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ORIGINAL ARTICLE

Comparison of Meteorological Drought Indices for Different Climatic Regions of an Indian River Basin

Abhishek A. Pathak[1] · B. M. Dodamani[1]

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Abstract

Droughts being a regional phenomenon has a vicious impact on agricultural production as well as on the socioeconomic status of an area. Meteorological drought is not only the result of rainfall deficit but also influenced by temperature in the form of evapotranspiration. There are several indices that could assess meteorological drought. Because of the complex phenomenon underling in the interaction between climatic, hydrological and ecological variables hampers to ascertain the suitability of a drought index to a particular region. The present work aims to compare different meteorological drought indices for a given climatic condition at the regional level. The Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI) and Standardized Precipitation Evapotranspiration Index (SPEI) were employed to study the variation of drought characteristics calculated from these indices. The study was implemented in the Ghataprabha river basin, which is one of the potential lands for agriculture in the basin of river Krishna. The study area possesses negative trends in rainfall and significant increasing trends in the temperature when tested with the Mann-Kendell trend test. Several drought events were observed through SPI, RDI, and SPEI over the basin. SPEI identified the highest number of drought events with high duration and severe intensity as compared to SPI and RDI. The alike performance was noticed between RDI and SPI whereas SPEI does not harmonize with them at any timescale of the study period. The study recommends to consider RDI and SPI in the humid (subhumid) region and SPEI at the semiarid (arid) region to assess the impact of drought effectively. The study also suggests to use an appropriate drought index for analysis of drought, which could lead to an adequate preparedness for the future drought hazards.

Keywords Aridity index · Mann-Kendell trend · Meteorological drought · SPI · RDI · SPEI

1 Introduction

Meteorological drought is one of the primary drought types and often defined by a period of diminished precipitation over a region. Numerous drought indices were developed to quantify meteorological drought with a different perspective, and most of them consider precipitation as a major input (Loukas and Vasiliades 2004). Among various drought indices, the Standardized Precipitation Index (SPI) is studied throughout the world (Dahal et al. 2015; Thomas and Prasannakumar 2016; Bacanli 2017). Even though SPI was proven superior to Palmer Drought Severity Index (PDSI) (Guttman 1998; Paulo and Pereira 2006) and other rainfall based indices (Dogan et al. 2012), it has major disadvantage by being less sensitive to the low rainfall and it will underestimate wetness and dryness caused by rainfall extremities (Tsakiris and Vangelis 2005; Naresh Kumar et al. 2009). The estimation of the SPI will not consider the role of other meteorological variables (temperature, humidity, and evapotranspiration) which are crucial in the drought formation (Teuling et al. 2013). Meanwhile, researchers evaluated the role of temperature via evapotranspiration on the different water resources sectors (Ciais et al. 2005; Dai 2011).

To overcome the drawback of SPI for not accounting the atmospheric evapotranspiration demand, Tsakiris et al. (2007) and Vicente-Serrano et al. (2010) proposed Reconnaissance Drought Index (RDI) and Standardized Precipitation Evapotranspiration Index (SPEI), respectively. These indices follow the similar mathematical procedure of SPI and incorporate precipitation and effect of temperature in the form of PET to quantify meteorological drought. PET is one of the key

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✉ Abhishek A. Pathak
abhipathak2013@gmail.com

[1] Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka, Surathkal, Mangalore, Karnataka, India

variables in the RDI and SPEI, and the formulation of PET has a significant impact on them (Vangelis et al. 2013).

Even though the similarity between SPEI and RDI with SPI was observed (Masud et al. 2015), a significant discrepancy in the drought duration was detected at a higher (6 and 12 month) time scale (Khalili et al. 2011). Several studies (Xu et al. 2015; Vicente-Serrano et al. 2015) compared SPEI and RDI with SPI from various climatic regions and isolated conclusions were derived. However, none of the drought indices has been accepted globally for any climatic region (Halwatura et al. 2015) because each region has its own climatic characteristics (rainfall, land use/ cover, flora, fauna, humidity, temperature, etc) and these characteristics interact differently with others along with the influence of anthropogenic activity and climate change. These conditions of the environment make drought as a highly regional phenomenon.

India being a drought-prone country, many researchers studied meteorological drought with the aid of SPI in various climatic regions of the country (e.g. Mahajan and Dodamani 2016; Ghosh and Srinivasan 2016). Whereas limited studies on SPEI (Niranjan Kumar et al. 2013; Mallya et al. 2016; Das et al. 2016; Aadhar and Mishra (2017) and RDI (Kusre and Lalringliana 2014; Surendran et al. 2017), have been observed throughout India.

From the literature, it can be recapitulated that, many studies have been considered the single index to assess drought characteristics of a region and only a few studies were attempted to suggest appropriate drought index for specific climatic regions (Wable et al. 2018). The selection of proper drought index for a region is essential because each region has its prevailing climatic variable/s which plays a crucial role in the regional hydrological cycle and every drought index may not be capturing these critical climatic parameters effectively. Application of a single drought index for the whole region/ country which, possesses various climatic regions may yield erroneous results and could lead to wrong interpretation of drought. Further, this may lead to an improper formulation of drought mitigation and preparedness strategies.

In the Indian context, many sub-basins of major river basins comprises two or more climatic zones, and only a few researches compared SPI, RDI, and SPEI in these basins, however, according to authors best of knowledge no studies have been focused on examining the PET-based drought indices exclusively at the regional level. The present study aims to compare the popular meteorological drought indices for the Indian climate by considering a typical basin that consists of three major climatic zones of the country. The study encompasses the following objectives 1) Investigation of trends associated with the meteorological variables 2) Assessment of drought characteristics, estimated from SPI, RDI, and SPEI and its spatiotemporal variation in the sub-basin of river Krishna at various time scales. 3) Comparison of these drought indices at different climatic regions within the study area.

2 Description of Study Area and Data

This study was conducted for the Ghataprabha river basin, which is a sub-basin of river Krishna in India. The study area (Fig. 1) is positioned between the Northern latitude of $15^0 45'$ and $16^0 25'$ and Eastern longitude of $74^0 00'$ and $75^0 55'$ and is agriculturally dominated. The River rises from the Western Ghats of India at an altitude of 884 m. The total length of the Ghataprabha River, up to the confluence with the River Krishna is 260 km. The total catchment area of sub-basin is 8829 km^2, a major portion of the basin (77.2%) lies in the state Karnataka which ranks second, in terms of the area prone to drought in India after Rajasthan (KSAPCC 2011). The major portion of the basin is semiarid and rainfall is the major source of water for agriculture. The average annual rainfall (1970 to 2013), of the basin, varies from 650 mm to 2000 mm and the annual mean temperature of the basin fluctuates from 25.1^o C to 26.6^o C (Fig. 2).

In the present study, the gridded daily rainfall data of 0.25^o resolution (Pai, et al. 2014), from 1970 to 2013 was obtained from the India Meteorological Department (IMD), Pune. The Daily maximum and minimum temperature data of 0.25^o resolution, from 1970 to 2013 was secured from recently developed NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) data sets (Thrasher et al. 2013). To develop NEX-GDDP data sets, initially the Bias-Correction Spatial Disaggregation (BCSD) method was employed to downscale CMIP5 GCMs, latter these data sets were bias-corrected using Quantile mapping technique with the aid of climatic data sets of Global Meteorological Forcing Dataset (GMFD). Further spatial disaggregation methods were applied to get a finer resolution (0.25 X 0.25 degree) of NEX-GDDP data sets (Thilakarathne and Sridhar, 2017). Twenty-five grid points of rainfall and temperature which covers the Ghataprabha River basin were considered and named from A1 to D7.

3 Methodology

3.1 Nonparametric Trend Test and Aridity Index

The study area spreads over from the hilly region (elevation of 1054 m) to flat terrain (elevation of 500 m) and the climatic variables behave differently in each of these regions with respect to elevation. To assess drought characteristics in each region, the basin has been categorized in to humid, subhumid and semiarid region based on Aridity Index (AI) (UNEP 1992). The UNEP aridity index can be defined as the ratio of average annual Precipitation (P) to the average annual potential evapotranspiration (PET) over the time period. In this study, temperature-based Penman-Monteith PET has been calculated (Allen et al.

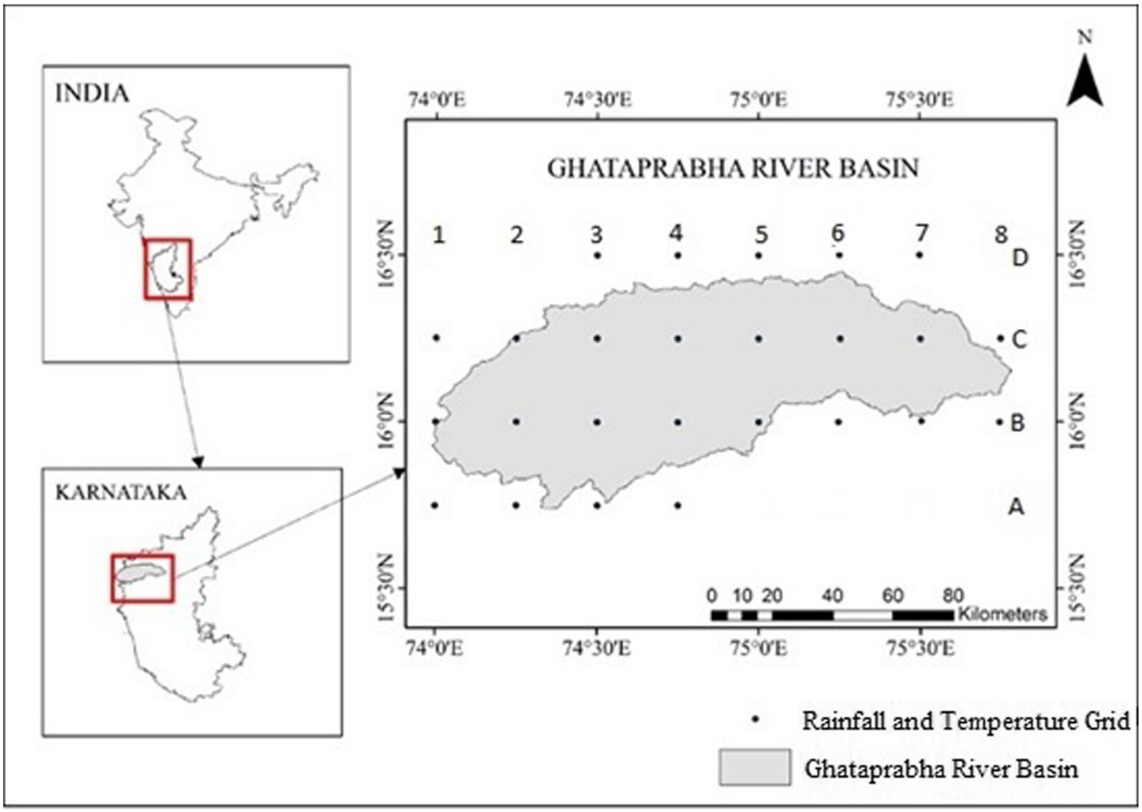

Fig. 1 Location map of Ghataprabha river basin

1998) and the same has been used for calculation of Aridity Index (AI) and drought indices (RDI and SPEI). AI has been calculated for all the stations and classified according to the UNEP classification, which classifies the area as humid, subhumid, and semiarid if the value of P/PET >0.75, 0.5 < P/PET ≤0.75 and 0.2 < P/PET ≤0.5, respectively (Paulo et al. 2012).

To quantify the trend in a time series data, Mann Kendall (MK) test has been widely used in the field of water resources and climatic studies (Ahn and Palmer 2015; Mahajan and Dodamani 2016). The MK test as initially formulated by Mann (1945) as a non-parametric test for trend detection and the test statistic was introduced by Kendall (1975). The present work considered a non-parametric Mann Kendall (MK)

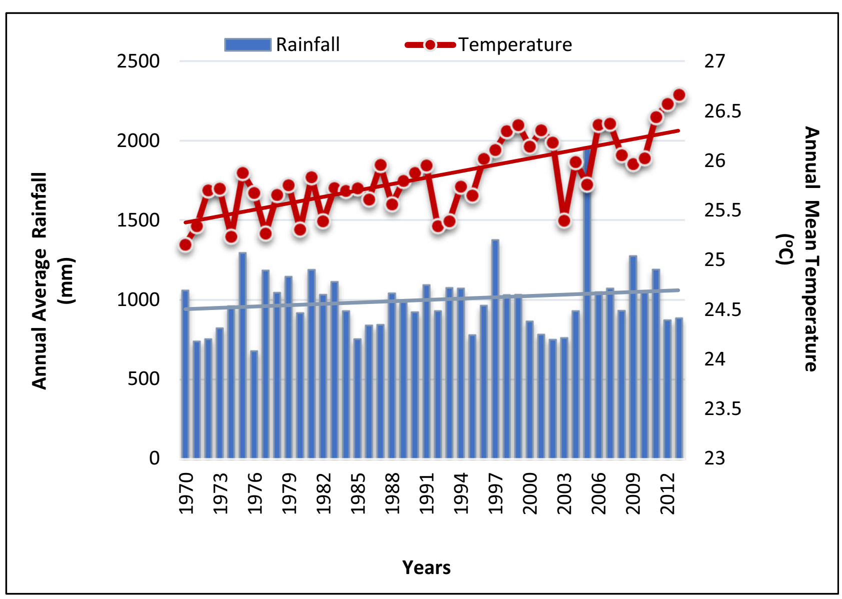

Fig. 2 Annual average rainfall and annual mean temperature of the basin

test to identify trends in the meteorological variables (Rainfall, Temperature, and PET). The trend test has been conducted for all the stations at a 95% confidence level and the magnitude of the trend has been quantified by Sen's slope (Sen 1968) method. Formulations and equations of the MK test and Sen's slope method can be found in many standard literatures (Kumar Raju and Nandagiri 2017; Bacanli 2017).

3.2 Drought Indices

3.2.1 Standardized Precipitation Index (SPI)

SPI was formed by Mckee et al. (1993) to indicate meteorological drought, and it defines the number of standard deviations that the observed cumulative rainfall at a given time scale would deviate from the long-term mean (Subash and Ram Mohan 2011; Surendran et al. 2017). The only input for calculation of SPI is long term precipitation records preferably 30 years. Calculation of SPI involves the following steps

- The probability density function (PDF) of suitable distribution is determined to describe the long-term time series of precipitation observations.
- The cumulative probability of an observed precipitation amount is computed.
- The inverse normal (Gaussian) function, with mean zero and variance one, is then applied to the cumulative probability which results in the SPI.

The present study considers two-parameter Gamma distribution to arrive the SPI.

3.2.2 Reconnaissance Drought Index (RDI) and Standardized Precipitation Evapotranspiration Index (SPEI)

The Reconnaissance Drought Index (RDI) and Standardized Precipitation Evapotranspiration Index (SPEI) were developed to overcome the limitations of SPI by accounting climatic water demand. RDI and SPEI consider the effect of temperature in the form of evapotranspiration. RDI is an extended version of the Aridity Index and formulated by Tsakiris and Vangelis (2005) as a quotient of atmospheric water deficit. The ratio of monthly Precipitation (P) to Potential evapotranspiration (PET) is considered as input for RDI. During the initial formulation of RDI lognormal distribution was implemented but the latter Gamma distribution was suggested (Tsakiris et al. 2007).

SPEI was developed by Vicente-Serrano et al. (2010), which reflects the monthly climatic water balance. This index provides the measure of water surplus or deficit for a given time period. SPEI considers the fitting of 3 parameter Log-Logistic distribution to the difference between P and PET. The calculation procedure of RDI and SPEI are as same as SPI, the only difference is the input variables. Therefore drought intensity expressed through these indices can be classified using a unified class definition (Table 1).

The detailed description of SPEI and RDI was provided by Vicente-Serrano et al. (2010) , Beguería et al. (2014), Tsakiris et al.(2007), Zarei et al. (2016). The present study calculates SPI, RDI, and SPEI at 3, 6 and 12-month time scales for all the stations and implemented 2 parameter Gamma distribution for SPI and RDI whereas 3 parameter Log-Logistic distribution was considered to calculate SPEI with R package "SPEI" developed by Beguería and Vicente-Serrano (2013).

Drought characteristics like severity, duration and intensity can be defined by considering a threshold value (in this study −1) for all the indices. Drought event (episode) is the period when the magnitude of SPI, RDI, and SPEI falls below the threshold level, and drought duration is the period in which the magnitude of drought index is below the threshold value. The severity is the sum of negative values during the drought duration, and intensity is defined as the ratio of the drought severity to drought duration.

4 Results and Discussions

4.1 Aridity Index and Trend Analysis of Meteorological Variables

The aridity index is calculated as the ratio of average annual precipitation to the average annual PET for all the stations. The values of the Aridity index range from 0.41(for station D7) to 3.43 (for station D1). Based on the Aridity index, the basin was classified into three zones (Fig. 3). The humid climate was observed in the western side of the basin while the semiarid condition in the eastern part. A layer of transition zone was observed between humid and semiarid zones, and that was classified as sub-humid zone, which clearly differentiates between humid and semiarid zones. The average annual rainfall varies spatially between 5000 mm in the humid region to 626 mm in the semiarid region (Fig. 4). Annual PET of the basin (Fig. 5) varies from 1088 mm to 1360 mm from the humid region to the semiarid region, respectively. The eastern

Table 1 Classification of drought conditions according to the SPI as given by (Lloyd-Hughes and Saunders 2002)

SPI values	Classification
2.0 or more	Extremely wet
1.5 to 1.99	Severe wet
1.0 to 1.49	Moderate wet
0.01 to 0.99	Mild wet
−0.99 to 0	Mild drought
−1.0 to −1.49	Moderate drought
−1.5 to −1.99	Severe drought
−2.0 or less	Extreme drought

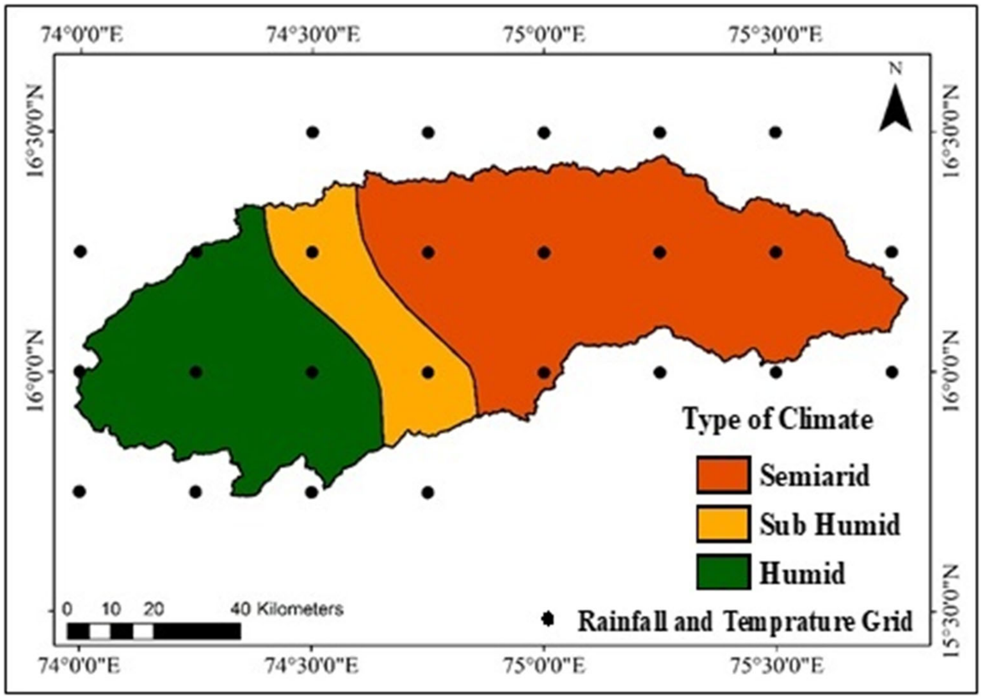

Fig. 3 Climatic zones of the study area

portion of the basin, being the semiarid region, characterized by low rainfall and high PET forces the area to become more susceptible to frequent droughts.

Prior to the Mann- Kendell trend test, meteorological datasets are tested for serial correlation with a 95% confidence level. The Annual rainfall and annual PET do not possess any serial correlation whereas, annual temperature showed significant autocorrelation at lag-1. To address the effect of serial correlation of annual temperature, the Modified Mann-Kendell (MMK) test based on the variance correction approach (Hamed and Rao 1998) was employed. The results of MMK did not diverge from the decision of the MK test. Therefore MK test along with the Sen's slope test was performed for the original data sets of annual rainfall, annual

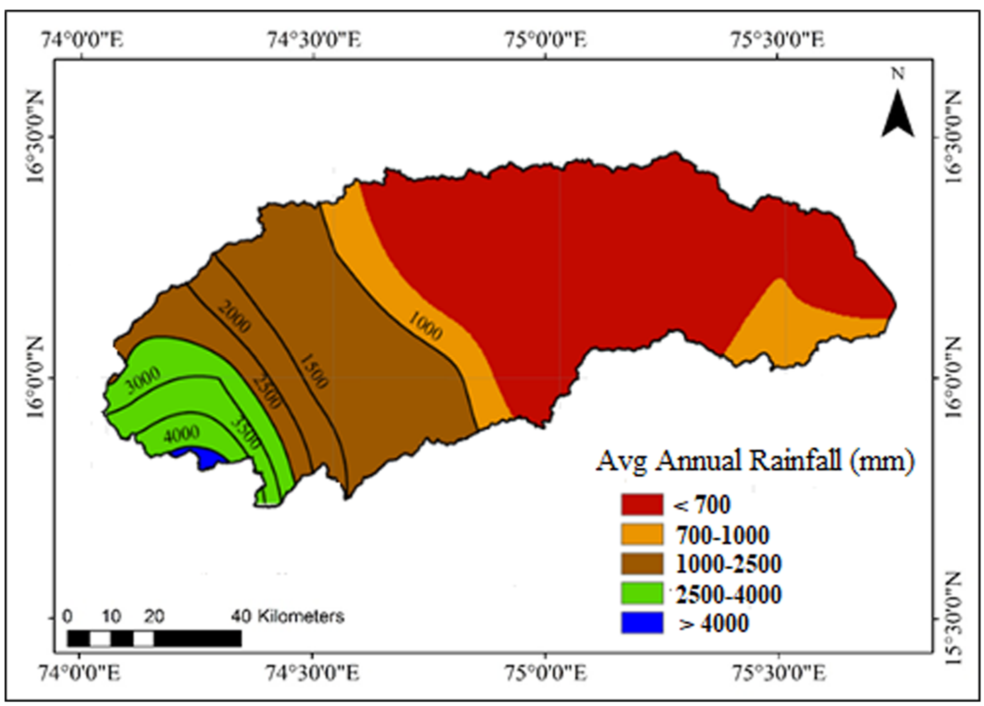

Fig. 4 Average annual rainfall of the basin

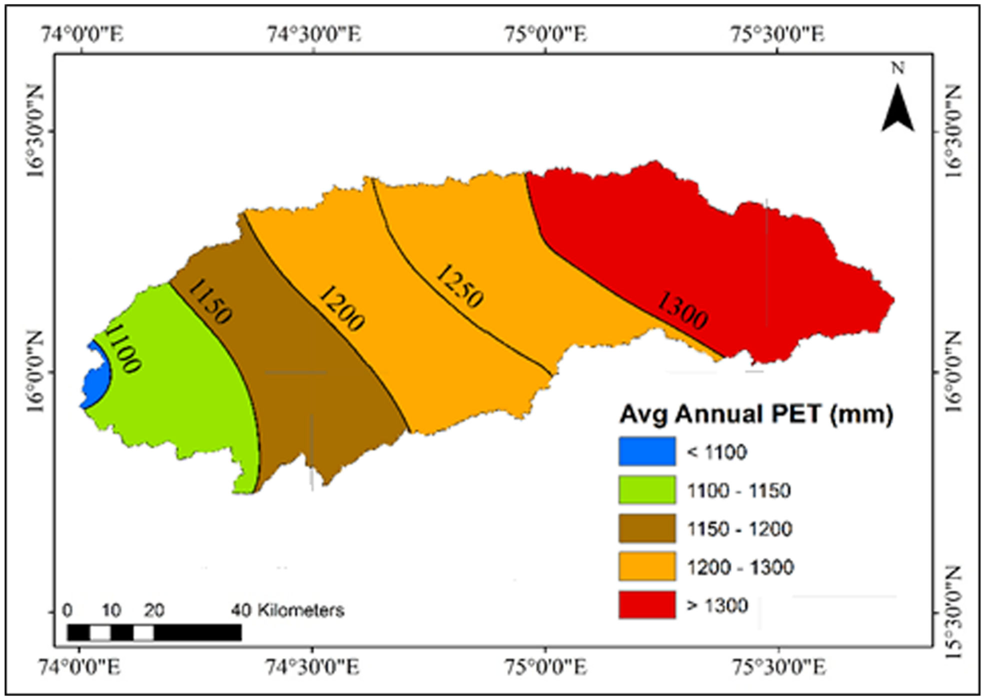

Fig. 5 Average annual PET of the basin

mean temperature and annual PET for all the stations and statistics were tabulated in Table 2 along with the values of aridity index.

Out of all stations, increasing rainfall trend was observed in the four stations (A1, A2, B3 and C2) of humid region, three stations (A4, B4, and D3) of sub-humid region and five stations (B6, B7, C5, D4, and D5) of semiarid region with the average increase of 46.4, 35.33 and 18.94 mm per decade, respectively. Whereas negative rainfall trends were conveyed by three stations (A3, B2, C1) of humid region, eight stations (B5, B8, C4, C6, C7, C8, D6, D7) of semiarid region and one station (C3) of sub-humid region with the average decrease of 35.1, 14.126 and 45.6 mm per decade, respectively. The station B1 of the humid region had no trend in precipitation. From overall rainfall trend analysis, it was noted that 60% of the stations in the semiarid region, 37% of the stations in the humid region and 25% of the stations in the sub-humid region showed negative rainfall trend but no stations passed the significance test at 95% confidence.

A significant increasing trend in annual mean temperature was observed for all the stations of the basin with an average magnitude of 0.2^0 C per decade, and a significant negative trend was observed in one station (A4). Along with the annual mean temperature, annual PET trends were also increasing for all the stations, however significant increasing trends were noted in the two stations (A1, A2) of humid region and four stations (B7, B8, C8, D7) of semiarid region with the average magnitude of 6 mm per decade. The maximum number of stations in the semiarid region exhibited a decreasing trend in precipitation and an increasing trend in PET, indicating that the region will be more vulnerable to severe drought in the future. For a better understanding of drought characteristics in different regions, SPI, SPEI, and RDI for different time scales (3,6 and 12 month) are analyzed for all the stations of each climatic regions. Since it is difficult to represent the results of all the stations of the basin, one station from each climatic region was selected and results are presented with different drought indices with a multi-temporal scale. However, for comparison and representation, station B2, B4, and C7 are considered from humid, sub humid and semiarid region, respectively.

4.2 Characteristics of Different Drought Indices

Meteorological drought in the study area was assessed by considering three drought indices namely SPI, RDI, and SPEI. These indices follow a similar calculation procedure by considering rainfall for SPI and both rainfall and PET for calculation of RDI and SPEI. Analysis of drought indices with various times scales will picturize the influence of drought on different sectors of water resources. Drought at smaller time scales (3, 6 months) will have an impact on seasonal crop failure and soil moisture; while a higher time scale (12, 24 and 48 months) will affect the reservoir levels, streamflow and groundwater levels. In this study SPI, RDI and SPEI were calculated for all the stations and for various time scales (3, 6 and 12 month). However, for representation and comparison purposes B2, B4 and C7 stations are considered from humid, sub humid and semiarid regions, respectively.

A significant number of droughts were observed from all the indices for various time scales. Temporal variation of SPI,

Table 2 Rainfall and temperature trends of the weather stations and their magnitudes with the aridity index

Station ID	Precipitation Trend		Temperature Trend		PET Trend		Aridity Index	Type of Climate
	Z	Sen-slope	Z	Sen-slope	Z	Sen-slope		
A1	0.35	4.45	**5.41**	0.02	**1.97**	0.48	3.43	Humid
A2	0.64	10.14	**5.45**	0.02	**1.99**	0.42	2.44	Humid
A3	−1.14	−3.73	**5.03**	0.02	1.65	0.36	1.00	Humid
A4	1.91	5.49	**−2.17**	−0.04	1.55	0.39	0.61	Sub humid
B1	0.00	0.04	**5.47**	0.02	1.85	0.45	1.68	Humid
B2	−0.31	−2.24	**5.33**	0.02	1.87	0.39	1.74	Humid
B3	0.08	0.28	**5.07**	0.02	1.45	0.37	0.81	Humid
B4	1.83	1.97	**5.03**	0.02	1.41	0.38	0.57	Sub humid
B5	−0.30	−2.89	**5.02**	0.02	1.63	0.45	0.46	Semiarid
B6	1.39	3.14	**5.01**	0.02	1.85	0.51	0.45	Semiarid
B7	1.32	2.91	**4.72**	0.02	**2.30**	0.63	0.47	Semiarid
B8	−0.27	−0.82	**4.89**	0.02	**2.66**	0.73	0.47	Semiarid
C1	−0.86	−4.56	**5.35**	0.02	1.35	0.32	1.48	Humid
C2	1.28	3.69	**5.01**	0.02	1.28	0.34	0.88	Humid
C3	−1.65	−4.56	**5.03**	0.02	1.28	0.37	0.60	Sub humid
C4	−0.13	−0.27	**4.93**	0.02	1.26	0.39	0.43	Semiarid
C5	0.01	0.03	**4.78**	0.02	1.53	0.49	0.42	Semiarid
C6	−0.43	−1.02	**4.84**	0.02	1.75	0.61	0.42	Semiarid
C7	−0.62	−1.31	**4.72**	0.02	1.93	0.60	0.45	Semiarid
C8	−1.12	−3.13	**4.66**	0.02	**2.32**	0.73	0.43	Semiarid
D3	1.51	3.14	**5.01**	0.02	1.26	0.38	0.51	Sub humid
D4	0.54	1.04	**4.95**	0.02	1.43	0.39	0.43	Semiarid
D5	1.08	2.35	**4.82**	0.02	1.69	0.54	0.44	Semiarid
D6	−0.60	−1.04	**4.89**	0.02	1.81	0.59	0.44	Semiarid
D7	−0.23	−0.82	**4.84**	0.02	**2.15**	0.59	0.41	Semiarid

Bold values indicate significant trend at 95% confidence level

RDI, and SPEI for a 3-month time scale are depicted in Fig. 6 and major drought episodes were observed in the years of 1971–72, 1982–83, 2002–2003 and in 2012. SPI of 3-month time scale, identified 2, 6, 11 number of extreme droughts in the humid, sub humid and in the semiarid stations, respectively. It was also noted that the stations B2, B4, and C7 are under extreme drought during the years 1994 (Jun), 2003 (Jun-Sep) and in 2012 (May-Jun). Results of the 3-month SPEI identified the highest number of extreme droughts in the semiarid station (9 times) as compared to sub-humid (2 times) and humid station (8 times).

In the humid station, severe drought condition was observed through RDI with the duration of seven months (July 1971 to January 1972) and severity of 10.87 with the average intensity of −1.55. In the sub-humid station, SPEI captured critical drought with the severity of 10.30 and duration of 6 month (July-71 to December-71) with the average intensity of −1.71. Similarly, RDI identified severe drought in the semiarid station with a duration of five months (August 90 to December 90) and severity of 10.48 with the average intensity of −2.328.

Drought characteristics for 3- month SPI (Table 3) revealed that the humid station experiences 70 drought months among them, 32 months with 7 drought episodes were having duration ≥3 months. Similarly, in the sub humid and in the semiarid station 17 and 29 months out of 57 and 65 months of drought duration lasts equal or more than 3 months, respectively. Details of drought characteristics of 3 month SPI, RDI, and SPEI at each climatic station are presented in Table 3.

Characteristics of SPI, RDI, and SPEI are susceptible to vary with the timescales. Smaller time scale (3 month) possess shorter drought duration and the higher number of drought episodes, with the instant shift of severity from dry condition to wet condition and the other way around, however, droughts of higher (12 month) time scale indicates fewer drought episodes with higher duration. The effect of variation of time scale on SPEI characteristics is portrayed in Table 4, and it was noted that there is no much difference between drought

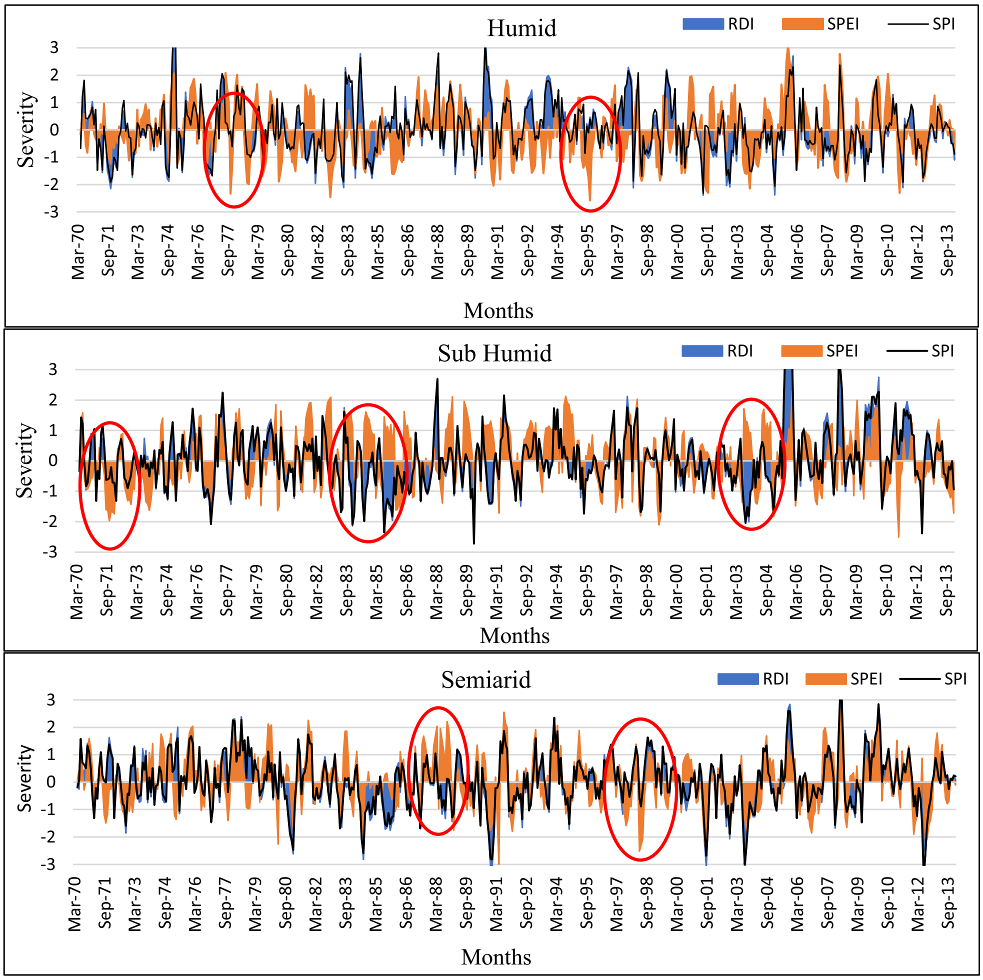

Fig. 6 Temporal variation of drought severity for selected stations of the basin

durations of SPEI for the humid station with the change in the timescale. While in the sub humid and semiarid station, drought duration increases significantly with the time scale, and the corresponding decrease in drought episodes can be observed. Similar variations are noted for SPI and RDI also.

Drought characteristics as revealed through SPEI indicates that the drought duration and severity are well correlated and as the duration of drought increases severity will also increase (Fig. 7). SPI and RDI also possessed a similar relation between duration and severity. An empirical relationship between drought duration and severity was developed for all the three indices of each station and presented in Table 5. The negligible numeric difference was observed between the coefficients of the equations of SPEI and RDI in the humid

Table 3 Drought characteristics of SPI, RDI and SPEI

Station	Index		Drought with duration ≥3 months		
		Total Duration (months)	Duration (months)	No. of Drought Events	Severity
B2	SPI	70	32	7	43.78
	RDI	80	30	7	45.47
	SPEI	107	67	17	102.98
B4	SPI	57	17	4	26.47
	RDI	66	19	4	28.90
	SPEI	79	35	9	51.06
C7	SPI	65	29	7	55.94
	RDI	83	43	10	75.35
	SPEI	80	44	12	66.51

Table 4 SPEI drought characteristics with different time scale

Time scale	Climatic Stations								
	B2			B4			C7		
	Duration (months)	Episodes	Average severity	Duration (months)	Episodes	Average severity	Duration (months)	Episodes	Average severity
3	107	48	3.3	79	41	2.6	80	41	2.8
6	108	34	4.6	86	33	3.12	87	30	4.12
12	109	18	9.01	93	14	12.35	101	16	8.79

station, whereas in the semiarid station, SPEI and SPI produced a similar equation for the relationship between severity and duration.

The numerical difference between coefficients of the equations, which explains drought severity and duration of SPEI index for all stations is low. From this, a single equation that describes the relationship between drought duration and severity of SPEI for the whole basin was deduced and presented in the following eq.

$$Y = 1.56X - 0.38$$

Where Y is drought severity and X is the duration of drought. These equations will help to estimate drought severity directly based on drought duration for different time scales and it will also help to prepare drought mitigation and preparedness strategies for the area.

4.3 Comparison of SPI, RDI, and SPEI at Various Climatic Regions

Similar behaviour of RDI and SPI was observed in all the stations and SPEI follows a similar pattern of SPI (RDI) in the semiarid station (C7), but a significant difference in the intensity can be observed (Fig. 6). In the humid and sub-humid station (B2 and B4), the behaviour of SPEI differed from SPI (RDI). In the humid station (Fig. 6), RDI and SPI represent mild wet conditions in the months of July, August and September of 1995 while, SPEI remarked severe drought in the period. Similarly, several discrepancies (highlighted with a circle) between SPEI and RDI (SPI) can be noted for other two stations also. Comparison of drought characteristics of the drought indices exposed that SPI and RDI were showing similar drought duration (≥3 months) and severity in humid and sub-humid stations (Table 3). The highest number of droughts were identified by SPEI for all the stations.

Spatial variation of 3-month SPI, RDI and SPEI denote the propagation of drought severity and its withdrawal for the months of October, November, December of the year 1980 and January 1981 (Fig. 8). Severe drought was observed by SPI and RDI in the semiarid region during the month of October. Whereas SPEI demarcated mild drought in the semiarid and trace of severe drought in the humid region.

In the month of November, SPEI picturized moderate drought in the semiarid region and in the portions of the humid region. Severe drought along with the trace of extreme drought was observed through SPI and RDI in the semiarid region. Severe and extreme droughts identified by SPI and RDI were further creeps into the basins covering most of the semiarid region in the month of December. Whereas SPEI possesses moderate and severe drought in humid and semiarid regions, respectively. SPI captures the initiation of drought recovery in the humid region in the month of December. During January, SPI and RDI showed most of the basin recovered from drought except, mild drought in the small portion of the semiarid region while SPEI possesses

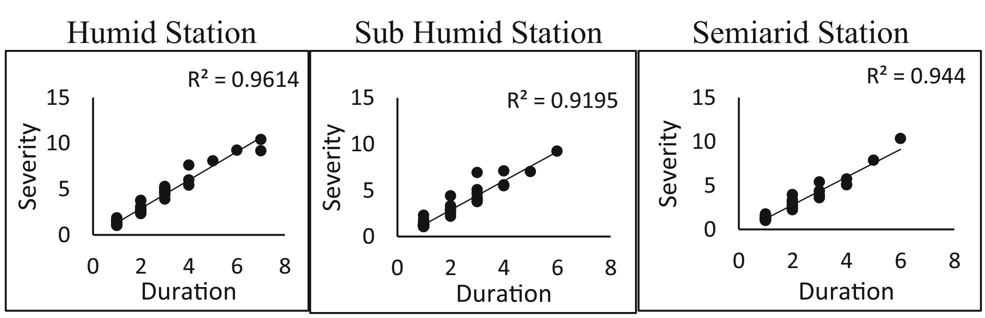

Fig. 7 Relationship between drought duration and severity for SPEI index for representative stations of each climatic region

Table 5 Empirical relationship between drought severity and duration

Climatic Station	Index	Equation
Humid	SPI	Y=1.40X-0.29
	RDI	Y=1.54X-0.37
	SPEI	Y=1.56X-0.34
Sub Humid	SPI	Y=1.60X-0.34
	RDI	Y=1.62X-0.51
	SPEI	Y=1.56X-0.34
Semiarid	SPI	Y=1.58X-0.73
	RDI	Y=1.91X-0.93
	SPEI	Y=1.55X-0.45

mild drought in the semiarid and humid region. Spatial analysis of SPI, RDI, and SPEI at various climatic regions reveals that the semiarid region suffers severe and extreme drought events regularly whereas the sub-humid region exposed the least number of severe drought events. The value of SPEI significantly differed from SPI and RDI in both severity and area coverage. This is because the variation of P, P/PET, and P-PET behave differently in the different regions and calculation of PET will also play a crucial role in the variation of SPEI and RDI ((Beguería et al. 2014; Mohammed and Scholz 2017). These results convey that, even though SPEI and RDI consider the same inputs and follow the same procedure of calculation, a remarkable

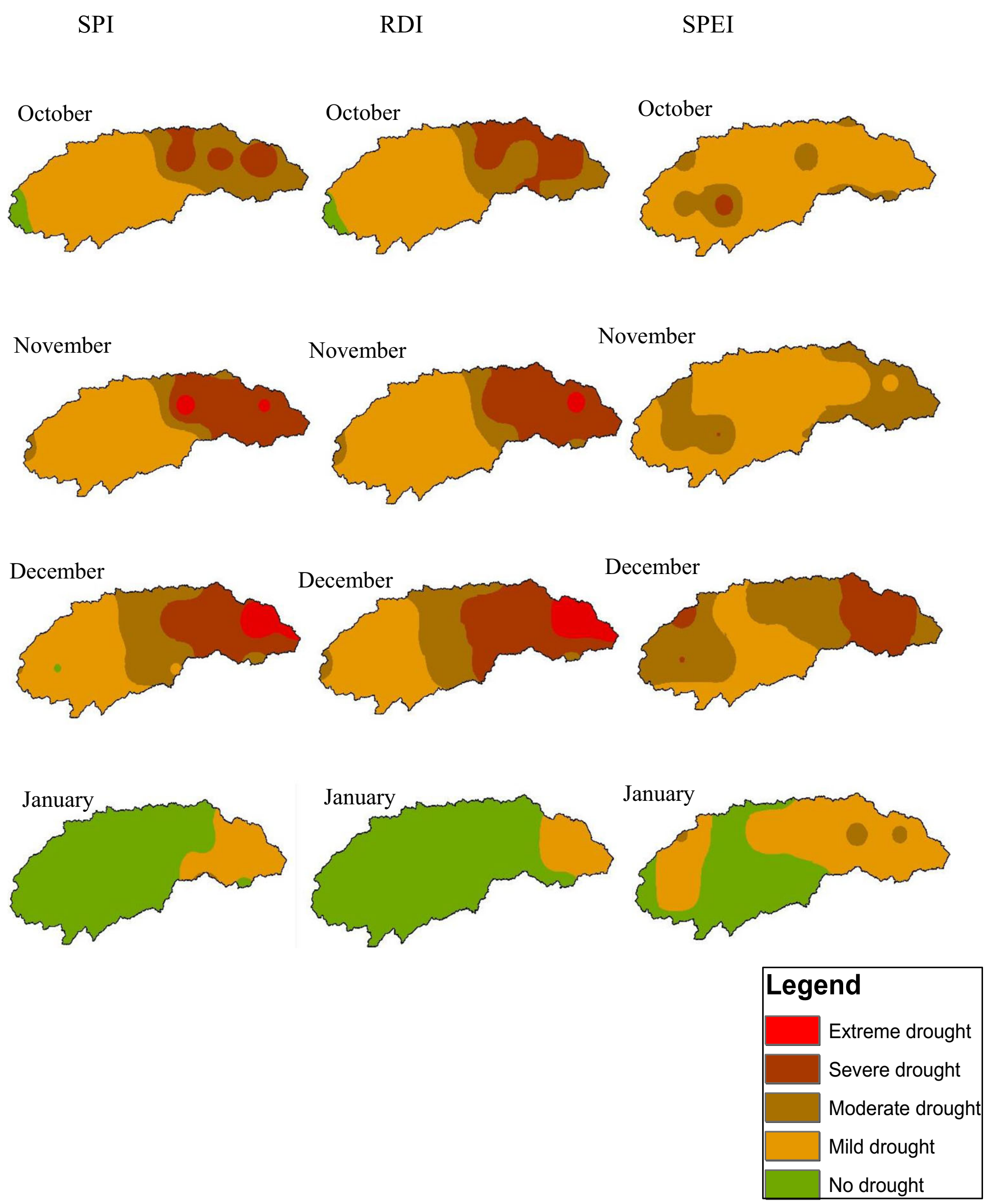

Fig. 8 Spatial variation of drought severity over the basin for the selected months of year 1980–1981

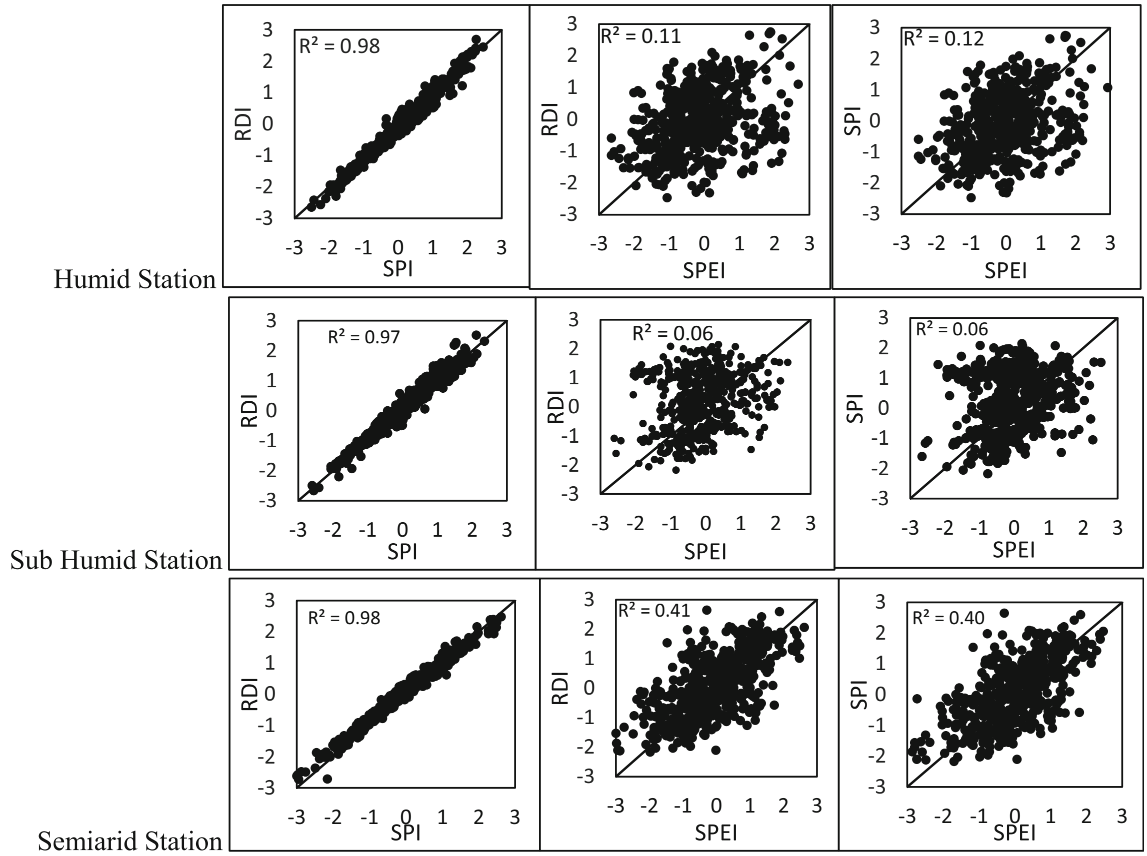

Fig. 9 Scatter plots between drought indices for representative stations of each climatic region

difference among these indices can be observed both in spatial and temporal scale.

The comparison between SPI, RDI, and SPEI was further analyzed with the Pearson correlation coefficient and graphical approach. The Correlation Coefficient (CC) between SPI and RDI is very high for all the time scales and for all the stations (Table 5). In the semiarid station CC between SPI and RDI with SPEI varies from 0.51 to 0.6 while in the humid and sub-humid station poor CC was observed. A high correlation between SPI and RDI and poor correlation of SPI (RDI) with SPEI may be due to the fitting of predefined two-parameter Gamma distribution to the inputs of SPI and RDI whereas three-parameter Log-Logistic distribution to the input of SPEI.

Scatter plots of SPI vs RDI, SPI vs SPEI and RDI vs SPEI are presented in Fig. 9 for different time scales for all the stations. A strong linear relationship between SPI and RDI was observed for all the stations and R2 value between the indices increases with increases in the time scale. Similar results were also reported by Xu et al. (2015) in China. There was no exact relationship observed among SPI (RDI) and SPEI in the humid and sub-humid station, however, scatter between SPI (RDI) and SPEI is less in the semiarid region as compared to the humid and sub-humid region. This may be due to the reason that the RDI responds more to rainfall while SPEI gives equal weightage to both precipitation and PET (Vicente-Serrano et al. 2015).

Frequencies of different dry and wet classes for each time scale are presented in Fig. 10 in terms of percentage of months. RDI exhibited the highest number of extreme droughts in the semiarid and subhumid region whereas SPEI and RDI presented the highest no of severe droughts in semiarid and humid (sub-humid) station, respectively. It was noted that as time scale increases, the number of extreme droughts identified by RDI and SPEI is also increasing in the semiarid and humid station. Whereas it is the fact that as the time scale of analysis increases, the frequency of extreme drought decreases (Thomas et al. 2016). As per the above observation SPEI and RDI were giving contradictory results in humid and semiarid stations, respectively. The humid region is characterized by more rainfall whereas PET will be dominating in the semiarid region. The RDI was inclined more towards rainfall and Coefficient of Variation (CV) of rainfall (0.47) of the humid station is higher than that of the semiarid station (0.33). The semiarid region was characterized by high PET as compared to that of the humid region and SPEI was equally governed by PET, therefore, it is advocated to use SPEI in the semiarid region whereas RDI or SPI in the humid and sub-humid region to get reliable results.

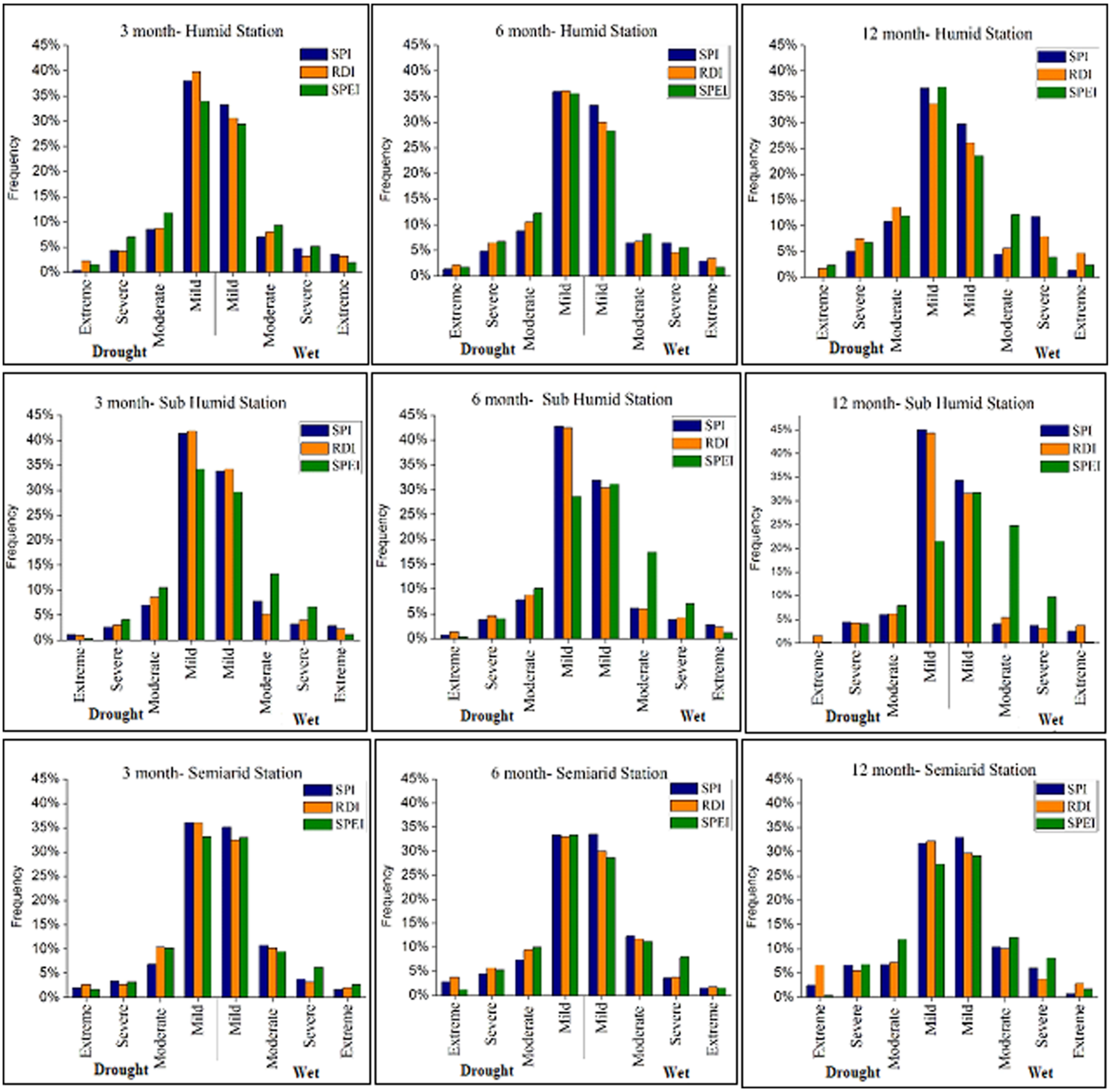

Fig. 10 Frequencies of SPI, RDI and SPEI in each category of wet and drought in terms of percentage of months

5 Conclusions

The Mann-Kendell and Sens's slope tests were applied to evaluate trends in the rainfall, temperature, and PET over the Ghataprabha river basin. Popularly used meteorological drought indices were incorporated to study the variation of drought pattern for 3, 6 and 12-month time scale over the study area. Further spatiotemporal drought characteristics obtained from SPI, RDI and SPEI for selected stations of all the climatic zones were compared.

- Trend analysis of meteorological variables revealed a decreasing trend in the rainfall, and a significant increasing trend in temperature for all the stations of the basin, which indicates that the basin may undergo high severe droughts in the future.
- RDI and SPI are performing similarly for all the stations. In the humid and sub-humid stations, the behavior of SPEI diverged from RDI and SPI whereas it follows a similar pattern of SPI and RDI in the semiarid station

- Even though SPEI and RDI consider the same inputs and follow the same procedure of calculation, a remarkable difference among these indices can be observed both in spatial and temporal scale. The high correlation between SPI and RDI for all the stations and for all the time scales emphasizes the tendency of RDI towards rainfall.
- SPI or RDI could be considered in the humid region where it experiences high rainfall. However, SPEI can be utilized to capture drought characteristics effectively in the semi-arid region, where it was characterized by high PET.
- This study recommends to use suitable distributions for calculation of drought indices and examine their sensitivity towards the climatic variables which takes a critical part in establishing the drought condition for an area. Since each region associated with its own climatic condition and spatial variability of anthropogenic activity, the response of drought will be different from region to region. Thus, the study suggests to investigate the suitability of drought indices for a region before formulating the preparedness strategies.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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