Temporal and spatial analysis and monitoring of drought (meteorology) and its impacts on environment changes in Iran

Vahid Safarianzengir\textsuperscript{1} | Ahmad Fatahi\textsuperscript{2} | Behrouz Sobhani\textsuperscript{1} | Sahar Amiri Doumari\textsuperscript{3}

\textsuperscript{1}Faculty of Social Sciences, University of Mohaghegh Ardabili, Ardabil, Iran
\textsuperscript{2}Department of Agricultural Economics, Faculty of Agriculture and Natural Resources, Ardakan University, Ardakan, Iran
\textsuperscript{3}Department of Natural Resources, Ardakan University, Yazd, Iran

\textbf{Abstract}

The consequences of climate change, primarily due to natural and human factors, have caused many problems in the last decade that have affected different sections of society. One of the most important consequences is the occurrence of natural atmospheric—climatic disasters (drought). One of these regions is Iran in the Middle East, which has been suffering from this drought in the last decade. This investigation aims to evaluate and monitor drought and its impacts on environment changes in Iran. To conduct this research, the TERRA satellite data and the MODIS sensor were used over a 21-year period, and the Normalised Differential Vegetation Index and Palmer Drought Severity Index Indicators were used to monitor drought and to estimate the soil moisture by the Soil Moisture Calculation satellite. Finally, to estimate the amount of precipitation and evapotranspiration, cumulative precipitation and real evapotranspiration, actual evaporation and transpiration were used. Findings showed that in the investigation region, the severity and frequency of drought have increased in recent years. Soil moisture has also decreased, indicating the inverse relationship between drought intensity and soil surface moisture, meaning that as the intensity of drought increases, the amount of soil surface moisture decreases. However, in the investigation region during the study course, the accumulation of rain showed a direct relationship with evaporation and transpiration. The highest monthly drought intensity of Palmer was 5.65\% in May 2000. Also, the highest amount of wet year in November 2018 is 3.6\%. The highest amount of rainfall was 61.25 mm in October 2018. Based on the results obtained in this research, drought has occurred in the investigation region, the intensity of which in the south, eastern and centre half of the country, especially the provinces of south Khorasan, Semnan, Hormozgan, Sistan and Baluchestan, Khuzestan and Ilam more it has been more than other provinces. To manage and control drought in the investigation region, in the various sectors affected by drought (agriculture,
INTRODUCTION

Meteorological drought is an intricate natural hazard that has long created problems for human societies and has caused many problems in various social, economic and environmental fields. Drought is a decrease in rainfall from the long-term annual average of the region at a given time. Lack of water affects different sections of the life of living organisms. The decreased rainfall in recent years has been very effective by climate fluctuations (Li et al., 2007). Droughts are more ordinary in arid and semi-arid areas (Huang et al., 2015; Spinoni et al., 2015). One of these regions is Iran, in the Middle East, which in recent decades has been involved in natural hazards such as drought, which has led to problems in different sections of agriculture and horticulture, economic and social and catchment area and so on (Fanni et al., 2016; Tiuma et al., 2015). Drought and uncontrolled abstraction of groundwater in recent years has created many problems for the provinces of Iran (Alizadeh et al., 2017; Huajjun et al., 2017; Zeinali & Safarianzengir, 2017). These include falling groundwater levels, subsidence of the groundwater resulting from this decline, affecting water quality and things like the migration of villagers to cities, marginalization, unemployment and other social problems pointed out (Jinum & Jeonbin, 2017; Ostad-Ali-Askar et al., 2018; Xu & Luo, 2019). Iran country is located on the arid belt of the world and for this reason; vast areas of the central plateau of Iran are deserts and deserts (Safarianzengir et al., 2019; Sobhani et al., 2019a; Sobhani & Safarianzengir, 2019). A comprehensive look at the country's problems in the natural sector, indicating the problems of water shortage crisis, intensification of destructive floods and increasing its damage, soil erosion, frequent and prolonged droughts, over-harvesting of water resources, drainage of aquifers, negative balance is about 70% of the country’s aquifers and the risk of land subsidence in the major productive and residential plains of the country (Safarianzengir & Sobhani, 2020; Sobhani & Safarianzengir, 2020; Sobhani et al., 2019b). Drought is a creeping and calm calamity that causes devastation and damage such as drought, environment, economic and social (Danandehmehr et al., 2020; Mohammad et al., 2020; Mtilatila et al., 2020). Drought is also one of the most main natural disasters in agriculture and horticulture and water resources and catchment area. In the last decade, different areas of the world have witnessed much more severe droughts (Fanglei et al., 2020; Linhao et al., 2020; Maa et al., 2020). Also, drought is a natural hazard that occurs in all climatic conditions and in all regions of the world. Drought, as a climatic hazard, strongly impacts all aspects of human activities (Farrokhi et al., 2021; Pieter et al., 2020; TalebMorad et al., 2021). Drought has many direct and indirect effects on life, economic, social and environmental structure (Giri et al., 2021; Parmeshwar et al., 2021). However, these effects can be divided into two groups, direct and indirect. In societies whose economy is based on agriculture, the direct effects of drought appear in the form of reduced food production due to reduced cultivation and crop yields (Dariusz et al., 2021; Das et al., 2021). The impacts of drought and dryness on the environment in the study area can include consequences such as damage to animal species, including hydrological effects, including damage to plant communities, effects on air quality (soil and pollution), landscape quality and vision (vegetation and dust), infrastructure and welfare facilities and loss of life, including increase water and wind erosion, reducing soil quality, severe soil erosion due to unbalanced distribution of precipitation and irregularity in the ecological cycle and climatic conditions (Fooladi et al., 2021; Javadinejad et al., 2021; Rezaei, 2021). Accordingly, it is necessary and important to address this issue in the study area with an accurate and efficient method. Other domestic and foreign researchers have researched using different models in the field of drought, including; Ghasemi et al. (2017) in a study predicted drought with Standard Precipitation Index (SPI) and Effective Drought Index (EDI) indices by Adaptive Network-Based Fuzzy Inference System (ANFIS) modelling method in Kohgiluyeh and Boyerahmad Province. Bayazidi (2018) evaluated the drought of synoptic stations in the west of the country using Herbst's method and adaptive neural-fuzzy model. Torabipoudesh
et al. (2018) estimated drought using intelligent networks. Aktiarkajhe and Dinpejouh (2018) used the EDI to study the periods of drought. Zeleki et al. (2017) used SPI and Palmer Drought Severity Index (PDSI) and satellite data to investigate drought in Ethiopia. Quesada et al. (2018) examined hydrological changes in a consistent approach to assessing changes in floods and droughts. Jinum and Jeonbin (2017) studied the observed characteristics of drought based on the standard evapotranspiration index Standard Precipitation Evapotranspiration Index (SPEI) in central Asia. Modarresirad et al. (2017) examined the meteorological and hydrological drought in western Iran, and Kis et al. (2017) analysed dry and wet conditions by Regional Climate Model. According to the review of the research literature (temporal and spatial monitoring of drought and its effects) in the study area for monitoring and evaluation of drought, an individual drought index such as SPI, PNI, DI, CZI, MCZI, PNPI and so on, has been used more. In this study, using new, innovative methods of several drought indicators (Meteorology) based on remote sensing and satellite image indicators, drought was monitored and evaluated. First, Normalised Differential Vegetation Index (NDVI) and PDSI indices were estimated using satellite imagery MODIS and TERRA. Then, in order to better compare and analyse the output of the results of NDVI and PDSI drought indices, soil moisture was estimated using Soil Moisture Calculation (SMAP) satellite to provide a more accurate output and analysis for the study area in drought assessment. Based on the investigation conducted on the importance of drought and its hazards, in the case of the studied method, it can be acknowledged that the drought parameter is very important in natural hazards. According to the studies, the existing methods that have been done so far for studying the drought were general and have not been sufficient. The purpose of this research is to overcome this lack and to monitor and analyse drought to manage drought hazards in Iran, located in southwest Asia.

2 | MATERIALS AND METHODS

2.1 | Study area

Iran with a region of 1,640,195 km² in the southern half of the northern temperate zone between 25°03’ and 39°47’ N latitude of the equator and 44°05’ and 63°18’ E longitude of half Greenwhich’s is located. About 90% of the country’s territory is located in the Iranian plateau. Much of Iran, on the scale of general meridional currents, corresponds to the air subsidence zone. In this regard, in a uniform pattern of climate distribution, it is located in the desert regions of the world; however, climatic diversity in Iran is very high. Iran’s climate is located in the dry northern area and in the middle latitude on the earth in the equatorial region, Iran’s climate is dry and barren, Iran’s climate has a different climate and diverse climate. Having a temperature difference in Iran is one of the most obvious differences between Iran’s climate and other sections of the world. By comparing the climate of different parts of the country, we can well understand this diversity and temperature difference in these areas. So that the difference in temperature in winter between the hottest and coldest point of this land sometimes reaches more than 50°C. The location of the investigation region is presented in Figure 1.

2.2 | Research methodology

To conduct this research, the method of drought (meteorology) several indicators based on remote sensing was used. First, two drought indices NDVI and PDSI were extracted using satellite (MODIS) and (TERRA) and for further analysis and processing of the output of the mentioned indicators were transferred to ENVI 5.3 software. For accurate evaluation of NDVI and PDSI remote sensing indices, the output of both indices was compared with the soil moisture of the study area. To do this, soil moisture was calculated using the SMAP satellite using remote sensing data. Then, data related to satellite indicators used in this study were extracted from Moderate Resolution Imaging Spectroradiometer (MODIS) satellites and the Thermal Emission and Reflection Radiometer (TERRA) sensor using coding in the Google Earth Engine environment. The data were then transferred to the ENVI 5.3 software environment for processing, and finally ArcGIS software was used for further analysis and image output. To fully describe the working method of this study, all three drought (meteorological) indicators used are explained separately.

2.2.1 | Indicators based on satellite images

Normalised Differential Vegetation Index

The NDVI is widely used to distinguish healthy vegetated areas from unhealthy and uncovered areas. This index shows the condition of vegetation on the ground in large areas. The study of the temporal behaviour of vegetation, climate modelling, global vegetation classification, agricultural monitoring, desertification and drought studies, environmental protection, global energy and water balance study are among the applications of the NDVI index. How to calculate the NDVI index is the ratio
between the difference and the sum of the red bands (0.6–0.7 μm) and the near infrared (0.7–1.5 μm). Due to the fact that vegetation in the red visible band has the highest rate of absorption, and naturally the lowest rate of reflection and in the near-infrared band has the lowest rate of absorption and, consequently, the highest rate of reflection. The NDVI vegetation index is able to distinguish vegetation from other phenomena. In this method of satellite data processing, the identification of vegetation types is not monitored and is done with the opinion of experts. ENVI 5.3 software detects the amount of vegetation on the ground only based on the spectral reaction reflected from the ground and provides us with numerical values based on the amount of vegetation that indicates the percentage, amount or characteristics of vegetation on the ground. This plant index is known as one of the most famous, simple and practical plant indicators, which was first presented by Rouse et al. (1974) and Rahimzadeh et al. (2008, 2009). The NDVI is expressed as:

\[
\text{NDVI} = \frac{p_2 - p_1}{p_2 + p_1}
\]

In this equation, \(p_1\) is the red band and \(p_2\) is the infrared band near. \(p_1\) (RED band) and \(p_2\) (NIR band) are the reflection rates in bands two and one, respectively. This index has values between −1 and +1. Positive numerical values are related to dense vegetation and numerical value is 0 and values close to it are related to areas without vegetation and wet and watery places have figures close to −1. The usual range of green plant changes is 0.2–0.8 (Lim & Kafatos, 2002). The NDVI index is usually between 0.05 and 0.1 for thin plant areas, between 0.1 and 0.6 for normal and semi-dense plant areas and between 0.6 and 0.7 for very dense and rich plant areas (Hamzeh et al., 2017).

**Palmer Drought Severity Index**

The PDSI Index is calculated according to precipitation and temperature datum as well as the amount of soil moisture available Air Warning Center. Among the
computational inputs, all the main quantities of the water balance equation, such as evaporation-transpiration, soil nutrition, runoff and moisture losses from the surface layer, can be determined and calculated (Miller & Hays, 1994). Of course, the effects of human activities in this balance such as irrigation have not been considered. PDSI is not just a meteorological indicator, but more commonly called a Palmer Hydrological Drought Index (PHDI). Because its basis considers the current state of moisture (precipitation), the outflow and storage currents of moisture and long-term rivers (Guttman, 1991). Palmer introduced the PDSI index to track and demonstrate the impact of persistent drought (or wet year periods) on drought indices. His reason and motivation for developing the above index were that a wet month in the middle of a long-term drought did not have a significant effect, in other words, a series of months with near-normal rainfall after a severe drought did not mean the end of the drought (Guttman, 1991). Table 1 shows the Palmer drought intensity rating, which ranges from very high to very dry conditions.

**Soil moisture calculation**

Soil moisture meter Soil Moisture Active Passive US NASA (SMAP) operates in the microwave spectrum of the electromagnetic spectrum and, depending on the wavelength, can penetrate different through the cloud cover; however, microwave observations in the field of spatial separation are weak. The spatial resolution of most microwave sensors is at least one time smaller than visible and near-infrared sensors. The spatial separation of MODIS from the 250 m level and the scepticism of precipitation and soil moisture microwave is 10–40 km. Soil moisture observations provide the prerequisites for predicting large-scale drought events (Bindlish et al., 2009).

**Activated satellite mission for soil humidity**

The SMAP satellite was launched in the early morning hours of 31 January 2015 from Vandenberg Air Force Base off the coast of central California. The purpose of the latest satellite that NASA has launched into earth orbit is to measure and estimate the amount of water in the surface layer of the soil. The satellite's job is to gather information to help predict floods and droughts. The mission of the satellite is 3 years and its purpose is to track the amount of water in the soil so that it can help the inhabitants of low-lying areas to predict floods and reduce its damage, and farmers can use these data to prepare for drought conditions. The SMAP satellite measures the surface moisture of the earth's soil with coverage of 2–3 days. SMAP moisture measurements along with hydrological models are used to know the soil moisture status of different regions of the earth. Applications of SMAP: SMAP satellite observations are used to describe the hydrological and environmental processes affecting the terrestrial and atmospheric cycles of water, energy and carbon. SMAP data are used in hydrology, meteorological and climatic forecasts, water resources management and agriculture. The data of this satellite are also used in the management of hazards, such as fire, flood and drought monitoring, management and prevention of other unexpected events. SMAP satellite consists of two active and inactive radar and radiometric sensors. Using these two active and inactive radar and radiometry sensors simultaneously, NASA paved the way for the use of Synergistically Based Algorithms to calculate soil moisture at a spatial resolution of 9 km and a depth of 5 cm provided soil. The evaluation results of the radiation meter as well as the active/inactive product indicated the good performance of this sensor in the validation stations and achieved the goal of achieving a measurement accuracy of 0.04 m$^3$/m$^3$; this means that the sensor could measure up to at least 0.04 m$^3$ of water per cubic metre of soil. The first soil moisture map prepared by this satellite was prepared on 21 April 2015. Unfortunately, the satellite's radar sensor malfunctioned on 7 July of that year (a month and a half after imaging began). Despite many attempts to return the sensor to normal, it became virtually impossible to use it. Since then, NASA has tried to replace the satellite's radar sensor. The best option for this purpose was the Sentinel 1 satellite. NASA’s SMAP satellite mission is specifically designed and developed to map and monitor soil surface moisture (Entekhabi et al., 2010). The satellite also included a high-resolution L-band radar that simultaneously produced post-distribution measurements. An important development

| Drought classes               | PDSI values                  |
|------------------------------|------------------------------|
| Very intense moist year      | 4 or much                    |
| Intense moist year           | 3 to 3.99                    |
| Average moist year           | 2 to 2.99                    |
| Mild moist year              | 1 to 1.99                    |
| Somewhat moist year          | 0.5 to 0.99                  |
| Normal                       | −0.49 to 0.49                |
| Somewhat drought year        | −0.50 to −0.99               |
| Mild drought year            | −1 to −1.99                  |
| Average drought year         | −2 to −2.99                  |
| Intense drought year         | −3 to −3.99                  |
| Very intense drought year    | −4 or fewer                  |
in SMAP was the product introduction with increasing the spatial resolution to 9 km that it was achieved by combining active and inactive observations. This product with great scepticism supported a wider range of applications. The results of the optometry evaluation, as well as the inactive active product, indicated the good efficiency of this sensor in accreditation stations and provided the goal of accurately measuring 0.04 mm; that is, the sensor could measure at least 0.04 m³ of water in the per cubic metre of soil (Chan et al., 2016). With the continued work of radiation-meter and extensive accreditation, it has been shown that soil moisture information is provided with great quality. Currently, a variety of methods are being developed to increase the spatial resolution of the radiation meter. SMAP products are made available to two NASA data centres called NASA’s Alaska Satellite Facility and the US National Snow and Ice Data Center (Taghizadeh & Ahmadi, 2018).

3 | RESULTS AND DISCUSSION

After calculating NDVI and PDSI indices using TERRA satellite and MODIS satellite datum for a period of 21 years (1999–2019) and calculating soil moisture using SMAP satellite in Iran, the output is in the form of graphs and graphic maps obtained. At first, to investigate the vegetation situation in various areas of the country, daily data related to the NDVI index of the whole country during the mentioned 21 years were obtained, and finally, these data became the annual data of the NDVI index. Most drought assessment systems are based primarily on meteorological data. Meteorological datum can be used in conjunction with other data and information to estimate the potential impact of drought. The most important climatic parameters that are effective in assessing drought are precipitation and temperature parameters, which are more tools for measuring it than other climatic parameters. The results obtained from the NDVI index showed relatively high values of this index with different spatial distribution in all years in different areas of the investigation area (Iran). Surface temperature conditions fluctuate slightly, but large differences in the amount of vegetation in different months and lands with diverse vegetation in the study area can be the reason for this. Since the eastern, central and southern provinces of the research region are relatively arid areas with moderate to low vegetation, agricultural lands and pastures are used separately in satellite images. According to the results of the monthly monitoring of the changes in cumulative rainfall, the fluctuation of the time series has been decreasing very gently. The winter and spring rains have been increasing, while the summer and autumn rains have been decreasing. According to the findings, the highest values of cumulative rainfall during the study period of 21 years (1999–2019) in January 2004 was with a cumulative rainfall of 57.14 mm, in January 2005 with a cumulative precipitation of 55.12 mm, in February 2017 with the amount of cumulative rainfall of 59.75 mm and in October 2018 with the amount of cumulative precipitation of 61.25 mm (Figure 2). According to the findings obtained from the actual evaporation and transpiration, its findings are consistent with cumulative precipitation. This means that the amount of evaporation and transpiration (AET) has increased during periods of increased precipitation. According to the results of the study of actual evaporation and transpiration during the study period of 21 years (1999–2019), the highest amount of actual evaporation and transpiration in march 1999 was 47.87 mm, the highest amount of actual evaporation and transpiration related to march 2005 with a value of 43.39 mm, also the highest amount of actual evaporation...
and transpiration with a value of 46.65 mm is related to October 2017. Finally, the highest amount of actual evaporation and transpiration was obtained with the amount of 44.52 mm related to May 2018 (Figure 3). Due to the outputs related to cumulative precipitation and evaporation and real transpiration, these two components were directly related to each other, that is, as the amount of precipitation increases due to the rising temperature in recent years, the amount of actual evaporation and transpiration also increases. Also, the higher the amount of vegetation, the greater the amount of actual evaporation in the research region. Considering the amount of drought and dryness monitoring with the palmer index on an annual scale, the severity of the drought and dryness has increased in recent years. Accordingly, the highest values of drought are related to 2000, 2001, 2008 and 2018 with the values of −5.65%, −4.89%, −4.74% and −5.54%, respectively (Figure 4). Given the output of these indicators, which was annual, considering its monthly monitoring form in zoning, more accurate results can be obtained. For this aim, the palmer drought index was calculated every month and zoning.

To monitor the drought in the investigation area using the palmer drought index, the study period was divided into four 5-year periods due to the long study period of 21 years (1999–2019). Also, to obtain a more accurate answer, namely high-precision drought monitoring, surface moisture was estimated using soil moisture meter (SMAP). In the first 5 years (1999–2004), the highest amount of drought is related to May 2000 with the rate of −5.65% of drought and the lowest amount of drought, that is the highest amount of way year is related to December 2004 with 1.02% of drought (Figure 5). According to the output of SMAP measuring images, the

**FIGURE 3** Monitoring diagram of actual evapotranspiration changes according to TERRA datum during the course (1999–2019)

**FIGURE 4** Monitoring of annual changes in drought index (PDSI) according to TERRA datum during the course (2000–2019)
results obtained from soil surface moisture in the same areas, namely the central, semi-eastern and northwestern parts, the soil surface moisture intensity have decreased, that is, as the amount and severity of drought increases, the amount and severity of surface moisture decreases (Figure 6a). Based on the output of TERRA satellite images of the semi-eastern, southern and northwestern regions near Lake Urmia, the study area had the maximum drought intensity (Figure 6b). In the second 5 years (2005–2009), the highest amount of drought is related to May 2000 with a rate of $-4.70\%$ of drought and the lowest amount of drought, that is the highest amount of wet year is related to February 2005 with $1.87\%$ of drought (Figure 7). According to the output of SMAP sensor
images, the results obtained from soil surface moisture in the same areas mentioned, that is, the western parts (Kermanshah and Ilam provinces), southeast (Zahedan and Kerman) and northwest (Ardabil and east Azerbaijan provinces), soil surface moisture intensity decreased. In other words, in the study area, drought has been more severe during this period than in the first 5 years (1999–2004). Similarly, the amount of soil surface moisture has decreased (Figure 8a). Based on the output of TERRA satellite images of the southeastern and northwestern regions (east Azerbaijan region and Ardabil province) and the western half near Kermanshah and Ilam provinces, the highest frequency and intensity of drought were included (Figure 8b).

In the third 5 years (2010–2014), the highest amount of drought was in January 2011 with −3.96% of drought
and the lowest amount of drought, that is, the highest amount of wet year is related to December 2012 with 1.44% of drought (Figure 9). According to the output of SMAP sensor images, the results obtained from soil surface moisture in the same areas, that is, the centre and semi-east sections of the investigation area and south of Lake Urmia, soil surface moisture has decreased. That is, as the amount and severity of drought increases, the amount and severity of surface moisture decreases (Figure 10a). Based on the output of TERRA satellite images, the semi-western regions (Kermanshah, Ilam and Lorestan provinces), the southeast (Zahedan region) and the northwest around Ardabil province and the eastern and southern regions of Lake Urmia included the highest amount of drought intensity (Figure 10b). In the fourth 5 years (2015–2019), the highest amount of drought is related to March 2018 with a rate of 5.54% of drought and the lowest amount of drought, that is, the

![Monitoring changes in monthly drought index (PDSI) according to TERRA datum during the course (2010–2014)](image)

**FIGURE 9** Monitoring changes in monthly drought index (PDSI) according to TERRA datum during the course (2010–2014)

![Drought abundance zoning map of the drought index (PDSI) and soil moisture during the course (2010–2014)](image)

**FIGURE 10** Drought abundance zoning map of the drought index (PDSI) and soil moisture during the course (2010–2014)
highest amount of wet year is related to November 2018 with 3.68% of drought (Figure 11). According to the output of SMAP sensor images, the results obtained from soil surface moisture in these areas, that is, the central and south sections of the research region, soil surface moisture, have decreased, that is, as the amount and severity of drought increases, the amount and severity of surface moisture decrease (Figure 12a). According to the output of TERRA satellite images, the semi-southwestern regions (Khuzestan, Ilam and Chaharmahal Bakhtiari provinces), the central part (Isfahan and Semnan region) and the northeast (around north Khorasan province)
included the highest frequency and intensity of drought (Figure 12b).

The average rainfall in the water year 2020–2021 compared to 2019–2020 has decreased by 50% and in the eastern half of the country, the shortage of cumulative rainfall in the recent wet year was reduced by more than 70% compared to the previous wet year. Eastern provinces such as Sistan and Baluchestan, Hormozgan, Kerman, South Khorasan, Razavi Khorasan and North Khorasan had between 50% and 70% less than normal rainfall in the recent wet year. Continuation of low rainfall in the study area for more than one season causes drought and gradually increases the duration of drought with prolonged low rainfall. Last rainy years, all provinces of the country received less than normal rainfall, and severe to very severe drought has prevailed throughout the country. Severe drought in the study area reduces production or lack of harvest and poor quality and insufficient growth of agricultural products in large areas of the country. Also, the reduction of river water discharge has reduced farmers’ crops and damage to the environment and wildlife. Most of the country’s lakes will dry up, and in the hot season, forest fires will be more extensive and intense. The impacts of drought on water resources in the research region can cause a sharp decline in groundwater aquifers, the destruction of groundwater aquifers, endangering the condition of wells in the area, the invasion of pests and plant diseases, water salinity and be arable lands. To manage drought in the study area, pre-drought strategies such as drought forecasting, cultivation of drought-resistant plants and cultivation of plants with low water requirements can be used. And solutions during the drought crisis, such as identifying capacities to deal with drought waste, holding consultative meetings with experts and operators and preparing a water supply plan in the research region acted. Drought in the investigation area will lead to lack of access to water, environmental degradation, depletion of surface water, death of animal and plant species, desertification and dust, will reduce crops. Drought and climate change are serious and, of course, global issues; the most important action that the people and the government can take in the study area is to adapt to water scarcity and to develop activities commensurate with the available water capacity, while respecting the right to environmental water. After a long period of meteorological and hydrological drought, its socio-economic effects reduce agricultural production and mass migration. This type of drought has great effects on various economic dimensions, especially certain types of economic products and goods. Decreased water quality has a negative impact not only on drinking water sources but also on natural ecosystems that are dependent on water resources.

3.1 Discussion and validation of research results

This method is known in most studies as a suitable method for monitoring, analysis and comparison, including Mirzaei et al. (2015) in the research of developing an integrated model of water resources (WEAP) for modelling drought conditions. Peiravi et al. (2015) in their study entitled modelling the effect of drought on the total hardness and solids of groundwater solution in Mashhad plain; a theoretical drought classification method for the multivariate drought index based on distribution properties of standardised drought indices (Hao et al., 2016); Adib and Gorjizadeh (2016) in the study and monitoring of drought using drought indicators; decreasing spatial variability of drought in southwest China during 1959–2013 (Liu et al., 2017); Zolfaghari and Nourisamal (2016) in a research on the application of drought index (CPEL) in determining appropriate variables for drought analysis of Iran; Parsamehr and Khosravani (2017) in the research to determine the drought using multi-criteria decision making based on TOPSIS; and finally, Fathizadeh et al. (2017) examined the relationship between meteorological drought and solar variables in some of Iran's synoptic stations and confirmed the efficiency of the models used. However, with the comparisons made, the methods used in this study, namely the analysis and monitoring of drought to manage drought hazards in Iran, had acceptable efficacy. According to the accepted and accurate results obtained from the present study and compare it with the findings of other researchers, and high confidence percentage of remote sensing drought indices used, it is suggested that these remote sensing indicators used in this study be used in other areas affected by drought.

4 Conclusion

Considering the specific climatic conditions of Iran and the climatic conditions of arid regions, it is not possible to use the same methods and indicators to study drought and expect exactly the same results. Therefore, the relationship between each of the satellite indicators and drought in each region should be studied separately and for each region, depending on the specific climatic conditions and vegetation, selected the appropriate index for drought monitoring. Drought is one of the natural disasters that occur gradually and under the influence of weather elements in a long time. In the recent decade, different sections of southwest Asia, including Iran, have experienced drought. In this study, drought analysis and
monitoring were performed to manage drought hazards in Iran. MODIS and TERRA data were used for this purpose. The NDVI and PDSI indices were also used to monitor changes in drought and, finally, SMAP was used to estimate soil moisture. The research findings showed that the highest amount of cumulative precipitation with 61.25 mm was obtained in October 2018, while the highest actual evaporation and transpiration during the 21-year study period (1999–2019) was related to March 1999 with an amount of 47.87 mm. Based on the outputs obtained from the cumulative precipitation rate and the actual evaporation and transpiration, the results indicated a direct relationship between these (accompanied by an increase in air temperature) of the two components. The results of annual drought monitoring with the Palmer drought index have led to an increase in drought components. The results of annual drought monitoring with the Palmer drought index have led to an increase in drought in recent years, with the highest amount during the study period (1999–2019) is related to 2000 with a rate of −5.6% of the PDSI drought index. In the monthly monitoring of drought using the Palmer index, the highest amount in the first 5 years of the monthly investigation course (1999–2004), related to May 2000 with a rate of −5.6%, while the lowest amount of monthly drought or the highest amount of wet year, the monthly rate for the fourth 5 years of the monthly study period (2015–2019) is 3.68% related to November 2018. According to the results obtained from SMAP sensor for estimating soil surface moisture, the amount of soil surface moisture in recent years has been greatly reduced and this intensity has been more intense in the warm months of the year. Also, there is a reverse relationship between soil surface moisture intensity and drought intensity. Dry analysis and monitoring to manage drought hazards in Iran were conducted in this study. By having images of vegetation indices in longer years, we can understand a better trend of drought in the country. On the other hand, comparing the conditions obtained from this research to the real conditions shows the high power of estimating the vegetation status and drought conditions in different regions. Overall, it can be concluded that the combined drought indices used in this study based on TERRA, MODIS and SMAP satellite imagery can be a good alternative, for meteorological drought indicators to estimate, especially in areas with limited and missing meteorological parameter data. According to the trend of rising temperatures and climate change in the short term is not a solution to adapt to existing resources and water scarcity in the study area. Therefore, the officials and those involved in the water crisis at the current stage should not have a cross-sectional and immediate view. Rather, they should prevent the spread of a drought crisis based on emergency response and the development of a regular and ongoing long-term plan for preparedness and prevention.

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AUTHOR CONTRIBUTIONS
Vahid Safarianzengir: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; software; writing – review and editing. Ahmad Fatahi: Validation; visualization; writing – original draft; writing – review and editing. Behrouz Sobhani: Conceptualization; data curation; formal analysis. Sahar Amiri Doumari: Project administration; supervision; validation; visualization; writing – original draft; writing – review and editing.

ORCID
Vahid Safarianzengir https://orcid.org/0000-0001-5259-0231

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