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ORIGINAL PAPER

Modified version for SPEI to evaluate and modeling the agricultural drought severity

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Abstract
Drought is a climatic phenomenon that can occur in various regions with different climate conditions. Generally, drought has negative impacts on different fields such as environment, rangelands, and water resources. The agricultural section (especially rain-fed agriculture) is one of the parts that is directly affected by different types of drought especially meteorological and agricultural droughts. The standardized precipitation evapotranspiration index (SPEI) is one of the newest and most applied indices to assess drought characteristics. In this paper, a modification is suggested for SPEI with the substitution of observed precipitation (OP) with effective precipitation (EP) to evaluate drought, with an emphasis on consideration of drought effects on agricultural section. To calculate EP, Food and Agriculture Organization of the united nation method (FAO), US Bureau of Reclamation (USBR), the Simplified version of Soil Conservation Service of the US Department of Agriculture method (USDA-SCS simplified), and the CROPWAT version of USDA-SCS method (USDA-SCS CROPWAT) were used. To compare the calculated SPEI based on OP (SPEIOP) and EP (SPEIEP) (based on different EP calculation methods), the correlation coefficients (CC) between SPEIOP and SPEIEP in four synoptic stations with at least 30 years of climatic data and annual yield loss (%) in winter wheat (*Triticum sativum*) (simulated using AquaCrop model) in the suitable reference periods for agricultural drought were used. Results showed, in Fasa, Drodzan, and Zarghan stations, the CC between SPEI based on EP using the USBR method (SPEIUSBR) and annual Y_L% had the highest values (in 42.11%, 68.42%, and 36.84% of *Triticum sativum* all reference periods, respectively). In Shiraz station, the CC between SPEI based on EP using the FAO method (SPEIFAO) and annual Y_L% had the highest values (in 47.37% of all reference periods). In all stations, the SPEIUSBR had the most reference periods with significant CC at 0.05 or 0.01 levels.

Keywords SPEI · Effective precipitation · Agricultural drought · USBR USDA-SCS simplified · USDA-SCS CROPWAT

Introduction

Drought is one of the most harmful environmental phenomena with a devastating impact on agricultural activities, human life, surface and underground water resources, wildlife, rangeland plants, environmental programs, and socio-economic sections (Zarei 2018; Sisi et al. 2018; Rezaei Banafsheh et al. 2015; Zamaniyan et al. 2012). Drought happens during a period of water deficit in a region due to low precipitation, high evapotranspiration, high groundwater derivation, or a mixture of the mentioned factors (Zarei and Mahmoudi 2017; Zamaniyan et al. 2012). Therefore, the evaluation of drought and its characteristics can play a focal role in managing this phenomenon and eliminating its negative impacts. For this purpose, in the recent decades, drought indices have implemented study (such as Standardized precipitation index (SPI), China Z index (CZI), Reconnaissance Drought Index (RDI), standardized precipitation evapotranspiration index (SPEI), and other drought indices) to assess drought severity, frequency of occurrence, and some characteristics (Liyan et al. 2018; Prabnakorn et al. 2018; Zarei and

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Moghimi 2017; Vicente-Serrano et al. 2010; Tsakiris et al. 2007; McKee et al. 1993).

SPEI that was introduced by Vicente-Serrano et al. (2010) is one of the indices that has attracted many researchers in recent years. Wable et al. (2018) compared the RDI, SPEI, SPI, and two other drought indices using the decision criteria such as Robustness, Tractability, Transparency, Sophistication, and extendability in western India. The results of this paper showed that SPEI is the most suitable drought index for monitoring drought conditions. Adnan et al. (2018) compared 15 various drought indices in Pakistan. The result of this research indicated the SPI, SPEI, and RDI have had a good capability to monitor drought status in Pakistan. Liu et al. (2018) used SPEI to assess impacts of drought on the crop yield in the North China plain. Results of this paper showed that the correlation between agricultural crop yields and the SPEI time series increased in the winter wheat growth stage.

Zuo et al. (2018) evaluated the spatiotemporal patterns of drought in the Shandong Province of Eastern China using SPEI. According to their findings, a significant decreasing trend in the SPEI at the coastal stations for all the time scales was detected. Haro-Monteagudo et al. (2017) used SPI, SPEI, and PDSI to evaluate the utility of drought indices in measuring climate risks in agricultural productivity. Results indicated that the seasonal SPEI (3 months) was found to be the most suitable one in monitoring water availability and drought conditions.

Tajbakhsh et al. (2015) evaluated meteorological drought in Iran using SPEI. Accordingly, due to a considerable decrease in temperature in winter, the effect of evapotranspiration may not be significant. During spring, summer, and autumn, the effect of evapotranspiration is influenced heavily on precipitation in most provinces, especially the southern provinces of Iran. Gidey et al. (2018) used vegetation health index (VHI) to assess the long-term agricultural drought onset in northern Ethiopia. The results of this paper showed, when rainfall increases, that VHI tends to increase. So, the event of agricultural drought diminished. The review of drought condition using SPEI can be found in several manuscripts such as Jia et al. (2018), Liyan et al. (2018), Mathieu and Aires (2018), Peng et al. (2018), Soh et al. (2018), Virgílio et al. (2018), Xu et al. (2018) Garcia et al. (2017), Zare Abyaneh et al. (2015), Beguería et al. (2014), and Vicente-Serrano et al. (2012).

Tigkas et al. (2018) introduced a modified version for SPI named the Agricultural Standardized Precipitation Index (aSPI). In aSPI, the observed precipitation is replaced by the effective precipitation (Tigkas et al. 2018). The assessment of the correlation coefficients between SPI and aSPI and crop yield response in four regions of the study area in this paper under Mediterranean conditions showed that aSPI is more robust in identifying agricultural drought. Tigkas et al. (2016) presented a modified version for Reconnaissance Drought Index (RDIe). In RDIe, the observed precipitation is replaced by the effective precipitation. According to the results, modified RDI in an area with agricultural activities has better performance in studying the impacts of drought.

The aim of the present study is to introduce a new version of SPEI to assess agricultural drought based on the replacement of the OP with the EP. In the next stage, the accuracy of the modified SPEI (based on EP) will be evaluated in comparison with the original SPEI (based on OP).

Material and methods

Study area

Fars province is located between latitude 27° 05′ to 31° 55′ N and longitude 50° 07′ to 55° 54′ E, including 28 cities with a total area of about 125,000 km^2 (Fig. 1). It is located in the southwest of Iran with an average elevation about 2015 m from the sea level, the average annual precipitation of the study area is near to 340 mm/year and the average mean annual temperature of the study region is around 18 °C. The climate conditions of this area based on modified De-Martonne index (De Martonne 1926; Zareiee 2014; Aguirre et al. 2018; Zarei et al. 2019) is mainly arid and semi-arid. The main cultivated crops in this region are winter wheat and winter barley. The study area includes more than 120 hydrological unit with a negative groundwater bill in most of these plains (discharge from groundwater is more than recharge). In this paper, meteorological data of four synoptic stations with suitable time duration (least 30 years) were used to calculate original SPEI and modified SPEI. Some of the climatic characteristics and geographical positions of selected synoptic stations are presented in Table 1.

Methodology

Data collection and potential evapotranspiration (PET) calculation

In this study, meteorological data of Fasa and Shiraz synoptic stations from 1967 to 2017 and Drodzan and Zarghan synoptic stations from 1988 to 2017 collected from Iran Meteorological Organization (IMO) were used. Before using the data, missing values of meteorological data in all stations were estimated via the normal ratio method (Mahdavi 2002), suitability of time duration in all stations was evaluated using Mockus method (Eq. 1) and the homogeneity of data series in all stations was assessed using the double mass curve method (Mahdavi 2002).

$$N = (4.3\, t \times \mathrm{Log}\, R)^2 + 6 \quad (1)$$

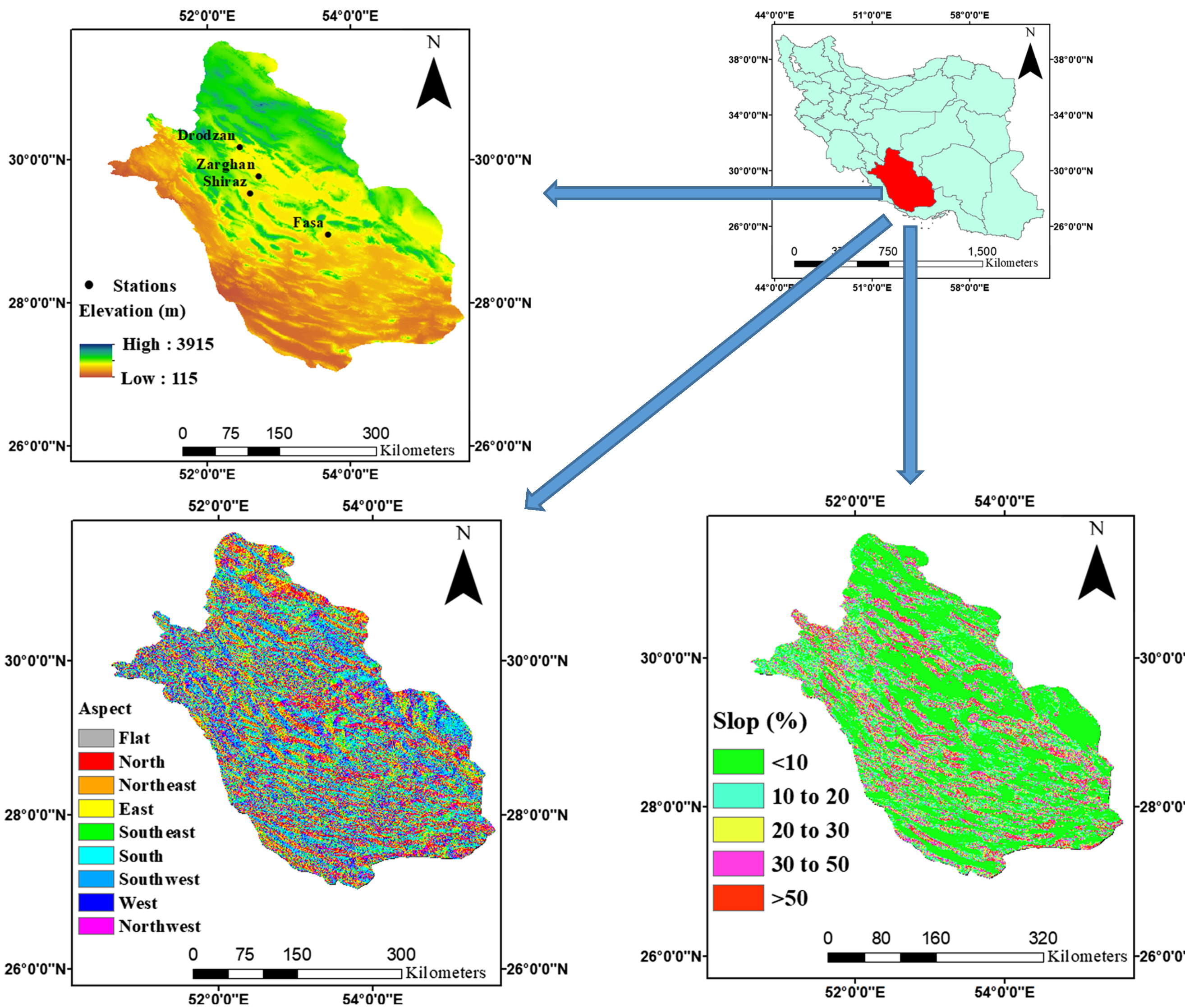


Fig. 1 Digital elevation map (DEM), slop map and aspect map of the study area and geographical position of the selected synoptic stations

where N is the minimum necessary data series duration; t is the t student with the freedom degree of n-6; and R is the ratio of return period parameter of 100 to 2 years.

To calculate the potential evapotranspiration (PET) parameter, FAO Penman-Monteith (FAO-56) equation (Eq. 2) and CROPWAT 8 software were used (Allen et al. 1998; Ahani et al. 2012; Zarei et al. 2015).

$$\mathrm{PET} = \frac{0.408\,\Delta(R_n - G) + \gamma \dfrac{900}{T+273} U_2.VPD}{\Delta + \gamma(1 + 0.34U_2)} \tag{2}$$

where PET is the potential evapotranspiration; Δ is the

Table 1 Geographical location and meteorological characteristics of the selected synoptic stations

Stations name	Latitude	Longitude	Elevation (m a.s.l)	Average precipitation (mm/year)	Average temperature (C)	Average potential evapotranspiration (mm/year)	Climate condition	Time duration
Fasa	28.97	53.68	1288.32	288.98	19.39	1732.48	Arid	1967–2017
Shiraz	29.53	52.60	1483.69	320.63	18.22	1781.94	Semi-arid	1967–2017
Zarghan	29.78	52.72	1596.12	305.99	16.39	1561.79	Semi-arid	1988–2017
Drodzan	30.18	52.45	1652.22	458.18	17.62	1805.41	Semi-arid	1988–2017

Climate condition estimated based on modified De- Martonne index (De Martonne 1926; Aguirre et al. 2018) slope of the saturation vapor pressure function; R_n is the net radiation; G is the soil heat flux density; γ is the psychometric constant; T is the mean air temperature; U_2 is the average 24-h wind speed at 2-m height; and VPD is the vapor pressure deficit.

Effective precipitation (EP) calculation methods

In regard to the aims of researchers, different definitions are available for EP. For example, the hydrology science entry for EP is the percentage of precipitation that becomes a runoff (Mahdavi 2002); in agricultural science, the entry says the percentage of rainfall that can be used productively by the plants (Tigkas et al. 2016, 2018). In this research, we focus on the approach of EP in the fields of water consumptive use in plant development (EP in agricultural science). Many different methods are introduced to estimate EP indicator such as evaluating EP using weighted lysimeters, monitoring of soil moisture in the root zone of plants, and using empirical methods. (Tigkas et al. 2018; Ebrahimpour et al. 2014). Regarding the fact that necessary data for non-empirical methods were not available to calculate EP, empirical methods include the FAO method, USBR method, USDA-SCS simplified method, and USDA-SCS CROPWAT method were used in this study.

FAO method Using the FAO method, EP can be measured on a monthly time scale. In this method, for months with the amount of precipitation less than 70 mm/month, Eq. 3 and for months with the amount of precipitation equal or more than 70 mm/month, Eq. 4 was used to calculate EP (Tigkas et al. 2018; Tigkas et al. 2016; Brouwer and Heibloem 1986):

$$EP = 0.6\,R - 10 \tag{3}$$

$$EP = 0.8\,R - 25 \tag{4}$$

where EP is the effective precipitation and R is the monthly precipitation.

USBR method The USBR method introduced by the US Bureau of Reclamation and recommended to use for arid and semi-arid regions (Tigkas et al. 2018; Stamm 1967). The range of the effective precipitation based on the USBR method is presented in Table 2.

USDA-SCS simplified and USDA-SCS CROPWAT methods These methods were developed by the Soil Conservation Service of the US Department of Agriculture (USDA-SCS) and recommended for arid and semi-arid regions (Tigkas et al. 2018; Kourgialas et al. 2015; Hess 2010; USDA 1970). EP based on the USDA-SCS simplified method calculating via Eq. 5:

$$EP = 1.9443\,R^{0.82416} - 4.56 \tag{5}$$

EP based on the USDA-SCS CROPWAT method is calculated by Eqs. 6 and 7. Equation 6 is applicable for months with the amount of precipitation equal or less than 250 mm/month and Eq. 7 is applicable for months with the amount of precipitation more than 250 mm/month:

$$EP = \frac{R\,(125 - 0.2\,R)}{125} \tag{6}$$

$$EP = 0.1\,R + 125 \tag{7}$$

where EP is the effective precipitation and R the is monthly precipitation.

Percentage of annual yield loss calculation

Generally, vegetation has development patterns that follow the seasonal weather variability. For evaluating the vegetation response to drought, the constant and progressively increasing reference periods including 1, 3, 6, and 12 months (reference periods in 1-month time scales were Nov, Dec, Jan, Feb, Mar, Apr, May, and Jun, in 3-month time scales were Nov to Jan, Dec to Feb, Jan to Mar, Feb to Apr, Mar to May, and Apr to Jun, in 6-month time scales were Oct to Mar, Nov to Apr, Dec to May, and Jan to Jun, in 12-month time scales were Oct to Sep in each years) was selected to assess the effect of drought severity (Tigkas et al. 2018).

In this paper, to assess the impacts of drought on agricultural productions, changes in the percentage of annual yield loss (Y_L%) in winter wheat (*Triticum sativum)* under arid and semi-arid climate conditions influenced by the severity of drought were used, Y_L% expressed as:

$$Y_L\% = \frac{Y_i - Y_p}{Y_p} \times 100 \tag{8}$$

where Y_i is the annual crop yield and Y_p is the potential yield for each year. Potential yield is the total yield of the crop

Table 2 Calculation of effective rainfall based on monthly precipitation using USBR method (Tigkas et al. 2018)

Range of monthly rainfall (mm)	Range of effective rainfall (%)	Range of effective rainfall (%) that used in this research
0 to 25.4	90 to 100	95
25.4 to 50.8	85 to 95	90
50.8 to 76.2	75 to 90	82.5
76.2 to 101.6	50 to 80	65
101.6 to 127	30 to 60	45
127 to 152.4	10 to 40	25
More than 152.4	0 to 10	5

without any environmental stresses especially stresses caused by water shortage (Sadras et al. 2015; Shirshahi et al. 2018). In this research to calculate YL% for the selected stations the water-driven simulation crop, AquaCrop model was used. The simulation was performed for the entire study period, based on P, T, and PET data of each station. In Fars province, *Triticum sativum* was planted in November and harvested in June. To provide the necessary information about *Triticum sativum* for AquaCrop model in Fars province, the results of the researches by Mousavizadeh et al. (2016), Zand-Parsa et al. (2016), Shamsnia and Pirmoradian (2013), Bahadori and Sepaskhah (2012), and Salemi et al. (2011) that calibrated AquaCrop model for winter wheat in the study area and regions with similar climate conditions were used.

Original and modified SPEI indices (SPEIOP and SPEIEP)

The standardized precipitation evapotranspiration index (SPEI) was introduced by Vicente-Serrano et al. (2010). To estimate SPEI, in the first stage, the differences between the precipitation (P_i) (in original SPEI, P_i is observed precipitation and in modified version of SPEI, P_i is effective precipitation) and potential Evapotranspiration (PET_i) for month i (D_i) was calculated and was aggregated at different time scales (D^k):

$$D_i = P_i - \mathrm{PET}_i \quad (9)$$

$$D^k = \sum_{i=0}^{k-1} P_{n-i} - \mathrm{PET}_{n-i} \quad (10)$$

In the next stage, based on L-moment procedure (because this method is the most robust and easy approach (Ahmad et al. 1988)), the probability density function of a three-parameter log-logistic distribution is applied to take the negative values of Dk into account:

$$F(x) = \frac{\lambda}{k}\left(\frac{x-\mu}{k}\right)^{\lambda-1}\left[\left(1+\frac{x-\mu}{k}\right)^{\lambda}\right]^{-2} \quad (11)$$

where k, λ, and μ are scale parameters

Finally, to calculate SPEI, the obtained values of $F(x)$ are converted into corresponding Z-standardized normal values. It is suggested to refer Vicente-Serrano et al. (2010), Jia et al. (2018), Liyan et al. (2018), Mathieu and Aires (2018), and Peng et al. (2018) for more details about SPEI. The SPEI drought classification is presented in Table 3.

Comparison of original (SPEIOP) and modified SPEI (SPEIEP) values

To compare and assess calculated SPEIOP and SPEIEP, correlation coefficients between the original and modified SPEI values and annual percentage of yield loss in each station at different reference periods (constant and progressively increasing reference periods include 1, 3, 6, and 12 months) were used. In this regard, in the first stage, the normality of data series of calculated SPEIOP and SPEIEP in all stations and all-time scales using the Kolmogorov-Smirnov test were evaluated. In the next stage, to calculate correlation coefficients between the SPEIOP and SPEIEP and annual percentage of yield loss, in normal data series and in non-normal data series, Pearson test and Spearman Rho test were utilized, respectively.

Table 3 Category of SPEI drought index values (Vicente-Serrano et al. 2010)

Category	Range of SPEI index values
Extreme wet	≥ 2
Very wet	1.5 to 1.99
Moderate wet	1 to 1.49
Normal	− 0.99 to 0.99
Moderate dry	− 1.49 to − 1
Severe dry	− 1.99 to − 1.5
Extreme dry	≤ − 2

Results and discussion

Calculated PET

Results of the calculated potential evapotranspiration (PET) (in monthly time scale) in selected synoptic stations showed that Drodzan and Zarghan stations had the highest and the least amount of the average of potential evapotranspiration (respectively). The estimated monthly PET in selected stations based on the FAO-56 equation is presented in Fig. 2.

Calculated effective precipitation (EP)

Results of the calculated EP in selected synoptic stations based on different methods of EP calculation methods showed that the monthly average of EP using the USBR method had the least amount of EP (in all stations). The monthly average of EP using the USDA-SCS CROPWAT method had the most amount of EP (in all stations). According to the results, the estimated EP based on the USDA-SCS CROPWAT method was more than the USDA-SCS simplified method and the estimated EP based on the USDA-SCS simplified method was more than the FAO method (Figs. 3 and 4 for example). It seems that differences in the amount of calculated EP using different methods of EP calculation depend on the

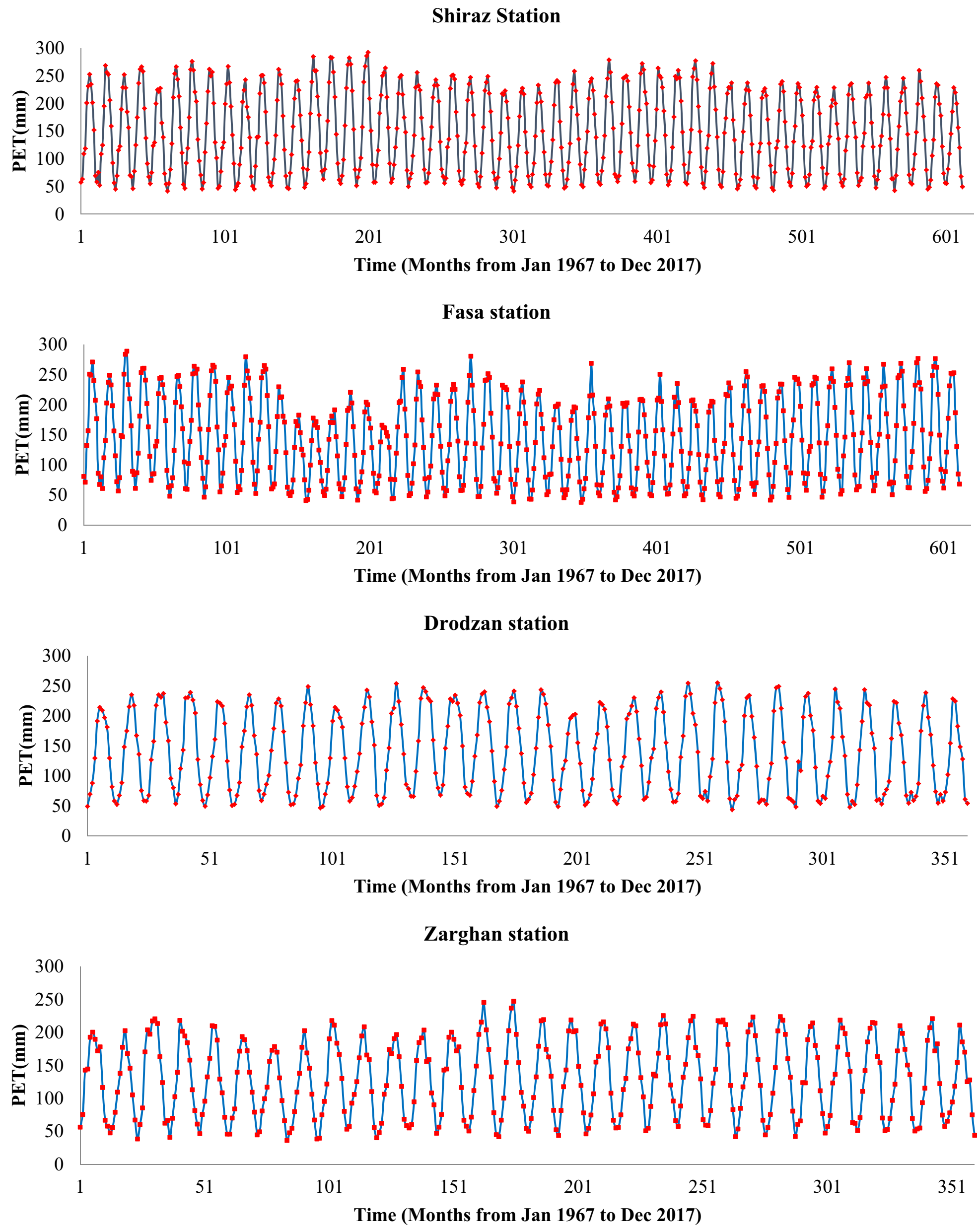


Fig. 2 Calculated monthly potential evapotranspiration (PET) in selected stations based on FAO Penman-Monteith equation

nature of the procedures and equation of methods to estimate EP.

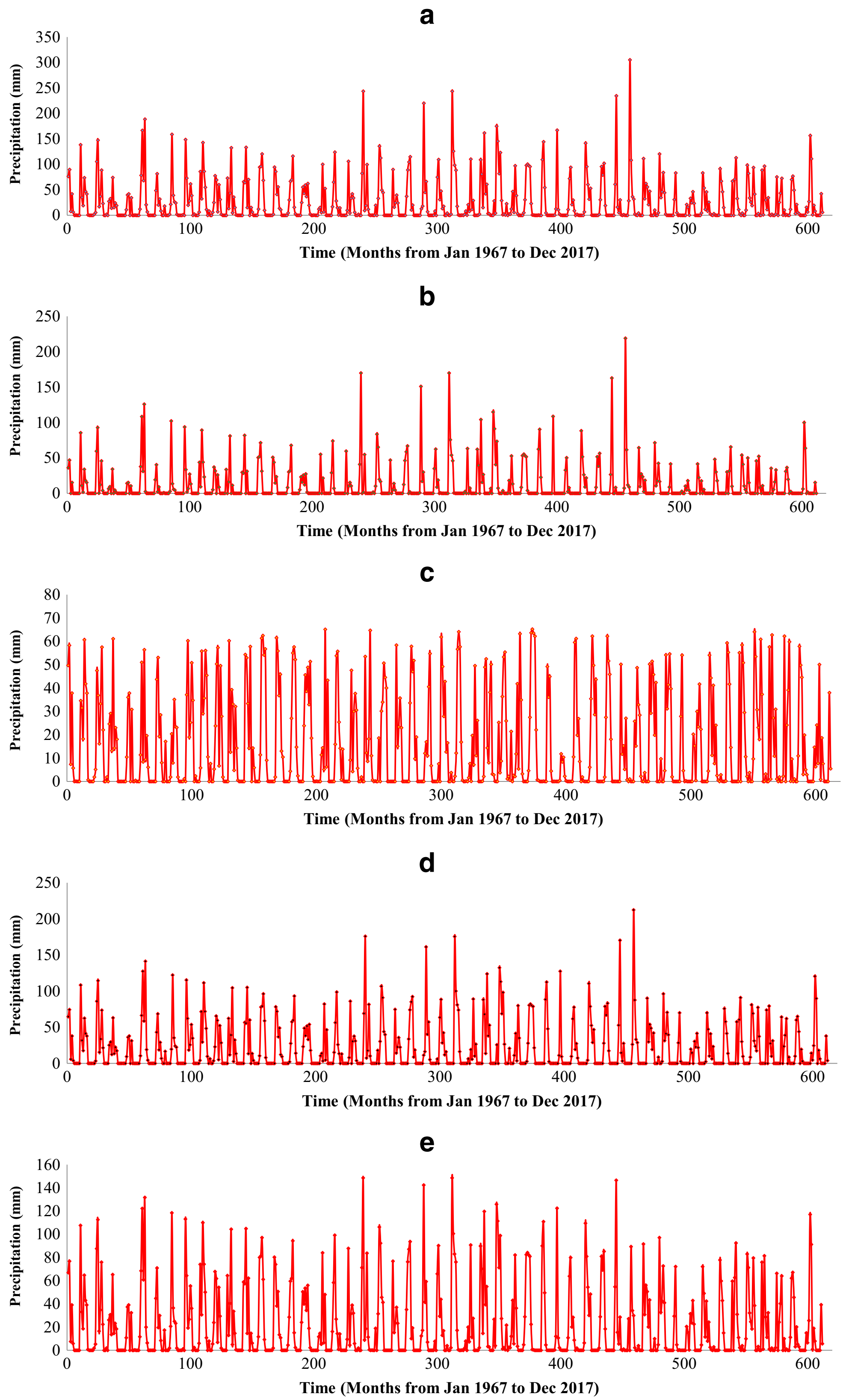
Percentage of annual yield loss (Y_L %)

Calculated percentage of annual Y_L showed that fluctuations of Y_L% affected by changes in climatic parameters in Shiraz and Fasa stations were more than Drodzan and Zarghan stations. Annual Y_L% in Shiraz station varies from 7.96 to 99.54%, in Fasa station varies from 11.42 to 93.9%, in Drodzan station varies from 0.18 to 26.44%, and in Zarghan station varies from 0.56 to 30.95%. The calculated percentage of annual yield loss in selected stations is presented in Fig. 5. Results showed that the maximum values of annual Y_L% occur in stations with less amount and inappropriate distribution of annual precipitation in growing season of winter wheat such as Fasa and Shiraz stations and the minimum values of annual Y_L% occur in stations with higher amount and appropriate distribution of annual precipitation in growing season of winter wheat such as Drodzan and Zarghan stations.

Original and modified SPEI (SPEIOP and SPEIEP)

After determining P, EP (based on different EP calculation methods) and PET in constant and progressively increasing reference periods include 1, 3, 6, and 12 months; SPEIOP and SPEIEP (based on different EP calculation methods) for all periods were calculated. Calculated

Fig. 3 Observed (OP) and calculated effective precipitation (EP) based on different effective precipitation calculation method in Shiraz stations (for example). **a** OP, **b** EP using FAO method, **c** EP using USBR method, **d** EP using USDA-SCS simplified method, and **e** EP using USDA-SCS CROPWAT method



SPEIOP and SPEIEP showed that in all stations and all-time scales normal class of drought severity had the most frequency of occurrence. According to the results, in all stations and all reference periods, the estimated values of

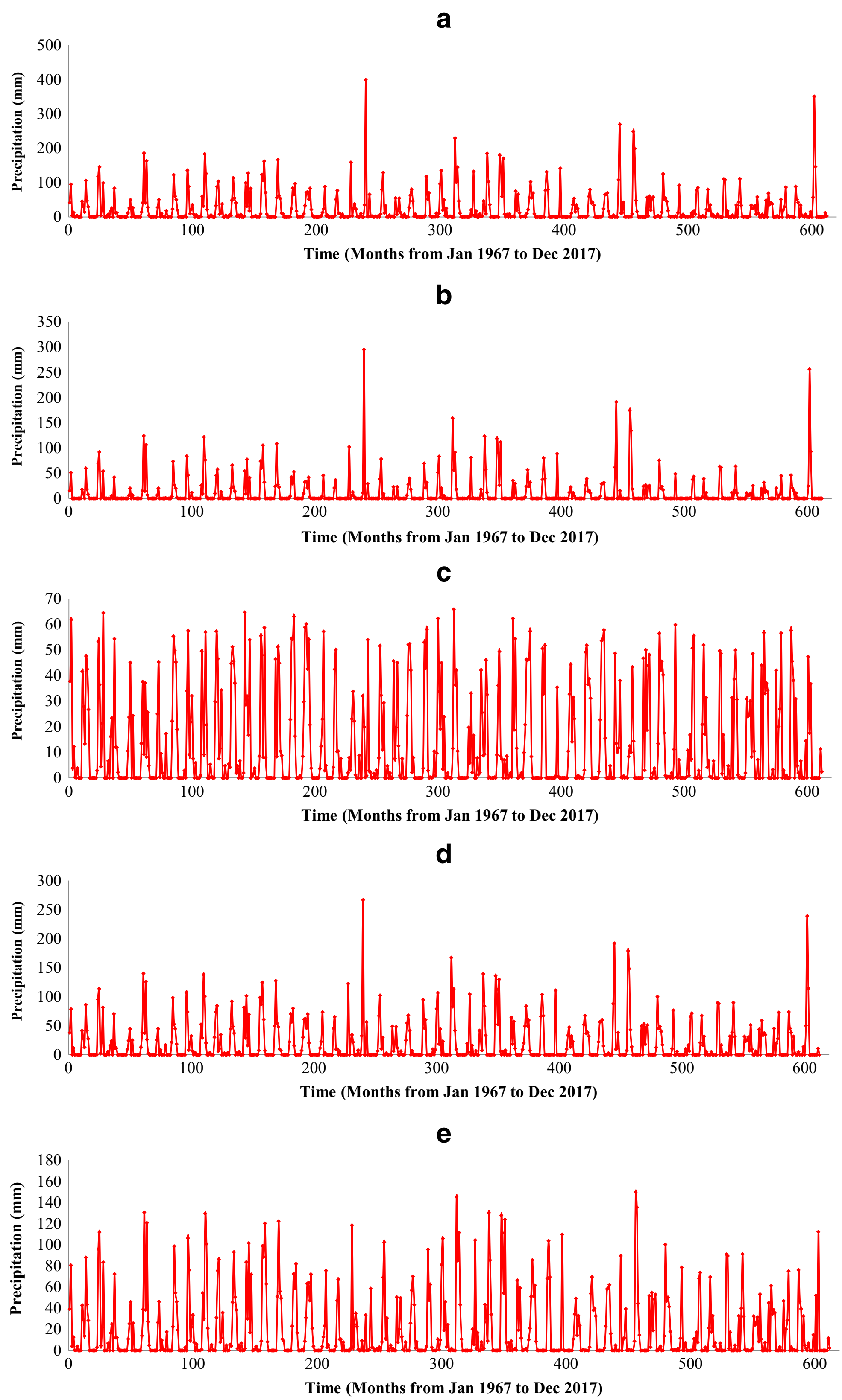


Fig. 4 Observed (OP) and calculated effective precipitation (EP) based on different effective precipitation calculation method in Fasa stations (for example). **a** OP, **b** EP using FAO method, **c** EP using USBR method, **d** EP using USDA-SCS simplified method, and **e** EP using USDA-SCS CROPWAT method

SPEI using EP based on USDA-SCS CROPWAT method (SPEIUSC) and SPEIOP were more than SPEIEP based on other methods of EP calculation (respectively). Estimated values of SPEIUSBR were the least values for

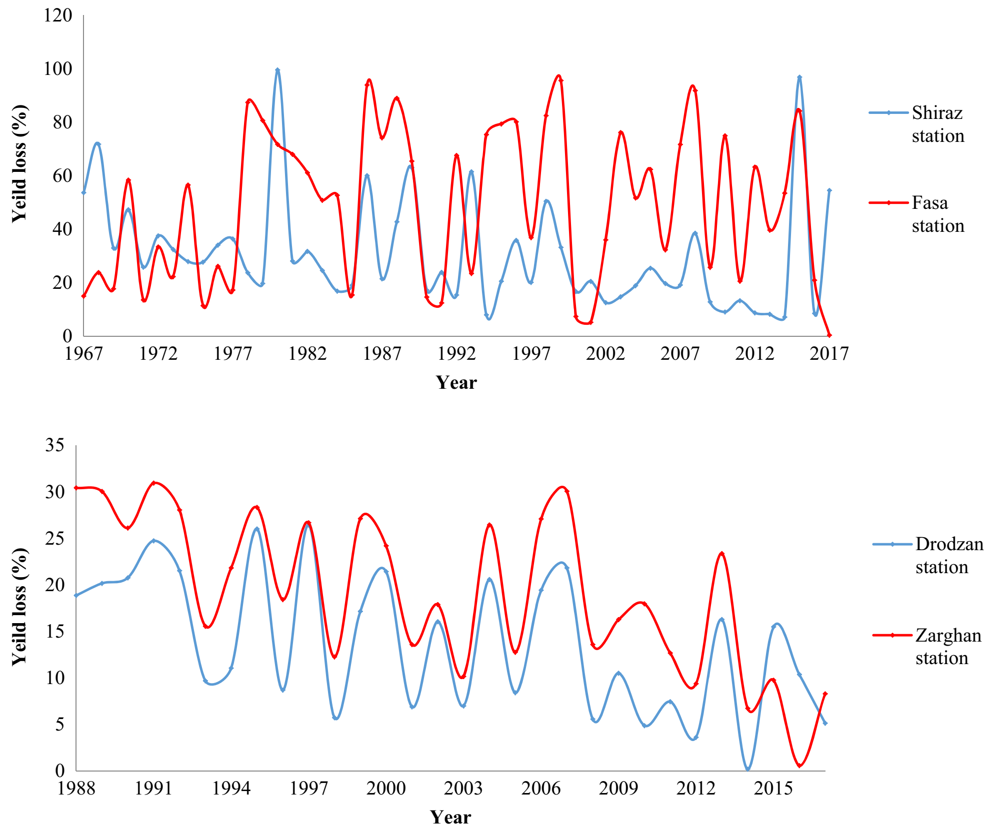


Fig. 5 Annual percentage of yield loss in selected synoptic stations (modeled with AquaCrop model)

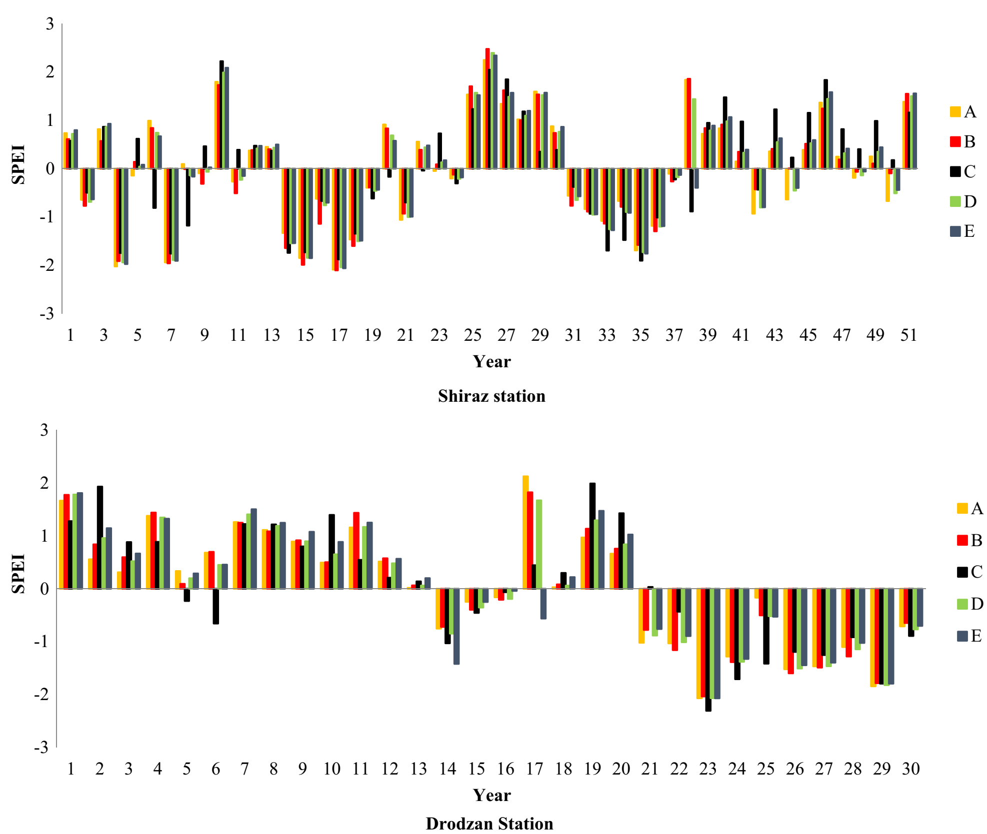


Fig. 6 Calculated SPEI index based on observed precipitation and effective precipitation using different effective precipitation calculation method in Shiraz and Drodzan stations (for example). **a** SPEIOP, **b** SPEIFAO, **c** SPEIUSBR, **d** SPEISS, and **e** SPEIUSC

Table 4 Normality test of calculated data series of SPEI values based on observed precipitation and effective precipitation using different effective precipitation calculation methods

Reference period		Significant level at Fasa station					Significant level at Shiraz station				
		SPEIOP	SPEIFAO	SPEIUSBR	SPEISS	SPEIUSC	SPEIOP	SPEIFAO	SPEIUSBR	SPEISS	SPEIUSC
12 months	Oct–Sep	0.200*	0.061*	0.200*	0.188*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
6 months	Oct–Mar	0.200*	0.200*	0.072*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	Nov–Apr	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	Dec–May	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	Jan–Jun	0.200*	0.071*	0.200*	0.052*	0.187*	0.200*	0.200*	0.200*	0.200*	0.200*
3 months	Nov–Jan	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.193*	0.200*
	Dec–Feb	0.200*	0.083*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	Jan–Mar	0.006	0.009	0.001	0.003	0.003	0.031	0.039	0.004	0.033	0.033
	Feb–Apr	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	Mar–May	0.000	0.000	0.000	0.001	0.000	0.005	0.005	0.004	0.006	0.005
	Apr–Jun	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
1 month	Nov	0.009	0.008	0.009	0.009	0.009	0.000	0.000	0.000	0.000	0.000
	Dec	0.164*	0.200*	0.182*	0.192*	0.063*	0.026	0.200*	0.003	0.015	0.005
	Jan	0.071*	0.200*	0.001	0.053*	0.038	0.017	0.155*	0.011	0.041	0.027
	Feb	0.200*	0.200*	0.076*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	Mar	0.068*	0.011	0.026	0.031	0.045	0.041	0.083*	0.012	0.015	0.016
	Apr	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	May	0.021	0.028	0.018	0.018	0.018	0.003	0.003	0.003	0.001	0.003
	Jun	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.193*	0.200*

SPEIOP is calculated SPEI index based on OP; SPEIFAO is calculated SPEI index using EP based on FAO method; SPEIUSBR is calculated SPEI index using EP based on USBR method; SPEISS is calculated SPEI index using EP based on USDA-SCS simplified method; and SPEIUSC is calculated SPEI index using EP based on USDA-SCS CROPWAT method. *Data series is normal at the 0.05 significant levels (based on Kolmogorov-Smirnov test)

SPEI. Calculated 12-month SPEIOP and SPEIEP using different EP calculation methods in Shiraz and Drodzan stations are presented in Fig. 6 (for example).

Comparison and evaluation of SPEIOP and SPEIEP

To compare the SPEIOP and SPEIEP, in the first stage, the normality of calculated SPEIOP and SPEIEP data series in all stations and all-time scales using Kolmogorov-Smirnov test were evaluated (Tables 4 and 5). Normality test showed that, in 12-month and 6-month time scales of reference periods, data series of calculated SPEIOP and SPEIEP in all stations were normal at 0.05 significant level. In 3-month and 1-month time scales of reference periods, more reference period data series of calculated SPEIOP and SPEIEP were normal at 0.05 significant level. The SPEI data series in some of the reference periods were non-normal, these periods were mainly in months of seasons with the warmer and lower amounts of precipitation (Tables 4 and 5). It seems, considering the climate condition of the study area (arid and semi-arid), that fluctuations of climatic parameters such as precipitation, temperature, and other factors in warmer and less precipitated months and seasons are more than other months and seasons.

In the next stage, correlation coefficients between SPEI and annual Y_L% in each station at all reference periods (in normal data series using Pearson test and in non-normal data series using Spearman Rho test) were estimated (Tables 6 and 7).

Results indicated, in Fasa station, correlation coefficients (CC) between calculated SPEIOP and annual Y_L% in 26.32% of all reference periods were significant at 0.05 or 0.01 levels, CC between calculated SPEIFAO and annual Y_L% in 31.58% of all reference periods were significant at 0.05 or 0.01 levels, CC between calculated SPEIUSBR and annual Y_L% in 42.11% of all reference periods were significant at 0.05 or 0.01 levels, CC between calculated SPEI using EP based on USDA-SCS simplified method (SPEISS) and annual YL% in 31.58% of all reference periods were significant at 0.05 or 0.01 levels and CC between calculated SPEIUSC and annual YL% in 36.84% of all reference periods were significant at 0.05 or 0.01 levels. Regardless of the significant or non-significant correlation coefficients, CC between data series of SPEIOP and annual Y_L% in 5.26% of all reference periods had the highest values, CC between data series of SPEIFAO and annual Y_L% in 21.05% of all reference periods had the highest values, CC between data series of SPEIUSBR and

Table 5 Normality test of calculated data series of SPEI values based on observed precipitation and effective precipitation using different effective precipitation calculation methods

Reference period		Zarghan station					Drodzan station				
		SPEIOP	SPEIFAO	SPEIUSBR	SPEISS	SPEIUSC	SPEIOP	SPEIFAO	SPEIUSBR	SPEISS	SPEIUSC
12 months	Oct–Sep	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
6 months	Oct–Mar	0.200*	0.200*	0.200*	0.200*	0.200*	0.133*	0.107*	0.200*	0.133*	0.200*
	Nov–Apr	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	Dec–May	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	Jan–Jun	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
3 months	Nov–Jan	0.200*	0.200*	0.200*	0.200*	0.200*	0.019	0.008	0.018	0.008	0.019
	Dec–Feb	0.181*	0.200*	0.097*	0.173*	0.123*	0.183*	0.200*	0.200*	0.113*	0.148*
	Jan–Mar	0.015	0.067*	0.026	0.047	0.042	0.200*	0.200*	0.058*	0.162*	0.127*
	Feb–Apr	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
	Mar–May	0.004	0.052*	0.003	0.003	0.004	0.002	0.000	0.000	0.000	0.000
	Apr–Jun	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*
1 month	Nov	0.041	0.200*	0.042	0.200*	0.041	0.000	0.000	0.000	0.000	0.000
	Dec	0.069*	0.200*	0.168*	0.083*	0.023	0.087*	0.200*	0.200*	0.116*	0.012
	Jan	0.200*	0.200*	0.157*	0.200*	0.200*	0.064*	0.046	0.092*	0.067*	0.119*
	Feb	0.200*	0.200*	0.200*	0.200*	0.200*	0.133*	0.107*	0.200*	0.133*	0.200*
	Mar	0.175*	0.200*	0.173*	0.200*	0.169*	0.108*	0.022	0.001	0.009	0.015
	Apr	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.200*	0.073*	0.200*	0.200*
	May	0.200*	0.111*	0.200*	0.200*	0.200*	0.001	0.001	0.001	0.001	0.001
	Jun	0.200*	0.200*	0.200*	0.200*	0.200*	0.019	0.008	0.018	0.008	0.019

SPEIOP is calculated SPEI index based on OP; SPEIFAO is calculated SPEI index using EP based on FAO method; SPEIUSBR is calculated SPEI index using EP based on USBR method; SPEISS is calculated SPEI index using EP based on USDA-SCS simplified method and SPEIUSC is calculated SPEI index using EP based on USDA-SCS CROPWAT method. *Data series is normal at the 0.05 significant levels (based on Kolmogorov-Smirnov test)

annual Y_L% in 42.11% of all reference periods had the highest values and CC between data series of SPEIUSC and annual Y_L% in 31.58% of all reference periods had the highest values (Table 6).

In Shiraz station, correlation coefficients (CC) between calculated SPEIOP, SPEIUSBR, SPEISS, and SPEIUSC methods and annual Y_L% in 31.58% of all reference periods were significant at 0.05 or 0.01 levels, CC between calculated SPEIFAO and annual Y_L% in 21.05% of all reference periods were significant at 0.05 or 0.01 levels. Regardless of the significant or non-significant correlation coefficients, CC between data series of SPEIOP and annual Y_L% in 21.05% of all reference periods had the highest values, CC between data series of SPEIFAO and annual Y_L% in 47.37% of all reference periods had the highest values, CC between data series of SPEIUSBR and annual Y_L% in 5.26% of all reference periods had the highest values and CC between data series of SPEIUSC and annual Y_L% in 26.32% of all reference periods had the highest values (Table 6).

In Zarghan station, correlation coefficients (CC) between calculated SPEIOP, SPEIFAO, SPEIUSBR, and SPEIUSC methods and annual Y_L% in 10.53% of all reference periods were significant at 0.05 or 0.01 levels. Regardless of the significant or the non-significant correlation coefficients, CC between data series of SPEIOP and annual Y_L% in 31.58% of all reference periods had the highest values, CC between data series of SPEIFAO and annual Y_L% in 26.32% of all reference periods had the highest values, CC between data series of SPEIUSBR and annual Y_L% in 36.84% of all reference periods had the highest values and CC between data series of SPEISS and annual Y_L% in 5.26% of all reference periods had the highest values (Table 7).

In Drodzan station, correlation coefficients (CC) between calculated SPEIOP, SPEIFAO, SPEISS, and SPEIUSC methods and annual Y_L% in 73.68% of all reference periods were significant at 0.05 or 0.01 levels, CC between calculated SPEIUSBR and annual Y_L% in 89.47% of all reference periods were significant at 0.05 or 0.01 levels. Regardless of the significant or the non-significant correlation coefficients, CC between data series of SPEIOP and annual Y_L% in 5.26% of all reference periods had the highest values, CC between data series of SPEIFAO and annual Y_L% in 21.05% of all reference periods had the highest values, CC between data series of SPEIUSBR and annual Y_L% in 68.42% of all reference periods had the highest values, and CC between data

Table 6 Correlation coefficients (R) between annual yield loss (Y_L%) and calculated SPEI index based on observed precipitation effective precipitation using different effective precipitation calculation methods

Reference period		Fasa station					Shiraz station				
		SPEIOP	SPEIFAO	SPEIUSBR	SPEISS	SPEIUSC	SPEIOP	SPEIFAO	SPEIUSBR	SPEISS	SPEIUSC
12 months	Oct–Sep	0.357^{*}	0.376^{**}	0.378^{**}	0.369^{**}	0.363^{**}	−0.050	−0.096	−0.093	−0.068	−0.055
6 months	Oct–Mar	0.096	0.088	0.185	0.103	0.235	0.289^{*}	0.268	0.231	0.284^{*}	0.284^{*}
	Nov–Apr	0.234	0.261	0.266	0.264	0.268	0.084	0.050	0.072	0.071	0.101
	Dec–May	−0.040	0.031	−0.009	−0.030	−0.027	−0.070	−0.054	−0.056	−0.063	−0.066
	Jan–Jun	0.231	0.255	0.348^{*}	0.266	0.321^{*}	0.011	−0.037	−0.029	−0.003	0.000
3 months	Nov–Jan	0.328^{*}	0.324^{*}	0.329^{*}	0.328^{*}	0.328^{*}	-0.395^{**}	-0.408^{**}	-0.395^{**}	-0.399^{**}	-0.395^{**}
	Dec–Feb	0.120	0.145	0.102	0.142	0.146	0.118	0.096	0.120	0.104	0.123
	Jan–Mar	*− 0.120*	*− 0.122*	*− 0.153*	*− 0.127*	*− 0.236*	*− 0.273*	*− 0.248*	*− 0.205*	*− 0.274*	*− 0.274*
	Feb–Apr	0.162	0.166	0.284^{*}	0.181	0.275	0.239	0.215	0.213	0.231	0.230
	Mar–May	*− 0.008*	*− 0.090*	*− 0.016*	*− 0.011*	*− 0.008*	*0.040*	*0.021*	*0.026*	*0.030*	*0.033*
	Apr–Jun	0.268	0.300^{*}	0.291^{*}	0.276^{*}	0.278^{*}	−0.187	−0.188	−0.183	−0.183	−0.186
1 month	Nov	*− 0.297**	*− 0.291**	*− 0.297**	*− 0.294**	*− 0.297**	*0.373***	*0.386***	*0.376***	*0.379***	*0.376***
	Dec	0.092	0.138	−0.015	0.096	−0.003	*− 0.005*	0.002	*− 0.029*	*− 0.019*	*0.030*
	Jan	0.131	0.116	*0.153*	0.135	*0.236*	*0.273*	0.269	*0.205*	*0.274*	*0.275*
	Feb	0.096	0.088	0.185	0.103	0.235	0.289^{*}	0.268	0.231	0.284^{*}	0.284^{*}
	Mar	−0.006	*0.090*	*0.016*	*0.011*	*0.008*	*− 0.040*	−0.057	*− 0.026*	*− 0.030*	*− 0.033*
	Apr	−0.040	0.031	−0.009	−0.030	−0.027	−0.070	−0.054	−0.056	−0.063	−0.066
	May	*0.297**	*0.291**	*0.298**	*0.294**	*0.297**	*− 0.373***	*− 0.386***	*− 0.376***	*− 0.379***	*− 0.376***
	Jun	0.328^{*}	0.324^{*}	0.329^{*}	0.328^{*}	0.328^{*}	-0.395^{**}	-0.408^{**}	-0.395^{**}	-0.399^{**}	-0.395^{**}

SPEIOP is calculated SPEI index using OP; SPEIFAO is calculated SPEI index using EP based on FAO method; SPEIUSBR is calculated SPEI index using EP based on USBR method; SPEISS is calculated SPEI index using EP based on USDA-SCS simplified method; and SPEIUSC is calculated SPEI index using EP based on USDA-SCS CROPWAT method. Single asterisk "*" and double asterisks "**," R is significant at the 0.05 and 0.01 significant levels (to assess R, in normal data series the Pearson test and in non-normal data series that showed with italic characters, Spearman Rho test were used)

series of SPEIUSC and annual Y_L% in 5.26% of all reference periods had the highest values (Table 7). It seems that the higher CC of SPEIUSBR with Y_L% in the most stations (75% of selected stations) is due to more accuracy and ability of the USBR method to estimate EP in different ranges of OP.

Calculated CC between data series of SPEIOP and SPEIEP and annual Y_L% showed that in some of the reference periods, CC was positive and in some of the reference periods, CC was negative. In cases with negative CC, by increasing the SPEIOP and SPEIEP values, the conditions of the study area become wetter and annual Yl% will decrease or by decreasing the SPEIOP and SPEIEP values, the conditions of the study area become drier and annual Yl% will increase; therefore, CC between data series of SPEIOP and SPEIEP and annual Y_L% will be negative. In cases with positive CC, by increasing the SPEIOP and SPEIEP values, the conditions of the study area become wetter but annual Yl% of the study area increased or by decreasing the SPEIOP and SPEIEP values, the conditions of the study area become drier but annual Yl% of the study area decreased; therefore, CC between data series of SPEIOP and SPEIEP and annual Y_L% will be positive. The reason of the positive and negative values of CC can be the unsuitability time distribution of precipitation, the frosting of crops, affected by a severe temperature drop, flash rains and hail occurrence especially in spring and etc. in the growth period of winter wheat.

Results of the research by Tigkas et al. (2018) to present a modified version for SPI (aSPI) based on replacement of OP with EP showed that aSPI is more robust than the SPI in identifying agricultural drought. Results of research by Tigkas et al. (2016) to present a modified version for RDI (RDIe) based on replacement of OP with EP showed that the RDIe in an area with agricultural activities has better performance to assess the impacts of drought. It seems that the results of this paper are similar to the results of researches done (Tigkas et al. 2016, 2018) in the case of RDIe and aSPI indices.

Conclusion

Drought is a climatic phenomenon that has always been damaging human societies, different parts of the

Table 7 Correlation coefficients (*R*) between annual yield loss (Y_L%) and calculated SPEI index based on observed precipitation and effective precipitation using different effective precipitation calculation methods

Reference period		Zarghan station					Drodzan station				
		SPEIOP	SPEIFAO	SPEIUSBR	SPEISS	SPEIUSC	SPEIOP	SPEIFAO	SPEIUSBR	SPEISS	SPEIUSC
12 months	Oct–Sep	0.292	0.262	0.055	0.261	0.209	0.544**	0.537**	0.639**	0.579**	0.547**
6 months	Oct–Mar	−0.081	−0.118	−0.119	−0.084	−0.089	0.075	0.109	0.364*	0.109	0.131
	Nov–Apr	0.246	0.210	−0.163	0.200	0.124	0.410*	0.414*	0.665**	0.471**	0.437*
	Dec–May	0.055	0.039	0.058	0.056	0.054	0.493**	0.527**	0.454*	0.490**	0.489**
	Jan–Jun	0.158	0.160	−0.031	0.119	0.105	0.464**	0.474**	0.670**	0.506**	0.484**
3 months	Nov–Jan	0.285	0.298	0.285	0.297	0.285	_0.506**_	_0.479**_	_0.506**_	_0.479**_	_0.506**_
	Dec–Feb	0.427*	0.377*	0.071	0.418*	0.403*	0.399*	0.384*	0.559**	0.450*	0.424*
	Jan–Mar	_0.093_	0.168	_0.090_	_0.102_	_0.099_	−0.132	−0.187	−0.302	−0.162	−0.171
	Feb–Apr	−0.062	−0.090	−0.110	−0.076	−0.079	0.273	0.293	0.683**	0.328	0.357
	Mar–May	_−0.053_	0.086	_−0.064_	_−0.079_	_−0.069_	_−0.509**_	_−0.568**_	_−0.481**_	_−0.516**_	_−0.516**_
	Apr–Jun	0.117	0.100	0.108	0.110	0.109	0.635**	0.599**	0.604**	0.624**	0.625**
1 month	Nov	_−0.282_	−0.248	_−0.282_	−0.251	_−0.282_	_−0.506**_	_−0.479**_	_−0.506**_	_−0.479**_	_−0.506**_
	Dec	0.479**	0.391*	0.324	0.476**	0.410*	0.461*	0.434*	0.473**	0.478**	_0.525**_
	Jan	−0.100	−0.151	−0.102	−0.105	−0.105	0.100	_0.138_	_0.327_	0.133	0.149
	Feb	−0.081	−0.118	−0.119	−0.084	−0.089	0.075	0.109	0.364*	0.109	0.131
	Mar	0.021	0.004	0.026	0.019	0.018	0.454*	_0.568**_	_0.481**_	_0.516**_	_0.516**_
	Apr	0.055	0.039	0.058	0.056	0.054	0.493**	0.527**	0.454*	0.490**	0.489**
	May	0.307	0.278	0.309	0.285	0.308	_0.506**_	_0.479**_	_0.507**_	_0.479**_	_0.506**_
	Jun	0.285	0.299	0.285	0.301	0.285	_0.506**_	_0.479**_	_0.507**_	_0.479**_	_0.506**_

SPEIOP is calculated SPEI index using OP; SPEIFAO is calculated SPEI index using EP based on FAO method; SPEIUSBR is calculated SPEI index using EP based on USBR method; SPEISS is calculated SPEI index using EP based on USDA-SCS simplified method and SPEIUSC is calculated SPEI index using EP based on USDA-SCS CROPWAT method. Single asterisk "*" and double asterisks "**," *R* is significant at the 0.05 and 0.01 significant levels (to assess *R*, in normal data series the Pearson test and in non-normal data series that showed with italic characters, Spearman Rho test were used)

environment, agricultural sections, natural resources, wildlife, etc. Various drought indices have been presented for the evaluation of drought, that SPEI is one of the most important and recommended indices for assessing the severity of drought in different time scales. This index is based on the ratio of P (OP) and PET parameters. The hypothesis of this study is that replacement of the observed precipitation with effective rainfall in SPEI can be effective in increasing the accuracy of the SPEI to assess characteristics of agricultural drought.

Therefore, in this paper, a new version of SPEI to assess agricultural drought based on the replacement of the OP with EP was introduced. EP parameter was estimated using four methods of EP calculation, including FAO, USBR USDA-SCS simplified, and USDA-SCS CROPWAT. To evaluate the accuracy of calculated SPEIOP and SPEIEP, correlation coefficients (CC) between SPEI and annual Y_L% in winter wheat (*Triticum sativum)* in the 19 reference periods were evaluated. Results showed that, regardless of the significant or the non-significant correlation coefficients, in Fasa, Drodzan, and Zarghan stations, calculated SPEIUSBR had the highest values of CC with annual Y_L% (in 42.11%, 68.42%, and 36.84% of all reference periods, respectively). In Shiraz station, calculated SPEIFAO had the highest values of CC with annual Y_L% (in 47.37% of all reference periods). In all stations, calculated SPEIUSBR had the most reference periods with significant CC at 0.05 or 0.01 levels. In all stations, calculated SPEISS had the least values of CC with annual Y_L%. According to the results, almost in all stations, correlation between Y_L% and SPEIEP was more than the correlation between Y_L% and SPEIOP. On the other hand, the number of time periods with a significant correlation between SPEIEP and Y_L% in SPEIUSBR was more than other SPEIEP indices. It seems that the higher CC of SPEIUSBR with Y_L% is due to more accuracy of the USBR method to estimate EP in different ranges of OP. So, it is suggested to assess agricultural drought, SPEIOP replaces with SPEIUSBR. Finally, the results of the presented paper are proper for areas with arid and semi-arid climate (according to the climate of selected stations). Therefore, it should be noted that to use the modified SPEI in different climate conditions, the model requires calibration and adaptation.

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Compliance with ethical standards

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

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