Monitoring, analyzing and estimation of drought rate using new fuzzy index in cities of west and southwest of Iran, located in the north of the Persian gulf

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Abstract

Drought is one of the natural hazards affecting all activities of living things. High and low droughts occur in different parts of the country, and their effects are more noticeable in arid and semiarid regions. One of these areas is the south-west of Iran. The purpose of this study is drought modelling and analysis in the south-west of Iran. To do this, climatic parameters were first used, including precipitation, temperature, sunshine, relative humidity and wind speed in the period of 32 years (1987–2018) at 15 stations in the south-west of Iran. For modelling the TIBI fuzzy index, at first, four indices (SET, SPI, SEB and MCZI) were fuzzy in MATLAB software, and then the indices were compared and finally SAW multivariate decision-making model was used to prioritize areas affected by drought. The results of this study showed that the highest frequency of drought at 6- and 12-month scale occurred in Islamabad Gharb station and the lowest frequency was in Hamedan airport station. The T.I.B.I index accurately reflects the four indicators: 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 SAW multivariate decision-making method, the Islamabad Gharb station with a score of 1 was more prone to drought occurrence.

Keywords T.I.B.I index · SAW · Fuzzy logic · MATLAB · Modelling · Drought

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1 Introduction

In recent years, there has been a decrease in rainfall; this decrease in rainfall has been manifested in the form of drought (Sobhani and Safarianzengir 2019a; Sobhani et al. 2019a, b). Drought is one of the natural hazards that affect many areas in the world. In recent years, different regions of the world have experienced severe drought (Mirzaei et al. 2015). Also, drought is one of the most important natural disasters affecting agriculture and water resources, which is widespread, especially in arid and semiarid regions (Shamsnya et al. 2008; Sobhani and Safarianzengir 2020; Sobhani et al. 2020a). Drought is very common in arid and semiarid regions (Sobhani et al. 2018; Safarianzengir et al. 2019; Safarianzengir and Sobhani 2020). Drought is also referred to as a climate phenomenon with a lack of humidity and rainfall relative to normal conditions. This phenomenon strongly affects all aspects of human activity (Zeinali and Safarianzengir 2017). Drought is a natural phenomenon that has a complex process due to the interactions between various meteorological factors and occurs in all climatic conditions and all regions of the world (Samadian-Fard and Assadi 2017; Sobhani et al. 2019c; Sobhani and Safarianzengir 2019b). Drought is one of the natural and dangerous hazards that are caused periodically by lack of rainfall (Jafari et al. 2017; Sobhani et al. 2020a, b). During the past decades, frequent and severe droughts caused considerable ecological, agricultural and financial loss around the world (United Nations 2008; Piao et al. 2010; Wang et al. 2018; Lai et al. 2019). The PERSIAN Climate Data Record (PERSIAN-CDR) (Ashouri et al. 2014) and Climate Hazards Group (CHG) Infrared Precipitation with Stations (CHIRPS) (Funk et al. 2014, 2015) are the most famous long-term SREs with data records of more than 30a and therefore are suitable to be applied in drought monitoring or other climatic applications. Performances of both products have been widely evaluated and verified in several studies, including accuracy analysis (Katsanos et al. 2016; Zambrano et al. 2016; Tan and Santo 2018; Baez-Villanueva et al. 2018; Gao et al. 2018), performance in climatic extremes (Miao et al. 2015; Katiraie-Boroujerdy et al. 2017), hydrological modelling (Tuo et al. 2016; Zhu et al. 2016; Poméon et al. 2017) and downscaling of climate models (Lai et al. 2019). Although the CHIRPS generally presented better performance, the PERSIAN-CDR is still adequate for hydrological drought monitoring (Lai et al. 2019). Integration of optical and TIR information has a great potential to capture the drought effects on the grass canopy in terms of reductions in daily GPP and ET. 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 (2018) studied the drought of the synoptic stations of the west of Iran using the HERBST and the neuro-fuzzy method and concluded that the determination coefficient and the error rate were good only in Kermanshah, Mianeh and Piranshahr stations. Torabipodeh et al. (2018) studied the prediction of droughts using smart grids and concluded that the use of wavelet neural network model could be effective in drought prediction. Moradi et al. (2008) in a study simulated the relationship between aquatic and climatic droughts using probabilistic models in Babylon Plain. The occurrence of droughts and wet years in the Babol River is more influenced by the droughts and wet years of Ghaemshahr station. Ekhtiyarikhajeh and Dinpazhoh (2018) 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 2009–2010 for Tabriz, Bandar Anzali and Zahedan stations, respectively, are the driest dry years during the 60-year statistical period. Huanga et al. investigated the relationship between hydrological drought, climate indicators and human activity in the Columbia River basin. The results show that the use of maximum and minimum annual is not a suitable way to check characteristics of volume and duration of flood and drought and to assess drought, other methods, such as the standard index, should be widely used. Kossada et al. studied hydrological changes in a consistent approach to assess flood and drought changes and concluded that most of the methods used to detect extreme hydrological trends are not suitable for trend detection and cannot be used in decision-making. Therefore, they proposed a method based on the theory of implementation and threshold level. Modaresirad et al. (2017) studied the drought of meteorological and hydrological in the west of Iran. The results showed that the SPI index can show two main characteristics of meteorological and hydrological droughts and also provide accurate estimation for recurrence of a severe drought. Zeleke et al. (2017)) used the standard precipitation index (SPI) and Palmer drought 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 in the spring and summer season, while the drying trend in the southern and south-western part is associated with the warming of the Atlantic and the surface water temperature in the western Pacific Ocean. Other internal and external researchers have investigated various models in the field of drought, including Zahiri et al. (2014), Shokrikouchak and Behnia (2013), Haddadi and Heidari (2015), Montazeri and Amirataee (2015), Sobhani et al. (2015), Salahi and Mojtabapour (2016), Zolfaghari and Nouri-Sameleh (2016), Damavandi et al. (2016), Fanni et al. (2016), Gholam Ali et al. (2011), Huanga et al. Keshtarsani (2015), Alizadeh et al. (2017), Zeinali et al. (2017), Huanga et al. (2015), John Dermian et al. (2015), Touma et al. (2015), and Spinoni et al. (2015). The results of Alizadeh et al. (2017), in research named at the modelling of dispersion of drought caused by climate change. According to the studies done inside and outside the country, this study was conducted for monitoring, modelling and estimation of drought rate in the west and south-west of Iran using new fuzzy index.

2 Materials and methods

2.1 Study area

The present study conducted modelling, monitoring and prediction of drought in the south-west of Iran using climatic data including precipitation, temperature, sunshine, least relative humidity and wind speed (as monthly and yearly and in 6- and 12-month scale) for the period of 32 years (1987–2018) for 15 stations in five provinces (Hamedan, Lorestan, Khuzestan, Kermanshah and Ilam) by implication of TIBI new index (calculated by four valid indicators of WMO including (SET, SPI, SEB and MCZI). The position of the study area is presented in Fig. 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, SAW multivariate decision-making model was used.

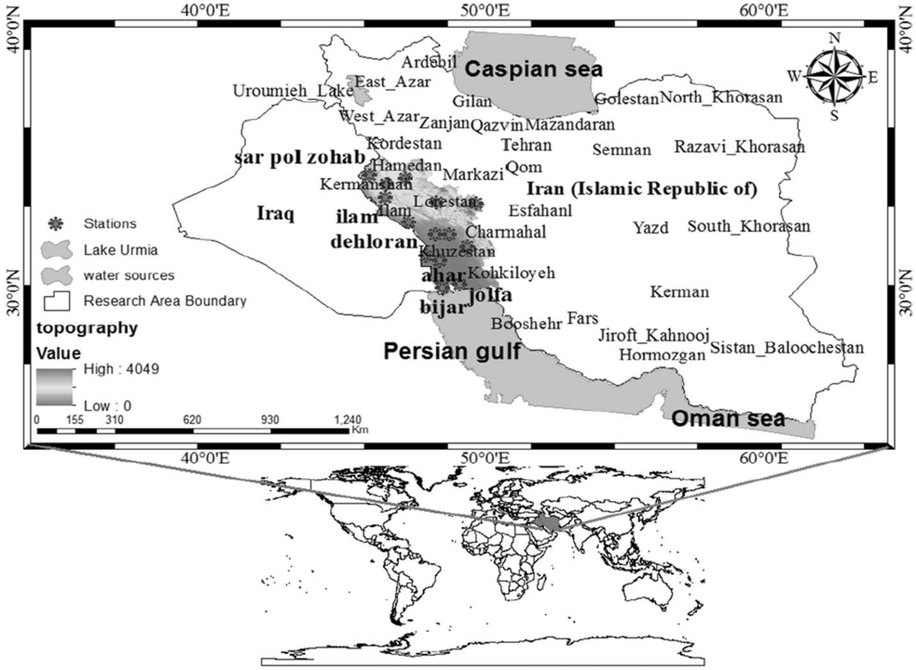

Fig. 1 Location of the study area in the world map

2.2 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 in accordance with the three, four, eight, and so on, linguistic terms, so for the standardization of the SET and SPI indicators, Eq. (1) was used, and for standardization of SEB and MCZI indices, Eq. (2) was used:

$$x_{ij} = \frac{x_j\max - x_j}{x_j\max - x_j\min} \tag{1}$$

$$x_{ij} = \frac{x_j - x_j\min}{x_j\max - x_j\min} \tag{2}$$

In these relationships, x_{ij} represents the standardized value, x_j the desired index value, xjmax the maximum value in the number series and $x_j$min the lowest value in the numeric series (Mulchsfaki 2006). One of the ways in which linguistic expressions in regular words can be converted to their corresponding fuzzy numbers is to

Table 1 Linguistic variables and fuzzy values of input indices (SET, SPI, SEB and 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 to − 0.5
DA	− 1 to − 1.39
DH	− 1.5 to − 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

use membership functions in the MATLAB software, with the range of four inputs between 2 ± (Table 1) and the output index domain between 0 and 1 (Table 2).

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 as below.

2.3 The standardised precipitation evapotranspiration new fuzzy index (T.I.B.I)

The new fuzzy climatic index (T.I.B.I: combined index based on four indices: SET, SPI, SEB and MCZI) is presented to correct some of the disadvantages of the SPEI index. The fuzzy index (T.I.B.I) was obtained by combining the four indices of SET (standardized evapotranspiration torrent white index), SPI (standardized precipitation index), SEB (standardized evapotranspiration Blaney–Criddle FAO index) and MCZI (modified CZI index) in the fuzzy inference system. To calculate the index (T.I.B.I), the first four indices were calculated. After calculating the four indices according to the method described in T.I.B.I, based on Table 3, the architecture of the fuzzy model of drought monitoring was evaluated which is shown in Fig. 2.

Table 3 Classification of drought and wet year severity based on fuzzy modelling of T.I.B.I index

Drought classes	The index value of T.I.B.I
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 drought	0.44–0.59
Mild wet season	0.29–0.44
Moderate wet season	0.15–0.29
Severe wet season	0.06–0.15
The very severe wet season	0–0.06

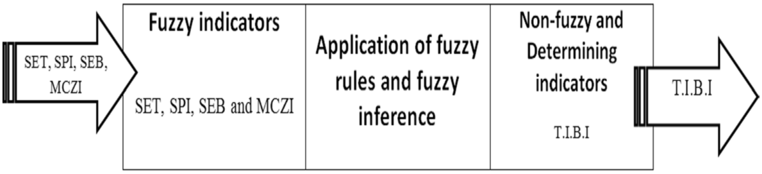

Fig. 2 General architecture of the fuzzy model of drought monitoring

2.4 ANFIS (adaptive neuro-fuzzy inference system) neural network model

In this step, the possibility of modelling and prediction of dust was studied in the studied area using the ANFIS model (Ansari et al. 2010). In this study, the drought phenomenon in a series of time (276 months) was considered in two models of ANFIS neural networks in each station. The fuzzy system is a system based on the "conditional-result" logical rules that using the concept of linguistic variables and fuzzy decision-making process depicts the space of input variables on the space of the output variables. A SOGNO fuzzy system with four inputs, one output and two laws and an equivalent ANFIS system were presented. This system has two inputs x and y and one of outputs. In the end, the error rate of the resulting models is compared and the function that obtains the lowest error rate at the lowest analysing time was selected as a membership function. The branches of this graph are encoded with circles. These circles specify the type of rules (or and or). The last node on the left is the input, and the last node on the right is the output. The five-layer ANFIS structure described above is visible in this structure. In the Surface Viewer, different modes of output index in the form of fuzzy membership functions are displayed in the Surface Viewer as well as changes in the values of the input index classes and can give more details of the level of changes in the new index between 0 and 1. According to the classification and changes in the matching eight octaves, the four inputs are aggregated and output one image using MATLAB software.

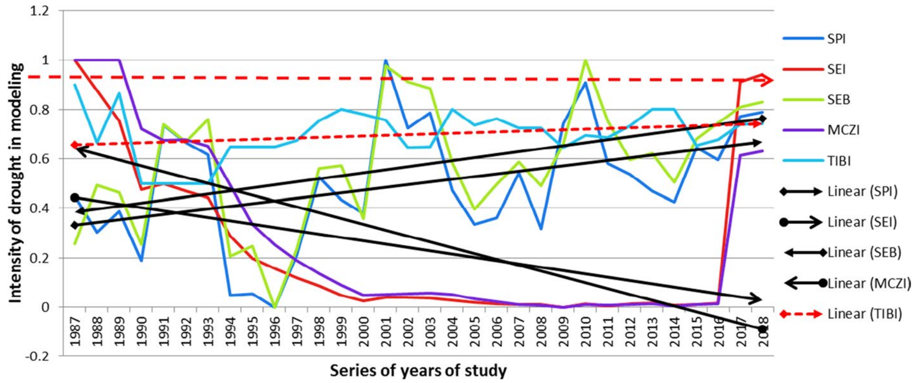

Fig. 3 Fluctuation of the indexes at Islamabad West station at 6-month scale and a statistical period of 1987–2018

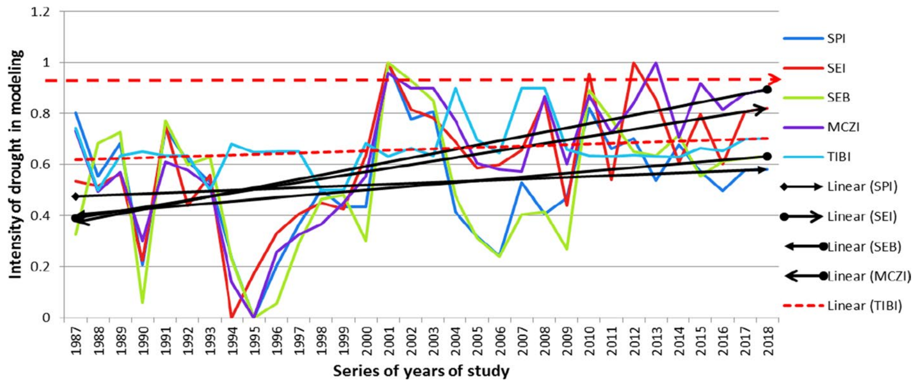

Fig. 4 Fluctuation of the indexes at Islamabad West station at 12-month scale and statistical period of 1987–2018

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 analyse 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 Islamabad Gharb station was presented in both 6-and 12-month scales (Figs. 3 and 4). 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 0.74. The analysis of these figures shows that at the 6- and 12-month scale at Islamabad Gharb station, the amount of temperature was different in drought conditions, which has been decreasing on a 6-month scale from April 1994 to August 1997 and has been increasing since then, from July 1996 to 2003, while the impact of rainfall on a 12-month scale is weaker than the 6-month scale. It means that from May 1994 to November 1997, a decreasing trend occurred and the severity of the drought on the 12-month scale then increased from June 1997 to December 2002, followed by the uniform pattern. The indicators of (SET, SPI, SEB and MCZI) effect on the TIBI index and to some extent represent a trend, indicating that the new TIBI fuzzy index reflects the four indicators very well. The scale of its drought classes is presented in Table 3. The T.I.B.I index at the 12-month scale shows a sharper shape than the 6-month scale.

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 Islamabad Gharb, Sarpolzahab and Aligodarz had most percentages of drought on a 6-month scale (9.66, 7.34 and 8.49, respectively). Stations with a lower percentage of drought frequency were more frequently in north-eastern and south-western parts of the region including the stations of Hamedan Nogheh, Gankavar and Masjed soleyman with frequency percentages of 2.27, 2.52 and 2.59 (Table 4 and Fig. 5). According to the model, in the 12-month scale, the north-western part of the study area was more exposed to drought. The most exposed to drought stations were Hamedan Nogheh, Islamabad Gharb and Sarpolzahab with TIBI amounts of 5.88, 18.68 and 16.51, respectively, and subeastern and southern stations of the study area were less exposed to drought including Kangavar, Khorramabad and Safiabad with drought frequency percentages of 1.77, 1.26 and 2.29, respectively (Table 5 and Fig. 6). 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 dry conditions. Accordingly, in the modelling of the new fuzzy index of T.I.B.I, the severity of the south-west drought at 6 months was more than the 12-month scale. Based on the results of the present study, the annual drought severity at the 6-month scale began in 1997 and continued until 2002, and continued to change slight swing and after that time, from 2003 onwards. However, on a 12-month scale, the intensity of drought has been rising from 1996 to 2004, and droughts have been increasing steadily since 2005.

Table 4 Percentage of drought incidence frequency in different classes and 6-month timescale

Station names	Normal	Mild drought	Mediocre drought	Severe drought	Very severe drought	Total
Hamedan airport	3	2	1.91	0.26	0.10	3.27
Hamedan Nogheh	4.1	1.06	2.03	1.07	0.09	3.19
Kermanshah	1.09	2	1.39	2.37	0.05	3.81
Islamabad Gharb	1.08	9.17	6.07	3.25	0.34	9.66
Gankavar	2.36	14.12	2.09	0.43	0	2.52
Sarpolzahab	12.02	10.68	5	2.08	0.26	7.34
Ilam	1.12	4.05	1	2.47	0	3.47
Dehloran	4	3.13	2.18	1.06	0.19	3.43
Khorramabad	4.06	2.38	2.59	0.65	0.12	3.36
Aligodarz	2.14	1.08	4	4.41	0.08	8.49
Safiabad	1.96	4	3.96	2.18	0.04	6.18
Abadan	0.63	3.89	2.79	1.27	0	4.06
Dezful	3	6	4.56	2.16	0.03	6.75
Masjed soleyman	1	5	1.88	0.71	0	2.59
Ahvaz	3.68	2	2.96	2.15	0.14	5.25

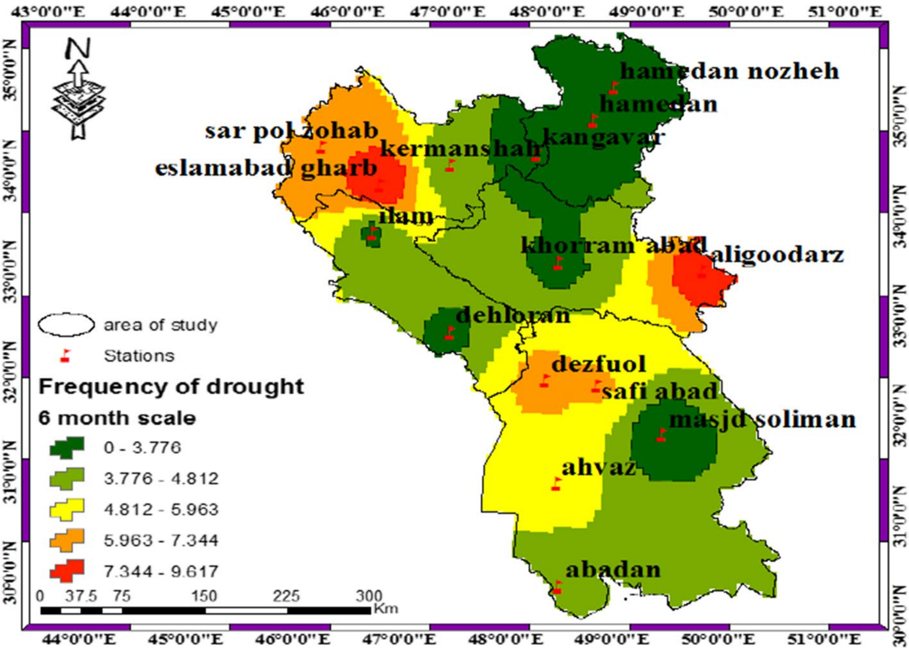

Fig. 5 Mapping of frequency per cent of drought occurrence in studied stations at a 6-month scale, in the statistical period (1987–2018)

Table 5 Frequency per cent of drought occurrence in different classes and 12-month timescale

Station names	Normal	Mild drought	Mediocre drought	Severe drought	Very severe drought	Total
Hamedan airport	4.12	1.02	2.12	0.41	0.19	2.72
Hamedan Nogheh	3.25	1.06	3.14	2.53	0.21	5.88
Kermanshah	5.62	2	2.12	3.56	0.11	5.79
Islamabad Gharb	14.13	13.35	14.07	4.36	0.25	18.68
Gankavar	6	0.21	1.12	0.64	0.01	1.77
Sarpolzahab	2.08	12.68	13.14	3.08	0.29	16.51
Ilam	2.03	3.03	2.1	1.32	0	3.33
Dehloran	1.04	2.07	1.03	2.08	0	3.11
Khorramabad	2.08	1.15	1.12	0.14	0	1.26
Aligodarz	1.09	2.13	3	1.39	0	4.39
Safiabad	3.01	3	1.07	1.12	0	2.19
Abadan	1.78	2.14	1.54	2.41	0	3.95
Dezful	6	1.33	2.33	1.10	0.09	3.52
Masjed soleyman	0.17	4	3.21	2.41	0.11	5.73
Ahvaz	4.09	1	1.25	1.08	0.08	2.41

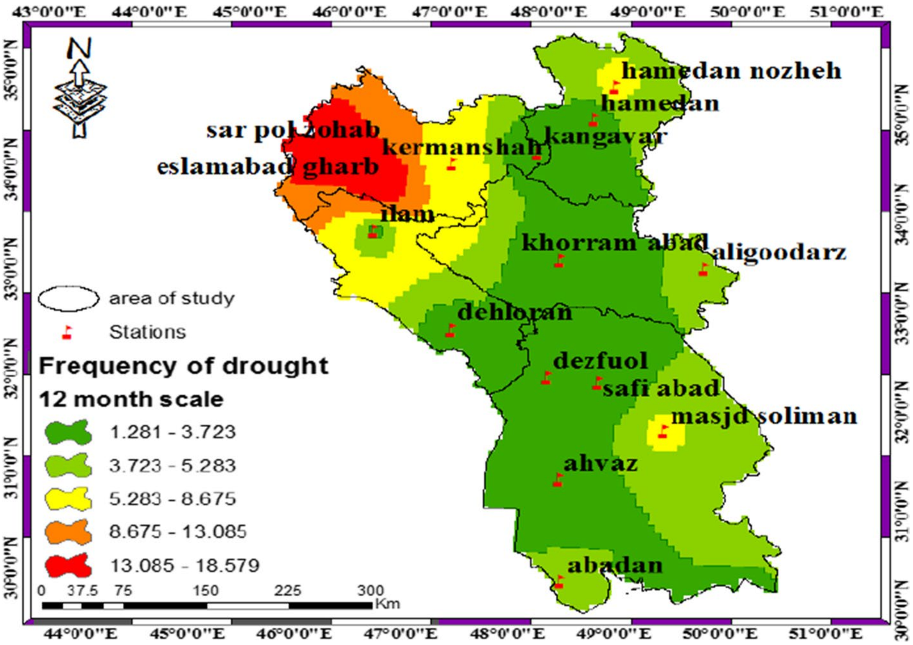

Fig. 6 Mapping of frequency per cent of drought occurrence in studied stations at a 12-month scale, in the statistical period (1987–2018)

3.2 Assessment of drought-affected areas based on the SAW model

Prioritization of the stations involved in drought was analysed using SAW model. To calculate and analyse 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. The results of the implementation of the SAW 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 which were identified by combining the 6- and 12-month scale. According to the SAW model, the north-western part of the study area was most exposed to drought. The three stations of Islamabad Gharb, Sarpolzahab and Hamedan Nogheh with priority values of 1, 0.86 and 0.26 were most affected, respectively, by the drought, and three stations of Khorramabad, Gankavar and Hamedan airport were rated as 0.01, 0.02 and 0.08, respectively, and had less priority for drought occurrence (Table 6 and Fig. 7).

4 Conclusion

Drought is a hazardous phenomenon in different parts of the planet, and its harmful effects are evident in the affected areas. One of these areas is South-West Asia, in which the west of Iran has been involved by it in recent years. Researchers conducted many

Table 6 Prioritization of drought in engaged stations based on SAW model and statistical period of 1987–2018

Station names	SAW values	SAW rating score
Hamedan airport	0.08	13
Hamedan Nogheh	0.26	3
Kermanshah	0.25	4
Islamabad Gharb	1	1
Gankavar	0.02	14
Sarpolzahab	0.86	2
Ilam	0.12	9
Dehloran	0.11	10
Khorramabad	0.01	15
Aligodarz	0.22	6
Safiabad	0.10	11
Abadan	0.15	8
Dezful	0.16	7
Masjed soleyman	0.25	5
Ahvaz	0.09	12

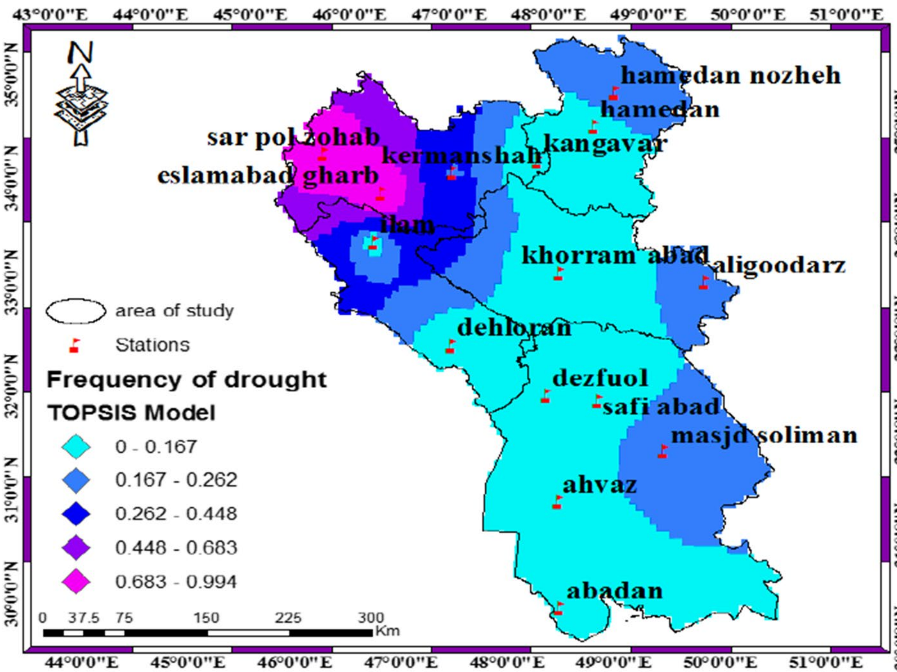

Fig. 7 Final map of areas affected by drought in the north-west of Iran based on SAW model during the statistical period (1987–2018)

studies to monitor drought in the west of Iran with different models, but they did not adequately cover the subject quality. The purpose of this study was to model and monitor the drought phenomenon in the west of 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 are more than 12-month scale, but drought persistence is more at 12-month scale. The drought was less continuous in the short term and affected by evapotranspiration parameters, while the intensity of drought in the long periods was 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 6- and 12-month scale has occurred in Sar-e-Pol-e-Zahab station. The percentage of drought frequency in Sanandaj, Sar-e-Pol-e-Zahab and Khorramdarreh 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 Saqqez.

Finally, based on the SAW multivariate decision-making model, Ilam station with a score of 1 was more exposed to drought and the Sar-e-Pol-e-Zahab station with a score of 0.04 was in the final priority exposed by drought. In this study, modelling and monitoring of the drought phenomenon were performed in the south-west of 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 Shamsinia et al., by study on drought modelling in Fars Province using time-series analysis; Mirzai et al. by research on the development of WEAP integrated water resource model for modelling drought conditions; Peiravi et al. in their study on the modelling of the drought effect on the total hardness and solids of groundwater solution in Mashhad plain; Adib and Gorgizadeh by drought monitoring using drought indices; by study on application of the drought index (CPEL) in determining the appropriate variables for the analysis of drought in Iran; Parsamehr and Khosravani in their study of drought determination using multi-criteria decision-making based on TOPSIS methods; Alizadeh et al. by research on the modelling of the droughts dispersion due to climate change in Iran by using a dynamical system; Zeinali and Safarian-Zengir by drought monitoring in Urmia Lake basin using fuzzy index; and Fathi-Zadeh et al. by study on the relationship between meteorological drought and solar variables in some of Iran's synoptic stations which confirmed the efficiency of the method. Also, the modelling performed in the present study about modelling and monitoring the drought phenomenon in south-western Iran using the new T.I.B.I fuzzy index had an acceptable efficiency.

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Compliance with ethical standards

Conflicts of interest There are no conflicts to declare.

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