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Assessment, Management and investigation of the effects of climate change on drought in western cities of Iran

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Abstract

Drought is a hazardous phenomenon, as a result of climatic parameters abnormalities. The effects of high and low drought occur in different parts of the country, and its effects are more noticeable in arid and semi-arid regions. One of these areas is western Iran, which has been affected by this phenomenon in recent years. The purpose of this study is drought modelling and investigation in western Iran. To do this, climatic parameters were first used, including precipitation, temperature, sunshine, relative humidity and wind speed in 32 years (1987-2018) at 16 stations in western Iran. For modelling the TIBI fuzzy index, at first, four indices (SET, SPI, SEB, MCZI) were been fuzzy in Matlab software, then the indices were compared and finally, by Vikor multivariate decision-making model was used to prioritize areas affected by drought. The results of this study showed that the impact of rainfall on the drought intensity on the 12-months scale is weaker than the 6-months scale. In the six months, from May 1998 to August 2006, the trend was increasing and then followed the steady pattern, but on a 12-month scale, from August 1995 to December 2001, the trend was increasing and after this month it followed the mostly steady pattern. The highest frequency of drought at 6 and 12-month scale occurred in Ilam station and its lowest was in Sarpule-Zahab station. The T.I.B.I index accurately reflects the four indicators of SET, SPI, SEB and MCZI. Based on the modelling, T.I.B.I fuzzy index showed relative superiority to the SPEI fuzzy index. Finally, according to the Vikor multivariate decision-making method, the Ilam station with a score of 0.99 was more prone to drought occurrence.

Keywords: Climate Change, Management, Surface Water Reduction, T.I.B.I Drought Index, Western Cities of Iran.

1- Introduction

One of the challenges of natural hazards that we face in recent years in the country is the drought phenomenon. Drought as one of the most important climatic phenomena is severely affecting all aspects of human activities. Study of the characteristics of drought and its prediction can be effective in reducing the damage caused by it (Sobhani and Goldost. 2015; Sobhani and Safarianzengir. 2019b; Huanga et al. 2016; Safarianzengir and Sobhani. 2020). In recent years, different regions of the world have experienced severe drought (Mirzaee et al. 2015). One of the most important problems for human especially in recent years is the water crisis and the occurrence of drought. (Karimi et al. 2016; Kis et al. 2017; Zahiri et al. 2014; Salehi and Mojtabapour. 2016). Drought is one of the natural and dangerous hazards that are caused periodically by lack of rainfall (Jafari et al. 2017). Also, drought is one of the most important natural disasters affecting agriculture and water resources, which is widespread especially in arid and semi-arid regions (Shamsnia et al. 2008; Zolfaghari and Nourizamara 2016; Damavandi et al. 2016; Fanni et al. 2016. Drought is a natural phenomenon that has a complex process due to the interactions of various meteorological factors and occurs in all climatic conditions and all regions of the world (Samadianfard and Asadi 2017; Alizadeh 2017; Touma et al. 2015; Spinoni et al. 2015);Ganguli and Ganguly (2016) studied the time-space trend of United States meteorological drought. According to the results, the spatial coverage of severe meteorological drought in recent years (after 2010) exceeded the droughts of the 1930s (periods of dust storms) and the 1950s. Hao et al (2016) presented a drought theory method for multivariate drought index based on a linear hybrid index. Based on the standard index of drought, theoretical distribution of linear combination index (LDI) is derived which can be used for drought classification using per cent method. The results of comparing this method with experimental methods show its satisfactory performance for drought classification. Setiawan et al (2017) in studying the drought relationship with the ENSO (El Niño-Southern Oscillation) phenomenon concluded that even severe seasonal droughts could be predicted using the MME model. Kang and Siderar (2017) have reviewed the distributive statistical and spatial model for assessing future drought indicators in Virginia. They concluded that agricultural drought incidence had an overall increase (1.3%), by using the average of SSI group. Saada and Roman (2017) have studied the polynomial modelling and simulation of the SPI (Standardized Precipitation Index) index in Jordan and found that the short-run scale is not suitable because Jordan is a dry country and SPI (Standardized Precipitation Index) reliability has not been studied in a shorter time. Zeleke et al (2017) have used the Standard Precipitation Index (SPI) and Palmer drought severity index (PDSI) and satellite data to investigate the drought in Ethiopia. The results showed that the observed dry and wet periods in the north of the study area mainly depend on the change of the ENSO (El Niño-Southern Oscillation) in the spring and summer season, while the drying trend in the south and southwest is associated with the warming of the Atlantic and the surface water temperature in the western Pacific Ocean. Mirabbasi et al (2017) have analyzed the droughts of the northeast of Iran using the jntegrated deficit index (IDI). The results of their research have shown that the number of dry months in the studied area (especially in humid areas) has increased significantly in recent years. Zeinali et al (2017) investigated the drought and the possibility of its prediction in the Lake Urmia basins. Their results indicated an increasing trend in temperature in this basin. The highest rate of drought occurrence was observed in Urmia station and the least rate in Mahabad. Bayazidi (2019) studied the drought of the synoptic stations of Western Iran using the HERBST and the neuro-fuzzy method and concluded that the determination coefficient and the error rate was good only in Kermanshah, Mianeh and Piranshahr stations. Torabipodeh et al (2019) studied the prediction of droughts using Smart Grids and concluded that the use of wavelet neural network model could be effective in drought prediction. Ekhtiarikhaje and Deeppazhouh (2019) studied the application of the Effective Drought Index (EDI) to study the drought periods and concluded that according to the results, water years of 2007-2008, 2008-2009 and 2001-2002 for Tabriz, Bandar Anzali and Zahedan stations respectively are the driest dry year during the 60-year statistical period. According to the studies done inside and outside the country, this study was conducted to model and monitor the drought phenomenon in western Iran using the new fuzzy index T.I.B.I.

2- Materials and methods

The present study conducts modelling, monitoring and prediction of drought in Iran using climatic data including precipitation, temperature, sunshine, least relative humidity and wind speed (as monthly and yearly and in 6 and 12 months' scale) for the period of 32-year (1987-2018) for 16 stations in 6 provinces (Zanjan, Kordestan, Hamedan, Kermanshah, Lorestan and Ilam) by implication of TIBI new index (that calculated by four valid indicators of WMO (World Meteorological Organization) including SET (Standardized Evapotranspiration Torrent White Index), SPI (Standardized Precipitation Index), SEB (Standardized Evapotranspiration Blanney Creedale FAO Index), MCZI (Modified CZI Index). The position of the study area was presented in (Figure 1).

For modelling of the new TIBI index, the climatic data were first normalized, then four indices of SET, SPI, SEB and MCZI were calculated separately and the fuzzy modelling of the four indices was performed in the Matlab software and eventually to prioritize the drought-affected areas, Vikor model was used.

2- 1- Fuzzy Index of T.I.B.I

The fuzzy index (T.I.B.I) is presented to resolve some of the disadvantages of the SPEI index. Indicator T.I.B.I was derived from the combination of indicators (SET, SPI, SEB, and MCZI). This index is the result of drought monitoring fuzzy modelling architecture, which was designed using fuzzy logic in a fuzzy inference system. The design of this model and the determination of the T.I.B.I index are described below. The number of fuzzy numbers and numerical load on each standard domain can be determined following the three, four, eight, and so on linguistic terms, so for the standardization of the SET and SPI indicators, equation 1 was used and for standardization of SEB and MCZI indices, equation 2 was used.

$$x_{ij} = \frac{x_j max - x_j}{x_j max - x_j min} \quad (1)$$

$$x_{ij} = \frac{x_j - x_j min}{x_j max - x_j min} \quad (2)$$

In these relationships, xij represents the standardized value, xj the desired index value, xjmax the maximum value in the number series, and xjmin represents the lowest value in the numeric series (Malchovsky. 2006). One of the ways in which linguistic expressions in regular words can be converted to their corresponding fuzzy numbers is to use membership functions in the Matlab software, with the range of four inputs between ±2 Table (1) and the output index domain is between 0 and 1 (Table 2).

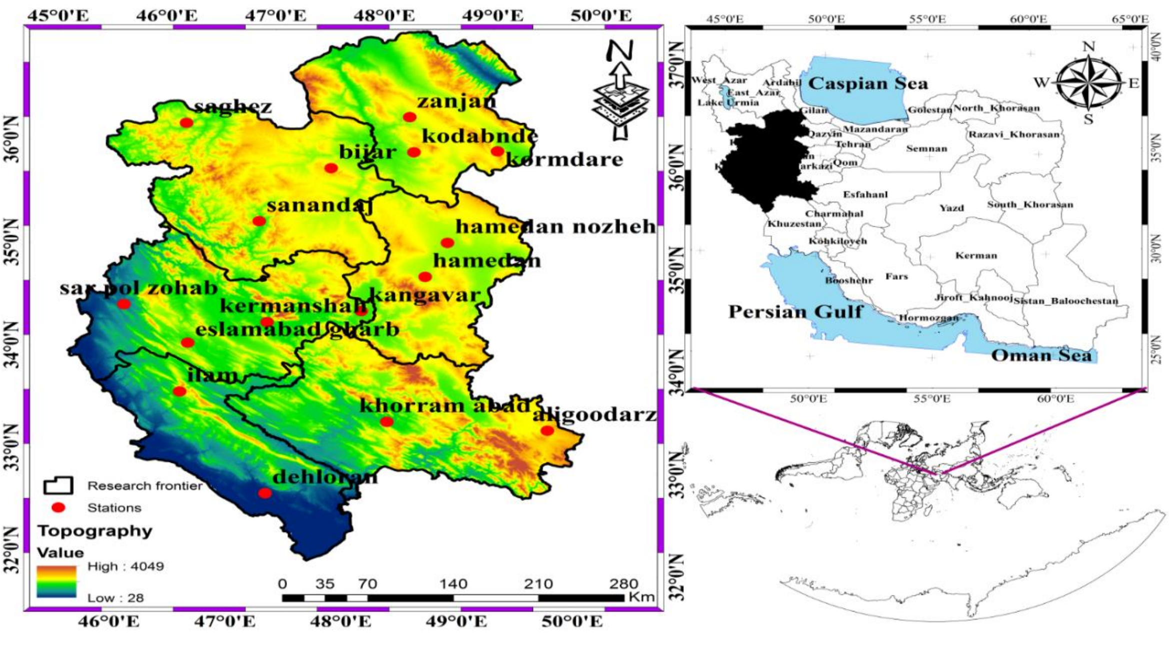

Fig 1. Study area situation in Iran map, this figure illustrates the study area of the present study

Table 1- linguistic variables and fuzzy values of input indices (SET, SPI, SEB, MCZI)

Language variables	Fuzzy value
WVH	2≥
WH	1.5-1.99
WA	0.99-1.39
WS	0.5-0.99
N	-0.39-0.39
DS	-0.99- -0.5
DA	-1- -1.39
DH	-1.5- -1.99
DVH	-2≤

Table 2- linguistic variables and fuzzy values of the new index derived from the modelling of T.I.B.I

Language variables	Fuzzy value
WVH	0, 0, 0, 0.1
WH	0, 0.1, 0.1, 0.2
WA	0, 0.2, 0.2, 0.4
WS	0.2, 0.35, 0.35, 0.5
N	0.3, 0.5, 0.5, 0.7
DS	0.5, 0.65, 0.65, 0.8
DA	0.6, 0.8, 0.8, 1
DH	0.8, 0.9, 0.9, 1
DVH	0.9, 1, 1 , 1

After the modelling of the T.I.B.I fuzzy index, the effect of climate parameters on the drought of the studied stations was investigated. Then drought was monitored. In drought monitoring based on T.I.B.I, trend, the severity of persistence and frequency of drought occurrence were studied and the trend of the indices was determined by linear trend method. Frequency relationship was used to obtain the percentage of drought occurrence in different classes.

3- Results and Discussion

3-1- Monitoring of drought fluctuations based on four integrated indicators in T.I.B.I

In order to investigate the effect of indices drought fluctuations in drought conditions of stations, it is possible to analyze the changes in the indicators (SET, SPI, SEB and MCZI) as appeared in the TIBI index. Considering a large number of stations, for the sake of better understanding, only the drought series graph of Ilam station was presented in both 6-and 12-month scale Figures (2) and (3) (in these figures, the cross-sectional red line shows drought margin on a 6-month and more scale with the amount of 0.74 and a 12-month and more scale with the amount of 0.76. The analysis of these figures shows that at the 6 and 12-month scale at Ilam station, the amount of evapotranspiration was similar in drought conditions, which decreased from February 1993 to June 1996, and after this month an increase was observed, while the impact of rainfall on a 12-month scale is weaker than the 6-month scale. It means that from May 1998 to August 2006, an increasing trend occurred and after that followed by the same pattern, but on a 12-month scale from August 1995 to December 2001, the trend has been incremental, and after this month the situation has behaved almost uniformly. The indicators (SET, SPI, SEB, and MCZI) affect the TIBI index and show somehow a trend, indicating that the new TIBI fuzzy index reflects the four indicators very well. The scale of its drought classes was presented in (Table 3). The T.I.B.I index at the 12-month scale shows a sharper shape than the 6-month scale.

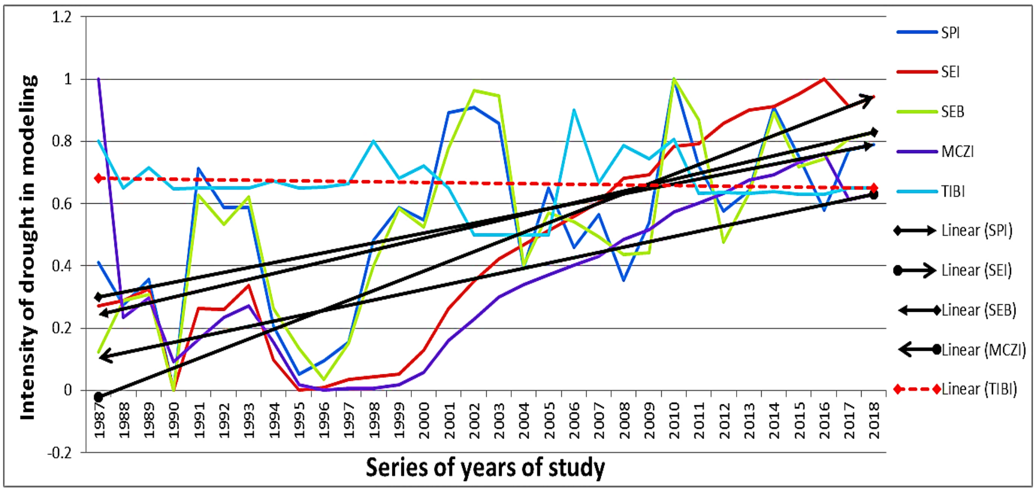

Fig 2- Indicators oscillation at Ilam station at 6-month scale and statistical period of 1987-2018, this chart shows the fluctuations in the intensity of the combined drought indices.

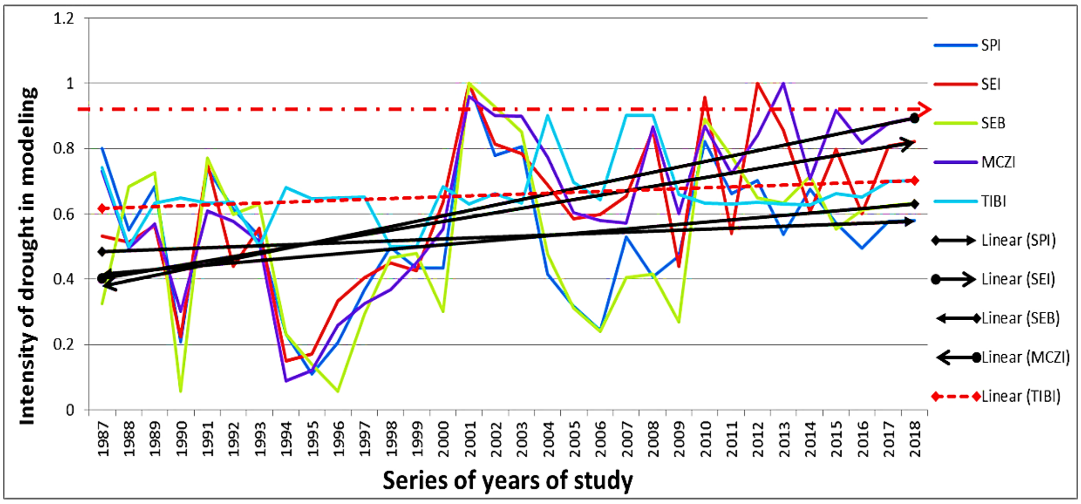

Fig 3- Indicators oscillation at Ilam station at 12-month scale and statistical period of 1987-2018, This chart shows the fluctuations in the intensity of the combined drought indices.

Table 3- Wet year and drought severity classification based on fuzzy modelling of T.I.B.I

Drought classes	T.I.B.I Indicator values
Very severe drought	0.96-1
severe drought	0.87-0.96
moderate drought	0.74-0.87
Mild drought	0.59-0.74
normal	0.44-0.59
Gentle mild	0.29-0.44
moderate wet year	0.15-0.29
severe wet year	0.06-0.15
very severe wet year	0.-0.06

According to the results obtained from the frequency of drought at the 6 and 12-month scale, the total frequency percentage of droughts at 6-months was more than 12-months in the area. The stations of Ilam, Aligudarz and Kermanshah had most percentages of drought (11.15, 7.61, 14.13 and 7.55 respectively). Stations with a lower percentage of drought frequency were more frequently in East part of the region including the stations of Sanandaj, Sarpulzahab and Khorramdarreh with frequency percentage of 1.99, 2.39 and 2.91. According to the model, in the 12-month scale, the western half of the study area, especially the Ilam and Kermanshah stations were more exposed to drought. The most exposed to drought stations were Ilam, Kermanshah and Saqez with TIBI amount of 7.59, 5.96 And 5.11 respectively. According to the definition of drought based on the T.I.B.I index, the values of 0.74 and higher at a scale of 12 and 6 months are considered to be as dry conditions. Accordingly, in the modelling of the new fuzzy index of T.I.B.I, the severity of the southwest drought at 12 months was more than the 6-month scale. Based on the results of the present study, the severity of drought at 6-month scale began from 2000 and it increased by 2018, and at 12-month scale, from 1996 to 2018, the severity of drought increased more rapidly and afterwards, since 2005, the intensity of the drought has continued as a slight change.

3-2- Assessment of drought-affected areas based on the Vikor model

Prioritization of the stations involved in drought was analyzed using Vikor model. To calculate and analyze the statistical data, each of the parameters took weight and then the desirability and The lack of desirability of each of the studied stations were investigated in terms of drought frequency per cent and, finally, an appropriate option was selected from an approximate approach to ideal proportions (Sobhani and Safarianzengir, 2019a). The results of the implementation of the Vikor model using the degree of importance of the criteria derived from the entropy method indicate that, in terms of drought, more and fewer places are involved with drought were identified by combining the two 6 and 12-month scale. According to the Vikor model, the southwest and southeast of the study area were most exposed to drought. The three stations of Ilam, Kermanshah and Aligodarz with priority values of 1, 0.62, and 0.61 were most affected respectively by the drought and three stations of Sarpulzahab, Hamedan Airport and Kangavar were rated as 0.04, 0.05 and 0.10 respectively had less priority for drought occurrence Table (4) and Figure (4).

Table 4-Prioritization of stations involved with drought based on the Vikor model and statistical period of 1987-2018

Stations names	*Vikor rating score*	*Vikor values*	*Stations names*	*Vikor values*	*Vikor rating score*
Sanandaj	13	**0.13**	Sarpulzahab	0.04	**16**
Bijar	8	**0.36**	Ilam	1	**1**
Saghghez	4	**0.47**	Dehloran	0.47	**5**
Hamedan airport	15	**0.05**	Khorramabad	0.20	**9**
Hamedan nozheh	11	**0.19**	Aligodarz	0.61	**3**
Kermanshah	2	**0.62**	Zanjan	0.42	**7**
Eslamabad gharb	6	**0.41**	Khorramdarreh	0.19	**10**
Gankavar	14	**0.10**	Khodabandeh	0.14	**12**

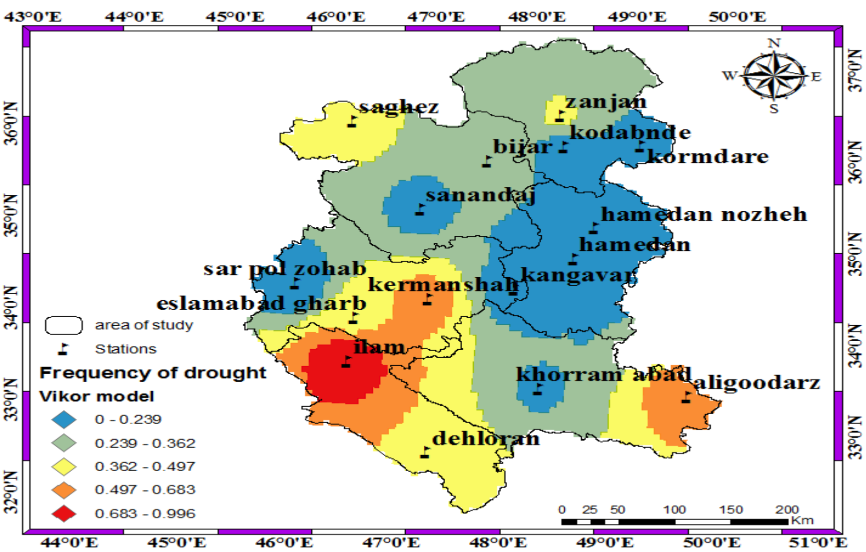

Fig 4- The final map of areas affected by drought in the west of Iran based on the Vikor model, during the statistical period (1987-2018), in the figure above, the intensity of the drought is obtained Vicker's model is displayed in the ArcGIS software.

3-3- Comparison of the results with other researchers

In this study, modelling and monitoring the drought phenomenon performed in western Iran using the new fuzzy index of T.I.B.I. in most studies, this method has been considered as the appropriate method for drought monitoring, analysis and modelling including Shamsnia et al. (2008), by study on drought modeling in Fars province using time series analysis; Mirzaee et al. (2015) by research on the development of WEAP integrated water resource model for modeling drought conditions; Peiravi et al. (2015) in their study on the modeling of the drought effect on the total hardness and solids of groundwater solution in Mashhad plain; Adib and Gorgizadeh (2017) by drought monitoring using drought indices; Zolfaghari and Nourizameleh (2016) by study on application of the Drought Index (CPEL) in determining the appropriate variables for the analysis of drought in Iran; Parsamehr and Khosravani (2018) in their study of drought determination using multi-criteria decision making based on TOPSIS methods; Alizadeh et al. (2017), by research on the modeling of the droughts dispersion of due to climate change in Iran by using a dynamical system; Zeinali and Safarianzengir (2017) by drought monitoring in Urmia Lake basin, using fuzzy index and Fathizadeh et al. (2018) by study the relationship between meteorological drought and solar variables in some of Iran's synoptic stations confirmed the efficiency of the method. Also, the modelling performed in the present study about modelling and monitoring the drought phenomenon in western Iran using the new T.I.B.I fuzzy index had an acceptable efficiency.

According to the comparison of the results of the present study with the findings of the Manuscript results of other researchers, it was found that the method and model used in the present study has high accuracy and less error in fuzzy and output the results. And the results of the present study can be used with a high level of confidence in the planning sections to reduce drought and proper use of water resources. Due to the high accuracy and level of reliability of the model and the method used in the present study, it is recommended to use the present model in other areas that suffer from drought.

4- Conclusion

Drought is a hazardous phenomenon in different parts of the planet that its harmful effects are evident in the affected areas. One of these areas is Southwest Asia, which western part of Iran has been involved by it in recent years. Researchers conducted many studies to monitor drought in western Iran with different models, but it does not adequately cover the subject quality. The purpose of this study was to model and monitor the drought phenomenon in western Iran using the new fuzzy T.I.B.I index in the 6 and 12-month scale. In the study area, severity and the number of drought repetitions at 6-month scale is more than 12 months′, but drought persistence is more at 12 months’ scale. The drought had less continuous in short-term and affected by evapotranspiration parameters, while the intensity of drought in the long periods had less responsive to temperature variations. The trend of drought in the west of Iran increased and the trend of temperature increase was more rapid. The highest percentage of drought incidence at 6 and 12-month scale was in Ilam station and its lowest in both 6 and 12-month scale has occurred in Sar-e-Pul-e-Zahab station. The percentage of drought frequency in Sanandaj, Saralpolzahab and Khoramdarreh stations was higher at 12-month scale than 6-month scale. According to the results, modelling was considered at a high confidence level and the new fuzzy index of T.I.B.I was superior to the SPEI fuzzy index. Also, according to the results of modelling by the new index T.I.B.I, the 6-month scale had a higher intensity than the 12-month scale. Based on the results of modelling at 6-month scale, the highest percentage of drought frequency was reported in the southern half of the study area at stations of Kermanshah, Ilam and Aligudarz stations, and at the 12-month scale in the west of the studied area at stations of Ilam, Kermanshah and Saqez. Finally, based on the VIKOR multivariate decision-making model, Ilam station with a score of 1 was more exposed to drought and the Sarpul-Zahab station with a score of 0.04 was in the final priority exposed by drought.

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6- Conflicts of Interest

No potential conflict of interest was reported by the authors.

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