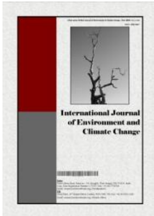

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Assessment of Meteorological Drought with Application of Standardized Precipitation Evapotranspiration Index (SPEI) for Tripura, Northeast India

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Authors' contributions

This work was carried out in collaboration among all authors. Author APMS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author DJ managed analyses of the study and author GSY managed the literature searches. Author SG managed the collection of data. All authors read and approved the final manuscript.

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ABSTRACT

Drought is one of the major water-related natural hazards. Understanding the spatial and temporal variation of rainfall is of great importance in water resources planning and management as it is related with food security and management of scarce water resource, which becomes critical in case of drought events. The advent of GIS to produce spatially interpolated drought map helps the water managers to undertake appropriate measures in drought relief and prioritization of drought mitigation works. Limitation of literature on Tripura suggests that study of drought over Tripura could help in strengthening of mitigation planes and rationalization of disaster management policies. Hence, the present study is focused to investigate the drought persistence and severity in the Tripura state of India during the period 1980-2013, using Standardized Precipitation Evapotranspiration Index (SPEI). Three time scale i.e., 3, 6 and 12 month time scales were opted

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for the study. Gridded monthly precipitation data distributed over the four districts of Tripura was used for drought analysis. Significant drought events were detected over the study area during the selected period. Annual analysis of SPI time series showed that the study area received the intense drought during the year 1985. Geospatial technique was used to generate the SPEI drought map for the year 1985.

Keywords: Drought; standardized precipitation evapotranspiration index; time scale; GIS; Tripura.

1. INTRODUCTION

Drought is an extreme hydrological event that relates to rainfall amount, duration, intensity, frequency and distribution. Extreme variabilities of parameters such as temperature, evaporation, relative humidity and wind speed leads to occurrence of climate hazards including droughts. Frequent droughts and inappropriate management of agroecosystem makes dryland susceptible to rapid degradation [1]. Based on its impact, drought can be categorized into four kinds viz. meteorological, hydrological, agricultural and socioeconomic [2]. Indian sub-continent experiences enhance vulnerability to drought hazard due to its unique geophysical setting and socio-economic conditions. The occurrence of drought is common over all types of climatic conditions and not prevalent to the arid and semi-arid region only. According to India Meteorological Department (IMD) the deviation from the normal rainfall with 75% less than normal is declared drought. Drought events are more prevalent in the north-eastern region of India in comparison with western region of the country [3]. Monitoring of drought should be at the highest priority to implement appropriate measures to control its negative impacts. However, limited studies have been reported on the study of drought occurrences in northeast region of India. Several indices make possible to analyze drought even though it begins slowly, has unstructured complex impacts and spread silently. Appropriate index is selected based on availability of data and index capability in determining drought characteristics for a region across space and time [4].

McKee et al. [5] developed SPI is the most appreciated drought indices for drought monitoring and warning system with the advantages of multiscale drought assessment [6] [7] [8]. However, SPI captures the drought only under lack of precipitation but not able to account the drought conditions under changes in temperatures and consequent changes in atmospheric evaporative demand [9]. Therefore, a drought index which considers both precipitation and temperatures is of relevance to understand the variability of drought under climate change. A drought index, Standardized Precipitation and Evapotranspiration (SPEI) has been developed by Vicente-Serrano et al. [10] to consider Potential Evapotranspiration (PET) along with precipitation as a basis for drought analysis. SPEI has been identified as an important drought index to understand the drought characteristics all over the world [11-12] and including South-Asian Continents [13-15]. So, the present study will assessed the spatial and temporal variation by the SPEI at multiple time scales over the Tripura state considering time scales of 3, 6 and 12 months to identify the worst event.

2. MATERIALS AND METHODS

2.1 Study Area and Data

The State of Tripura having an area of 10,492 km^2 is situated between the latitudes of 22° 56′ N and 24° 32′ N and the longitudes of 90° 09′ E and 92° 10′ E with elevation ranging from 600 to 900 m above mean sea level. The average precipitation of the area is about 2100 mm and climate is humid tropical. The study was carried out district wise, which includes four districts viz. North Tripura, West Tripura, Dhalai and South Tripura. The details of the districts are given in Table 1 and the location of study area is shown in Fig. 1. The gridded rainfall data having spatial resolution of 0.3° × 0.3° for the period 1980–2013were acquired from Global Weather Data for SWAT.

2.2 Standardized Precipitation Evapotranpiration Index (SPEI)

The drought index, SPEI is based on the climatic water balance, the accumulated monthly difference (in mm) between precipitation and PET as follows:

$$D = P - PET \qquad \text{Eq.1}$$

Where P is the monthly precipitation (mm) and PET is the monthly potential evapotranspiration (mm). The PET can be estimated based on Thornthwaite [17] model, which considers the monthly average air temperature and geographical location of the region of interest as input variables. The estimated D value represents the water demand or surplus (P-PET). In case of SPEI, the standardized drought indices can be produced with three-parameter log-logistic distribution to fit the *D* (Eq. 3) series following to Vicente-Serrano et al. [10]. The probability density function (pdf) (f(x)) and cumulative distribution function (CDF) (F(x)) of the three-parameter log-logistic distribution are given as follows:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left(1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right)^{-2} \quad \text{Eq. 2}$$

where α, $\beta$and $\gamma$are the scale, shape and origin parameters respectively and these parameters of the log logistic distribution are obtained by following the L-moment procedure as follows:

$$\beta = \frac{2w_1 - w_2}{6w_1 - w_0 - 6w_2} \quad \text{Eq. 3}$$

$$\alpha = \frac{(w_0 - 2w_1)\beta}{\Gamma(1+1/\beta)\Gamma(1-1/\beta)} \quad \text{Eq. 4}$$

$$\gamma = w_0 - \alpha\Gamma(1+1/\beta)\Gamma(1-1/\beta) \quad \text{Eq. 5}$$

where w_0, $w_1$and w_2 are the probability weighted moments calculated based on Yue and Hashino [18], as follows:

$$W_r = \frac{1}{n}\binom{r}{n-1}^{-1}\sum_{j-1}^{n-r}\binom{r}{n-j}x_j \quad \text{Eq. 6}$$

where *n* is the sample size and $x_j$is the ordered vector of observations in descending order. Next, the cumulative distribution function of log-logistic distribution can be calculated with the estimated parameters as follows:

$$F(x) = \left[1-\left(\frac{x-\gamma}{\alpha}\right)^{-\beta}\right]^{-1} \quad \text{Eq. 7}$$

With the values of F(x), the SPEI values were calculated as follows:

$$SPEI = W - \frac{C_0 + C_1W + C_2W^2}{1 + d_1W + d_2W^2 + d_3W^3} \quad \text{Eq. 8}$$

where $W = \sqrt{-2\ln(P)}$ for P ≤ 0.5

where P is the probability of exceeding a determined D value, P = 1 – F(x). If P>0.5, then P is replaced by 1- P and the sign of the resultant SPEI is reversed. The constants are C_0 = 2.5515517, C_1 = 0.802583, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, and d_3 = 0.001308. By substituting the C_0, C_1 and C_2 values in Eq. 8, we found the SPEI values at various time scales. The SPEI values and the corresponding climate conditions are summarized in Table2.

2.3 Drought Analyses

Standardised Precipitation Evapotranspiration Index was adopted for analysis of drought for the entire state of Tripura for the period of 1980-2013. Three time scales namely 3, 6 and 12 months were considered for the analysis. Monthly precipitation and calculated evapotranspiration were used for calculation of SPEI index. The month signifying the wet period during Kharif season to the specific time scale was selected [19]. Months of September and October were selected to represent 3 and 6 month time scale, respectively; while December for SPI 12 months. Drought is detected when SPEI value is less than -1, so the time between the consecutive negative zero value can considered as duration of the event. Drought characterization is important for understanding the behaviour of drought and to assess their cumulative effect on drought [20-21]. Drought severity is defined as the cumulative deviation for SPEI values below a threshold level, while the time period when this occurs is termed as the drought duration [22].

3. RESULTS AND DISCUSSION

SPEI based approach was adopted for investigation of historical drought to evaluate the meteorological drought vulnerability of Tripura. This process facilitates the decision makers to develop strategies on water resources management to mitigate the drought impact and also to formulate drought preparedness plans. SPEI were calculated for North Tripura, West Tripura, South Tripura and Dhalai districts in all three time scales presented in (Figs. 3, 4, 5 and 6). Droughts detected years are illustrated in Tables 3, 4, 5 and 6.

3.1 Drought Analysis

Analysis of SPEI for drought occurrence resulted in observation of distributed drought events. On analysis of SPEI 3, the study area encountered 25 drought events which comprised of 18 moderate droughts, 6 severe droughts and 1 extreme drought. The worst drought in 3 months

Table 1. Detail of Districts of Tripura [16]

District	Latitude °N	Longitude°E	Elevation (m)
North Tripura	24.19	92.18	56
West Tripura	23.88	91.56	74
Dhalai	23.88	91.87	97
South Tripura	23.57	91.56	97

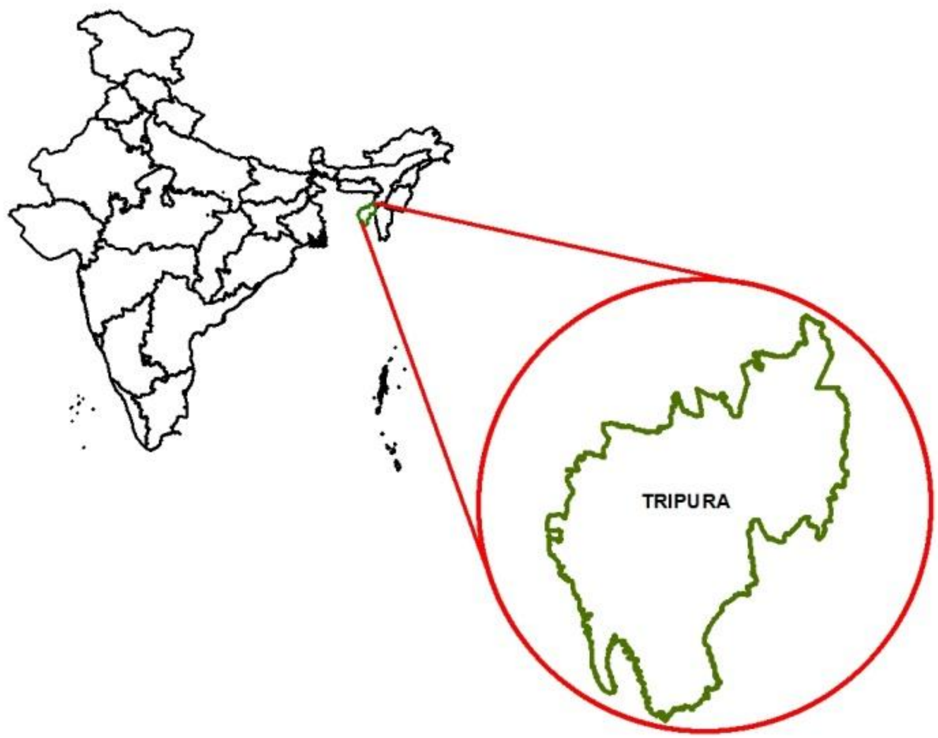

Fig. 1. Location of study area [16]

Table 2. SPEI value for different drough class [16]

Drought Class	SPEI value
Moderate drought	− 1.00 to − 1.49
Severe drought	− 1.50 to − 1.99
Extreme drought	− 2.00 and less

Table 3. SPEI value at different time scale in North Tripura

Station	Year	SPEI 3	SPEI 6	SPEI 12
North	1983	-1.62	-	-
Tripura	1985	-1.27	-1.62	-1.12
	1987	-1.38	-2.02	-1.01
	1988	-	-	-2.91
	2005	-1.26	-1.75	-1.04
	2006	-1.75	-1.55	-1.12

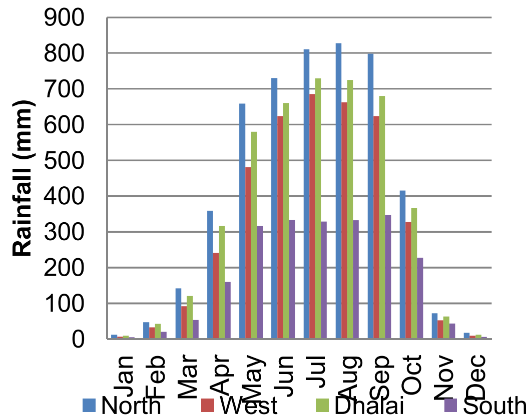

Fig. 2. Monthly rainfall distribution over the study area [16]

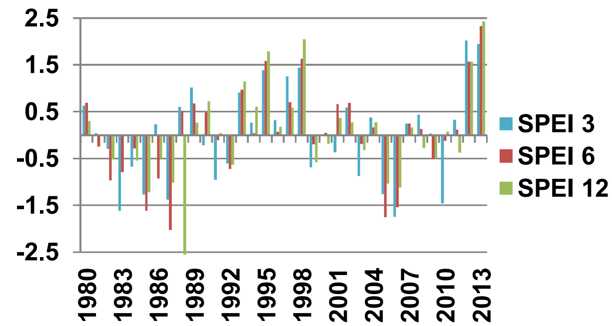

Fig. 3. North Tripura [16]

Table 4. SPEI value at different time scale in West Tripura

Station	Year	SPEI 3	SPEI 6	SPEI 12
West Tripura	1982	-	-1.07	-1.08
	1984	-1.25	-1.22	-
	1985	-2.10	-2.03	-1.93
	1987	-	-1.36	-1.26
	1992	-1.14	-1.16	-1.28
	2005	-	-1.23	-1.26
	2006	-1.14	-	-1.25
	2011	-1.45	-1.25	-1.47
	2013	-1.17	-	-

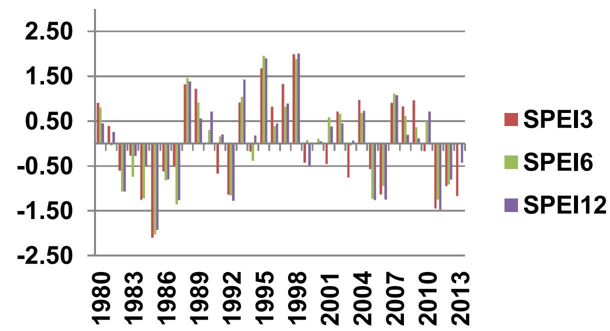

Fig. 4. West Tripura [16]

Table 5. SPEI value at different time scale in Dhalai

Station	Year	SPEI 3	SPEI 6	SPEI 12
Dhalai	1984	-1.08	-1.27	-
	1985	-1.56	-1.76	-1.57
	1987	-	-1.42	-1.20
	2005	-	-1.33	-1.32
	2006	-1.36	-1.15	-1.45
	2011	-1.91	-1.58	-1.84
	2012	-1.12	-1.19	-1.11
	2013	-1.55	-	-

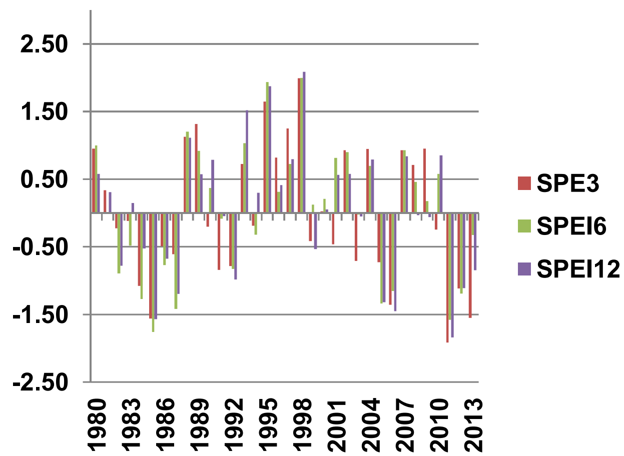

Fig. 5. Dhalai [16]

Table 6. SPEI value at different time scale in South Tripura

Station	Year	SPEI 3	SPEI 6	SPEI 12
South Tripura	1982	-1.12	-1.40	-1.42
	1984	-1.27	-1.42	-
	1985	-1.91	-1.96	-1.92
	1986	-	-1.25	-1.34
	1987	-	-1.32	-1.29
	1991	-1.33	-	-
	1992	-1.33	-1.18	-1.37
	2003	-1.24	-	-
	2005	-	-1.16	-1.15
	2006	-1.09	-	-1.27

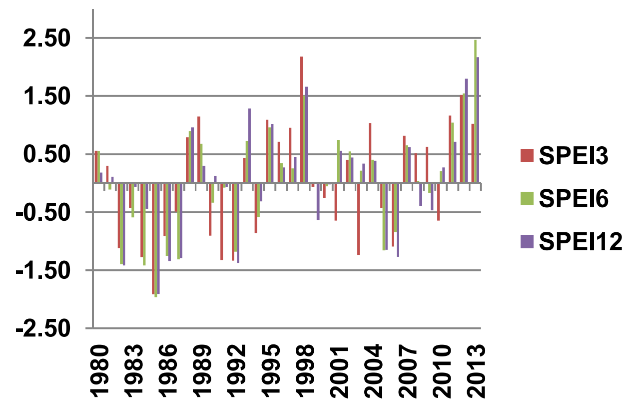

Fig. 6. South Tripura [16]

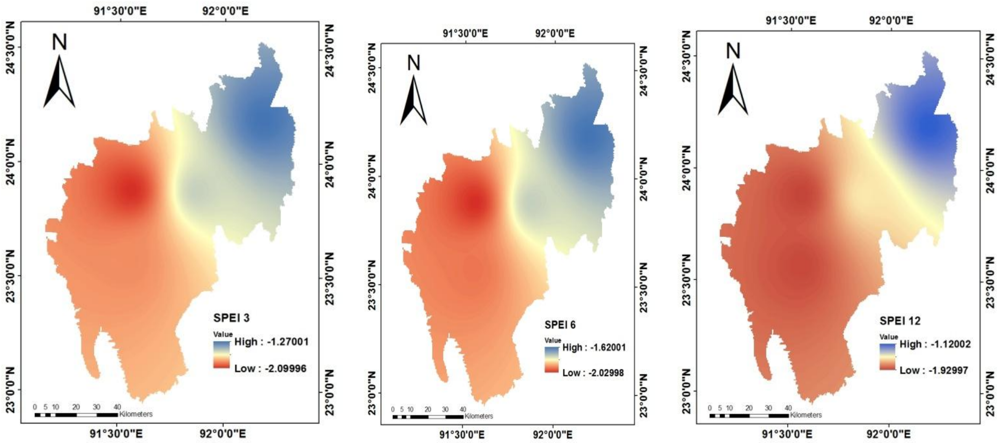

Fig. 7. Spatial map of different SPEI timescale of 1985 [16]

time scale occurred at a magnitude of -2.10 in the year 1985 in West Tripura district. In case of SPEI 6 analysis, 25 drought events were observed with 17 moderate, 6 severe and 2 extreme drought conditions. The highest magnitude of -2.03 was observed in the year 1985 in West Tripura district in this time scale. The highest time scale (SPEI 12) in the study resulted with 24 drought events constituted with 19 moderate, 4 severe and 1 extreme conditions. In this time scale a magnitude of -1.93 was encountered in the year 1985 in West Tripura district. From the above analysis it can be briefed that West Tripura had received extreme drought conditions and also it can be highlighted that the year 1985 has received the most consistent drought events in all the time scale.

3.2 Spatial Drought Severity Map

The Inverse Distance Weighting (IDW) method is employed for spatial interpolation of SPEI values over the entire study area. IDW weights the influence of each SPEI value by a normalized inverse of the distance from the rain gauge station to the interpolated point. It is assumed by IDW method that SPEI value has more influence at the rain gauge station and it diminishes with distance. The SPEI value of neighboring stations is also considered by the IDW approach. The spatial display maps for SPEI values were prepared by using Spatial Analyst tool of Arc GIS for drought year and are displayed in Fig. 7. The year 1985 was observed as most consistent drought occurring year in all considered timescale for the recorded station and severity is represented by spatial coverage of red color.

4. CONCLUSIONS

Standardized Precipitation Evapotranspiration Index has successfully assessed the drought condition in Tripura. Overall drought analysis of three time scale for the entire region of Tripura reveled that total of 74 droughts have been observed comprising of 54 moderate drought, 16 severe drought and 4 extreme droughts. The study period exhibited moderate drought conditions dominantly over the entire state [23]. The most consistent drought event was observed during the year 1985. Moderate to extreme droughts occurred over the districts in the considered time scales. The maximum number of droughts was observed in the South Tripura district however, North Tripura faced minimum numbers of droughts during the study.

The persistence of drought is particularly during the wet season of the region, so need for contingency plan for agriculture farmers should be on priority. Spatial visualization of SPEI with GIS technique aids to better depict drought conditions all over the Tripura territory and help stakeholders to lay drought contingency plans leading to holistic drought management strategies. Identification of affected area will provide significant aid to take up the mitigation as well as future prospect management on priority basis. Hence, drought study particularly defining the spatial and quantitative aspect is the need of the hour in the northeastern region of India.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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