



# Analyzing meteorological and hydrological droughts in the Darreh Dozdan River basin through drought indices

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## ABSTRACT

This study evaluates meteorological and hydrological droughts in the Darreh Dozdan River Basin (DDRB) in Iran, while also investigating the relationship between these two types of droughts. Additionally, the study aims to assess the effectiveness of gamma and log-normal distributions in estimating the values of the Streamflow Drought Index (SDI). In this study, monthly streamflow and precipitation data from the Tange Siab station for the years 1970 to 2022 were used to monitor hydrological and meteorological drought. Six indices available in the DIP software were used to monitor meteorological drought, while hydrological drought was assessed with the SDI and DrinC software. To investigate the relationship between meteorological and hydrological drought, the Pearson correlation test was used. The results indicated that the Standardized Precipitation Index (SPI) and the China-Z Index (CZI), with a determination coefficient of approximately 0.7, are the most suitable indices for assessing meteorological drought in the DDRB. The findings showed that the DDRB has experienced meteorological and hydrological droughts for 9 and 25 years, respectively, with varying intensities according to the SPI and SDI indices. Furthermore, the results revealed a positive but weak correlation between meteorological and hydrological drought indices, suggesting that hydrological drought in the DDRB is primarily influenced by human activities. Additionally, both distributions had the same performance in hydrological drought classification.

## Highlights

- SPI and CZI indices are the most suitable for monitoring meteorological drought.
- The gamma and lognormal distributions provide the same SDI classification.
- Meteorological and hydrological droughts have a weak positive correlation.
- Human activities drive hydrological drought in the Darreh Dozdan River Basin.



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## 1. Introduction

Iran is characterized as an arid and semi-arid country with limited precipitation, receiving less than one-third of the global average annual rainfall (Shariati et al., 2025). Climate change has significantly impacted Iran, resulting in rising temperatures and declining rainfall. The effects on water resources across various basins are evident, with several wetlands and lakes completely drying up (Esmacili et al., 2024). Drought is one of the environmental phenomena and an inseparable part of climate change. Drought can occur anywhere and lead to water shortages, but its characteristics, such as intensity, duration, and extent, vary from one place to

another (Mousavikhah et al., 2020). Drought is considered a slow and creeping phenomenon that, by affecting agricultural sectors, water resources, and vegetation in various regions, especially in arid and semi-arid areas, can accelerate the expansion of desert areas (Zarei and Solaimani Sardo, 2022). Drought is classified into various types: meteorological drought, hydrological drought, agricultural drought, and socio-economic drought (Dehghani et al., 2020). Meteorological drought refers to a deficiency of precipitation in a specific area over a defined period of time (Khazaei et al., 2015). Hydrological drought is described as a period during which surface and groundwater resources are insufficient to meet water demand (Khazaei et al., 2015). The hydrological

drought is related to the effects of periods of low precipitation, including drizzle, rain, snow, snow pellets, ice crystals, and hail, on surface and groundwater resources such as river flow, lake levels, reservoirs, and groundwater (Nazaripour, 2017). Agricultural drought, characterized by insufficient soil moisture, will have significant impacts, including a reduction in crop yield (Nikdad et al., 2022). Socio-economic drought refers to a situation where water systems are unable to meet the water needs of society and industry (Khazaee et al., 2015).

One of the important and fundamental steps in drought and wet year studies in any region is to determine the indices that can be used to assess the intensity and duration of drought and wet year and subsequently evaluate their impact on the water resources of the area (Khodaghali and Saboohi, 2018). The use of drought indices in summarizing many parameters that affect drought is useful for planners at various levels. By utilizing drought indices, the intensity and extent of drought can be quantified and periodically assessed (Mousavikhah et al., 2020). Drought indices are among the most important tools for monitoring and designing an effective drought crisis warning system. These indices provide a good guide for identifying the key components of drought as well as for making appropriate management decisions to mitigate the adverse effects of drought (Khodaghali and Saboohi, 2018). Although each drought index has its strengths and weaknesses based on its capabilities and limitations, these indices are much more suitable tools for decision-making compared to raw data (Mousavikhah et al., 2020). Drought indices use indicators to determine the severity of drought. Frequently, drought indicators are classified into two categories: meteorological indicators that include climatic parameters such as precipitation, temperature, evapotranspiration, and hydrological indicators that involve parameters such as streamflow, soil moisture snowpack, groundwater, and reservoir levels (Ndairagije and Li, 2022).

Among meteorological indicators, precipitation is one of the most important. This is because precipitation is the most influential variable that directly affects soil moisture, surface flows, and changes in groundwater levels (Mousavikhah et al., 2020). On the other hand, among the climatic variables, precipitation is considered the most unstable, especially in dry and semi-arid regions. For this reason, precipitation is the primary factor that should be accounted for when examining any case of drought (Amini et al., 2009). To date, numerous meteorological drought indices based on precipitation data have been developed and utilized in various studies. Some of the most commonly used meteorological drought indices based on precipitation data are the standardized precipitation index (SPI) (Kartal and Nones, 2024), percent of normal index (PNI) (Mhelezi and Limbu, 2024), decimal index (DI) (Zarei and Solaimani Sardo, 2022), Z-score index (ZSI) (Katipoğlu et al., 2020), China-Z index (CZI) (Kartal, 2023), and modified China-Z index (MCZI) (Dehghani et al., 2020). Evaluating meteorological drought indices based on precipitation data is vital for effective resource management, disaster preparedness, agricultural planning, ecosystem conservation, and policy development, all of which contribute to the overall resilience of a basin in the face of changing climatic conditions.

Among hydrological indicators, streamflow is one of the most important and key components in understanding various environmental and ecological processes in the river basin. The streamflow drought index (SDI) is a crucial tool for understanding hydrological droughts and their impacts on water resources, ecosystems, and human activities. To date, various studies have used the SDI to monitor hydrological drought in different basins (Mesbahzadeh and Soleimanisardoo, 2018; Dehghani et al., 2020a; Kartal and Nones, 2024). Probability distribution functions play an important role in calculating SDI. A review of various studies shows that gamma and log-normal distributions have good performance for calculating SDI (Dehghani et al., 2020a; Katipoğlu, 2023; Yisfa et al., 2024).

A review of various sources in Iran shows that, to date, no studies have been conducted on monitoring meteorological and hydrological drought in the Darreh Dozdan River Basin (DDRDB). Therefore, this study aimed to monitor meteorological drought in the DDRDB using precipitation data-based indices and determine the most appropriate drought indices. Additionally, this study addresses the monitoring of hydrological drought in the same basin using the streamflow drought index, while comparing the performance of gamma and log-normal distributions in estimating the values of this index. Furthermore, this study examines the relationship between meteorological drought and hydrological drought.

## 2. Materials and Methods

### 2.1 Study area

The Darreh Dozdan River is one of the rivers of Lorestan Province, Iran. According to the "Guide Lines and Criteria for Classification and Coding Basin and Study Areas in IRAN (No. 310)," which were prepared by the Research Office of the Iran Water Resources Management Company, the Department of Technical Affairs of the Ministry of Energy, and the Vice Presidency for Strategic Planning and Supervision in 2012, the Darreh Dozdan River is one of the rivers that flows in the second-level watershed called Karkkeh. There is only one rain gauge-hydrometric station on the Darreh Dozdan River, called Tange Siab, which has been established and operated since 1970 by the Iran Water Resources Management Company, a subsidiary of the Ministry of Energy of Iran, and which measures factors such as precipitation, flow rate, sediment, and chemical and physical quality of the water. Tange Siab Station is located in Kuhdasht County, Lorestan Province. Tange Siab Station is located at longitude 47°12'23"E and latitude 33°23'25"N and is 940 m above sea level.

### 2.2 Meteorological drought

In this study, monthly precipitation data from Tange Siab station for the years 1970 to 2022 (53 years) were used to monitor meteorological drought, and the Drought Indices Package (DIP) software (Version 2.0) was used to estimate meteorological drought indices. The Iran Water Resources Management Company produces DIP software. DIP software calculates meteorological drought indices SPI, PNI, DI, ZSI, CZI, and MCZI by receiving precipitation data.

#### 2.2.1 Standard precipitation index

The standardized precipitation index (SPI) is based on the fact that precipitation deficits have different effects on

groundwater, resource storage, soil moisture, snow cover, and creek flow (Dehghani et al., 2020). The standardized precipitation index calculates the precipitation deficit for multiple time scales as 3, 6, 12, 24, and 48 months. These time scales reflect the impact of drought on the availability of different water resources (Rindramampionona et al., 2024). Soil moisture conditions react twice as much to precipitation anomalies on a relatively short scale, while groundwater, river flow, and storage resources respond to precipitation anomalies over a longer period (Dehghani et al., 2020). SPI drought index is calculated from Eq. 1 (Dehghani et al., 2020).

$$SPI = \frac{P_i - \bar{P}}{SD} \tag{1}$$

where,  $P_i$  is the annual rainfall in the year  $i$ ,  $\bar{P}$  is average long-term rainfall and  $SD$  is the standard deviation of precipitation in the statistical period. A classification system is used to define the drought intensities resulting from the standardized precipitation index, as shown in Table 1 (Afzali et al., 2016).

Table 1 SPI drought index classes (Afzali et al., 2016)

SPI Rank	SPI values	Drought Classification
1	2 or more	Extremely wet
2	1.5 to 1.99	Very wet
3	1 to 1.49	Moderately wet
4	0.99 to 0.0	Normal
5	0.0 to -0.99	Near normal
6	-1 to -1.49	Moderately dry
7	-1.5 to -1.99	Severely dry
8	-2 and less	Extremely dry

### 2.2.2 Percent of normal index

The percent of normal index (PNI) is an index that is mostly used to understand the general public. This index is one of the simplest methods of measuring precipitation for a region (Dehghani et al., 2020). The PNI Index is always positive and is limited to zero from below and theoretically not limited from above (Boroghani et al., 2015). The PNI Index is calculated from Eq. 2 (Mousavikhah et al., 2020).

$$PNI = \frac{P_i}{\bar{P}} \times 100 \tag{2}$$

where,  $P_i$  is the annual rainfall in the year  $i$ ,  $\bar{P}$  is the average long-term rainfall in the statistical period. The different classes of this index are listed in Table 2 (Mhelezi et al., 2024).

Table 2 PNI drought index classes (Mhelezi et al., 2024)

PNI Rank	PNI values	Drought Classification
1	>100 %	Extremely wet
2	90 to 100 %	Very wet
3	80 to 90 %	Moderate wet
4	70 to 80%	Near normal
5	55 to 70%	Moderate drought
6	40 to 55%	Severely drought
7	<40%	Extremely drought

### 2.2.3 Decimal index

The decimal index (DI) approach was suggested by Gibbs and Maher (1967) and widely used in Australia (Coughlan, 1987). This index divides the occurrence of long-term rainfall into deciles of normal distribution (Smakhtin and Hughes, 2007). This method has relatively simple calculations but requires

long-term statistics to use (Dehghani et al., 2020). Decimals are calculated in this method in 4 steps. Step 1: Sorting the monthly rainfall data in ascending order. Step 2: Determining the decimal range using Eq. 3, Step 3: Estimating the rainfall values for each decile, and Step 4: Determining the statistical years that are placed in different deciles (Mousavikhah et al., 2020).

$$m_i = \frac{i(n+1)}{10} \tag{3}$$

where,  $m_i$  is the  $i$ -th decile,  $i$  is the decile number, and  $n$  is the number of rainfall data. The different classes of this index are listed in Table 3 (Mousavikhah et al., 2020).

Table 3 Classification of DI index (Mousavikhah et al., 2020)

Condition	Index value
Very intense wet	4
Intense wetness	3
Medium wetting	2
Poor wetness	1
normal	0
Poor drought	-1
Moderate drought	-2
Severe drought	-3
Very severe drought	-4

### 2.2.4 Z-score index

Triola (1995) established the Z-score index (ZSI) to track meteorological drought. Based on studies conducted in temperate regions of Europe and the United States, in this method, the total time series in the study period is considered a statistical community, and the index is calculated and used to determine the dry and wet months. In arid and semi-arid climates, due to the fact that the coefficient of variation of rainfall is high and the data do not follow the normal distribution, the use of this method makes the dry months less important, and instead the wet month is very exaggerated (Raziei et al., 2007). This index is calculated from Eq. 4 (Mousavikhah et al., 2020).

$$ZSI = \frac{P_i - \bar{P}}{SD} \tag{4}$$

where,  $P_i$  is the annual rainfall in the year  $i$ ,  $\bar{P}$  is the average long-term rainfall, and  $SD$  is the standard deviation of precipitation in the statistical period. This index is not the same as SPI because it does not require the data to be adjusted to fit the gamma or Pearson type III distribution (Katipoğlu et al., 2020). The classification of this index is given in Table 4 (Afzali et al., 2016).

Table 4 Classification of ZSI index (Afzali et al., 2016)

ZSI Rank	ZSI values	Drought Classification
1	2 or more	Extremely wet
2	1.5 to 1.99	Very wet
3	1 to 1.49	Moderately wet
4	0.99 to 0.0	Normal
5	0.0 to -0.99	Near normal
6	-1 to -1.49	Moderately dry
7	-1.5 to -1.99	Severely dry
8	-2 and less	Extremely dry

### 2.2.5 China-Z index and modified China Z index

The China International Climate Centre initially employed the CZI for drought monitoring in China (Kartal and Nones, 2024). China-Z index (CZI) presumes that rainfall values tend to follow a Pearson Type III distribution and is related to the Wilson–Hilferty cube-root transformation from the chi-square variable to the Z-scale (Kartal and Nones, 2024). CZI is estimated based on Eqs. 5, 6, and 7 (Kartal and Nones, 2024).

$$CZI_j = \frac{6}{C_{st}} \left( \frac{C_{st}}{2} \varphi_j + 1 \right)^{\frac{1}{3}} - \frac{6}{C_{st}} + \frac{C_{st}}{6} \quad (5)$$

$$C_{st} = \sum_{j=1}^N \frac{(X_j - \bar{X})^3}{N \times \sigma^3} \quad (6)$$

$$\varphi_j = \frac{X_j - \bar{X}}{\sigma} \quad (7)$$

where,  $t$  is the time, which can be equal to 1, 2, 3, ... 9, 12, 24 months, etc..  $C_{st}$  denotes a coefficient of skewness for the time step  $t$ ,  $\varphi_j$  shows a standard deviation (also called Z-Score, which is the statistical Z score computed for the same time step ( $t$ ),  $N$  is the total number of observation years,  $\bar{X}$  and  $\sigma$  are the average and standard deviation, respectively, while precipitation is denoted by  $X_j$  (Kartal and Nones, 2024). Sometimes, the median rainfall is employed to assess the modified China-Z index (MCZI), as opposed to the mean rainfall used in the calculation of the CZI (Kartal and Nones, 2024). The classification of these indices is given in Table 5 (Kartal, 2023).

Table 5 Classification of CZI index and MCZI index (Kartal, 2023)

CZI and MCZI Rank	CZI values	MCZI values	Drought Classification
1	$\geq 2$	$\geq 2$	Extremely wet
2	1.5 to 2	1.5 to 2	Very wet
3	1 to 1.5	1 to 1.5	Moderately wet
4	-1 to 1	-1 to 1	Near normal
5	-1.5 to -1	-1.5 to -1	Moderately dry
6	-2 to -1.5	-2 to -1.5	Severely dry
7	$\leq -2$	$\leq -2$	Extremely dry

### 2.3 Hydrological drought

In this study, monthly streamflow data from the Tange Siab station for the years 1970 to 2022 (53 years) were used to monitor hydrological drought, and DrinC software (Version 1.7) was used to estimate hydrological drought using the streamflow drought index with two statistical distributions, gamma and log-normal.

#### 2.3.1 Streamflow drought index

The computational principles of the streamflow drought index (SDI) are similar to the standard precipitation index (SPI), which is based on the average monthly flow of a river in a catchment area (Dehghani et al., 2020a). In this method, it is assumed that the time series of the volume of monthly river flows is available as  $Q_{ij}$ .  $i$  is the hydrological year, and  $j$  is the month corresponding to the hydrological year. The basis of this series is based on Eq. 8 (Dehghani et al., 2020a).

$$V_{ik} = \sum_{j=1}^n Q_{ij} \quad (8)$$

The basis of  $k$  is monthly, and its values from 1, 2, 3, 4, 5, and 6 represent the periods of 3, 6, 9, 12, 24, and 48 months, respectively. The cumulative volume of river flows for the base period  $K$  associated with year  $i$  of the hydrological year is used to calculate the SDI index. It is obtained from Eq. 9 (Dehghani et al., 2020a).

$$SDI_{ik} = \frac{V_{ik} - \bar{V}_k}{S_k} \quad (9)$$

Where,  $\bar{V}_k$  and  $S_k$  are the mean of the total discharge volume and the standard deviation of the cumulative flow volume for the  $k$  base period, respectively. This study also used Table 6, which Mesbahzadeh and Soleimanisardoo (2018) presented to classify hydrological drought states using the SDI index.

Table 6 Classification of SDI index (Mesbahzadeh and Soleimanisardoo, 2018)

SDI Rank	SDI values	Drought Classification
0	$0.0 \leq SDI$	Non-drought
1	$-1.0 \leq SDI < 0.0$	Mild drought
2	$-1.5 \leq SDI < -1.0$	Moderate drought
3	$-2.0 \leq SDI < -1.5$	Severe drought
4	$SDI < -2.0$	Extreme drought

### 2.4 Coefficient of determination

To identify the most suitable meteorological drought index and the appropriate statistical distribution for estimating the SDI index, linear regression was conducted using Microsoft Excel 2019 software. The criterion for measuring the performance of linear regression is the coefficient of determination ( $R^2$ ). The coefficient of determination is between zero and one, and if it is more than 0.6, it shows that the independent variable has been able to explain the changes of the dependent variable to a large extent. The formula for calculating the coefficient of determination is Eq. 10 (Ahmadpari et al., 2019).

$$R^2 = \left( \frac{\sum_{i=1}^n (o_i - \bar{o})(s_i - \bar{s})}{\sqrt{\sum_{i=1}^n (o_i - \bar{o})^2 \times \sum_{i=1}^n (s_i - \bar{s})^2}} \right)^2 \quad (10)$$

where,  $s_i$  is the predicted value,  $o_i$  the observed value,  $\bar{s}$  and  $\bar{o}$  are predicted and observed average values, and  $n$  is the number of data.

### 2.5 Pearson correlation coefficient

To investigate the relationship between meteorological and hydrological drought, the Pearson correlation test was used in Microsoft Excel 2019 software. The Pearson correlation coefficient is a value between -1 and 1. If the coefficient is 1, it indicates a complete positive correlation between the two variables; 0 indicates no correlation, and -1 indicates a complete negative correlation between the two variables (Jiang and Sun, 2025). The formula for calculating the Pearson correlation coefficient is Eq. 11 (Ahmadpari et al., 2018).

$$\text{Corr}(X, Y) = \frac{\text{Cov}(X, Y)}{\sigma_X \sigma_Y} \quad (11)$$

where  $X$  and  $Y$  are the values of two variables,  $\sigma_X$  is the standard deviation of variable  $X$ ,  $\sigma_Y$  is the standard deviation of variable  $Y$ , and  $\text{Cov}(X, Y)$  is the covariance between  $X$  and  $Y$ . The comparison of the Pearson correlation coefficient and correlation strength can be found in Table 7 (Jiang and Sun, 2025).

**Table 7** Pearson correlation strength table (Jiang and Sun, 2025)

The Range of Absolute Values of Correlation Coefficients	Correlation Strength
0.0–0.2	Extremely weak correlated or uncorrelated
0.2–0.4	Weak correlated
0.4–0.6	Medium correlated
0.6–0.8	Strong correlated
0.8–1.0	Highly correlated

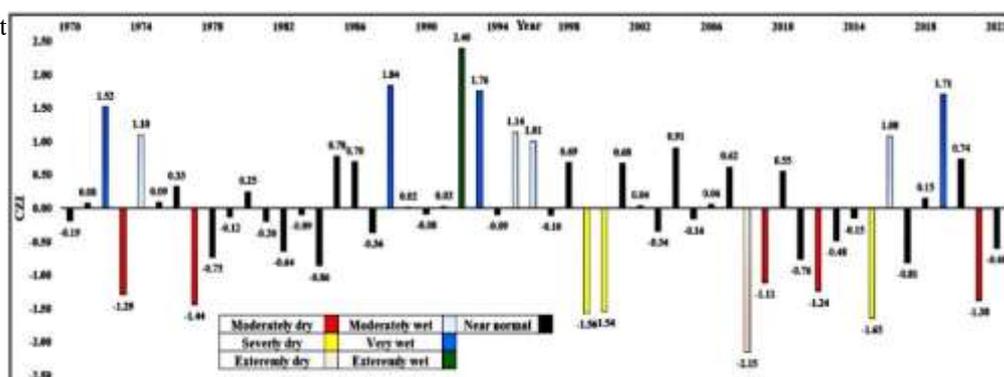
### 3. Results and Discussion

#### 3.1 Meteorological drought

##### 3.1.1 CZI index

Fig. 1 shows the results of meteorological drought monitoring with the CZI index for the DDRB. It shows that the DDRB

**Fig. 1** Meteorological drought assessment through CZI index



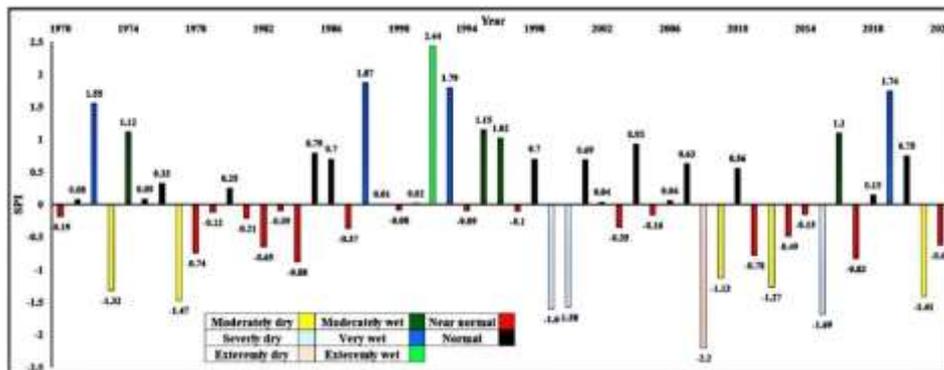
witnessed "extremely dry" conditions only in 2008 with a CZI value of about -2.15. With a CZI value of about 2.4, Figure 1 demonstrates that the DDRB was only "extremely wet" in 1992. The CZI index values in 5 years (1973, 1977, 2009, 2012, and 2021) range from -1.11 to -1.44, which, according to this index classification, the DDRB was in a "moderately dry" situation. The DDRB was classified as "moderately wet" based on the CZI index values for the four years (1974, 1995, 1996, and 2016), which range from 1.01 to 1.14. The CZI index values in years 1999, 2000, and 2015 were about -1.56, -1.54, and -1.65, respectively, which, according to this index classification, the DDRB was in a "severely dry" situation. The CZI index values in four years (1972, 1988, 1993, and 2019) ranged from 1.52 to 1.84, indicating that the DDRB was in a "very wet" state. The CZI index values in 35 years (from the 53 years studied) range from -0.86 to 0.91, which, according to this index classification, means the DDRB was in a "near normal" situation.

##### 3.1.2 SPI index

The DDRB's meteorological drought monitoring results using the SPI index are displayed in Fig. 2. It reveals that the DDRB experienced "extremely dry" conditions in 2008, with an SPI value of about -2.2. In fact, for 2008, the performance results of both the SPI and CZI indices are consistent with each other.

Fig. 2 shows that the DDRB was only "extremely wet" in 1992, with an SPI value of about 2.44. The SPI and CZI indices' performance outcomes for 1992 agree with one another. The DDRB was classified as "moderately dry" based on the SPI index values for the five years (1973, 1977, 2009, 2012, and 2021), which range from -1.13 to -1.47. This result also confirms the results of the CZI index.

**Fig. 2** Meteorological drought assessment through SPI index



The DDRB was categorized as "moderately wet" according to the SPI index values for the four years (1974, 1995, 1996, and 2016), which ranged from 1.02 to 1.15. This result is consistent with the CZI index results. The DDRB was classified as "severely dry" based on the SPI index values in 1999, 2000, and 2015, which were about -1.6, -1.58, and -1.69, respectively. This result is in agreement with the results derived from the CZI index. The SPI index values in four years (1972, 1988, 1993, and 2019) varied from 1.55 to 1.87,

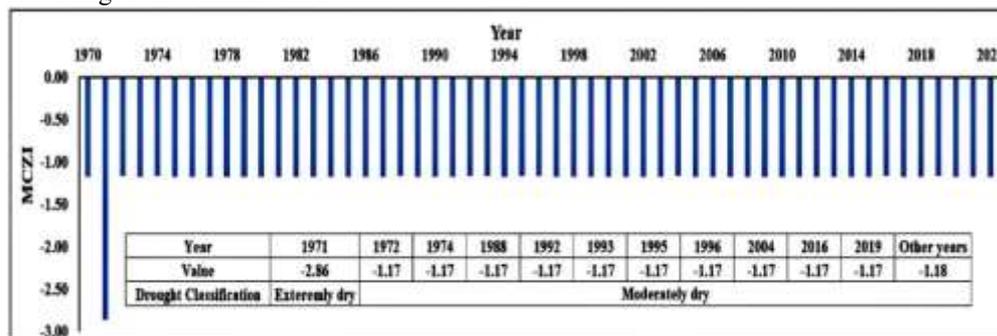
showing that the DDRB was in "very wet" condition. This result is consistent with the results obtained using the CZI index. The SPI index values in 18 years ranged from -0.88 to -0.08, indicating that the DDRB was in a "near normal" state. Also, the SPI index values in 17 years ranged from 0.01 to 0.93, indicating that the DDRB was in a "normal" condition. The total number of years that the DDRB has been in a "normal" and "near normal" state according to the SPI index is 35 years. In fact, the numerical value of the SPI index in these

35 years is very close to the CZI index, but the CZI index does not have a "normal" state and only has a "near normal" state, which ranges from -1 to +1 (in this study, it is in the range of -0.86 to 0.91.). Since the range of the SPI index in these 35 years is between -0.88 and 0.93, it can be said that this result is also consistent with the findings of the CZI index. Comparing all the results of the two indices, SPI and CZI, shows that these two indices estimate the drought and wet years conditions for the DDRB in a completely similar way.

### 3.1.3 MCZI index

Fig.3 shows the results of meteorological drought monitoring with the MCZI index for the DDRB. This index has a value of -2.86 for the year 1971, which, according to the classification

**Fig. 3** Meteorological drought assessment through MCZI index



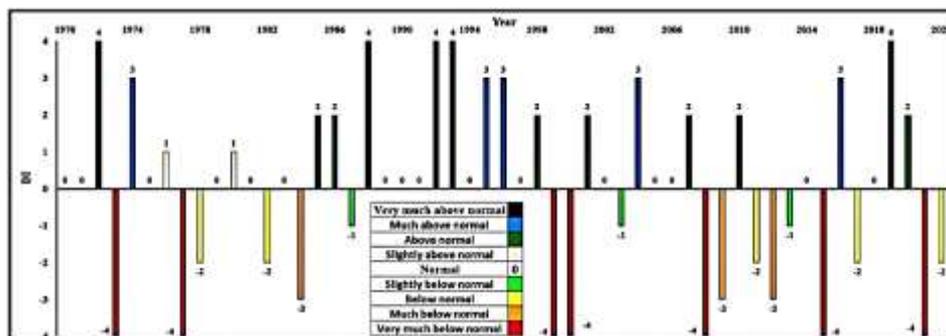
of this index, is in the "Extremely dry" class. The MCZI index values for 10 years are -1.17. Also, the MCZI index values for 42 years are -1.18. These values (-1.17 and -1.18) are in the "moderately dry" class according to the classification of the MCZI index. Therefore, the MCZI index is not able to determine the droughts and wet years of the DDRB on an annual scale because for all years except 1971, it shows the condition of this basin as "moderately dry." These results are consistent with the studies of Dehghani et al. (2020) and Mousavikhah et al. (2020). These studies also emphasized the inappropriate performance of the MCZI index for assessing meteorological drought in some regions of Iran.

### 3.1.4 DI index

Fig. 4 shows the results of meteorological drought monitoring with the DI index for the DDRB. It shows that the DDRB in the 16 years witnessed "normal" conditions with a DI value of about 0. Fig. 4 indicates that the DI index value for the years 1976 and 1980 is about 1. According to the classification of this index, over the past two years, the DDRB has experienced a "slightly above normal" situation. The DI index values over 7 years were approximately 2, indicating, according to this index classification, that the DDRB was in an "above normal" situation. The DI index values for the five years (1974, 1995, 1996, 2004, and 2016) were about 3, which, according to this index classification, the DDRB was in a "much above normal" situation. The DDRB was classified as being in a "very much

above normal" condition based on the DI index values for the five years (1972, 1988, 1992, 1993, and 2019), which were about 4. The DI index values for three years (1987, 2003, and 2013) were about -1. Based on the classification of this index, the DDRB was in a "slightly below normal" condition in these three years. Five years (1978, 1982, 2011, 2017, and 2022) had DI index values of about -2. This index's rating indicates that throughout these five years, the DDRB was in "below normal" condition. The DI index values in years 1984, 2009, and 2012 were about -3, which, according to the classification of this index, the DDRB was in a "much below normal" situation. The DI index values for the seven years were about -4, which, according to the classification of this index, the DDRB was in a "very much below normal" situation in these seven years.

**Fig. 4** Meteorological drought assessment through DI index



### 3.1.5 PNI index

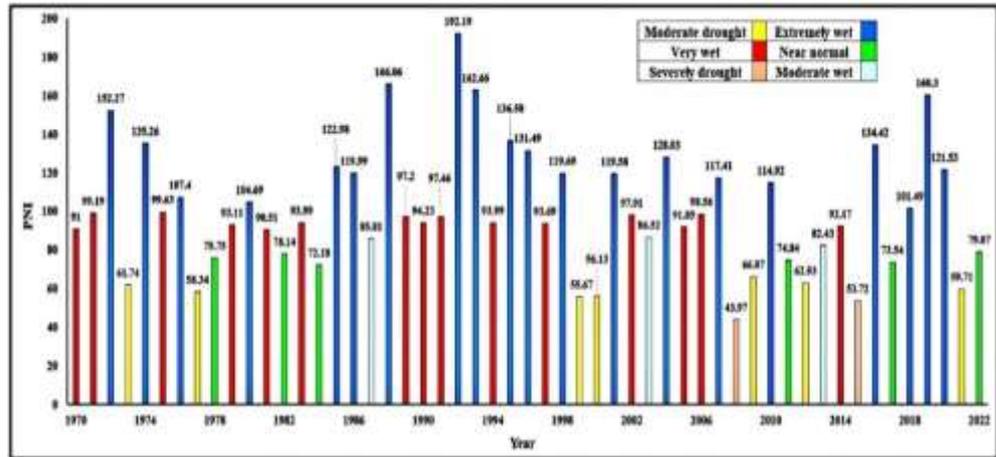
Fig. 5 shows the results of meteorological drought monitoring with the PNI index for the DDRB. The PNI index values in 20 years (from the 53 years studied) range from 101.49 to 192.19, which, according to this index classification, means the DDRB was in an "extremely wet" situation. The PNI index values in 15 years (out of 53 years investigated) vary from 90.51 to 99.63, indicating that the DDRB was "very wet" according to

the classification of this index. The PNI index values in 7 years (out of 53 years analyzed) range from 55.67 to 66.07, indicating that the DDRB experienced a "moderate drought" condition according to the index's classification. The PNI index values in the years 1987, 2003, and 2013 were about 85.81, 86.52, and 82.43, respectively, which, according to the classification of this index, the DDRB was in a "moderate wet" situation. The PNI index values in 2008 and 2015 were about

43.97 and 53.72, respectively, indicating that the DDRB was in a "severely drought" condition. The PNI index values in 6 years vary from 72.18 to 79.07, indicating that the DDRB

experienced a "near normal" condition according to the index's classification.

**Fig. 5** Meteorological drought assessment through PNI index

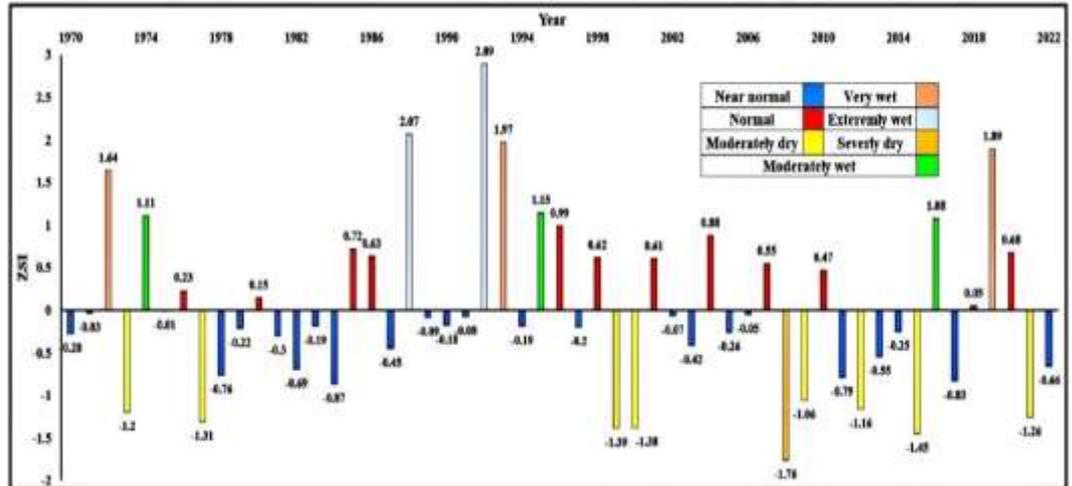


**3.1.6 ZSI index**

Fig. 6 shows the results of meteorological drought monitoring with the ZSI index for the DDRB. The ZSI index values in 24 years (from the 53 years studied) range from -0.87 to -0.01, which, according to this index classification, means the DDRB was in a "near normal" situation. According to the ZSI classification, the DDRB was in a "normal" state during the 12 years when the ZSI index values ranged from 0.05 to 0.99. According to the ZSI classification, the DDRB was "moderately dry" for eight years, with ZSI index values ranging from -1.45 to -1.06. Figure 6 shows that the

"extremely dry" state has not occurred in the DDRB. Also, the DDRB witnessed "severely dry" only in 2008 with a ZSI value of about -1.76. The ZSI index values in years 1972, 1993, and 2019 were about 1.64, 1.97, and 1.89, respectively, which, according to the classification of this index, the DDRB was in a "very wet" situation. The ZSI index values in years 1974, 1995, and 2016 were about 1.11, 1.15, and 1.08, respectively, indicating that the DDRB was in a "moderately wet" state. The ZSI index values in 1988 and 1992 were about 2.07 and 2.89, respectively, indicating that the DDRB was in an "extremely wet" condition.

**Fig. 6** Meteorological drought assessment through ZSI index



**3.2 Best meteorological drought index**

Figure 7 shows the relationship between annual precipitation and meteorological drought indices for the DDRB. It indicates that the coefficient of determination ( $R^2$ ) of all meteorological drought indices except the MCZI index is greater than 0.6. This means that all meteorological drought indices investigated in this study, except the MCZI index, are suitable for assessing meteorological drought in the DDRB. The CZI index, with a determination coefficient of 0.6973, and the SPI index, with a determination coefficient of 0.697, are the most appropriate indices for assessing meteorological drought in the DDRB.

**3.3 Hydrological drought**

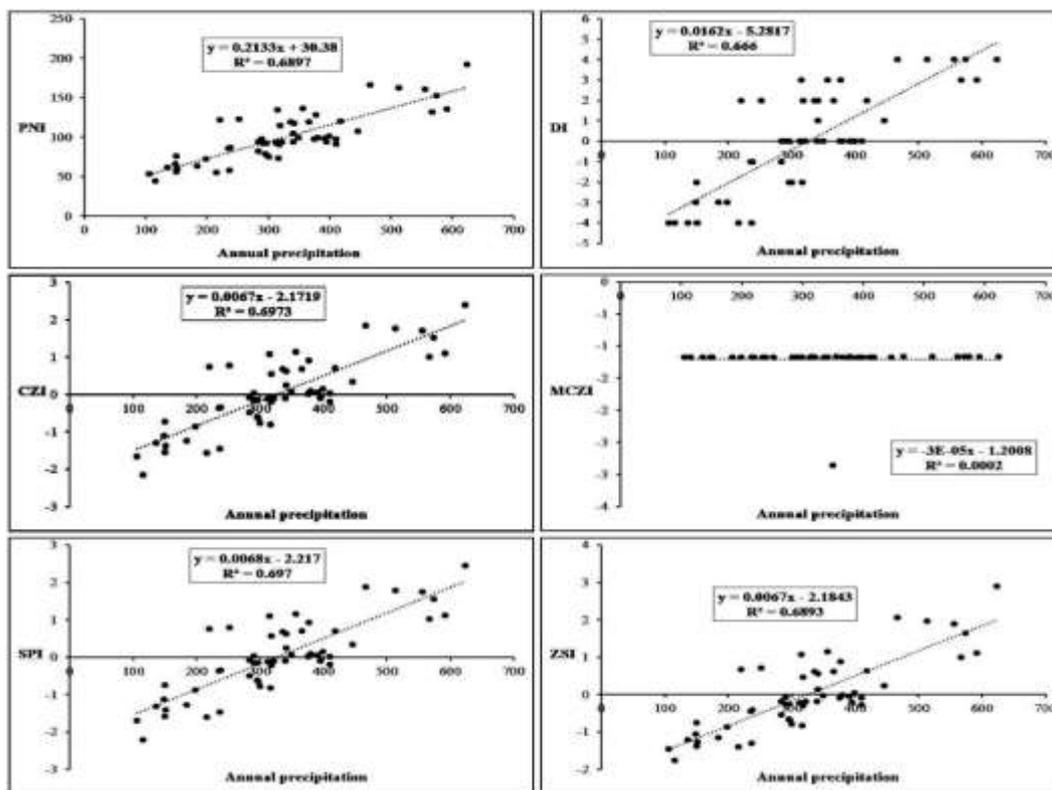
**3.3.1 SDI index with gamma distribution**

Fig. 8 shows the results of hydrological drought monitoring with the SDI index and gamma distribution for the DDRB. The SDI index values in 28 years (from the 53 years studied) range from 0.03 to 2.10, which, according to the SDI classification, means the DDRB was in a "non-drought" situation. The SDI index values in 17 years (of the 53 years analyzed) ranged from -0.96 to -0.06, indicating that the DDRB was experiencing "mild drought" conditions. The SDI index values in years 2004-2005, 2006-2007, and 2016-2017 were about -1.08, -

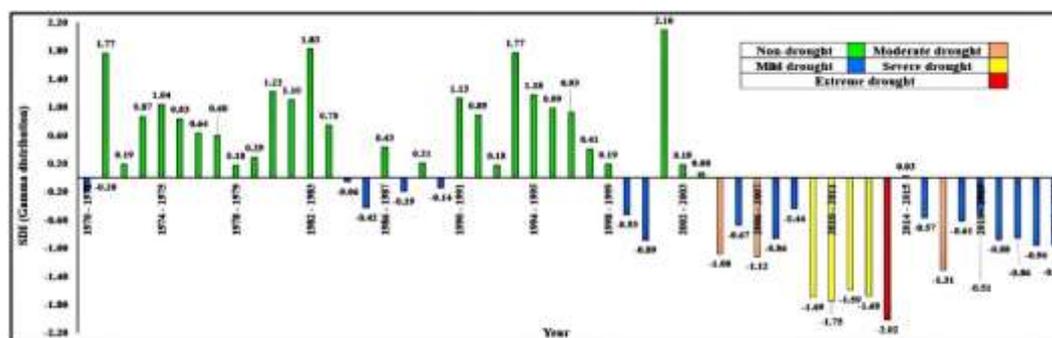
1.12, and -1.31, respectively, which, according to the classification of this index, the DDRB was in a "moderate drought" situation. The SDI index values in 4 years range from -1.75 to -1.59, which, according to the SDI classification,

means the DDRB was in a "severe drought" situation. The SDI index values show that the DDRB witnessed "extreme drought" only in 2013-2014 with an SDI value of about -2.02.

**Fig. 7** Relationship between annual precipitation and meteorological drought indices



**Fig. 8** Hydrological drought assessment through SDI index and gamma distribution



**3.3.2 SDI index with log-normal distribution**

Fig. 9 shows the results of hydrological drought monitoring with the SDI index and log-normal distribution for the DDRB. The SDI index values in 28 years (of the 53 years analyzed) ranged from 0.08 to 1.94, indicating that the DDRB was in a "non-drought" state. Out of the 53 years investigated, 17 years had SDI values between -0.95 and -0.01, which shows that the DDRB was in a "mild drought" condition. During 2004-2005, 2006-2007, and 2016-2017, the DDRB was classified as being in a "moderate drought" state based on the SDI index values, which were about -1.09, -1.13, and -1.34, respectively. The SDI index values across four years ranged from -1.85 to -1.66, indicating that the DDRB was experiencing "severe drought" conditions. The SDI index values indicate that the DDRB experienced "extreme drought" only in 2013-2014, with an SDI value of around -2.17.

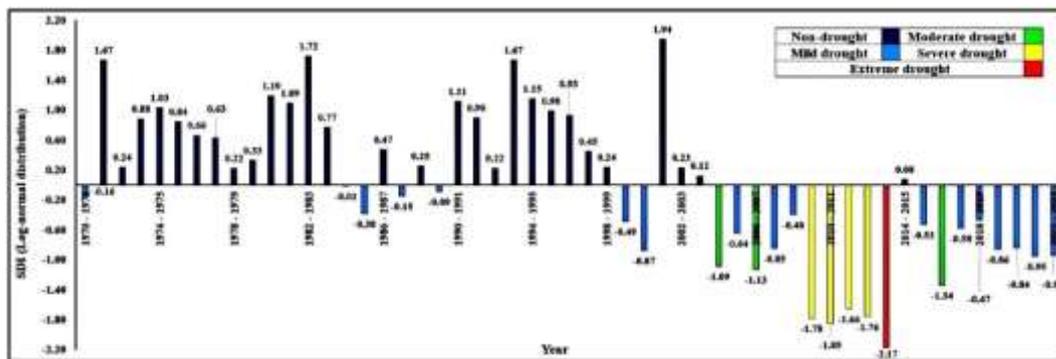
**3.4 Best statistical distribution for SDI index estimation**

Fig. 10 shows the relationship between annual streamflow and the SDI index with two statistical distributions, gamma and log-normal, for the DDRB. Fig. 10 shows that both statistical distributions (gamma and log-normal) have a high coefficient of determination (R<sup>2</sup>), which indicates the suitability of both statistical distributions for estimating the SDI index. Figure 10 also shows that the SDI is a strong index for assessing hydrological drought in the DDRB because the values of the coefficient of determination (R<sup>2</sup>) in both statistical distributions are almost close to one, which indicates a good relationship between streamflow and the SDI index. Comparison of the estimated SDI index results from two distributions, gamma and log-normal, shows that both distributions provide the same results in terms of classifying the hydrological drought situation and its absence in the DDRB. The agreement between the two distributions can

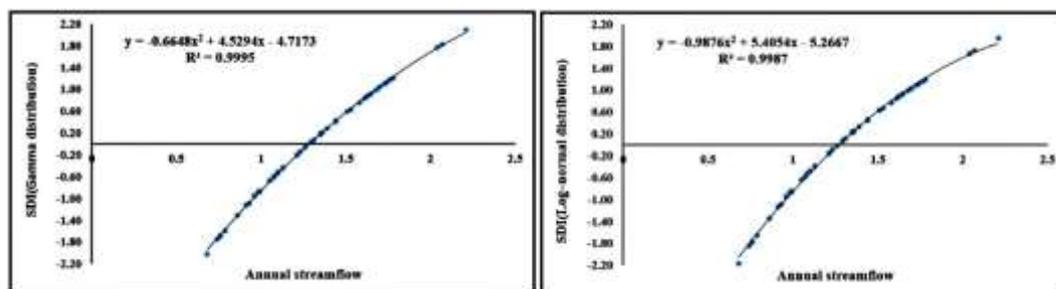
enhance confidence in the hydrological drought assessments made in the DDRB. It provides a reliable basis for decision-

making in water resource management, agricultural planning, and mitigation strategies.

**Fig. 9** Hydrological drought assessment through SDI index and log-normal distribution



**Fig. 10** Annual streamflow and SDI index



### 3.5 Meteorological and hydrological droughts

Table 8 shows the Pearson correlation coefficient between meteorological drought indices and the hydrological drought index for the DDRB. Comparison of the Pearson correlation coefficient between meteorological drought indices (SPI, CZI, DI, ZSI, PNI, and MCZI) and the estimated SDI index with gamma and log-normal distributions shows that the Pearson correlation coefficient values for all meteorological drought indices except the MCZI index are the same in both gamma and log-normal distributions, which is due to the closeness of the estimated values of the SDI index in both gamma and log-normal distributions. Table 8 shows that the Pearson correlation coefficient of the MCZI index with the SDI index is about -0.24 and -0.23, meaning that there is a weak negative correlation between these two indices. That is, as the MCZI index increases, the SDI index decreases, which shows that the MCZI index is an inappropriate index for assessing meteorological drought in the DDRB because increasing meteorological drought does not reduce hydrological drought. The Pearson correlation coefficient between the five meteorological drought indices (SPI, CZI, DI, ZSI, and PNI) and the hydrological drought index (SDI) shows that there is a positive and weak correlation between meteorological drought

and hydrological drought in the DDRB. This means that meteorological drought can be a primary factor that leads to hydrological drought. When there is insufficient rainfall, water resources such as rivers gradually dry up. Therefore, meteorological drought causes a decrease in the volume of surface water. However, the hydrological drought in the DDRB is more affected by other factors, such as human activities. Among the human activities, the water transmission line system from the Karkheh basin to the Qom city can be mentioned, in which water from three rivers is used for transmission, but the Darreh Dozdan River's share is 60 percent of the volume of transferred water. This shows the impact of the water transmission line system well, because in the years after the establishment of the water transmission line system, the hydrological regime of the Darreh Dozdan River has been affected and has experienced more drought. One of the parameters affecting hydrological drought is land use change in a basin. The results of Amini and Hesami (2017) indicate that in the eastern plains of Kurdistan, Iran, land use changes over a period of nine years have led to an average drop of 7 meters in groundwater levels. Therefore, a study should be conducted in the DDRB to assess the impact of human activities, such as land use changes and water transmission line systems, on hydrological drought.

Table 8 Pearson correlation coefficient between meteorological and hydrological drought indices

Index	SPI	PNI	MCZI	CZI	ZSI	DI
SDI (gamma)	0.24	0.22	-0.24	0.24	0.22	0.23
SDI (log-normal)	0.24	0.22	-0.23	0.24	0.22	0.23

### 4. Conclusion

This study monitored and assessed meteorological drought in the DDRB using indices such as SPI, PNI, DI, ZSI, CZI, and MCZI, while also evaluating hydrological drought with the

SDI index and comparing the performance of gamma and log-normal distributions in estimating its values. The most important results of this study can be stated as follows.

1. The DDRB has experienced meteorological and hydrological droughts for 9 years and 25 years, respectively, with different intensities according to the SPI and SDI indices.
2. The SPI and CZI indices, with a determination coefficient of approximately 0.7, are the most suitable indices for assessing meteorological drought in the DDRB, while the MCZI index fails to identify droughts and wet years, categorizing all years except 1971 as "moderately dry."
3. The gamma and log-normal distributions estimate the values of the SDI index to be close to each other, resulting in the same hydrological drought classification for both distributions.
4. There is a positive and weak correlation between meteorological drought and hydrological drought in the DDRB. This suggests that the hydrological drought in this basin is primarily influenced by human activities.

One of the limitations of this study is that there is only one rain gauge-hydrometric station on the Darreh Dozdan River, called Tange Siab. More rain gauge-hydrometric stations help improve the accuracy and reliability of results. Hence, it is suggested that the contribution of climate change and human activities to the hydrological drought be estimated.

#### Statements and Declarations

##### Data availability

The data produced in this research are presented in the paper.

##### Conflicts of interest

The author of this paper declared no conflict of interest regarding the authorship or publication of this paper.

##### Author contribution

H. Ahmadpari: Data Collection, Data Analysis, Investigation, Methodology, Resources, Software, Writing – original draft, Writing – review and editing; V. Khaustov: Conceptualization, Validation, Supervision, Writing – review and editing.

##### AI Use Declaration

This study did not incorporate artificial intelligence techniques; instead, all analyses and optimizations were conducted using conventional and widely accepted analytical methods.

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