مجله علمی‌پژوهشی مهندسی اکوسیستم بیابان
دورهٔ ۱۳، شمارهٔ ۳ (پیاپی ٤٤)، پاییز ۱٤۰۳، صفحه ۳۵ـ٤۸
مقاله پژوهشی

# Drought events monitoring in Iran over the past half century

**Fatemeh Dargahian[1], Mehdi Doustkamian[2], Somaye Heydarnezhad[3]**

Received: 06/10/2024 Accepted: 25/01/2025

## Abstract

Iran, due to its geographical location, has low rainfall and is considered a dry land. As a result, different regions of the country grapple with drought. The presence of water management systems, such as aqueducts and reservoirs, in most parts of the country, along with a variety of methods for conserving water for irrigation, may contribute to this claim. Considering that drought is an inherent phenomenon in Iran's climate, people have invented and used numerous methods to combat it and store water. The aim of this study is to monitor and evaluate drought in Iran. In order to realize this goal, precipitation data from synoptic, rain gauge, and climatology stations were extracted over a 51-year period, from 1970 to 2020. The results obtained from examining drought occurrences in five ten-year periods reveal that, with the exception of the third decade (1991 to 2000), drought has prevailed in the majority of Iran's regions compared to other decades. On the other hand, in the recent decades leading to 2020, the intensity of drought occurrences, especially in the Middle Zagros, has intensified, which has consistently been among the regions with the highest rainfall in Iran after the Caspian region. This situation can cause concern in Iran, a country where its agricultural production hub is established along the Zagros mountain range. Moreover, the fluctuating behavior of Iran's droughts, with return periods of 2 to 5 years, has complicated the management strategies for these types of hazards. These conditions appear to have created numerous issues in many areas of Iran, particularly in the agricultural sector of the western provinces, due to the lack of conformity with these types of occurrences.

**Keywords:** Drought monitoring, fluctuation, trend, periodic changes, Iran.

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1 Associated Professor Research institute of Forests and Rangelands, Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran.
2Ph.D of Climate change - Zanjan University
3. Desertification Researcher, Lorestan Agricultural and Natural Resources Research and Education Center, Iran.

Doi: 10.22052/deej.2025.255379.1073

## Introduction

Drought is a transient and reversible state of the climate, which unfortunately many mistakenly perceive as a random and rare phenomenon (Alizadeh et al., 2016). This phenomenon has the potential to occur in all climatic regions; however, its characteristics are different in various regions. (Karimi Nazar et al., 2009). Drought is a transient disruption and is distinct from arid lands, because arid lands are solely limited to areas with meager rainfall and constitute a permanent state of a region's climate. (Farjazadeh & Ahmadian, 2014). In opposition to aridity, which is a permanent phenomenon in arid climates, water scarcity also occurs in both arid and humid climates and is considered a natural condition in the climate. (Sultani & Saadati, 2006). To date, a precise and comprehensive definition of the drought phenomenon that is universally accepted has not been presented (Reddy et al., 2021), and the lack of a precise and globally agreed-upon definition of drought has added to the complexity and obscurity of this phenomenon (Hao & AghaKouchak , 2014). Researchers consider drought to be caused by a lack of rainfall over a continuous period of time. (Smakhtin & Hughes, 2004). In most definitions, drought refers to a continuous and stable period during which the amount of water available in an area decreases significantly (Bodner, et al, 2015). In the event of the occurrence or intensification of drought anywhere on Earth, numerous factors, including the establishment of high-pressure cells, ocean surface temperatures, teleconnection patterns, sunspots, albedo coefficient, western long waves, winds, and human activities, come into effect (Azizi, 2000). Drought is among the imperceptible natural disasters that not only exert diverse effects on living organisms, particularly plants and their species, but also its effects on microorganisms, animals, and humans are observably tangible (Carrão et al, 2016). In order to provide an operational definition of drought, it is necessary to categorize it into three types of meteorological, agricultural, and hydrological drought based on the level of effects (Salehovand et al., 2014). In conducted studies, precipitation is considered the most important parameter used in defining drought indicators; accordingly, drought and wet years are evaluated based on the amount of precipitation compared to the average precipitation of a region (Kebede, 2019). Some definitions of drought consider daily, weekly, or periodic rainfall. It appears that such definitions do not correspond with Iran's climatic conditions. Since rainfall is absent in most regions of Iran during various seasons of the year, defining drought as a short-term period of several days is not feasible (Zare Abianeh, 2013). The SPI index is capable of being used across diverse time scales (short term and long term) for agricultural, hydrological, and spatial purposes, at micro and macro levels. Moreover, the results of numerous studies have validated the effectiveness of the combined use of the SPI and SPEI indices in diagnosing the onset, monitoring, and forecasting of drought (Nasaji-Zavareh et al., 2021).

The study of meteorological drought in Iran using SPI and SPEI indices demonstrated that short-term droughts are more prevalent in the northwest and north regions, while long-term droughts are more prevalent in the south, southwest, and southeast regions (Sharafati et al. 2020). An examination of the advantages and disadvantages of 5 indices, SPI, RDI, RAI, ZSI, and SPEI, in drought monitoring in Turkey yielded the following results: the SPI and ZSI indices exhibited similarity, and the RDI and SPEI indices demonstrated correlation (Katipoğlu, et al., 2020). In the research on drought in Iran, the RAI rainfall anomaly index is employed as an alternative to the SPI standardized precipitation index (Khanmohammadi et al., 2022). A review of 10 drought indicators in the Ceyhan River basin of Turkey demonstrated that the SPI, SPEI, and RDI indicators possess a high correlation with one another (Yuce & Esit, 2021). SPEI differs from SPI in the quantification and characterization of drought. And the use of SPEI and SPI in assessing drought in diverse climates possesses the capability to be generalized to the entire country (Sadeghi & Sharafi, 2023). A comprehensive review of applied drought indicators demonstrated that, regarding drought indicators based on Iran's meteorological and hydrological data, local linear and non-linear regression statistical modeling is necessary, considering Iran's unique climates and a multivariate index. An Iranian drought index should be introduced, which will certainly produce more valuable results (Saeediyan, 2022). An explanation of the spatial patterns of drought intensities in Iran demonstrated the formation of spatial clusters of severe and very severe droughts in the northwest, northeast, and particularly the Caspian coast, which is considered a serious warning. This is particularly noteworthy in the area of water resource management and precipitation-based activities, such as agriculture (Heidari et al., 2023). Decadal changes in drought also demonstrate that in recent decades, the duration and scope of drought in Iran have increased, whereas the severity of drought has decreased (Torabinezhad et al., 2023). The increase in index intensity and the scope of drought during the autumn season can suggest a shift in the precipitation regime. Conversely, the increase in the scope of drought, particularly severe droughts during Iran's two primary rainfall seasons (winter and spring), is considered a critical warning for water resource management during the hot season (Karimi & Heidari, 2023). An examination of the probability of drought occurrence and the selection of the most suitable index in Iran's climatic regions indicates that the application of uncertainty management methods, such as cloud theory, improves the capability to predict the probability of drought in the future (Salimi et al., 2023). The spatiotemporal changes in Iran's predicted drought characteristics indicate that, on average, Iran will encounter heightened variations in drought severity in the future (sharafati et al., 2022). Drought imposes destructive effects on surface and subsurface water resources, agriculture, economic conditions, and generally all facets of life (Khairi et al.: 2021). Notwithstanding the occurrence of drought in almost all climates, this phenomenon assumes heightened significance in arid and semi-arid regions like Iran (Ghorbani et al., 2019). In consideration of the vital role of water in human life, it is imperative that the characteristics of drought be studied for each region. (Nikbakht et al., 2021). Drought monitoring is a system through which climatic and hydrologic parameters and their changes are continuously monitored, and the probability of drought intensity and scope is estimable. The overall objective of drought monitoring is to prepare and provide information that motivates individuals and responsible organizations to undertake actions that enhance planning reliability and mitigate damages caused by drought.

## Data and methodology

The objective of this study is to analyze the situation of droughts in Iran over the recent half-century. In this research, to analyze the situation of droughts in Iran, daily precipitation and temperature data from synoptic (411 precipitation and temperature stations), rain gauge (3303 precipitation stations), and climatological (546 precipitation and temperature stations) stations were extracted over a 51-year period (1970-2020), and their spatial distribution is displayed in Figure 1.

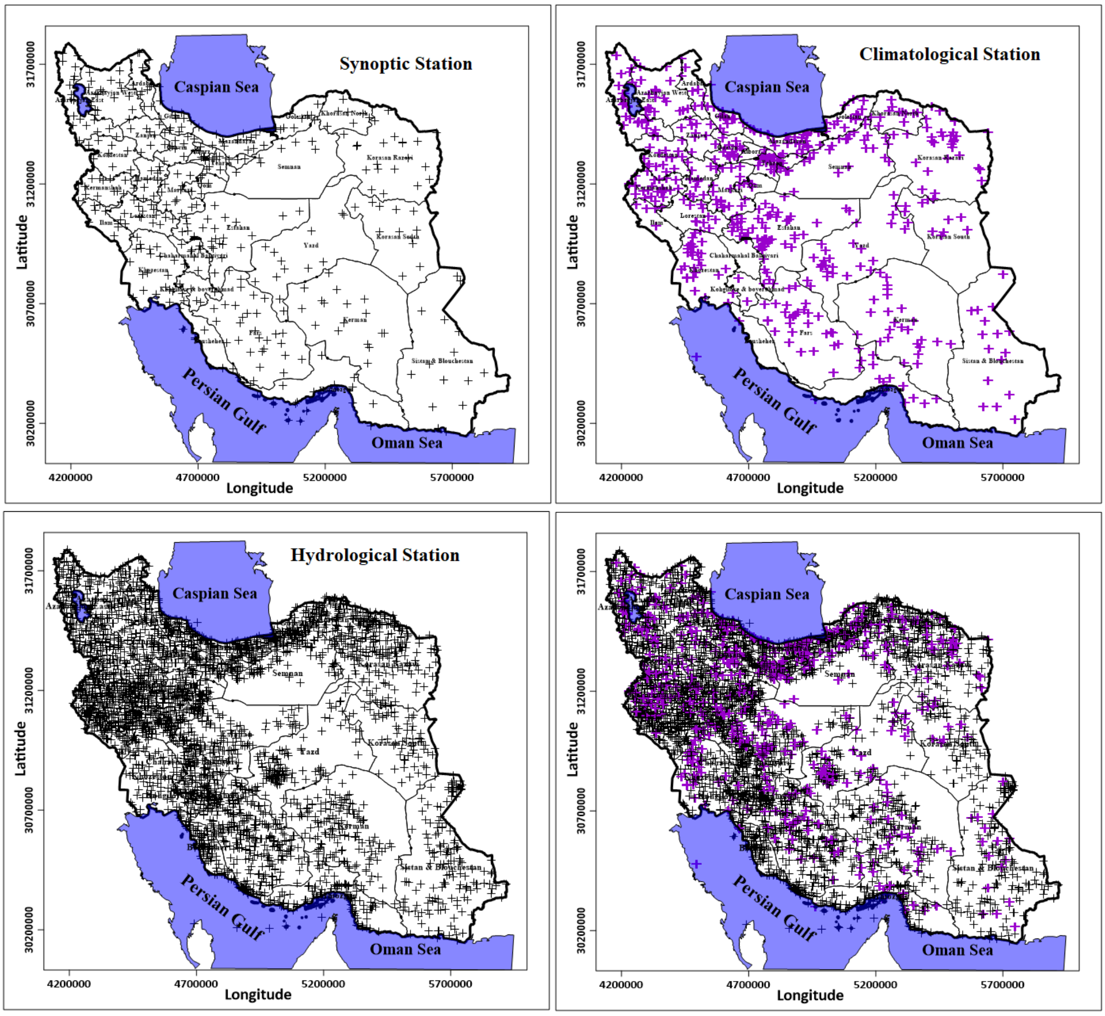

**Figure (1): Geographical location of the Study points…**

The stations located within the study area possess deficiencies in terms of time and space. As an example, some stations are active on certain days, and others are active on different days, and precipitation stations are not established at certain altitudes. On the other hand, climate data is predominantly measured at points, i.e., observation stations, whereas we frequently require climate information at a regional level. Consequently, the results of a climate analysis will be generalizable to extensive areas when interpolation is accepted as an integral component for converting point data to regional data. Interpolation is a process wherein quantitative values are estimated for data-deficient points, employing nearby, known measurement points (designated as locations, samples, or observations). This transformation using samples is possible when a relationship exists between the value of a sample and the values of its adjacent samples. In this situation, mediation will be possible. By employing valid evaluation methods, the kriging method was identified as the best interpolation method. Additionally, a grid with dimensions of 4260x18628 was selected for each daily rainfall map. Consequently, 18,628 daily maps with 30,459 cells were formed. The cell value for the aforementioned maps has been formed as a 30459x51 matrix at the annual scale. This matrix served as a basis for subsequent calculations. After creating a database, the SPEI index was utilized to calculate the drought index. Finally, by calculating the SPEI index, a matrix with dimensions 51x30459 was formed. Following the extraction of this index, the Mann-Kendall method was employed to examine the trend of drought severity, and spectral analysis was employed to examine the fluctuations governing drought.

The SPEI index fulfills the requirements of a drought index, as its multi-scalar nature facilitates its use by different scientific disciplines to identify, monitor, and analyze droughts. However, a fundamental advantage of the SPEI over other prevalent drought indices that consider the effect of PET on drought severity is its multi-scalar characteristics, which facilitate the identification of different drought types and impacts within the context of global warming. In the original version of the SPEI, we employed the Thornthwaite equation (Thornthwaite, 1948), which was employed to obtain the SPEI base v1.0. In the SPEI base v2.0, we utilized the FAO-56 Penman-Monteith equation (Allen et al. 2011). With the determination of the PET value, the difference between precipitation (P) and PET for month i is calculated.

$$D_i = P_i - PET_i \tag{1}$$

Which provides a simple measure of water surplus or deficit for the analyzed month.

The calculated Di values are aggregated at various time scales, following the same procedure as for the SPI. Selection of the most suitable statistical distribution to model the D series was difficult, given the similarity among the four distributions (Pearson III, Lognormal, Log-logistic, and General Extreme Value). The selection was made based on the behavior at extreme values. The log-logistic distribution demonstrated a gradual decrease in the curve for low values, and consistent probabilities were obtained for very low values of D, corresponding to 1 occurrence in 200 to 500 years. Additionally, no values were observed below the distribution's origin parameter.

The probability density function of a three-parameter Log-logistic distributed variable is expressed as:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left(1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right)^{-2} \tag{2}$$

where $\alpha$, $\beta$ and $\gamma$ are scale, shape and origin parameters, respectively, for $D$ values in the range ($\gamma > D < \infty$). Parameters of the Log-logistic distribution can be obtained through various procedures. Among them, the L-moment procedure is recognized as the most robust and straightforward approach. ( When L-moments are calculated, the parameters of the Log-logistic distribution can be obtained following: (Singh et al., 1993):

$$\beta = \frac{2W_1 - W_0}{6W1 - W_0 - 6W_2}$$

$$\alpha = \frac{(W_0 - 2W_1)\beta}{\Gamma(1+\frac{1}{\beta})\Gamma(1-\frac{1}{\beta})}$$

$$\gamma = W_0 - \alpha\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right)$$

where $\Gamma(\beta)$ is the gamma function of $\beta$. In Vicente-Serrano et al (2012), when the log-logistic $\alpha$, $\beta$ and $\gamma$ distribution parameters were calculated, the probability weighted moments (PWMs) method was used, based on the plotting-position approach (Hosking, 1990), where the PWMs of order s are calculated as:

$$w_s = \frac{1}{N}\sum_{i=1}^{N}(1-F_i)^S D_i \tag{3}$$

where N is the number of data, $F^i$ is a frequency estimator following the approach of Hosking (1990) and Di is the difference between Precipitation and Potential Evapotranspiration for the month i. nevertheless, It was observed that the use of Plotting Position formulas leads to a significant change in the standard deviation of the SPEI series as a function of the SPEI time-scale, which affects the spatial comparability of the SPEI values. In contrast, if the PWMs are calculated through the unbiased estimator provided by Hosking (1986), the standard deviation of the series remains constant across different SPEI time scales. The unbiased PWMs are calculated as follows:

$$w_s = \frac{1}{N}\sum_{i=1}^{N}\frac{\binom{N-i}{s}D_i}{\binom{N-1}{s}} \tag{4}$$

This method also resolves the issue of the SPEI model not having a solution in certain regions of the world. For these reasons, we recommend SPEI calculation using Unbiased PWMs. The probability distribution function of D according to the Log-logistic distribution is then provided as follows:

$$F(x) = \left[1 + \left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \quad (5)$$

With F($x$) the SPEI can easily be obtained as the standardized values of F($x$). For example, following the classical approximation of Abramowitz and Stegun (1965):

$$SPEI = W - \frac{C_0 + C_1W + C_2W^2}{1 + d_1W + d_2W^2 + d_3W^3} \quad (6)$$

$$W = -2\ln(P)$$

for $P \leq 0.5$, $P$ being the probability of exceeding a determined $D$ value, $P$=1-F($x$). If $P>0.5$, $P$ is replaced by $1-P$ and the sign of the resultant SPEI is reversed. The constants are: $C0$=2.515517, $C1$=0.802853, $C2$=0.010328, $d1$=1.432788, $d2$=0.189269, $d3$=0.001308.

The average value of the SPEI is 0, and the standard deviation is 1. As a standardized variable, the SPEI can be compared with other SPEI values across different time and space intervals. An SPEI of 0 indicates a value corresponding to 50% of the cumulative probability of $D$, under a Log-logistic distribution.

## Discussion

Figure 1 illustrates the spatial distribution of wet and dry years in Iran over five distinct periods: 1970–1980, 1980–1990, 1990–2000, 2000–2010, and 2010–2020. During the first period, arid regions were scattered across various parts of the country. These dispersions extend from the northwest to the southeast of the country. The extent of these areas is broader in the eastern half and in the desert regions. During this period, moderate and severe droughts occurred in the country. 20.2% of the country's area was affected by drought (Table 1).

During this period, moderate and severe droughts occurred in the country. 20.2 percent of the country's area was affected by drought (Table 1). In the same period, 39 percent of the country's area experienced moderate and severe wet periods (Table 2). Wet periods often occurred in the northern and southwestern regions of the country. A large area in the southeast of the country experienced moderate drought. In the second period, a significant change in the condition of wet and dry years is observed throughout the country. In this period, moderate and severe droughts, as well as moderate and severe wet years, have prevailed in various regions of the country.

The areas experiencing drought in the previous period in the northwest have transitioned to areas with wet conditions. In the southwest of the country, the wet years of the first period have shifted to a normal situation, and in parts of the southeast, drought has prevailed. In this period, the area affected by drought has increased by 7% compared to the first period, and the area with wet conditions has decreased by approximately 11%. In the third period, a significant portion of the country experienced wet conditions, with dry areas observed scattered across the northwest, northeast, central, and western regions. All southern coasts and eastern areas experienced wet years. During this period, only 1.9% of the country's area was affected by drought (Table 1). In the fourth period, in contrast to the third, drought expanded to large parts of the country. The central regions of the country, including Isfahan, Yazd, and Semnan, experienced dominant wet conditions. In small and scattered areas in the north and northwest, wet conditions prevailed. It is important to note that severe drought occurred in very small and scattered areas, while the majority of the country experienced moderate drought.

In the fifth period, a significant portion of the country is experiencing drought conditions. In contrast to the previous period, severe drought is also observed in many parts of the country. In the northwest, a small part of the center, as well as a part of Kerman province, moderate to severe drought has prevailed. Drought has intensified in the southwestern part of the country, specifically in the provinces of Khuzestan, Kohgiluyeh and Boyer-Ahmad, Chaharmahal and Bakhtiari, Bushehr, and Fars. The drought in the southwestern regions of the country can be attributed to the displacement of cyclone entry paths to higher latitudes. These cyclones play a significant role in rainfall in these areas. Droughts in the southeast of the country can be attributed to the reduction of monsoon rainfall in these regions. In summary, the third period was the wettest period, and the fifth and fourth periods were the driest periods within the studied timeframe.

With this description, it can be acknowledged that drought has become the dominant phenomenon of Iran's climate in recent decades. To the extent that in the fifth decade, only a quarter of the country's area was in normal and wet conditions. This issue can be regarded as a consequence of global warming in recent decades. As studies indicate, in certain regions, warming caused by greenhouse gases results in an increase in surface temperature, enhanced evapotranspiration, reduced soil moisture, and an increased frequency of droughts.

Figure 2 displays the severity of moderate droughts over 5 decades at the provincial scale. As is evident, moderate drought has been prevalent in most provinces during each of the 5 decades. Throughout the first to third decades, the severity of moderate drought in some provinces was at its lowest level. However, in the fourth and fifth periods, the severity of moderate drought increased in most provinces. The fifth period exhibited the most severe moderate drought. Only in East Azarbaijan province did the rate of moderate drought decrease compared to the previous four periods. Ilam province experienced a severe drought in the fourth period. Figure 3 illustrates the severity of severe droughts over 5 decades at the provincial level. This type of drought is also observed with varying degrees of intensity across all periods in different provinces. In the fourth period, severe drought was at its lowest intensity (almost in all provinces). The highest values related to severe drought were recorded in the fifth period. The most severe instances of severe drought occurred in the provinces of Kohgiluyeh and Boyer-Ahmad, followed in descending order by Bushehr, Khuzestan, Fars, and Isfahan. East Azerbaijan province did not experience severe drought during this period.

**Table (1): Percentage covered by drought during different periods in Iran**

| period | Normal (in the Drought direction) | Moderately Drought | Severely Drought | Extremely Drought | Total percent Drought |
|---|---|---|---|---|---|
| 1970-1980 | 19.1 | 17.7 | 2.5 | 0 | 20.2 |
| 1981-1990 | 24.6 | 23.6 | 3.5 | 0 | 27.1 |
| 1991-2000 | 9 | 8.7 | 0.8 | 0 | 9.1 |
| 2001-2010 | 23.1 | 44.3 | 1.7 | 0 | 46 |
| 2011-2020 | 9.6 | 56.9 | 19.1 | 0 | 76.1 |
| 1970-2020 | 28.9 | 53.4 | 0 | 0 | 53.4 |

**Table (2): Percentage covered by wet condition during different periods in Iran**

| period | Normal (in the wet direction) | Moderately Wet | Severely Wet | Extremely Wet | Total percent wet |
|---|---|---|---|---|---|
| 1970-1980 | 21.7 | 31.5 | 7.5 | 0 | 39 |
| 1981-1990 | 21.36 | 22.6 | 4.5 | 0 | 27.1 |
| 1991-2000 | 12.2 | 43.3 | 26.2 | 0 | 69.5 |
| 2001-2010 | 12.9 | 14.6 | 3.4 | 0 | 18.1 |
| 2011-2020 | 4.4 | 5.7 | 4.2 | 0 | 9.9 |
| 1970-2020 | 15.1 | 2.6 | 0 | 0 | 2.6 |

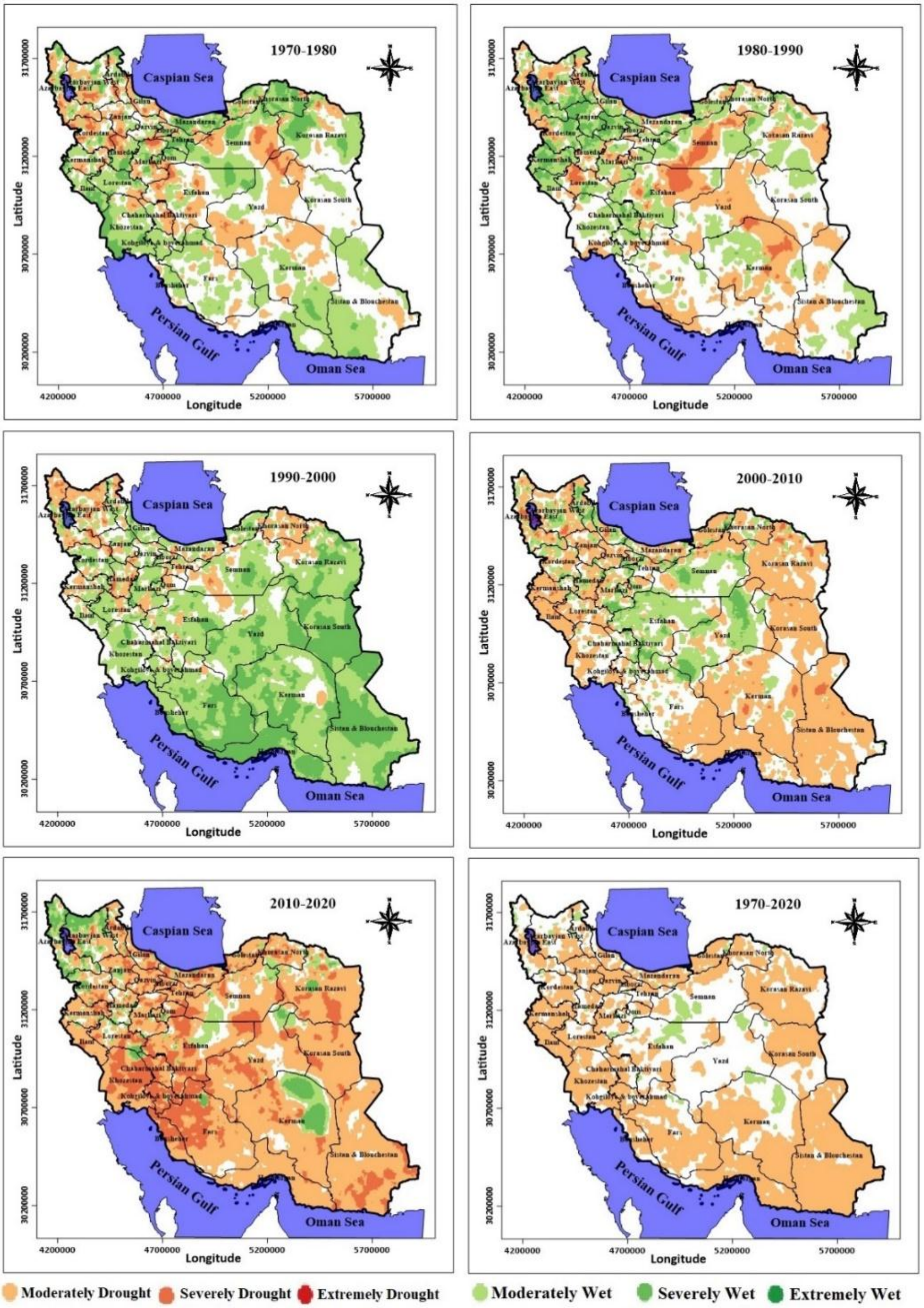

Figure 2: The percentage covered by drought and wet condition during different periods in Iran

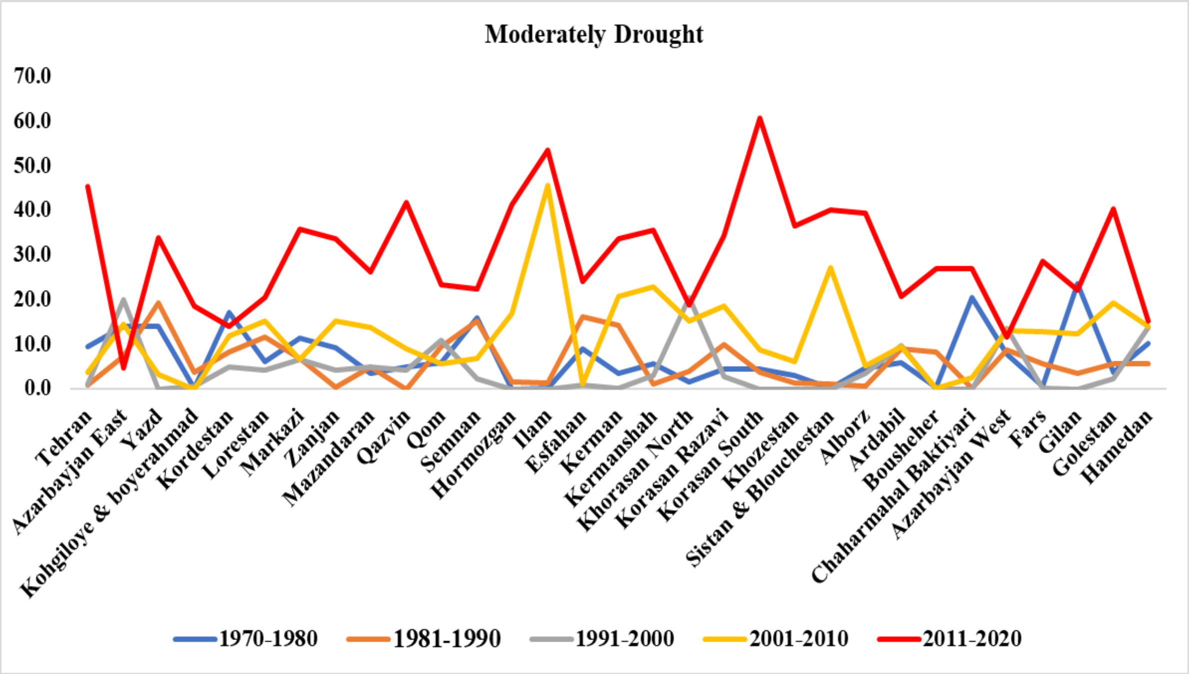

**Figure (2): The intensity of moderately droughts in the country by separation province during the studied periods**

Table (3) presents the percentage of area affected in different provinces and the proportional contribution of each province to the total drought-affected area of the country during the studied periods. As is evident, throughout the various decades, a percentage of each province's area is affected by drought, and each province contributes a percentage of the country's drought area in proportion to its size. The highest percentage of each province's area and its contribution to the country's total drought area are highlighted in red, while the lowest percentages are marked in blue in the table. During the first to fifth periods, the largest areas affected by drought were located in the provinces of Gilan, Yazd, North Khorasan, Ilam, and Bushehr.

Despite its humid climate, Gilan province had the highest percentage of drought-affected area among the country's provinces in the first period. Additionally, during the mentioned periods, the provinces of Yazd, Kerman, East Azarbaijan, and Sistan and Baluchistan accounted for the largest share of droughts in the country. Throughout the entire study period, the largest area of Ilam province was affected by drought, while Sistan and Baluchistan province accounted for the largest share of droughts nationwide. In the third period, the provinces of Hormozgan, South Khorasan, Sistan and Baluchistan, Bushehr, and Yazd did not experience drought. This period can be considered the wettest among the studied periods.

**Table (3): The total percentage of droughts during different periods based on the provincial scale (relative to the area of the province)**

| | 1970-1980 | | 1981-1990 | | 1991-2000 | | 2001-2010 | | 2011-2020 | | 1970-2020 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intensity | Compared to the province | Compared to the country | Compared to the province | compared to the country | Compared to the province | ompared to the country | Compared to the province | ompared to the country | Compared to the province | ompared to the country | Compared to the province | ompared to the country |
| Tehran | 23.52 | 0.20 | 15.22 | 0.13 | 33.00 | 0.27 | 18.38 | 0.15 | 95.26 | 0.79 | 41.11 | 0.34 |
| Azarbaijan East | 44.08 | 1.00 | 29.56 | 0.67 | 59.33 | 1.34 | 46.26 | 1.05 | 16.70 | 0.38 | 32.32 | 0.73 |
| Yazd | 45.77 | 3.63 | 47.30 | 3.75 | 0.02 | 0.00 | 18.12 | 1.44 | 81.47 | 6.46 | 15.77 | 1.25 |
| Kohgiloye & Boyerahmad | 2.72 | 0.03 | 17.86 | 0.17 | 4.25 | 0.04 | 27.38 | 0.27 | 95.41 | 0.92 | 75.85 | 0.73 |
| Kordestan | 54.07 | 0.96 | 25.09 | 0.45 | 17.59 | 0.31 | 37.31 | 0.66 | 48.89 | 0.87 | 50.46 | 0.90 |
| Lorestan | 12.52 | 0.22 | 41.37 | 0.72 | 14.71 | 0.26 | 52.28 | 0.91 | 57.40 | 1.00 | 59.68 | 1.04 |
| Markazi | 41.15 | 0.74 | 26.12 | 0.47 | 16.87 | 0.30 | 26.40 | 0.47 | 75.99 | 1.36 | 47.94 | 0.86 |
| Zanjan | 38.94 | 0.52 | 1.23 | 0.02 | 18.30 | 0.25 | 54.05 | 0.72 | 69.66 | 0.93 | 72.36 | 0.97 |
| Mazandaran | 9.57 | 0.14 | 19.82 | 0.29 | 25.79 | 0.38 | 42.79 | 0.63 | 77.82 | 1.14 | 67.68 | 0.99 |
| Qazvin | 19.01 | 0.18 | 0.17 | 0.00 | 16.44 | 0.16 | 51.88 | 0.50 | 90.41 | 0.87 | 84.25 | 0.81 |
| Qom | 19.77 | 0.14 | 33.02 | 0.23 | 25.35 | 0.18 | 32.09 | 0.23 | 73.02 | 0.52 | 37.67 | 0.27 |
| Semnan | 33.50 | 2.00 | 43.64 | 2.61 | 15.44 | 0.92 | 18.31 | 1.09 | 66.31 | 3.96 | 23.46 | 1.40 |
| Hormozgan | 9.11 | 0.39 | 38.02 | 1.63 | 0.00 | 0.00 | 72.55 | 3.12 | 94.91 | 4.08 | 89.20 | 3.84 |
| Ilam | 2.14 | 0.03 | 10.19 | 0.13 | 5.76 | 0.07 | 94.24 | 1.16 | 94.24 | 1.16 | 97.32 | 1.20 |
| Esfahan | 27.85 | 1.83 | 45.01 | 2.96 | 8.76 | 0.58 | 9.83 | 0.65 | 73.91 | 4.86 | 28.07 | 1.85 |
| Kerman | 26.27 | 2.92 | 42.52 | 4.73 | 1.79 | 0.20 | 65.58 | 7.29 | 67.82 | 7.54 | 59.77 | 6.64 |
| Kermanshah | 24.00 | 0.37 | 3.57 | 0.05 | 23.68 | 0.36 | 68.97 | 1.05 | 78.16 | 1.19 | 86.38 | 1.32 |
| Khorasan North | 4.01 | 0.07 | 18.72 | 0.32 | 60.17 | 1.04 | 48.52 | 0.84 | 65.81 | 1.13 | 57.31 | 0.99 |
| Khorasan Razavi | 13.09 | 0.93 | 26.24 | 1.87 | 12.58 | 0.90 | 69.54 | 4.96 | 78.70 | 5.61 | 71.98 | 5.13 |
| Khorasan South | 12.76 | 0.73 | 15.82 | 0.91 | 0.00 | 0.00 | 67.71 | 3.90 | 90.96 | 5.23 | 66.36 | 3.82 |
| Khozestan | 7.08 | 0.28 | 16.12 | 0.63 | 0.59 | 0.02 | 45.39 | 1.78 | 95.31 | 3.75 | 77.81 | 3.06 |
| Sistan & Baluchistan | 6.76 | 0.74 | 21.87 | 2.40 | 0.00 | 0.00 | 81.59 | 8.96 | 94.92 | 10.42 | 97.03 | 10.66 |
| Alborz | 34.87 | 0.11 | 19.49 | 0.06 | 16.92 | 0.05 | 26.67 | 0.09 | 88.21 | 0.28 | 62.56 | 0.20 |
| Ardabil | 23.96 | 0.26 | 33.79 | 0.36 | 31.18 | 0.33 | 30.26 | 0.32 | 61.14 | 0.66 | 33.79 | 0.36 |
| Bushehr | 7.90 | 0.11 | 34.20 | 0.48 | 0.00 | 0.00 | 8.96 | 0.13 | 98.23 | 1.37 | 63.68 | 0.89 |
| Chaharmahal Bakhtiari | 48.86 | 0.49 | 2.94 | 0.03 | 9.64 | 0.10 | 12.09 | 0.12 | 89.87 | 0.91 | 51.47 | 0.52 |
| Azerbaijan West | 35.97 | 1.00 | 32.08 | 0.90 | 47.52 | 1.33 | 47.64 | 1.33 | 27.89 | 0.78 | 35.67 | 1.00 |
| Fars | 11.80 | 0.90 | 23.90 | 1.82 | 1.69 | 0.13 | 42.60 | 3.24 | 91.40 | 6.96 | 72.81 | 5.55 |
| Gilan | 56.31 | 0.48 | 15.34 | 0.13 | 2.52 | 0.02 | 26.99 | 0.23 | 76.31 | 0.65 | 49.13 | 0.42 |
| Golestan | 16.88 | 0.21 | 20.42 | 0.26 | 8.90 | 0.11 | 58.90 | 0.74 | 84.95 | 1.07 | 72.38 | 0.91 |
| Hamedan | 29.53 | 0.35 | 20.47 | 0.24 | 50.00 | 0.59 | 46.80 | 0.55 | 41.23 | 0.49 | 39.97 | 0.47 |

Analysis of drought trends and oscillations: The drought trend in the country has been calculated using the Mann-Kendall method. Figure 4 presents the results of the trend analysis. As is evident, droughts have been increasing throughout the country. The lowest increasing trend is observable in parts of the central and desert regions, a portion of the southern coast, a section of the west, northwest, and also small areas in the northeast. The highest increasing trend of droughts is also visible in the southwest of the country, specifically in Khuzestan province.

In the southwest, west, northeast, a part of the center, and portions of Kerman and Sistan and Baluchistan provinces, an increasing trend of 0.6 to 0.8 is also present. On the other hand, 9.38 percent of the country also experiences a trend of 0.2 to 0.4 (Table 4). Spectral analysis was employed to investigate the prevailing oscillations in the country's droughts. The results of this method are presented in Figure 5. In 93 percent of the country's area, oscillations of 0 to 5 years prevail. 6.5 percent of the country's area experiences oscillations of 5 to 7 years, and 0.5 percent experiences oscillations of 7 to 9 years (Table 5).

Long-term oscillations are observable in the provinces of Sistan and Baluchistan and Zanjan. It can be asserted that the country's droughts exhibit short-term oscillations on a large scale. Scientists often refer to these types of short-term cycles as the Quasi-Biennial Oscillation (QBO) (Lana et al., 2005).

**Table (4): Classification Area of trends (in percent)**

| Classification (Trend) | Area (percent) |
|---|---|
| 0 to 0.2 | 2.134282 |
| 0.2 to 0.4 | 38.95064 |
| 0.4 to 0.6 | 15.47354 |
| 0.6 to 0.8 | 1.111605 |
| 0.8 > | 0.222321 |

**Table (5): Classification Area of oscillation cycle (in percent)**

| Classification (Cycle) | Area (percent) |
|---|---|
| 0 to 3 | 53.6 |
| 3 to 5 | 39.4 |
| 5 to 7 | 6.5 |
| 7 to 9 | 0.5 |

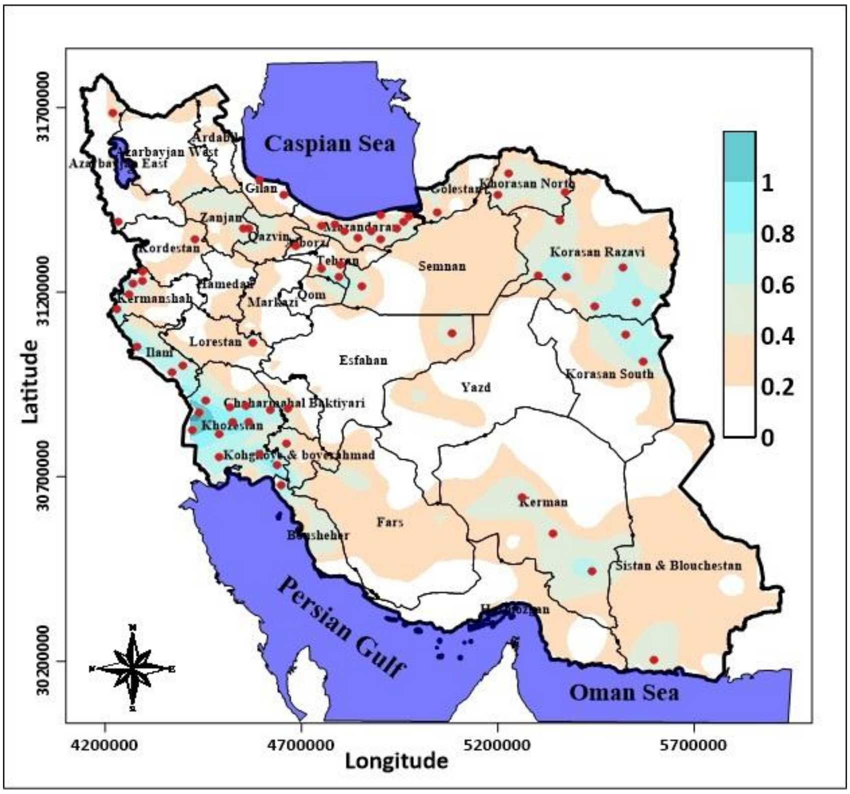

Figure (4): Spatial distribution of drought trends in Iran
(Significant red points at the 99% confidence level)

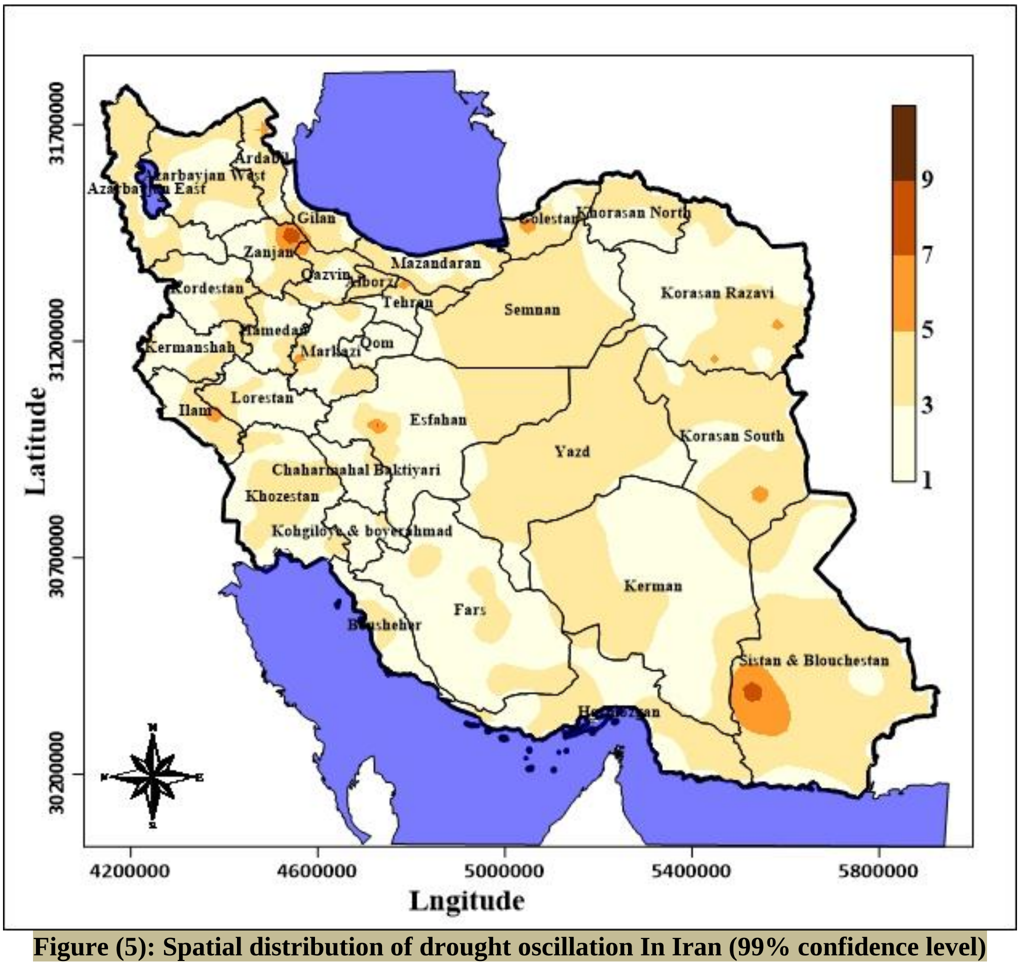

Figure (5): Spatial distribution of drought oscillation In Iran (99% confidence level)

## Conclusion

Drought is a climatic hazard that imposes adverse effects on agriculture, the environment, the economy, and human societies. This phenomenon occurs periodically in most parts of the world, with varying return periods. Studying this phenomenon can be an effective step in understanding its behavior and in managing and mitigating its destructive effects. In this research, the droughts of Iran were analyzed over a 50-year period from 1970 to 2020, in decadal intervals. The results of the analyses revealed that various regions of Iran are affected by mild to severe droughts across all periods. Therefore, drought can be considered an inherent phenomenon in the country. The only distinction between the various studied periods was the alteration in the location of drought and the increase or decrease in the area under its influence. A notable point is the occurrence of drought in extensive regions of Iran, which has expanded beyond the previously limited northwestern and northern areas of the country. The fifth and fourth periods were, respectively, the driest periods among those studied. In other words, in recent decades, droughts have manifested with greater magnitude and intensity. Surveys have indicated that the entire country has experienced an increasing drought trend. This upward trend was more pronounced in certain regions, such as Khuzestan. Furthermore, studies have demonstrated the existence of 0 to 9-year fluctuations in the country's droughts. The longest fluctuations (9 years) occur in portions of the Sistan and Baluchistan and Zanjan provinces. However, the most dominant fluctuations of droughts in Iran have been of the short-term variety, ranging from 2 to 4 years. The predominance of short-term fluctuations in Iranian droughts renders the management of such droughts in the vast area of Iran exceedingly challenging.

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