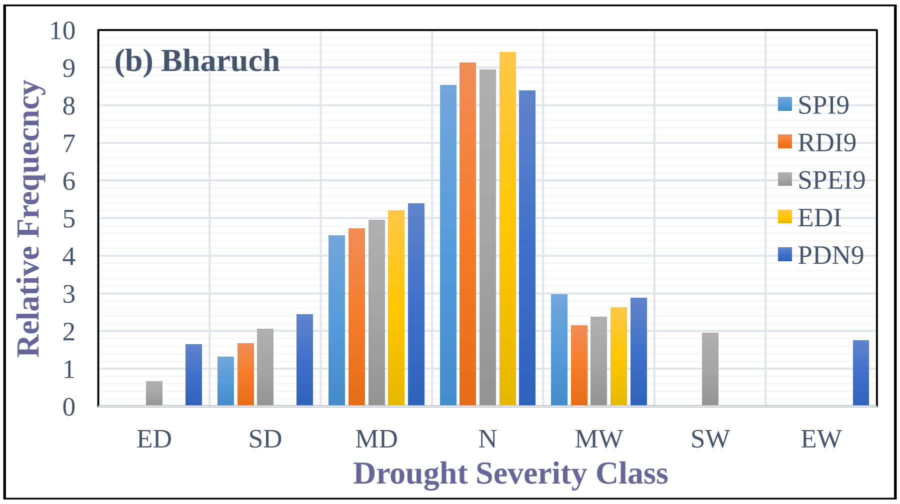
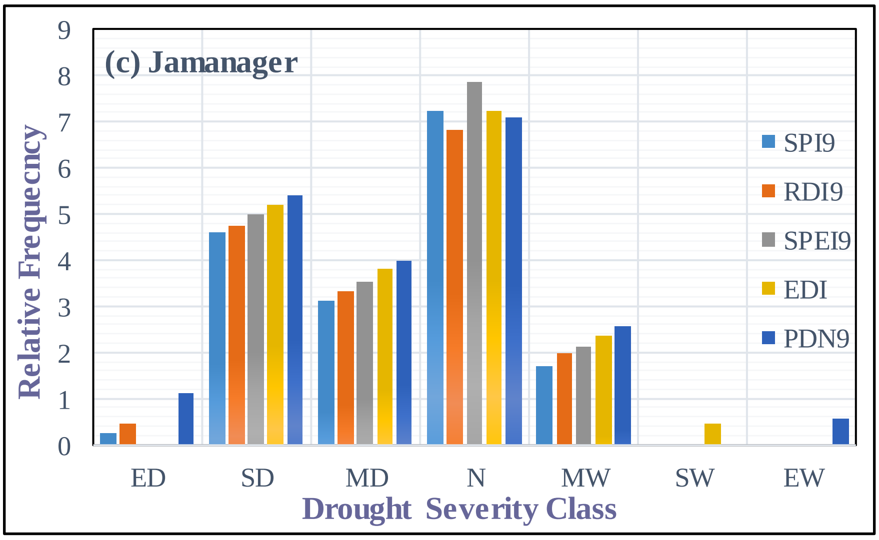
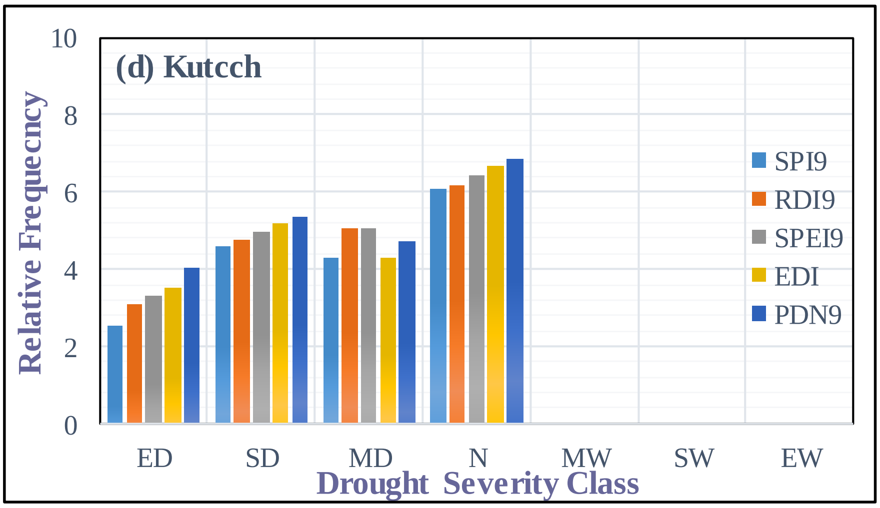


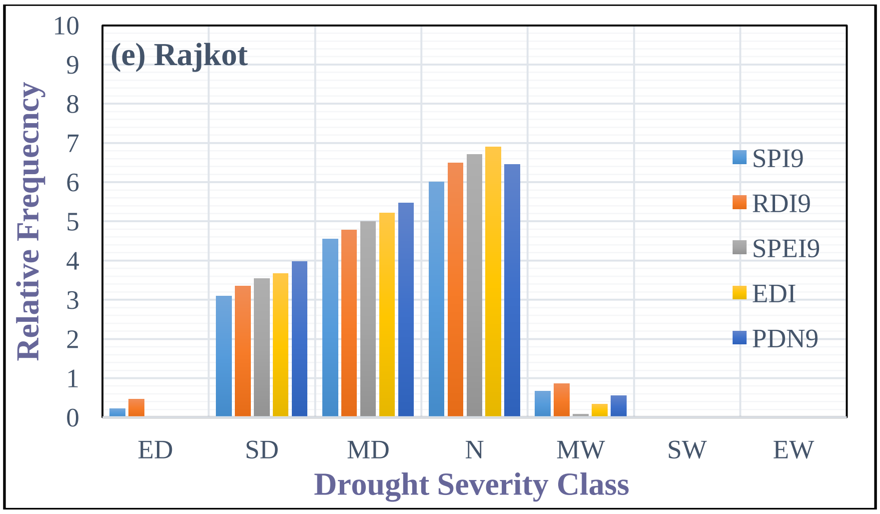
Fig. 3. Average correlation of a particular time-step drought index with all other indices time scales at (a) Ahmedabad, (b) Bharuch, (c) Jamanager, (d) Kutcch, (e) Rajkot, (f) Surendranagar, and (g) Valsad Districts

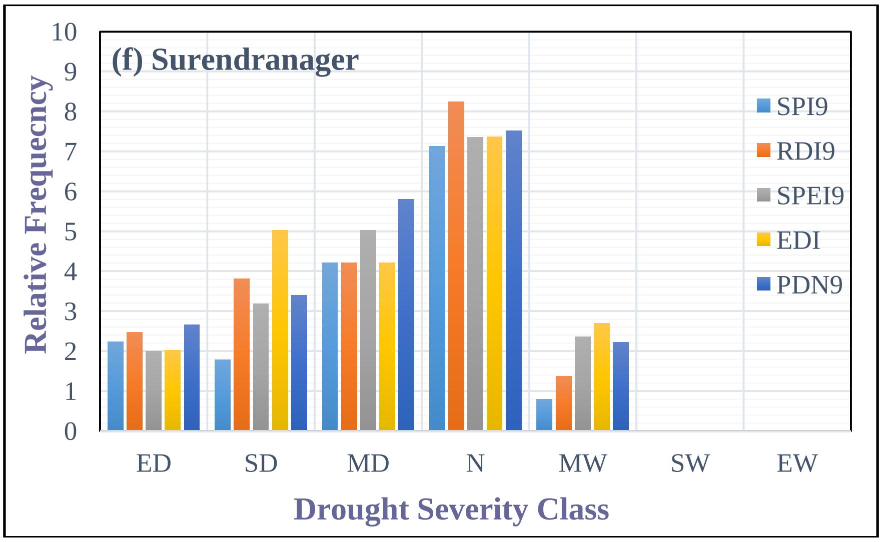





(c) Jamanager
Relative Frequecncy
9
8
7
6
5
4
3
2
1
0
SPI9
RDI9
SPEI9
EDI
PDN9
ED
SD
MD
N
MW
SW
EW
Drought Severity Class


(d) Kutcch
Relative Frequecncy
10
8
6
4
2
0
SPI9
RDI9
SPEI9
EDI
PDN9
ED
SD
MD
N
MW
SW
EW
Drought Severity Class


(e) Rajkot
Relative Frequecncy
10
9
8
7
6
5
4
3
2
1
0
SPI9
RDI9
SPEI9
EDI
PDN9
ED
SD
MD
N
MW
SW
EW
Drought Severity Class



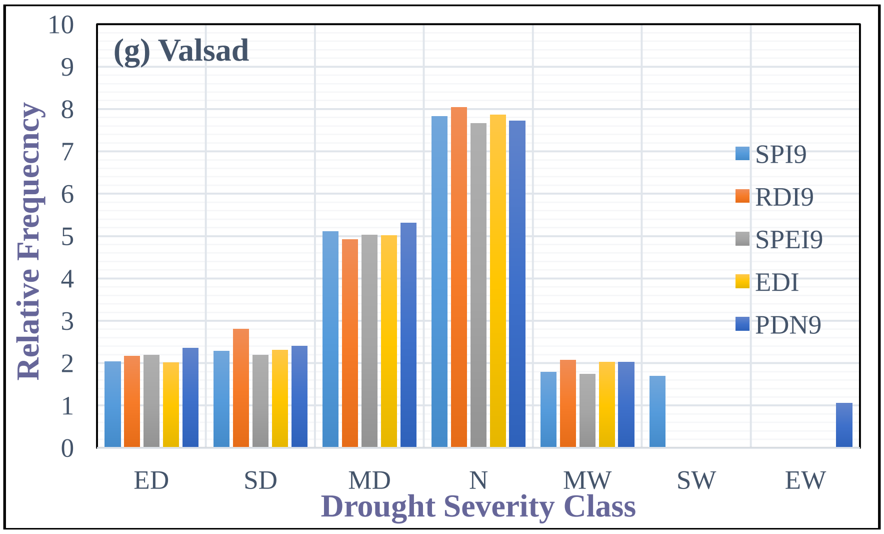


Fig. 4. In the monsoon months of the 1986-2015 dry spell, the drought frequency, classes of the selected indices were determined at (a) Ahmedabad, (b) Bharuch, (c) Jamanager, (d) Kutcch, (e) Rajkot, (f) Surendranagar, and (g) Valsad (D)

4. SUMMARY AND CONCLUSION

According to the study, parts of Gujarat in the northwestern and central regions are water-stressed and therefore more vulnerable to drought. Meteorological drought indices have been developed as a substitute for drought monitoring to determine drought-prone areas. According to comparison, of meteorological droughts in Gujarat, seven districts are at risk. Through the integration of multiple data sources, risk areas can be appropriately assessed, and management plans can be created to deal with hazards.

In this study, five drought indicators (the SPI, the SPEI, the RDI, the EDI, and the PDN) were evaluated for their effectiveness in detecting and monitoring droughts in Gujarat (India). As a result of meteorological drought, selecting an appropriate drought index is essential for developing effective drought, mitigation strategies in any area or region. This study examined the evaluation, of 5 meteorological drought indices, including SPI, RDI, SPEI, PDN, and EDI, to identify a suitable drought index, for Gujarat, India. Based on the study's findings, the following conclusions can be drawn:

1. A correlation matrix, based on the EDI and the 1-, 3-, 6-, 9-, and 12-month scale indices SPI, RDI, SPEI, and PDN found that all indices were strongly correlated, for similar time scales and poorly correlated,

for dissimilar time scales. The 9-month scale has the highest correlation, with EDI and is among the similar scale indices, of all the month scales considered in this study.

2. As a result, the 9-month scale is best suitable, for comparing drought indices, in the study area.
3. Evaluating drought indices, during historical drought periods (1986-2015) revealed, that SPEI-9 given better than other drought indices, in identifying drought characteristics, and it has the highest relative frequency, in 'severe dry' classes in all the six districts except Bharuch.
4. According to the results, of the evaluation of drought indices, based on the 5 drought indices, the severity of drought indices, based on rainfall is in the calculation of SPEI-9, RDI-9, SPI-9, EDI, and PDN-9.
5. This finding stresses the importance of the water balance in the research area, as well as the distinction between rainfall and PET for efficient drought monitoring.
6. In general, SPEI-9 outperforms other drought indices in detecting historical droughts and identifying drought characteristics. As a result, SPEI at a 9-month scale is recommended in the drought monitoring system for effective water resource planning and management in the study area.
7. Other probabilistic distributions for probability-based drought indices should be evaluated in the future as a follow-up to this study due to changing climate and socio-economic factors.
8. A study concentrating on the establishment of a comprehensive drought index is also proposed for the study area, given the availability of more drought-index defining characteristics.

In general, SPEI-9 outperforms other drought indices, in detecting historical droughts and identifying drought characteristics. As a result, SPEI at a 9-month scale is recommended, in the drought monitoring system, for effective water resource planning and management in the study area. The SPEI and RDI have shown similar performance despite having different underlying distributions. According to this similarity, long-term precipitation records may be useful for drought analyses (which can remove marginal differences between the indices). Due to the similarity in performance of several indices, the choice of an index may be partly determined by factors such as information requirements, calculation simplicity, and level of acceptance in operational practice. As a result of the changing climate and socioeconomic situations, different probabilistic distributions for probability-based drought indices should be evaluated in the future as a follow-up to this work. A study concentrating on the establishment of a comprehensive drought index is also proposed for the study area, given the availability of more drought-index defining characteristics.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Vicente-Serrano SM, Beguería S, López-Moreno JI, Angulo M, El Kenawy A. A new global 0.5 gridded dataset (1901–2006) of a multiscalar drought index: comparison with current drought index datasets based on the Palmer Drought Severity Index. Journal of Hydrometeorology. 2010;11(4): 1033-43.
2. Morid S, Smakhtin V, Moghaddasi M. Comparison of seven meteorological indices for drought monitoring in Iran. International Journal of Climatology: A Journal of the Royal Meteorological Society. 2006;26(7):971-85.
3. Pathak AA, Dodamani BM. Comparison of meteorological drought indices for different climatic regions of an Indian river basin. Asia-Pacific Journal of Atmospheric Sciences. 2020;56(4):563-76.
4. Vicente-Serrano SM, Beguería S, Lorenzo-Lacruz J, Camarero JJ, López-Moreno JI, Azorin-Molina C, Revuelto J, Morán-Tejeda E, Sanchez-Lorenzo A. Performance of drought indices for ecological, agricultural, and hydrological applications. Earth Interactions. 2012; 16(10):1-27.
5. Loukas A, Vasiliades L. Probabilistic analysis of drought spatiotemporal characteristics in Thessaly region, Greece. Natural Hazards and Earth System Sciences. 2004;4(5):719-31.
6. Shafer B A, Dezman L E. Development of a Surface Water Supply Index (SWSI) to assess the severity of drought conditions in snowpack runoff areas. Proceedings of the Western Snow Conference. 1982;164–175.

7. McKee TB, Doesken NJ, Kleist J. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology. 1993;17(22):179-183.
8. Palmer WC. Meteorological drought. US Department of Commerce, Weather Bureau; 1965.
9. Van Rooy M P. A rainfall anomaly index independent of time and space. Notes. 1965;14:43–48.
10. Tsakiris G, Vangelis HJ. Establishing a drought index incorporating evapotranspiration. European Water. 2005; 9(10):3-11.
11. Gibbs WJ, Maher JV. Rainfall deciles as drought indicators, bureau of meteorology bulletin no. 48. Commonwealth of Australia, Melbourne. 1967;29.
12. Ghulam A, Qin Q, Teyip T, Li ZL. Modified perpendicular drought index (MPDI): a real-time drought monitoring method. ISPRS Journal of Photogrammetry and Remote Sensing. 2007;62(2):150-64.
13. Byun HR, Kim DW. Comparing the effective drought index and the standardized precipitation index. Economics of drought and drought preparedness in a climate change context. López-Francos A. (comp.), López-Francos A. (collab.). Options Méditerranéennes. Sér. A. Séminaires Méditerranéens. 2010; 95:85-9.
14. Smakhtin VU, Hughes DA. Review, automated estimation, and analyses of drought indices in South Asia; 2004.
15. Shukla S, Wood AW. Use of a standardized runoff index for characterizing hydrologic drought. Geophysical research letters. 2008;35(2).
16. Wu H, Hayes MJ, Weiss A, Hu QI. An evaluation of the Standardized Precipitation Index, the China-Z Index, and the statistical Z-Score. International Journal of Climatology: A Journal of the Royal Meteorological Society. 2001;21(6): 745-58.
17. Tsesmelis DE, Karavitis CA, Oikonomou PD, Alexandris S, Kosmas C. Assessment of the vulnerability to drought and desertification characteristics using the standardized drought vulnerability index (SDVI) and the environment sensitive areas index (ESAI). Resources. 2018; 8(1):6.
18. Wable PS, Jha MK, Shekhar A. Comparison of drought indices in a semi-arid river basin of India. Water Resources Management. 2019;33(1):75-102.
19. Alley WM. The Palmer drought severity index: limitations and assumptions. Journal of Applied Meteorology and Climatology. 1984;23(7):1100-9.
20. Tsesmelis DE, Karavitis CA, Kalogeropoulos K, Tsatsaris A, Zervas E, Vasilakou CG, Stathopoulos N, Skondras NA, Alexandris SG, Chalkias C, Kosmas C. Development and Application of Water and Land Resources Degradation Index (WLDI). Earth. 2021;2(3):515-31.
21. Tsesmelis DE, Karavitis CA, Kalogeropoulos K, Zervas E, Vasilakou CG, Skondras NA, Oikonomou PD, Stathopoulos N, Alexandris SG, Tsatsaris A, Kosmas C. Evaluating the degradation of natural resources in the Mediterranean environment using the water and land resources degradation index, the case of crete island. Atmosphere. 2022;13(1): 135.
22. Pandey RP, Mishra SK, Singh R, Ramasastri KS. Streamflow drought severity analysis of Betwa river system (India). Water Resources Management. 2008;22(8):1127-41.
23. Jain VK, Pandey RP, Jain MK, Byun HR. Comparison of drought indices for appraisal of drought characteristics in the Ken River Basin. Weather and Climate Extremes. 2015;8:1-1.
24. Karavitis CA, Alexandris S, Tsesmelis DE, Athanasopoulos G. Application of the standardized precipitation index (SPI) in Greece. Water. 2011;3(3):787-805.
25. Karavitis CA, Chortaria C, Alexandris S, Vasilakou CG, Tsesmelis DE. Development of the standardized precipitation index for Greece. Urban Water Journal. 2012;9(6):401-17.
26. Lee SH, Yoo SH, Choi JY, Bae S. Assessment of the impact of climate change on drought characteristics in the Hwanghae Plain, North Korea using time series SPI and SPEI: 1981–2100. Water. 2017;9(8):579.
27. Byun HR, Wilhite DA. Objective quantification of drought severity and duration. Journal of Climate. 1999;12(9): 2747-56.
28. Deo RC, Byun HR, Adamowski JF, Begum K. Application of effective drought index for quantification of meteorological drought events: a case study in Australia.

Theoretical and Applied Climatology. 2017;128(1):359-79.
29. Dogan S, Berktay A, Singh VP. Comparison of multi-monthly rainfall-based drought severity indices, with application to semi-arid Konya closed basin, Turkey. Journal of Hydrology. 2012;470:255-68.
30. Tsakiris G, Pangalou D, Vangelis H. Regional drought assessment based on the Reconnaissance Drought Index (RDI). Water Resources Management. 2007; 21(5):821-33.
31. Asadi Zarch MA, Malekinezhad H, Mobin MH, Dastorani MT, Kousari MR. Drought monitoring by reconnaissance drought index (RDI) in Iran. Water Resources Management. 2011;25(13):3485-504.
32. Bhuiyan C, Singh RP, Kogan FN. Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data. International Journal of Applied Earth Observation and Geoinformation. 2006; 8(4):289-302.
33. Vangelis H, Tigkas D, Tsakiris G. The effect of PET method on reconnaissance drought index (RDI) calculation. Journal of Arid Environments. 2013;88:130-40.
34. Begueria S, Vicente-Serrano SM, Reig F, Latorre B. Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets, and drought monitoring. International Journal of Climatology. 2014;34(10):3001–3023.
35. Hargreaves GH, Samani ZA. Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture. 1985; 1(2):96-99.
36. Steinemann, A., Iacobellis, S. F., & Cayan, D. R. Developing and evaluating drought indicators for decision making. Journal of Hydrometeorology. 2015;16(4):1793–1803.
37. Gore PG, Ray KS. Variability in drought incidence over districts of Maharashtra. Mausam. 2002;53(4):533-8.
38. Mahmoudi P, Rigi A, Miri Kamak M. A comparative study of precipitation-based drought indices to select the best index for drought monitoring in Iran. Theoretical and Applied Climatology. 2019;137(3): 3123-38.
39. Pei Z, Fang S, Wang L, Yang W. Comparative analysis of drought indicated by the SPI and SPEI at various timescales in inner Mongolia, China. Water. 2020; 12(7):1925.
40. Barua S, Ng AW, Perera BJ. Comparative evaluation of drought indexes: a case study on the Yarra River catchment in Australia. Journal of Water Resources Planning and Management. 2011;137(2): 215-26.
41. Zarei A, Asadi E, Ebrahimi A, Jafary M M, Malekian A, Tahmoures M, Alizadeh E E. Comparison of meteorological indices for Spatio-temporal analysis of drought in Chahrmahal-Bakhtiyari province in Iran. Hrvatski Meteoroloski Casopis. 2017; 52(52):13-26.
42. Bayissa Y, Maskey S, Tadesse T, Van Andel SJ, Moges S, Van Griensven A, Solomatine D. Comparison of the performance of six drought indices in characterizing historical drought for the upper Blue Nile basin, Ethiopia. Geosciences. 2018;8(3):81.
43. Jamshidi H, Khalili D, Zadeh MR, Hosseinipour EZ. Assessment and comparison of SPI and RDI meteorological drought indices in selected synoptic stations of Iran. In World Environmental and Water Resources Congress 2011: Bearing Knowledge for Sustainability. 2011;1161-1173.
44. Tsesmelis DE, Vasilakou CG, Kalogeropoulos K, Stathopoulos N, Alexandris SG, Zervas E, Oikonomou PD, Karavitis CA. Drought assessment using the standardized precipitation index (SPI) in the GIS environment in Greece. In Computers in Earth and Environmental Sciences. 2022;1(1):619-633.
45. Behifar M, Kakroodi AA, Kiavarz M, Amiraslani F. Combination of meteorological indices and satellite data for drought monitoring in two different environments in Iran. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences. 2019;42:197-200.
46. Han M, Zhang H, DeJonge KC, Comas LH, Gleason S. Comparison of three crop water stress index models with sap flow measurements in maize. Agricultural Water Management. 2018;203:366-75.
47. Wang Y, Zhang C, Meng FR, Bourque CP, Zhang C. Evaluation of the suitability of six drought indices in naturally growing, transitional vegetation zones in Inner Mongolia (China). 2020;15(5):0233525.
48. Zehtabian G, Karimi K, Mirdashtvan M, Khosravi H. ComparabilityAnalyses of the SPI and RDI Meteorological Drought

Indices in South Khorasan Province in Iran. International Journal of Advanced Biological and Biomedical Research. 2013;1(9):981-92.
49. Karim R, Islam M, Hasan S. Comparison of standardized precipitation index with different time scales in Bangladesh. 2013;4(9):528–532.
50. Homdee T, Pongput K, Kanae S. A comparative performance analysis of three standardized climatic drought indices in the Chi River basin, Thailand. Agriculture and Natural Resources. 2016;50(3):211-9.
51. Memon AV, Shah NV. Assessment and comparison of SPI and RDI meteorological drought indices in Panchmahals District of Gujarat, India. Int. J. Curr. Microbiol. App. Sci. 2019;8(8): 1995-2004.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/86651