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Drought Assessment based on Different Metrological Drought indices in Sulaymaniyah Governorate, KRG, Iraq

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ABSTRACT

Drought is a dangerous situation that lowers individual standards of living. It is considered a devastating natural event. This study intends to thoroughly examine the occurrence and characteristics of drought events in the Sulaymaniyah Governorate from 1985 to 2015. The study employed three standardized indices: the standardized precipitation evapotranspiration index (SPEI), the standardized precipitation index (SPI), and the Reconnaissance Drought Index (RDI). These indices were utilized at different periods, namely 3, 6, 9, and 12 months. According to findings, the maximum percent of extremely dry highlighted in Sulaymaniyah and Dukan stations for SPI index and time scale three months was 48% and 30%, respectively; the maximum percent of severely dry highlighted using RDI index and time scale three months with 41%, 32%, 44% in Sulaymaniyah, Dukan, and Darbandikhan stations respectively. Results revealed that the years 1998, 1999, 2000, 2007, 2008, 2009, and 2010 saw a drought for the used indices, Dukan station has the maximum severity of 112.25 for SPEI12 for the event happened from Nov. 2007 to Sep 2015. The maximum durations were observed at Dukan station using SPI and SPEI as well, and Darbandikhan station has the highest drought frequency. The correlations of drought indices, using the coefficient of determination (R^2) showed the lowest and highest agreement between SPI-SPEI and SPI-RDI, respectively. The findings revealed that water resources in the study area are at risk of depletion due to drought. Therefore, water management techniques are required to mitigate drought in the study area.

Keywords: Climate change, DrinC, Drought severity, RDI, SPEI, SPI.

1. INTRODUCTION

In the twenty-first century, water scarcity is a significant issue **(Plummer and Baird, 2021)**. Global warming, increased water demand, decreased rainfall, and a lack of intelligent agriculture have contributed to the water resources issue. The variables above lead to several types of droughts **(Zhang et al., 2020; Farsani et al., 2021; Orimoloye et al., 2021;**

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Shi et al., 2021). Drought is when a region experiences an extended duration with less rainfall than usual. Various factors, including lack of rain, excessive water use, population increase, and human activity, can cause drought. According to (**Gil-Quintana et al., 2013; Ng et al., 2023)**, drought episodes have directly and indirectly affected the human population, society, and the agricultural industry. There are several types of droughts: hydrological, agricultural, meteorological, and economical **(Wilhite and Glantz, 1985; Svoboda et al., 2012).**

Meteorological drought refers to the extent of dryness based on shortages in precipitation compared to an average amount and by the duration of the dry period. To identify meteorological drought, a threshold of precipitation depletion over a specific time period has to be taken as an indicator. The selected deficiency standards, such as 80% of normal and the six-month associated duration, are expected to change locally based on the prevailing weather conditions. However, the onset of any other kind of drought, like hydrological or agricultural drought, begins with the meteorological drought precursor, lasting long enough to affect the hydrological and farming sectors (**Wilhite and Glantz, 1985)**. Agricultural drought can be caused in two ways: the first is the lack of moisture in the soil, and the second is that the yield is significantly lower than typical due to water scarcity. A period of below-normal conditions for one or more variables, such as stream flow, groundwater level, and reservoir storage, is called a hydrological drought. Hydrological drought commonly affects large regions, such as entire watersheds **(Dalezios et al., 2018)**. It may also arise when the demand for water by humans is strong during periods of average precipitation, and these heightened usages will lead to a depletion of water reserves **(UNDP, 2010).** The socio-economic drought denotes the differences between the supplies and demands of socio-economic goods during drought conditions.

Moreover, ecological drought is a lengthy and prevalent lack of water availability in ecosystems, causing environmental stresses **(Smakhtin and Schipper, 2008; Crausbay et al., 2017; Chandrasekara et al., 2021)**. Monitoring, Prediction, and impact assessment are among the primary components of a drought mitigation plan. Climate studies, statistical analysis, and application of coupled models have demonstrated their effectiveness in methodologies for drought prediction (**UNDP, 2010)**.

In recent decades, various drought indices have been founded to estimate drought events, including (SPEI), (SPI), (RDI),), Deciles (DI), rainfall anomaly index (RAI), standardized runoff index (SRI), palmer hydrological drought severity index (PHDI), palmer drought severity index (PDSI), palmer moisture anomaly index (Z-Index), surface water supply index (SWSI), percent of normal precipitation (PNPI), and china Z index (CZI). The formerly mentioned indices mostly use several estimates or subdivisions of the total water deficit that is caused by precipitation, temperature, solar radiation, and wind speed **(Chen and Sun, 2015; Li et al., 2015; Yu et al., 2019; Chandrasekara et al., 2021; Dilawar et al., 2022; Ng et al., 2023)**. Furthermore, various spectral indices have been utilized for drought estimation, namely the normalized difference vegetation index (NDVI), water storage deficit index (WSDI), bare soil index, normalized differential water index (NDWI), land surfaces temperature index (LST), Tasseled Cap Transformation Wetness (TCTW), and vegetation condition index (VCI), **(Fadhil, 2011; Kousari et al., 2014; Yu et al., 2019; Mohan et al., 2021; Gaznayee et al., 2022a; Gaznayee et al., 2022b; Alee et al., 2023).**

In a different study by **(Montes-Vega et al., 2023)**, the drought conditions in Spain's Donana National Park were evaluated using three distinct indices. The used indices were the groundwater recharge drought index (GRDI), (SPI), and (SPEI). This study's application of the GRDI index, which has been used to evaluate groundwater recharge rates, is a significant addition. A decrease in the average recharge rates is noted in the simulated data for the 21st century in contrast to the historical period between 1950 and 2009. **(Kartal, 2023),** evaluates Elazig, Turkey's drought characteristics. The (SPEI), (SPI), innovative polygon trend analysis (IPTA), and (CZI) drought indices were utilized in this work to conduct meteorological drought analysis. The precipitation data showed a downward trend, whereas the temperature and evaporation data showed an upward trend, all within a 95% confidence interval. Out of all the drought classifications, very severe drought has the lowest share, despite normal drought having the largest share. In a study by (**Ahmed et al., 2023)** in Balochistan, Pakistan, the (SPI), agricultural standardized precipitation index (aSPI), and (SPEI) indices were studied at various timescales (3, 6, 9, and 12 months) based on rainfall, minimum and maximum temperature between (1992–2021). (**Jamro et al., 2019)**, utilized SPEI3 to study spatio-temporal drought patterns in Pakistan between 1902 and 2015. Pakistan's whole area is covered by 327 grid cells. Furthermore, droughts were regionalized into five adjacent zones using the Spatial "K" luster Analysis using the Tree Edge Removal (SKATER) technique. In their research (**Dilawar et al., 2022)** on Karachi, Pakistan from 2000 to 2019. The Palmer Drought Severity Index (PDSI) generated an annual drought hazard map (DHM). Drought exposion was calculated utilizing population density, and gross domestic product, whereas, a drought vulnerability map (DVM) was designed using normal difference vegetation index, land surface temperature, nighttime illumination, land use/ land cover, and distance to water. Based on the findings, Karachi's southern and central parts were more prone to drought influence than the eastern and northern parts.

(Kourtis et al., 2023) used the ERA5 reanalysis precipitation dataset for 83 years, spanning 1940 to 2022, to examine the spatial heterogeneity and trends of the meteorological drought in Greece. The (SPI) was used to estimate droughts for 1-12 months. Five meteorological station's rainfall data were used to perform the evaluation. **(Muse et al., 2023),** used long-term monthly temperature and precipitation for 41 years, between 1980 to 2020, to investigate trends and examine yearly droughts in northern Somalia; this study uses six drought indices for the annual drought assessment: the percent of normal index (PNI), the discrepancy precipitation index (DPI), (DI), the standardized precipitation index using the gamma distribution (Gamma-SPI), the log normal standardized precipitation index (log-SPI), and the normal standardized precipitation index (normal-SPI). In a wide variety watershed in south China, recording the combined likelihood of meteorological-hydrological, meteorological-agricultural, and hydrological-agricultural droughts can be very useful in explaining the evolution of droughts under climate change **(Zhang et al., 2024)**, formulating edge and joint distribution functions for different drought indicators (SPI, SPEI, SSI, and SWI) for the years 1997–2017 and 2023–2099 using copula and SWAT approaches. Between 1997 and 2017, there was a mild drought likelihood of (26.15 to 41.06%), and the return period changed from (3.8 to 2.4) years. The combined likelihood of drought in meteorological-agricultural, meteorological-hydrological, and hydrological-agricultural drought mildly was 14.95 to 22.63 %, 24.4 to 31.32 %, and 6.18 to 22.05 %, respectively. In a recent investigation, it was demonstrated that the Standardized Relative Humidity Index (SRHI) can detect drought signals earlier than (SPI) (**Farahmand et al., 2015**).

SRHI identified drought onset either earlier or simultaneously with SPI, with a global average of about (60% of all events) and a mean lead time of 1.9 months. Furthermore, SRHI successfully identified the early indicators of the 2010 Russian drought, the 2011 Texas drought, and the 2012 Midwestern drought. Iraq, including the Kurdistan Regional Government (KRG), is geographically located in the world's most arid regions; its water resources are a handful and are mainly shared with neighboring countries **(UNESCO, 2014)**.

Water is essential to the agricultural sector's stability and sustainability and the basis of Iraq's economic and social development (**Alobaidy et al., 2010; Yaseen et al., 2018).** For the last two decades, Iraq has experienced recurrent droughts **(Al-Quraishi et al., 2021)**. Droughts are mostly frequent and severe in semi-arid and arid areas, lasting for weeks, months, years, and decades. **(Jasim and Awchi, 2020)**, They evaluated the meteorological drought in Iraq spanning 1970 to 2013. They also analyzed the drought characteristics and frequency of each drought class. From the findings, the most severe instances occurred between 1997 and 2001 and between 2007 and 2010. In addition, with a 33.44% incidence rate, most droughts fell within the mildly dry SPI classification classes. The northeastern region of Iraq exhibited the most significant drought rates, considering both the accumulation deficiency of rainfall and the duration of the drought.
(Abdulrazzaq et al., 2019) Studied spatial and temporal metrological drought in eleven stations located in western Iraq using the integration between Tropical Rainfall Measuring Mission (TRMM) data and SPI-12. The results revealed that the drought were mainly in the southern and southwestern of the study area. A different study by **(Hameed et al., 2018)** utilized SPEI at 0.25◦ spatial resolution between 1948 and 2009 to study metrological drought in Iraq. The results shows two significant drought periods during 1998–1999 and 2007–2008, the extremely dry and severely dry encompasses about 82% and 87% of the country, respectively. Additionally, to assess the drought caused by climate parameters such as precipitation, temperature, and PET, the long-term trends for the mentioned parameters are calculated at a monthly timescale.
(Gaznayee et al., 2022b) employed drought indices namely (MSAVI2), and (NDWI) to assess the drought severity and examine changes in vegetative cover, and water bodies in (KRG). Satellite data (Landsat) from 1998 to 2021 was used. Furthermore, the coefficient of variation (CV) and the SPI index were employed as meteorological drought indices. As per the results, the KRG experienced droughts in (1999, 2000, 2008, 2009, 2012, and 2021), and the vegetative cover decreased by 46.3%, 39.8%, and 36.4%, in (2012, 2008, and 2000), respectively. (**Al-Quraishi et al., 2021)** analyzed drought severity in Sulaymaniyah between 1998 and 2017. The (NDVI) and (NDWI) were used as spectral drought indices, and (SPI) was used as a meteorological drought index. The area of interest had a severe drought and deficient precipitation in 2000, 2008, 2009, and 2012. Furthermore, the study presented that the vegetation cover decreased by 33.3% in 2000, and Darbandikhan Lake lost 40.5% of its surface area in 2009. A different survey by **(Gaznayee et al., 2022a)** explored the effects of the drought on the land surface temperature and vegetation cover in KRG. In addition, Mann-Kendall and Sen's Slope statistical tests were used to assess the drought index variability for sixty selected locations.
KRG is currently dealing with concerns over the potential outcomes of climate change. Experts have expressed cautionary remarks regarding the likelihood of heightened occurrences of droughts and diminished precipitation levels.
The current study aims to evaluate drought conditions and characteristics by conducting an SPI index using different time scales (3, 6, 9, and 12 months) and alternative drought indices (SPEI and RDI) that have not been utilized in the area previously.

2. MATERIALS AND METHODS

2.1 Study Area

Sulaymaniyah is located in northern Iraq between longitude (44° 30' 30 E to 46° 20' 30 E) and latitude (34° 32' 15" N to 36° 34' 15" N), **Fig. 1**. Sulaymaniyahyah Governorate is the largest of the three Governorates that comprise the KRG, including about 67% of the KRG **(Al-Quraishi et al., 2021)**. According to topography, represented by the 30mx30m spatial resolution of the digital elevation model (DEM), the elevation ranges from 180 to 3400 m above mean sea level, which decreases from the east to the west **(USGS, 2019; Rashid, 2021)**, as shown in **Fig. 1**. The KRG, Iraq, has a semi-arid climate according to a study conducted by **(Mustafa et al., 2018)**. Winter precipitation, which runs from December to February, contributes to approximately 56% of the yearly rainfall. Springtime precipitation from March to May, which comprises about 28% of the annual total, is typified by shower-type rain accompanied by thunder and hail. Summer, which lasts from June to September, is identified by an abrupt rise in temperature, very little moisture, and a lack of precipitation **(Ahmed and Al-Manmi, 2021).**

2.2 Data Sets (Precipitation and Temperature)

Metrological data of monthly precipitation (P) and monthly mean temperature (Tm) were collected for the period 1985 to 2015 for the main three metrological stations of Sulaymaniyah, Dukan, and Darbandikhan as shown in **Fig. 1**, acquired from the Directorate of Meteorological and Seismology in Sulaymaniyah, Dukan Dam Directorate, and Darbandikhan Dam Directorate respectively. For the chosen period, the average annual rainfall is 688 mm, 667mm, and 570mm in Sulaymaniyah, Dukan, and Darbandikhan stations, respectively. The average yearly temperature is 19.59◦ C, 19.79◦ C, and 21 ◦ C in Sulaymaniyah, Dukan, and Darbandikhan stations, respectively. The minimum and maximum recorded temperatures were in January and July, respectively.

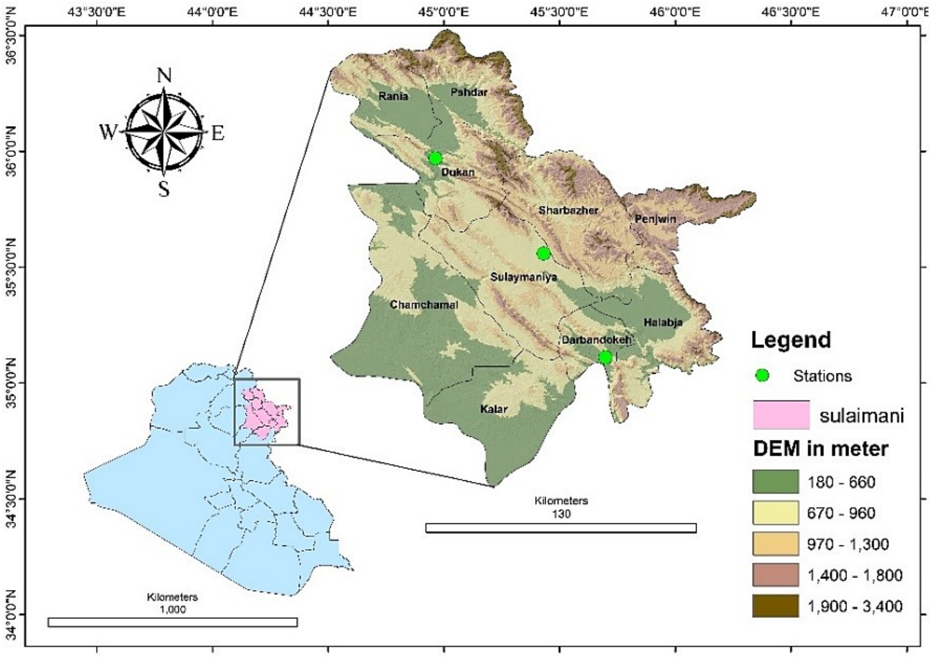


Figure 1. The study area

2.3 Standardized Precipitation Index (SPI)

The SPI is an easy-to-calculate, strong, and versatile index. The only necessary input parameter is precipitation. It works just as well to analyze dry periods as it does to analyze wet periods **(McKee et al., 1993; McKee et al., 1995; Kourtis et al., 2023)**; the SPI can predict drought and quantify its severity on various timescales. This index can only quantify the precipitation shortfall; the initial data could change as the record period expands. Based on the review paper **(Kartika and Wijayanti, 2023)**, it was found that nearly 57 percent of the articles employed the SPI index. The SPI quantifies precipitation deficits over time. Drought affects water availability in these timeframes. Short-term precipitation anomalies affect soil moisture, while long-term precipitation anomalies can be noticed in reservoir storage, streamflow, and groundwater **(McKee et al., 1993)** Computed the SPI for (3, 6, 12, 24, and 48) months for these reasons **(Svoboda et al., 2012)**. The SPI is applicable in all climatic regimes and for places that could be data-poor or lack long-term **(WMO and GWP, 2016)**. The standardized precipitation index (SPI) is the number of standard deviations by which observed data deviate from the calculated long-term mean. For the SPI, extended rainfall data is often changed to a probability distribution, such as a gamma distribution, and subsequently transformed into a normal distribution to achieve a mean SPI of zero **(McKee et al., 1995; Edwards and McKee, 1997)**. The corresponding mathematical expression is given in Eq. (1) **(Ahmed et al., 2023).**

$$SPI = \frac{X - \bar{X}}{\sigma} \tag{1}$$

X represents the observed precipitation, $\bar{X}$ denotes the average rainfall over an extended period, and σ represents the standard deviation of precipitation.

2.4 Standardized Precipitation Evapotranspiration Index (SPEI)

The SPEI was proposed as a probabilistic, multiscalar meteorological drought index. It has been frequently employed in prior research because it better correlates with hydrological and ecological variables by considering precipitation and temperature change (**Li et al., 2015**). Therefore, SPEI computation calls for long-term monthly precipitation and evapotranspiration data. One obtains the water balance deficit (*WBDi*) for a given i (monthly, seasonal, etc.) by subtracting the potential evapotranspiration (*PETi*) value from the total precipitation (*Pi*) value Eq. (2). The i time series aggregated across many periods is then fitted with the best theoretical log-logistic cumulative density function. Finally, the SPEI is produced as the standardized values of the probability density function of i. The interested reader is referred to **(Vicente-Serrano et al., 2010; Alee et al., 2023)** for further information on how the SPEI is computed.

$$WBDi = Pi - PETi \tag{2}$$

Numerous researchers have used the SPI thresholds for SPEI classification, even though the SPI thresholds were attained through the Gaussian distribution model **(Ng et al., 2023)**. The same approach has been conducted in the current study. The SPI and SPEI values for the various drought categories are shown in **Table 1. (Ahmed et al., 2023).**

Table 1. Drought categories used for SPI and SPEI Classification

Index values of drought	Drought class
≤2.00	Extremely wet
1.5 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Mildly drought (near normal)
-1.00 to -1.49	Moderately drought
-1.5 to -1.99	Severely drought
≤ -2.00	Extremely drought

2.5 Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) was designed to address the water shortage in a more precise manner as a kind of equilibrium between input and output in a water system **(Tsakiris and Vangelis, 2005; Tsakiris et al., 2007c).** It is based on potential evapotranspiration (PET) and cumulative precipitation (P). The calculation of the beginning value (αk) of RDI for the i-th year, based on a time interval of k months, is determined using Eq. (3) **(Tsakiris and Vangelis, 2005; Tsakiris et al., 2007c; Tigkas et al., 2015; Kourtis et al., 2023),**

$$\alpha_k{}^{(i)} = \frac{\sum_{i=1}^{k} Pij}{\sum_{j=1}^{k} PETij}, i = 1(1)N \; and \; j = 1(1)k \quad (3)$$

where N is the entire number of years for available data, and Pij and $PETij$ are the precipitation and potential evapotranspiration of the j-th month of the i-th year. The standardized form of the index $RDIst$ can be calculated using Eq. (4), provided that the lognormal distribution is applied:

$$RDI_{st}{}^{(i)} = \frac{y^{(i)} - y^{-}}{\hat{\sigma_y}} \quad (4)$$

where $y^{(i)}$ represents the ln $\alpha_k{}^{(i)}$, y^{-}denotes its average, and $\hat{\sigma_y}$ denotes its standard deviation. Periods with positive RDI values show moist periods, and those with negative values show dry periods. Mildly, moderately, severely, and extremely classes of drought severity can be distinguished, with corresponding RDI boundary values of (−0.5 to −1.0), (−1.0 to −1.5), (−1.5 to −2.0), and (< −2.0), respectively **(Tigkas et al., 2015).**

2.6 Indices Determination

SPI and RDI were found using Drought Indices Calculator (DrinC) software developed at the National Technical University of Athens; a program was designed to facilitate the computation of drought indices through a user-friendly interface. In addition, the program includes a module that uses temperature-based approaches to estimate potential evapotranspiration (PET). This module proves valuable in the computation of the (RDI). DrinC is increasingly used in semi-arid and arid regions for drought analysis, demonstrating its potential as a research and operational tool **(Tigkas et al., 2015)**. The software is in the public domain and can be downloaded for free from (https://drought-software.com). SPEI was found using SPEI calculator software developed to compute the SPEI automatically over a wide range of periods. The program can be acquired for free from the Spanish National Research Council's webpage (https://digital.csic.es/handle/10261/10002) **(Vicente-Serrano et al., 2010)**. Thornthwaite method (supported by both DrinC and SPEI calculator) was used to calculate PET; the data inputs were P and Tm with the observatory latitude with the values of (35.56, 35.97, and 35.11 in Sulaymaniyah, Dukan, and Darbandikhan respectively). The annual average calculated PET for the chosen span period was 1241.4mm, 1321.1mm, and 1449.4mm in Sulaymaniyah, Dukan, and Darbandikhan stations, respectively.

2.7 Drought Characteristics

The main components of a drought event include a) the drought onset time, which indicates the beginning of the period of water scarcity; b) the drought termination time, which indicates the point at which the scarcity of water diminishes to the extent needed to terminate the persistence of drought conditions; c) the drought duration, quantifiable in units such as weeks, months, years, etc., denoting the prolonged period throughout which a drought parameter stays below the critical threshold; and d) the drought severity, which measures the summation deficit of a drought parameter under the critical threshold. **Fig. 2** shows the components affected by drought **(Nikravesh et al., 2020; Ahmed et al., 2023)**. Furthermore, the intensity of a drought is determined by dividing the drought severity by its duration. A higher intensity value indicates a more severe drought.

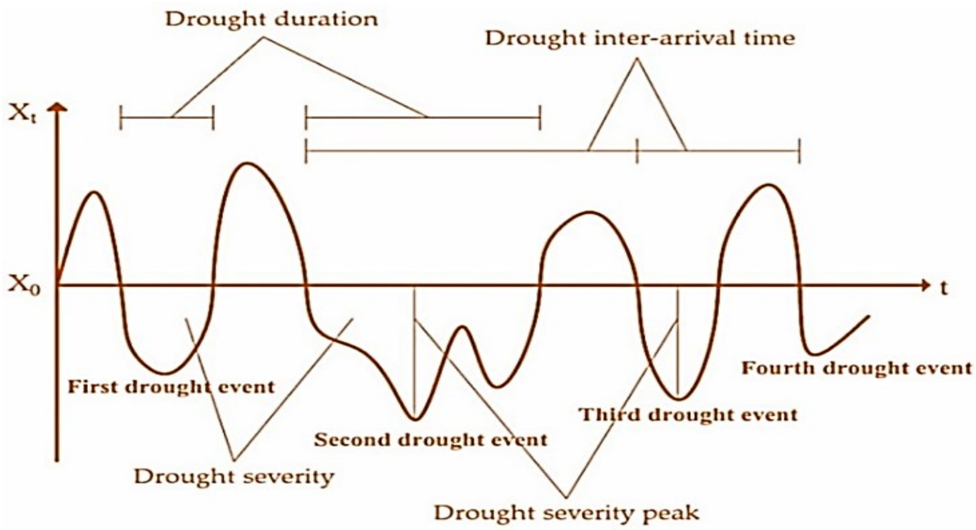


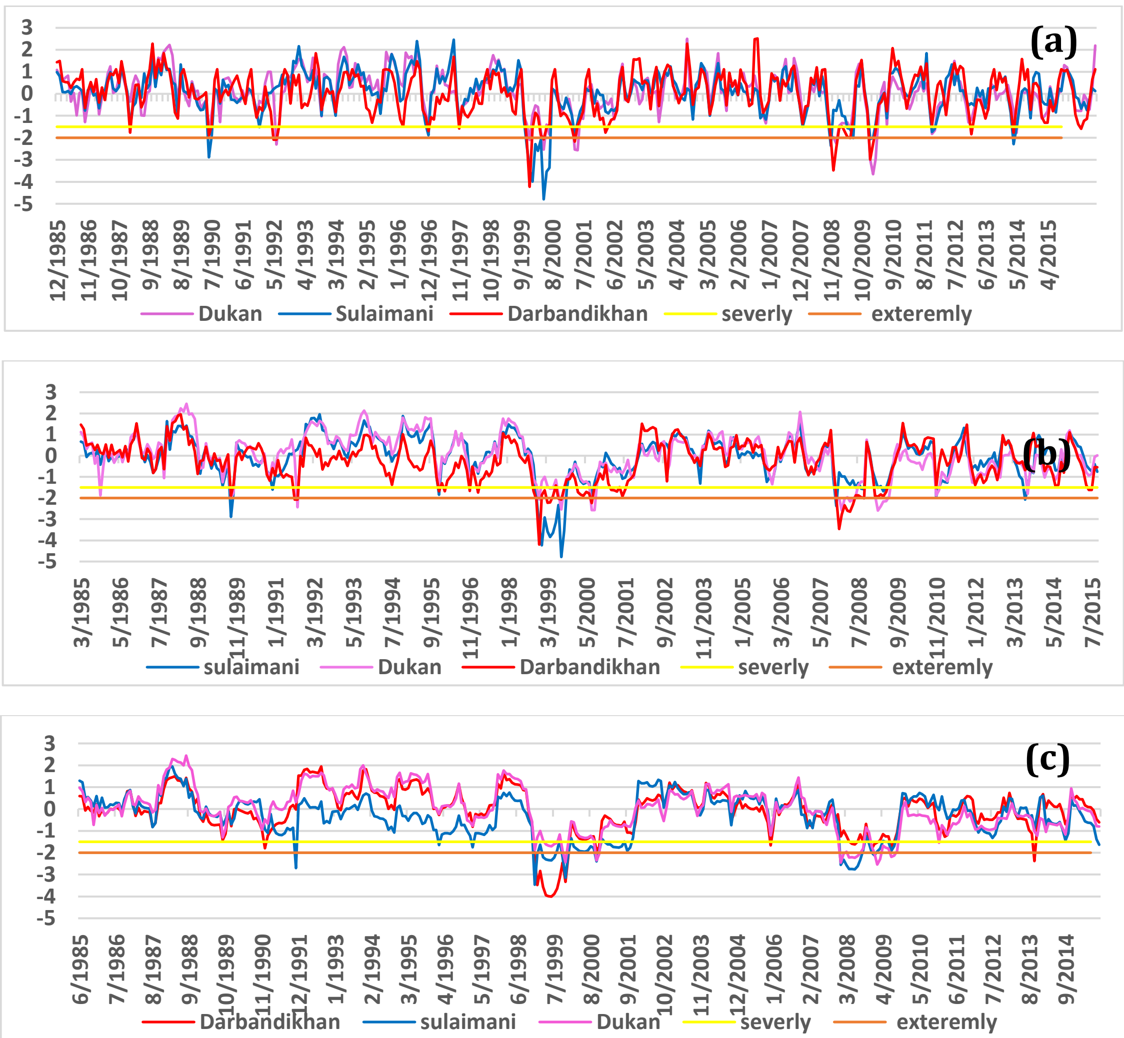
Figure 2. Drought Characteristics **(Nikravesh et al., 2020; Ahmed et al., 2023)**

As per Reference **(McKee et al., 1993)**, an occurrence is classified as a drought episode when the SPI readings consistently exhibit negative values and fall below −1.0. When the SPI is less than -1.0 in the first month, the drought period begins, and it ends when the SPI attains positive values. In this study, to delineate drought, the threshold value of −1 was set for the identifying of drought conditions, with the indices used (SPI, SPEI, and RDI) falling at or below this threshold value were employed as drought indicators **(Naz et al., 2020)**. Additionally, the assumption has been made that a drought began if the indices value was below a predetermined threshold (≤-1) for a minimum of three months in a row, ending when indices rose above zero. After determining the initiation and conclusion of a dry period, additional drought indicators such as peak, severity, duration, and intensity were examined.

3. RESULTS and DISCUSSION

3.1 SPI Results Analysis and SPI Drought Characteristics

The SPI was computed for the time scales of 3, 6, 9, and 12 months. The outcomes are shown in **Figs.** (**3 a- 3d)**. Further details are elaborated in the following:
Regarding the outcomes of SPI-3 drought events, extreme droughts were noticed for the respective stations and years as follows: Sulaymaniyah, 1998, 1999, 2008, and 2009; Dukan, 1998, 1999, 2000, 2008, and 2009; Darbandikhan, 1991, 1998, 1999, 2000, 2007, 2008, and 2009. For the SPI-6 drought events result, extreme droughts were noticed as follows for the stations and years: Sulaymaniyah, 1998, 1999, 2007, and 2013; Dukan, 1998, 1999, 2000, 2007, 2008 and 2009; Darbandikhan, 1991, 1998, 1999, 2000, 2007, and 2008. Regarding the outcomes of SPI-9 drought events, extreme droughts were noticed for the respective stations and years as follows: Sulaymaniyah, 1998 and 1999; Dukan, 1999, 2000, 2008, and 2009; Darbandikhan, 1991, 1998, 1999, 2000, 2008, and 2009.



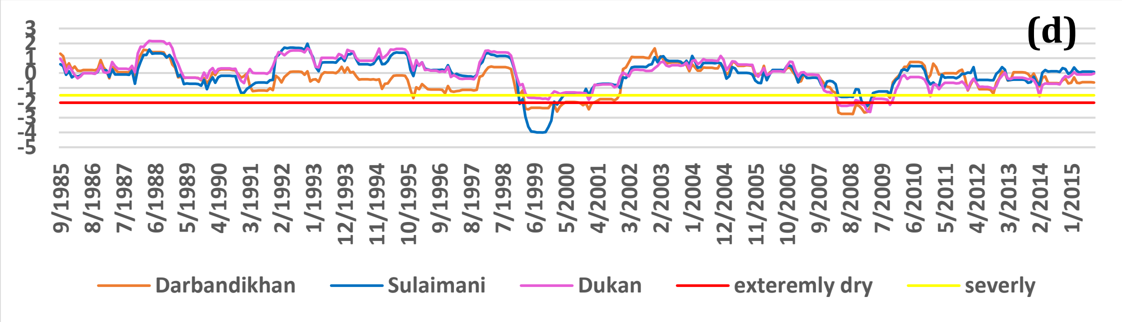


Figure 3. SPI values for time intervals of a) 3, b) 6, c) 9, d) 12 months

For the SPI-12 drought events result, extreme droughts were noticed as follows for the stations and years: Sulaymaniyah, 1999, 2000, and 2009; Dukan, 2008, and 2009; Darbandikhan, 1999, 2000, 2001, 2008, and 2009. Generally, for the most time series and all stations, the drought observed in the years 1998, 1999, 2008, and 2009 closely align with the findings of the previous research (**Al-Quraishi et al., 2021; Gaznayee et al., 2022b)**. The SPI drought characteristics for all stations regarding the onset period and the end of the period, duration, peak, severity, and intensity are presented in (**Tables 2-5**). For SPI3

Table 2. Drought Characteristics for all Station using SPI3

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaimani	Oct-98	Jul-99	10	-4.8	-29.56	2.96
	Mar-08	Jul-08	5	-2.01	-7.19	1.44
	Jan-09	May-09	5	2.05	-6.01	1.20
	Nov-10	Mar-11	5	-1.78	-5.46	1.09
Dukan	Oct-98	Jul-99	10	-2.53	-14.08	1.41
	Apr-00	Jul-00	4	-2.56	-7.27	1.82
	Nov-07	Jul-08	9	-2.26	-13.98	1.55
	Jan-09	Apr-09	4	-3.65	-10.58	2.64
Darbandikhan	May-91	Jul-91	3	-2.08	-5.59	1.86
	Nov-95	Apr-96	6	-1.69	-5.54	0.92
	Nov-98	Jul-99	9	-4.23	-16.69	1.85
	Feb-00	Jul-00	6	-2.17	-8.36	1.39
	Jan-01	Jul-01	7	-1.77	-8.59	1.23
	Nov-07	Jul-08	9	-3.49	-17.86	1.98
	Jan-09	May-09	5	-2.99	-7.80	1.56
	Feb-14	Jul-14	6	-1.32	-5.16	0.86
	Mar-15	Jul-15	5	-1.6	-5.71	1.14

For SPI3, the maximum peak, severity, and intensity occurred at Sulaymaniyah station from Oct.98 to Jul.99. For SPI6, the maximum peak was at Sulaymaniyah station, and the maximum severity and intensity occurred at Darbandikhan station. Regarding SPI9, the maximum peak was noticed at Sulaymaniyah station, and the maximum severity and intensity were at Darbandikhan station. Lastly, for SPI12, the maximum peak was at Sulaymaniyah station, the maximum severity was at Dukan station, and the maximum intensity was at Darbandikhan station. Among all-time series, the maximum peak and intensity were -4.8 and 2.96 at

Sulaymaniyah for SPI3 for the event that occurred from Oct.98 to Jul.99. The maximum severity was -86.22 at Dukan for SPI12 for the event that occurred from Nov. 2007 to Sep 2015. The maximum durations for SPI3, SPI6, and SPI12 were 10, 39, and 95 months at Dukan station; for SPI9, the maximum duration was 38 months at Sulaymaniyah station.

Table 3. Drought Characteristics for all Station using SPI6

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaimani	Nov-98	Nov-01	38	-4.78	-58.09	1.53
	Oct-05	Mar-06	6	-1.25	-4.12	0.69
	Oct-07	Sep-08	12	-2.38	-15.93	1.33
	Jan-09	Aug-09	8	-1.68	-9.09	1.14
	Nov-10	Apr-11	6	-1.92	-7.34	1.22
	Jun-13	Oct-13	5	-2.07	-6.24	1.25
Dukan	Oct-98	Nov-01	39	-2.57	-41.43	1.06
	Nov-07	Jul-09	21	-2.59	-34.88	1.66
Darbandikhan	Jul-91	Nov-91	5	-2.08	-5.67	1.13
	Nov-95	Oct-97	24	-1.74	-20.94	0.87
	Oct-98	Nov-01	38	-4.2	-60.11	1.58
	Nov-07	Sep-08	11	-3.46	-25.86	2.35
	Jan-09	Aug-09	8	-1.93	-11.59	1.45
	May-15	Sep-15	5	-1.62	-5.72	1.14

Table 4. Drought Characteristics for all Station using SPI9

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaimani	Dec-90	Aug-91	9	-1.8	-7.78	0.86
	Dec-98	Dec-01	38	-4.01	-66.19	1.74
	Mar-08	Oct-09	20	-1.62	-26.87	1.34
	Nov-10	Jul-11	9	-1.26	-6.03	0.67
Dukan	Dec-98	Nov-01	36	-2.44	-44.30	1.23
	Dec-07	Oct-09	23	-2.54	-43.41	1.89
Darbandikhan	Apr-91	Nov-91	8	-1.2	-10.00	1.25
	Feb-96	Oct-97	21	-1.75	-21.90	1.04
	Dec-98	Dec-01	37	-3.46	-69.63	1.88
	Jan-08	Oct-09	22	-2.76	-42.87	1.95
	Apr-12	Oct-12	7	-1.32	-7.00	1.00

3.2 SPEI Results Analysis and SPEI Drought Characteristics

The SPEI was computed for the time scales of 3, 6, 9, and 12 months. The outcomes are shown in **Figs.** (**4a- 4d)**. For most of the time series and across all stations, drought conditions were observed primarily in the years 1999, 2008, 2009, and 2010. The current findings are well-approved by research conducted by **(Hameed et al., 2018).**

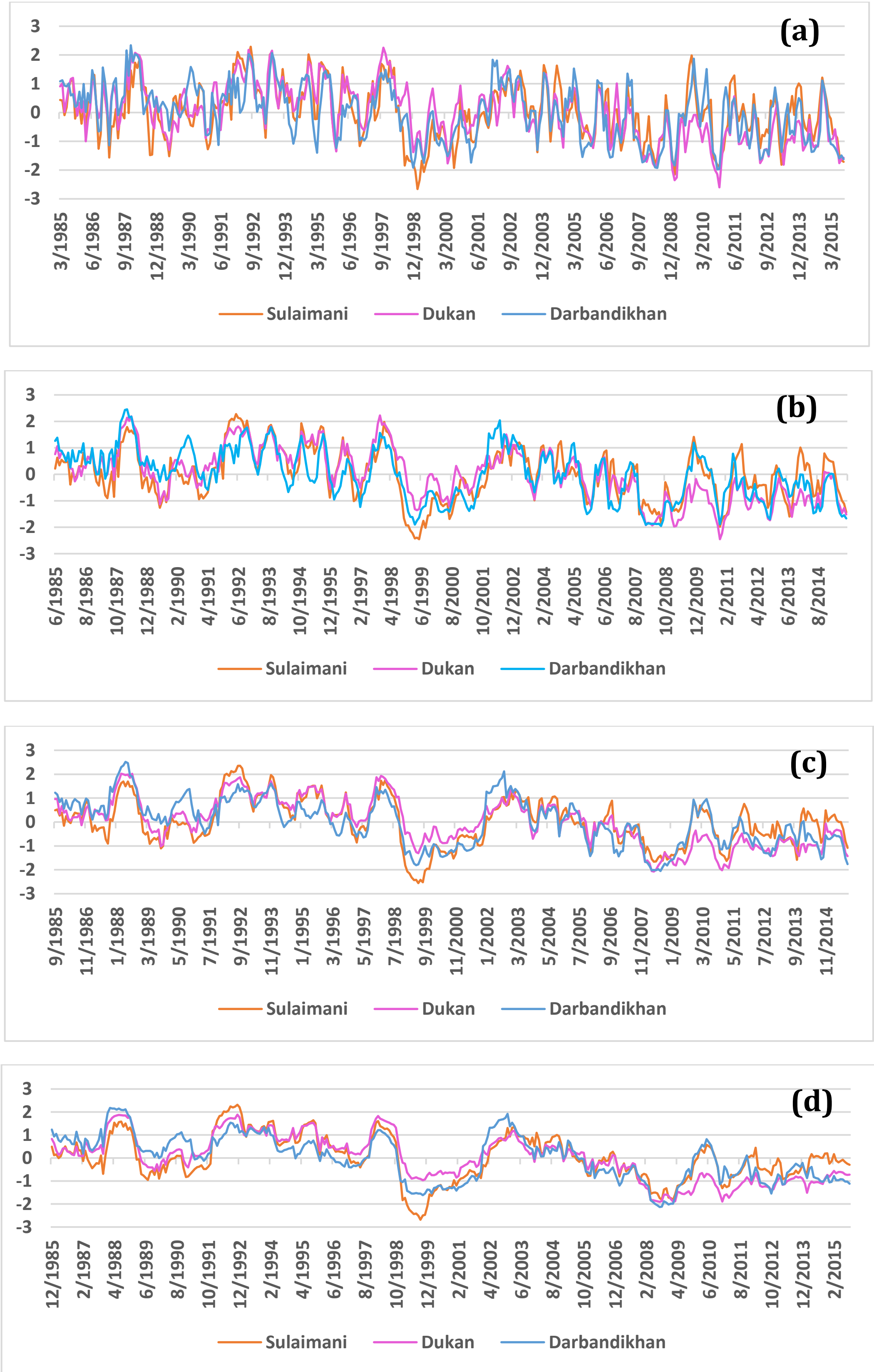


Figure 4. SPEI values for time intervals of a) 3, b) 6, c) 9, d) 12 months

The SPEI drought characteristics for all the stations regarding the onset period and the end of the period, duration, peak, severity, and intensity are presented in (**Tables 6-9**). The maximum durations for SPEI3, SPEI6, SPEI9, and SPEI12 were 42, 85, 94, and 95 months at Dukan station, respectively. The average drought duration was the longest in Dukan station using SPI and SPEI for the all-time series, which might ultimately impact the agricultural and hydrological drought.

Table 5. Drought Characteristics for all Station using SPI12

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaimani	Dec-90	Nov.91	12	-1.34	-9.62	0.80
	Jan-99	March.02	40	-4.01	-70.75	1.77
	Apr-08	Jan. 10	22	-2.24	-30.61	1.39
Dukan	Mar-99	Mar-02	37	-1.80	-43.46	1.17
	Nov-07	Sep-15	95	-2.58	-86.22	0.91
Darbandikhan	Apr-91	Apr-92	13	-1.21	-10.87	0.84
	May-96	Dec-97	20	-1.36	-21.10	1.05
	Dec-98	Dec-01	37	-2.45	-74.60	2.02
	Feb-08	Dec-12	24	-2.77	-53.06	2.21

Table 6. Drought Characteristics for all stations using SPEI3

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaymaniyah	Aug-98	Nov-00	28	-2.66	-35.61	1.27
	Oct-07	Sep-08	12	-1.67	-13.90	1.16
	Jan-09	Jul-09	7	-2.16	-6.33	0.90
	Aug-10	Mar-11	7	-1.82	-10.78	1.54
	Mar-13	Jul-13	5	-1.82	-5.38	1.08
	Jul-15	Sep-15	3	-1.72	-4.84	1.61
Dukan	Oct-07	Apr-11	42	-2.60	-47.78	1.14
	Jun-12	Jan-13	8	-1.76	-8.92	1.11
	Apr-13	Oct-14	19	-1.81	-17.19	0.90
	Jun-15	Sep-15	4	-1.76	-6.07	1.52
Darbandikhan	Nov-98	Aug-99	10	-1.92	-11.77	1.18
	Feb-00	Sep-00	8	-1.52	-7.73	0.97
	Mar-01	Jun-01	4	-1.74	-4.75	1.19
	Jun-05	Jan-06	8	-1.55	-8.56	1.07
	Jul-06	Mar-07	9	-1.57	-8.01	0.89
	Oct-07	Sep-08	12	-1.93	-18.46	1.54
	Jan-09	Jul-09	7	-1.84	-5.36	0.77
	Aug-10	Dec-10	5	-1.97	-7.85	1.57
	Jun-12	Oct-12	5	-1.63	-7.26	1.45
	Jun-14	Oct-14	5	-1.37	-5.71	1.14
	Mar-15	Sep-15	7	-1.62	-9.52	1.36

Table 7. Drought Characteristics all stations using SPEI6

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaymaniyah	Oct-98	Dec-01	39	-2.45	-46.61	1.20
	Oct-05	Apr-06	7	-1.23	-4.48	0.64
	Jan-08	Jul-09	19	-1.85	-22.77	1.20
	Oct-10	Apr-11	7	-1.98	-9.84	1.41
	May-13	Oct-13	6	-1.59	-5.89	0.98
Dukan	Mar-99	May-99	3	-1.36	-3.98	1.33
	Oct-07	Oct-14	85	-2.45	-95.45	1.12
	Jun-15	Sep-15	4	-1.52	-5.47	1.37
Darbandikhan	Dec-98	Sep-01	34	-1.89	-37.59	1.11
	Sep-05	Jan-06	5	-1.51	-6.25	1.25
	Aug-06	Mar-07	8	-1.40	-8.81	1.10
	Oct-07	Jul-09	22	-1.95	-31.31	1.42
	Oct-10	Apr-11	7	-1.89	-6.64	0.95
	Jun-12	Dec-12	7	-1.70	-8.16	1.17
	Jun-14	Jan-15	8	-1.48	-7.13	0.89
	May-15	Sep-15	5	-1.66	-7.38	1.48

Table 8. Drought Characteristics: All stations using SPEI9

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaymaniyah	Nov-98	Dec-01	38	-2.56	-51.72	1.36
	Jan-08	Sep-09	21	-1.66	-27.57	1.31
	Nov-10	Jul-11	9	-1.62	-9.51	1.06
Dukan	Apr-99	Jan-00	10	-1.31	-8.32	0.83
	Dec-07	Sep-15	94	-2.07	-106.66	1.13
Darbandikhan	Dec-98	Nov-01	36	-1.81	-43.13	1.20
	Nov-06	Sep-09	25	-2.05	-41.06	1.64
	Jun-12	Sep-15	40	-1.31	-32.07	0.80

Table 9. Drought Characteristics: All stations using SPEI12

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaymaniyah	Jan-99	Mar-02	39	-2.68	-53.74	1.38
	Apr-08	Jan-10	22	-1.83	-26.86	1.22
	Nov-10	Oct-11	12	-1.31	-10.43	0.87
Dukan	Nov-07	Sep-15	95	-1.91	-112.25	1.18
Darbandikhan	Mar-99	Dec-01	34	-1.55	-43.15	1.27
	Jan-08	Oct-09	22	-2.13	-33.26	1.51
	May-12	Sep-15	41	-1.55	-34.98	0.85

3.3 RDI Results Analysis and RDI Drought Characteristics

The outcomes of the RDI compution for scales of 3, 6, 9, and 12 months are presented in **Figs. (5 a-5d)**. Generally, drought is observed in 1998, 1999, 2000, 2007, 2008, and 2009 for the most time series and all stations. Further, the index exhibits significant fluctuations over a short period (3 months), with these fluctuations diminishing as the time scale extends, especially in (12 months). The RDI drought characteristics for all the stations regarding the onset period and the end of the period, duration, peak, severity, and intensity are presented in **Tables 10-13**. The longest durations for RDI3, RDI6, RDI9, and RDI12 were 10, 36, 37, and 39 months, respectively, at Sulaymaniyah. According to the finding durations and the RDI characteristics, which involve calculating aggregated deficits between precipitation and evaporative demand **(Tsakiris and Vangelis, 2005; Tsakiris et al., 2007c)**, it's advisable to consider RDI for agricultural drought analysis.

Table 10. Drought Characteristics all stations using RDI3

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaymaniyah	Oct-98	Jul-99	10	-4.50	-27.46	2.75
	Apr-08	Jul-08	4	-1.99	-6.92	1.73
	Jan-09	Mar-09	3	-1.94	-4.86	1.62
	Nov-10	Mar-11	5	-1.83	-6.46	1.29
Dukan	Oct-98	Jul-99	10	-2.28	-13.76	1.38
	Apr-00	Jul-00	4	-2.22	-6.21	1.55
	Nov-07	Jul-08	9	-2.00	-13.50	1.50
	Jan-09	Apr-09	4	-2.88	-9.02	2.25
	Nov-10	Feb-11	4	-1.99	-5.88	1.47
Darbandikhan	May-91	Jul-91	3	-1.85	-5.00	1.67
	Nov-98	Jul-99	9	-3.35	-15.71	1.75
	Jan-01	Jul-01	7	-2.06	-8.25	1.18
	Nov-07	Jan-08	3	-2.20	-6.07	2.02
	Mar-08	Jul-08	5	-1.93	-7.88	1.58

Table 11. Drought Chracteristics all stations using RDI6

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaymaniyah	May-89	Jul-89	3	-1.41	-3.41	1.14
	Nov-98	Nov-01	36	-4.63	-56.97	1.58
	Oct-05	Jan-06	4	-1.29	-4.20	1.05
	Jan-08	Sep-08	9	-1.79	-13.14	1.46
	Jan-09	Aug-09	8	-1.56	-8.87	1.11
	Nov-10	Apr-11	6	-1.99	-8.75	1.46
	May-13	Oct-13	6	-1.99	-7.34	1.22
Dukan	Nov-98	Dec-99	14	-2.22	-17.40	1.24
	Jun-00	Sep-00	4	-2.23	-6.30	1.58
	Nov-07	Sep-08	11	-2.33	-20.66	1.88
	Jan-09	Jul-09	7	-2.46	-13.19	1.88
	Nov-10	Apr-11	6	-2.01	-9.11	1.52
	May-14	Jul-14	3	-1.23	-3.32	1.11
Darbandikhan	Oct-98	Nov-01	18	-3.26	-51.87	2.88
	Nov-07	Sep-08	11	-2.71	-23.25	2.11
	May-15	Sep-15	5	-1.63	-6.43	1.29

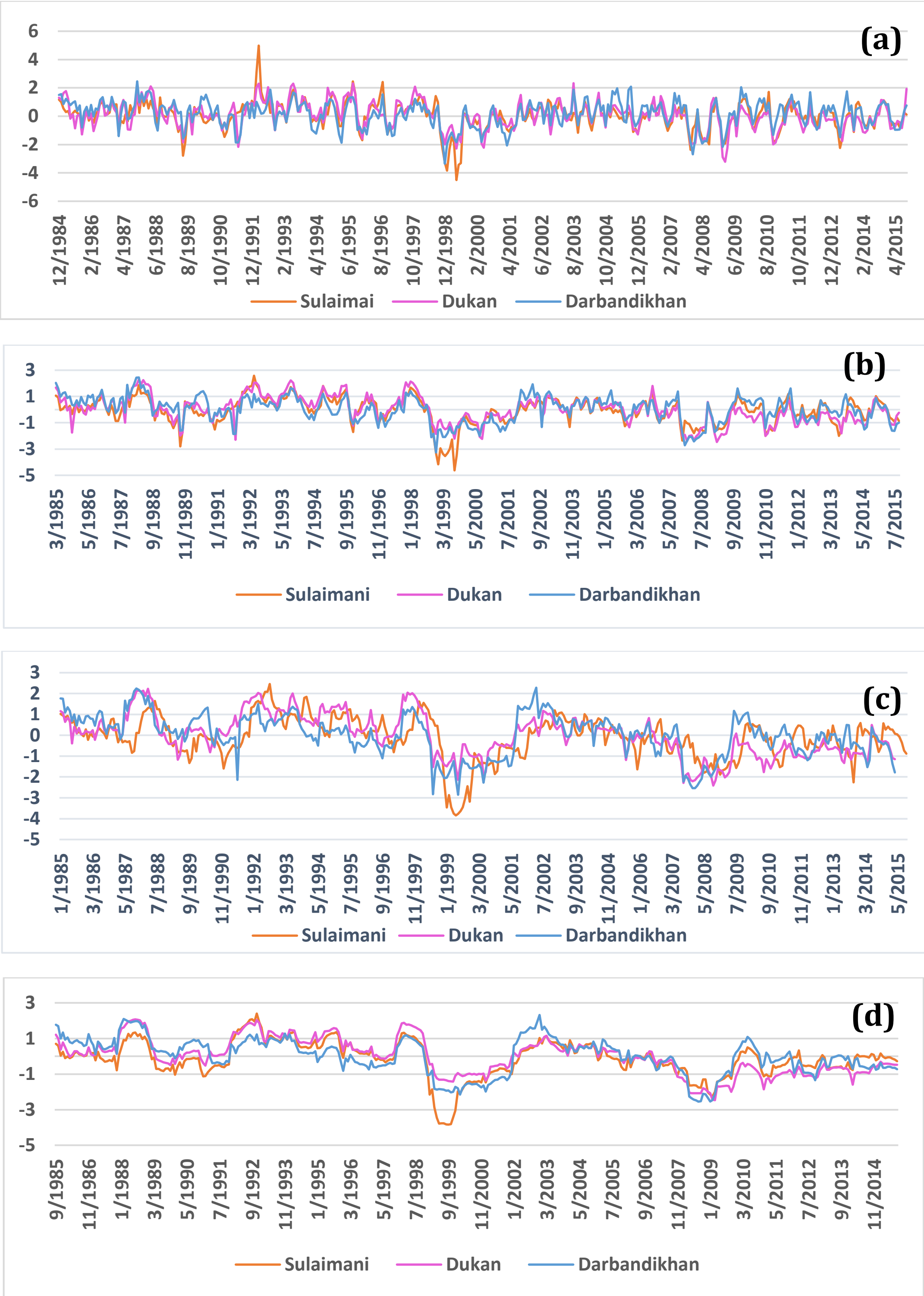


Figure 5. RDI values for time intervals of a) 3, b) 6, c) 9, d) 12 months

Table 12. Drought Characteristics all stations using RDI9

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaymaniyah	Dec-98	Dec-01	37	-3.84	-65.48	1.77
	Jan-08	Oct-09	22	-1.88	-30.31	1.38
	Dec-10	Aug-11	9	-1.53	-7.58	0.84
	Aug-13	Nov-13	4	-2.26	-5.20	1.30
Dukan	Dec-98	Dec-99	13	-2.14	-16.83	1.29
	May-00	Feb-01	10	-1.90	-10.68	1.07
	Dec-07	Oct-09	23	-2.41	-41.89	1.82
	Sep-10	Aug-11	12	-1.77	-13.88	1.16
Darbandikhan	Dec-98	Dec-01	37	-2.85	-56.19	1.52
	Jan-08	Sep-09	21	-2.54	-36.84	1.75

Table 13. Drought Characteristics all stations using RDI12

Station	Onset period	End period	Duration (months)	Peak	Severity	Intensity
Sulaymaniyah	Jan-99	Mar-02	39	-3.84	-70.04	1.80
	Apr-08	Jan-10	22	-2.27	-31.10	1.41
	Dec-10	Feb-12	15	-1.13	-8.41	0.56
Dukan	Apr-99	Jun-01	27	-1.43	-28.76	1.07
	Nov-07	Jan-10	27	-2.47	-47.25	1.75
	Nov-10	Jan-13	27	-1.86	-28.89	1.07
Darbandikhan	Mar-99	Dec-01	34	-2.15	-55.24	1.62
	Feb-08	Nov-09	22	-2.55	-38.51	1.75

3.4 Comparison of Indices and Stations and Drought Indices Frequency

Tables (14-16) shows the frequency of the occurrence of each drought class for each index (mildly dry, moderately dry, severely dry, and extremely dry) for the time series 3, 6, 9, and 12 months. According to findings, the highest number of drought events has descending order from Darbandikhan, Dukan, and Sulaymaniyah stations, respectively, for all index and all time scales. This pattern may be attributed to the relatively insufficient rainfall and higher temperature values specifically observed at the Darbandikhan station

Table 14. Drought indices frequency for Sulaymaniyah station's events

Indices	Time series (months)	Total events No.	% Mildly dry	% Moderately dry	% Severely dry	% Extremely Dry
SPI	3	25	16	20	16	48
	6	74	39	28	16	16
	9	69	30	35	16	19
	12	61	20	34	23	23
SPEI	3	63	40	17	35	8
	6	78	38	33	19	9
	9	68	31	40	16	13
	12	73	38	29	19	14
RDI	3	22	5	23	41	32
	6	73	32	36	19	14
	9	72	28	33	19	19
	12	64	22	38	16	25

Based on SPI3, the % of extremely dry conditions was highest for all stations, and it was lowest in SPEI, proving that SPEI is more reliable when estimating agricultural droughts due to its consideration of precipitation and temperature.

Table 15. Drought indices frequency for Dukan station's events

Indices	Time series (months)	Total events No.	% Mildly dry	% Moderately dry	% Severely dry	% Extremely dry
SPI	3	27	19	33	19	30
	6	59	34	29	15	22
	9	59	25	24	25	25
	12	132	58	17	17	8
SPEI	3	73	47	25	22	7
	6	92	39	34	25	2
	9	104	46	30	21	3
	12	95	36	40	24	0
RDI	3	31	23	26	32	19
	6	45	13	40	24	22
	9	67	19	42	25	13
	12	81	25	48	16	11

Table 16. Drought indices frequency for Darbandikhan station's events

Indices	Time series (months)	Total events No.	% Mildly dry	% Moderately dry	% Severely dry	% Extremely Dry
SPI	3	56	20	39	20	21
	6	91	26	23	33	18
	9	95	15	31	32	23
	12	102	11	42	17	30
SPEI	3	80	25	44	31	0
	6	96	27	49	24	0
	9	111	44	36	16	4
	12	122	28	34	34	3
RDI	3	27	11	33	44	11
	6	54	19	31	28	22
	9	58	9	34	33	24
	12	56	7	27	39	27

Figs. 6-8 displayed the comparison of the indices for all stations using a time scale of 12 months (SPI12 was selected due to its low fluctuation). While the RDI index value falls between the SPI and SPEI, and the SPI index records higher values for all stations, the SPEI index often has a lower value. The values of the indices at the Sulaymaniyah station are highly correlated compared to the other two stations.

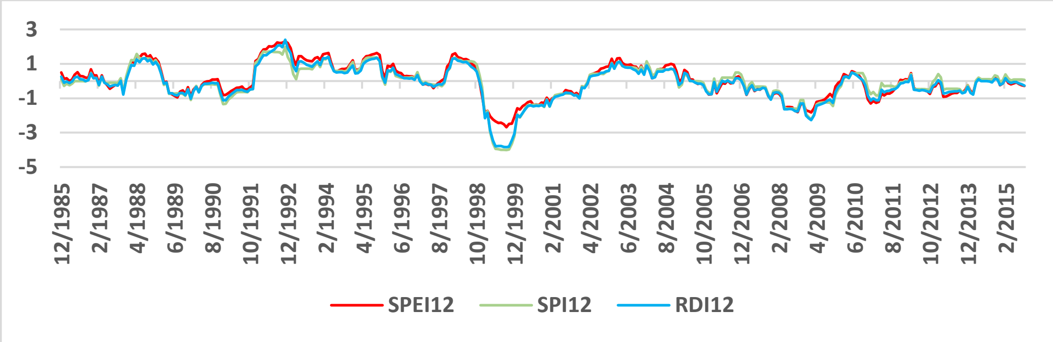


Figure 6. Indices comparison in Sulaymaniyah Station using a time interval of 12 months

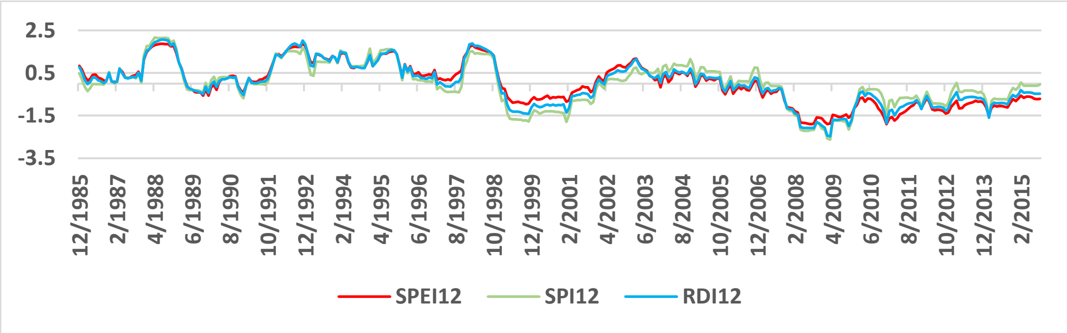


Figure 7. Indices comparison in Dukan Station using a time interval of 12 months

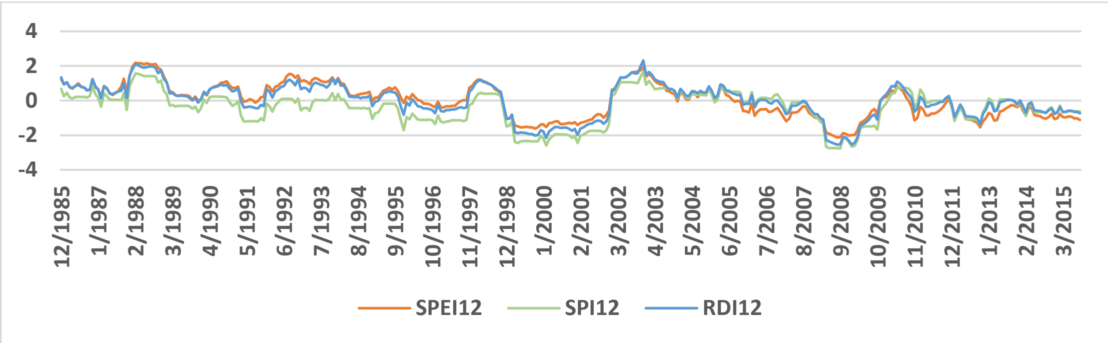


Figure 8. Indices comparison in Darbandikhan Station using a time interval of 12 months

3.5 Indices Correlation

According to **(Cheval, 2015; Kartika and Wijayanti, 2023)**, the SPI is assumed to be a universal drought index due to its simplicity, efficiency for solid and liquid precipitation, temporal versatility, and flexibility in identifying wet and dry periods. Therefore, the SPI was utilized as a reference index and the coefficient of determination to investigate the correlation between indices. According to the results, Sulaymaniyah station has a high correlation (R^2) between the SPI and other indices, with the SPEI index ranging from 0.59 to 0.90 and the RDI index from 0.90 to 0.98. For Dukan station, the (R^2) ranged between 0.27 to 0.83 for the SPEI index and 0.93 to 0.94 for the RDI index. The (R^2) for the Darbandikhan station varied from 0.40 to 0.65 using the SPEI index and from 0.83 to 0.90 using the RDI index. Strong relationships between SPI and RDI have been observed, with minimum correlations in the three-month time scale; the current study's findings are well-approved by the previous research **(Pillai et al., 2019; Bazrafshan et al., 2019; Lotfirad et al., 2021)**. However, this finding contrasts with the study conducted by **(Asadi Zarch et al., 2011)**, possibly due to differences in calculating PET, where a different method, Penman-Monteith, was utilized in their research. Generally, the correlation of drought indices showed the lowest and highest agreement between SPI-SPEI and SPI-RDI, respectively; the agreement index rises as the time scale is extended from three to twelve months.

4. CONCLUSIONS

The current study examined the features of droughts in terms of peak, severity, duration, and intensity in Sulaymaniyahyah Governorate over 31 years (1985–2015) in three main stations (Sulaymaniyah, Dukan, and Darbandikhan). Three standard metrological drought indices (SPI, SPEI, and RDI) were evaluated using various time scales (3, 6, 9, and 12 months). Additionally, an analysis was conducted to verify the significance of each index by comparing them. The main findings revealed that the maximum peak and intensity were observed at Sulaymaniyah station, Dukan station had the maximum severity, and Darbandikhan station had the highest number of drought events. A maximum drought intensity was observed using SPI in the time scale of 3 months, with SPEI recorded the minimum intensity in comparison to other indecis. Overall, the drought was observed in 1998, 1999, 2008, and 2009 using the SPI index for most of the time series and all stations. Using the SPEI index, the drought was observed in 1999, 2008, 2009, and 2010, while the RDI index was observed in 1998, 1999, 2000, 2007, 2008, and 2009. The correlation of drought indices showed the lowest and highest agreement between SPI-SPEI and SPI-RDI, respectively; the agreement index rises as the time scale is extended from three to twelve months. Moreover, the values of the indices at the Sulaymaniyah station are highly correlated to those of the other two stations. Further, RDI and SPEI can be used for agricultural drought analysis, as it can adequately describe the water balance, and it is particularly useful when reference periods related to the development stages of the crop are chosen. The SPEI is considered more appropriate than the SPI for studying climate change and drought variations as it incorporates both precipitation and evapotranspiration data. Generally, all indices exhibit significant fluctuations over short periods, with these fluctuations diminishing as the time scale extends. Stakeholders such as climate change experts, hydrologists, agronomists, and managers of water resources will benefit from this study's aid in creating a successful policy for mitigating droughts.

NOMENCLATURE

Symbol	Description	Symbol	Description
aSPI	Agricultural standardized precipitation index	SRHI	Standardized relative humidity index
CV	Coefficient of variation	SRI	Standardized runoff index
CZI	China Z index	SWSI	Surface water supply index
DI	Deciles	TCTW	Tasseled cap transformation wetness
DHM	Drought hazard map	Tm	Monthly mean temperature
DPI	Discrepancy precipitation index	TRMM	Tropical rainfall measuring mission
DVM	Drought vulnerability map	VCI	Vegetation condition index

GRDI	Groundwater recharge drought index	WSDI	Water storage deficit index
IPTA	Innovative polygon trend analysis	Z-Index	Palmer moisture anomaly index
KRG	Kurdistan regional government	N	The entire number of years for available data
LST	Land surfaces temperature index	Pi	The total precipitation for a given i (monthly, seasonal, etc.)
NDVI	Normalized difference vegetation index	$PETi$	The potential evapotranspiration for a given i (monthly, seasonal, etc.)
NDWI	Normalized differential water index	Pij	The precipitation of the j-th month of the i-th year
P	Monthly precipitation	$PETij$	The potential evapotranspiration of the j-th month of the i-th year
PHDI	Palmer hydrological drought severity index	$RDIst$	The standardized form of the RDI index
PNI	Percent of normal index	$WBDi$	The water balance deficit for a given i (monthly, seasonal, etc.)
PNPI	Percent of normal precipitation	X	Observed precipitation over an extended period
PSDI	Palmer drought severity index	$\bar{X}$	The average precipitation over an extended period
RAI	Rainfall anomaly index	$y^{(i)}$	Represents the ln ${\alpha_k}^{(i)}$
RDI	Reconnaissance drought index	y^{-}	Represent the average of ${\alpha_k}^{(i)}$
SPEI	Standardized precipitation evapotranspiration index	${\alpha_k}^{(i)}$	The beginning value of RDI for the i-th year
SPI	Standardized precipitation index	σ	The standard deviation of precipitation
SKATER	Spatial "K" luster Analysis using the Tree Edge Removal	$\hat{\sigma}_y$	The standard deviation of ${\alpha_k}^{(i)}$

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Declaration of Competing Interest

The author declare that have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Abdulrazzaq, Z.T., Hasan, R.H., and Aziz, N. A., 2019. Integrated TRMM Data and Standardized Precipitation Index to. *Civil Engineering Journal,* 5(7), pp. 1590-1598. https://doi.org/10.28991/cej-2019-03091355

Ahmed, G., and Al-Manmi, D., 2021. Trend detection of average annual rainfall and temperature in Sulaymaniyah governorate, Iraq. *Anbar Journal of Agricultural Sciences,* 19(2), pp. 221-233. https://doi.org/10.32649/AJAS.2021.175995

Ahmed, M.B., Muavia, A., Iqbal, M., Arshed, A., and Ahmad, M. M, 2023. Spatio-temporal drought assessment and comparison of drought indices under climatic variations in drought-prone areas of Pakistan. *Water and Climate Change,* 14(10), p. 3726–3752. https://doi.org/10.2166/wcc.2023.602

Alee, M.M., Mehr, A. D., Akdegirmen, O., and Nourani, V., 2023. Drought Assessment across Erbil Using Satellite Products. *Sustainability,* 15(8), P. 6687. https://doi.org/10.3390/su15086687

Alobaidy, A., Abid, H., and Maulood, B., 2010. Application of Water Quality Index for Assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq. *Journal of Water Resource and Protection,* 2(9). https://doi.org/10.4236/jwarp.2010.29093

Al-Quraishi, A., Gaznayee, H., and Crespi, M., 2021. Drought trend analysis in a semi-arid area of Iraq based on Normalized Difference Vegetation Index, Normalized Difference Water Index, and Standardized Precipitation Index. *Arid Land,* Volume 13, p. 413–430. https://doi.org/10.1007/s40333-021-0062-9

Asadi Zarch, M. A., Malekinezhad, H., Mobin, M. H., Dastorani, M. t., and Kousari, M. r., 2011. Drought Monitoring by Reconnaissance Drought Index (RDI) in Iran. *Water Resources Management,* 25, pp. 3485–3504. https://doi.org/10.1007/s11269-011-9867-1

Bazrafshan, O., Mahmoudzadeh, F., Asgarinezhad, A., and Bazrafshan, J., 2019. Adaptive Evaluation of SPI, RDI, and SPEI indices in Analyzing the. *Journal of Irrigation Sciences and Engineering,* 42(3), pp. 117-131. https://doi.org/10.22055/JISE.2017.22113.1585

Chandrasekara, S.S.K., Kwon, H.H., Vithanage, M., Obeysekera, J., and Kim, T.W., 2021. Drought in South Asia: A Review of drought assessment and prediction in South Asian Countries. *Atmosphere,* 12(3). https://doi.org/10.3390/atmos12030369

Chen, H., and Sun, J., 2015. Changes in drought characteristics over China using the standardized precipitation evapotranspiration index. *Climate,* 28, p. 5430–5447. https://doi.org/10.1175/JCLI-D-14-00707.1

Cheval, S., 2015. The Standardized Precipitation Index. *Romanian Journal of Meteorology,* 12(1-2), pp. 17-49.

Crausbay, S.D., Ramirez, A.R., Carter, S.L., Cross, M.S., Hall, K.R., Bathke, D.J., Betancourt, J.L., Colt, S., Cravens, A.E., Dalton, M.S., Dunhan, J.B., Hay, L.E., Hayes, M.J., McEvoy, J., McNutt, C., Moritz, M.A., Nislow, K.H., Raheem, N., and Sanford, T., 2017. Defining ecological drought for the Twenty-First Century. *Bulletin of the American Meteorological Society,* 98(12), p. 2543–2550. https://doi.org/10.1175/BAMS-D-16-0292.1

Dalezios, N. R., Dercas, N., and Eslamian, S., 2018. Water scarcity management: part 2: satellite-based composite drought analysis. *International Journal of Global Environment,* 17. https://doi.org/10.1504/IJGENVI.2018.10012400

Dilawar, A., Chen, B., Ashraf, A., Kayiranga, A., Hussain, Y., Ali, S., Jinghong, J., Shafeeque, M., Boyang, S., Sun, X., and Hussain, S., 2022. Development of a GIS-based hazard, exposure, and vulnerability analyzing method for monitoring drought risk in Karachi, Pakistan. *Geomatics, Natural Hazards and Risk,* 13(1), pp. 1700-1720. https://doi.org/10.1080/19475705.2022.2090863

Edwards, D., and McKee, t., 1997. Characteristics of 20th-century drought in the United States at multiple time scales., pp. 152-155. https://doi.org/10217/170176

Fadhil, A.M., 2011. Drought mapping using Geoinformation technology for some sites in the Iraqi Kurdistan region. *International Journal of Digital Earth,* 4(3), pp. 239-257. https://doi.org/10.1080/17538947.2010.489971

Farahmand, A., AghaKouchak, A,. and Teixeira, J., 2015. *A vantage from space can detect earlier drought onset: An approach using relative humidity,* https://doi.org/10.1038/srep08553

Farsani , N.T., Jamshidi , H.M., Mortazavi , M., and Eslamian S., 2021. Water harvesting and sustainable tourism. In: *water harvesting and conservation: basic concepts and fundamentals.* John Whiley and Sons Ld., pp. 447-455. https://doi.org/10.1002/9781119478911.ch29

Gaznayee, H.A.A., Al-Quraishi, A.M.F., Mahdi, K., Messina, J.P., Zaki, S.H., Razvanchy, H.A.S., Hakzi, K., Huebner, L., Ababakr, S.H., and Riksen, M., 2022. Drought severity and frequency analysis aided by spectral and meteorological indices in the Kurdistan Region of Iraq. *Water,* Sep 26, 14(19), p. 3024. https://doi.org/10.3390/w14193024

Gaznayee, H., Al-Quraishi, A., Mahdi, K., and Ritsema, C., 2022. A geospatial approach for analysis of drought impacts on vegetation cover and land surface temperature in the Kurdistan Region of Iraq. *Water,* Mar 16, 14(6), P. 927. https://doi.org/10.3390/w14060927

Gil-Quintana, E., Larrainzar, E., Seminario, A., Díaz-Leal, J.L., Alamillo, J.M., Pineda, M., and González, E.M., 2013. 1- Local inhibition of nitrogen fixation and nodule metabolism in drought-stressed soybean. *Experimental Botany,* April, 64(8), pp. 2171-2182. https://doi.org/10.1093/jxb/ert074

Hameed, M., Ahmadalipour, A., and Moradkhani, H., 2018. Apprehensive Drought Characteristics over Iraq. *Geosciences,* 8(2). https://doi.org/10.3390/geosciences8020058

Jamro, S., Dars, G.M., Ansari, K., and Krakauer, N.Y., 2019. Spatio-temporal variability of drought in Pakistan using standardized precipitation evapotranspiration index. *Applied Sciences,* 9(21), P. 4588. https://doi.org/10.3390/app9214588

Jasim, A.I., and Awchi, T., 2020. regional meteorological drought assessment in Iraq. *Arabian Journal of Geosciences,* 13(7). https://doi.org/10.1007/s12517-020-5234-y

Kartal, V., 2023. Assessment of drought using different tests and drought indices in Elazig, Turkey. *Water Science and Technology,* 88(7), p. 1767–1794. https://doi.org/10.2166/wst.2023.315

Kartika, F., and Wijayanti, P., 2023. *Drought disaster modeling using drought index: a systematic literature review.* https://doi.org/10.1088/1755-1315/1190/1/012026

Kourtis, I.M., Vangelis, H., Tigkas, D., Mamara, A., Nalbantis, I., Tsakiris, G., and Tsihrintzis, V.A., 2023. Drought assessment in Greece using SPI and ERA5 climate reanalysis data. *Sustainability,* 15(22), P. 15999. https://doi.org/10.3390/su152215999

Kousari, M.R., Dastorani, M.T., Niazi, Y., Soheili, E., Hayatzadeh, M., and Chezgi, J., 2014. Trend detection of drought in arid and semi-arid regions of Iran based on implementation of Reconnaissance Drought Index (RDI) and application of non-parametrical statistical method. *Water Resources Management,* 28, p. 1857–1872. https://doi.org/10.1007/s11269-014-0558-6

Li, X., He, B., Quan, X., Liao, Z. and Bai, X., 2015. Use of the standardized precipitation evapotranspiration index (SPEI) to characterize the drying trend in southwest China from 1982–2012. *Remote Sensing*, *7*(8), pp.10917-10937. https://doi.org/10.3390/rs70810917

Lotfirad, M., Esmaeili-Gisavandani, H., and Adib, A., 2021. Drought monitoring and prediction using SPI, SPEI, and random forest model in various. *Water and Climate Change,* 13(2). https://doi.org/10.2166/wcc.2021.287

McKee, T., Doesken, N., and Kleist, J., 1993. *The relationship of drought frequency and duration to time scale.* Anaheim, California, Boston American Meteorological Society, p. 179–184.

McKee, T., Doesken, N., and Kleist, J., 1995. *Drought monitoring with multiple timescales.* Dallas, Texas, Boston American Meteorological Society, pp. 233-236.

Mohan, K., Ramasamy, A., and Varghese, J., 2021. Drought severity assessment using automated land surface temperature retrieval technique. *Arabian Journal of Geosciences,* 14(22). https://doi.org/10.1007/s12517-021-08672-1

Montes-Vega, M., Guardiola-Albert, C., and Rodríguez-Rodríguez, M., 2023. Calculation of the SPI, SPEI, and GRDI indices for historical climatic data from Doñana National Park: Forecasting climatic series (2030–2059) using two climatic scenarios RCP 4.5 and RCP 8.5 by IPCC. *Water,* 15(13), P. 2369. https://doi.org/10.3390/w15132369

Muse, N.M., Tayfur, G., and Sadegh Safari, M.J., 2023. Meteorological drought assessment and trend analysis in Puntland Region of Somalia. *Sustainability,* 15(13), P. 10652. https://doi.org/10.3390/su151310652

Mustafa, N., Ibrahim, H., and Rashid, H., 2018. Aridity index based on temperature and rainfall data for Kurdistan Region-Iraq. *Journal of Duhik University Pure and Engineering Science,* 21(1), pp. 65-80. https://doi.org/10.26682/sjuod.2018.21.1.6

Naz, F., Dars, G.H., Ansari, K., Jamro, S., and Krakauer, N.Y., 2020. Drought Trends in Balochistan. *Water,* 12(2), P. 470. https://doi.org/10.3390/w12020470

Ng, J.L., Huang, Y.F., Chong, A.H., Lee, J.C., Abdulkareem, M., Noh, N.Md., Mirzaei, M., and Ahmed, A. N., 2023. Comparative assessment of drought indices for evaluating drought patterns in Peninsular Malaysia. *Water and Climate Change,* 14(11), pp. 4183–4197. https://doi.org/10.2166/wcc.2023.546

Nikravesh, G., Aghababaei, M., Nazari-Sharabian, M., and Karakouzian, M., 2020. Drought frequency analysis based on the development of a two-variate standardized index (Rainfall-Runoff). *Water,* 12(9), P. 2599. https://doi.org/10.3390/w12092599

Orimoloye, I.R., Belle , J.A., Olusola , A.O., Busayo , E.T., and Ololade, O.O., 2021. Spatial assessment of drought disasters, vulnerability, severity, and water shortages: a potential drought disaster mitigation strategy. *Natural Hazards,* 105(3), pp. 2735-2754. https://doi.org/ 10.1007/s11069-020-04421-x

Pillai, S., Anagha, B., Raja, P., Veluswamy, K., Rajan, K., and Manickam, J., 2019. Analysis of drought from humid, semi-arid, and arid regions of India using DrinC model with different drought indices. *Water Resources Management,* 33, pp. 1521–1540. https://doi.org/10.1007/s11269-019-2188-5

Plummer, R., and Baird, J. M., 2021. The emergence of water resilience: An introduction. *Water Resilience,* pp. 3-19. https://doi.org/10.1007/978-3-030-48110-0_1

Rashid, H.M., 2021. Modeling groundwater potential zones across Sulaymaniyah governorate using geographic information system and multi-influencing factor techniques. *UHD Journal of Science and Technology,* 5(1), pp. 13-20. https://doi.org/10.21928/uhdjst.v5n1y2021.pp13-20

Shi , S., Yu , J., Wang , F., Wang , P., Zhang , Y., and Jin , K., 2021. Quantitative contributions of climate change and human activities to vegetation changes over multiple time scales on the Loess Plateau. *Science of the total environment,* 755(prt2). https://doi.org/ 10.1016/j.scitotenv.2020.142419

Smakhtin, V., and Schipper, L., 2008. Droughts: The impact of semantics and perceptions. *Water Policy,* 10, pp. 131-143. https://doi.org/10.2166/wp.2008.036

Svoboda, M., Hayes, M., and Wood, D., 2012. *World metrological organization: standardized precipitation index user guide (WMO-No. 1090),* Geneva: https://library.wmo.int/idurl/4/39629

Tigkas, D., Vangelis, H., and Tsakiris, G., 2015. DrinC: a software for drought analysis based on drought indices. *Earth Science Informatics,* 8, pp. 697–709. https://doi.org/10.1007/s12145-014-0178-y

Tsakiris, G., Pangalou, D., and Vangelis, H., 2007c. Regional drought assessment based on the Reconnaissance Drought Index (RDI). *Water Resources Management,* 21, p. 821–833. https://doi.org/10.1007/s11269-006-9105-4

Tsakiris, G., and Vangelis, H., 2005. Establishing a drought index incorporating evapotranspiration. *Europian Water,* 9(10), pp. 3-11.

UNDP, 2011. *Drought impact assessment, recovery and mitigation framework and regional project design in Kurdistan Region (KR),* UNDP.

UNESCO, 2014. *Integrated drought risk management, DRM: a national framework for Iraq, An Analysis Report,* s.l.: s.n.

USGS, 2019. *United States Geological survey.* [Online] Available at: https://earthexplorer.usgs.gov/

Vicente-Serrano, S., Beguería, S., and López-Moreno, J., 2010. A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate,* 23(7), pp. 1696–1718. https://doi.org/10.1175/2009JCLI2909.1

Wilhite, D.A., and Glantz, M.H., 1985. Understanding the drought phenomenon: the role of definitions. *Water International,* 10, pp. 111-120. https://doi.org/10.1080/02508068508686328

WMO, and GWP, 2016. Handbook of drought indicators and indices. *British Medical Journal,* 1(2366). https://doi.org/10.1136/bmj.1.2366.1068-b.

Yaseen, A.K., Mahmood, M.I., Yaseen, G.K., Ali, A.A., Hh, M., and Mustafa, A.H., 2018. Area change monitoring of Dokan and Darbandikhan Iraqi lakes using satellite data. *Sustainable Resources Management Journal,* 32, pp. 25-41. https://doi.org/10.5281/zenodo.128484

Yu, W., Li, Y., Cao, Y., and Schillerberg, T.A., 2019. Drought assessment using GRACE terrestrial water storage deficit in Mongolia from 2002 to 2017. *Water,* 11(6). https://doi.org/10.3390/w11061301

Zhang, D., Sial, M.S., Ahmad, N., Fillipe, A.J., Thu, P.A., Zia-Ud-Din, M., and Caleiro, A.B., 2020. Water scarcity and sustainability in an emerging economy: a management perspective for future. *Sustainability,* 13(1). https://doi.org/10.3390/su13010144

Zhang, P., Cai, Y., Cong, P., Xie, Y., Chen, W., Cai, J., and Bai, X., 2024. Quantitation of meteorological, hydrological, and agricultural drought under climate change in the East River basin of south China. *Ecological Indicators,* 158. https://doi.org/10.1016/j.ecolind.2023.111304

تقييم الجفاف على أساس مؤشرات الجفاف المترولوجية المختلفة في محافظة السليمانية، حكومة إقليم كردستان ، العراق

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الخلاصة

الجفاف هو وضع خطير يخفض مستويات المعيشة الفردية. يعتبر حدثا طبيعيا مدمرا. تهدف هذه الدراسة إلى فحص شامل لحدوث وخصائص أحداث الجفاف في محافظة السليمانية من عام 1985 إلى عام 2015. استخدمت الدراسة ثلاثة مؤشرات موحدة: مؤشر التبخر والنتح القياسي لهطول الأمطار (SPEI) ، ومؤشر هطول الأمطار القياسي (SPI) ، ومؤشر الجفاف الاستطلاعي (RDI). تم استخدام هذه المؤشرات في فترات مختلفة ، وهي 3 و 6 و 9 و 12 شهرا. ووفقا للنتائج، فإن النسبة القصوى للجفاف الشديد التي تم تسليط الضوء عليها في محطتي السليمانية ودكان لمؤشر SPI والنطاق الزمني لمدة ثلاثة أشهر كانت 48٪ و 30٪ على التوالي. تم تسليط الضوء على النسبة المئوية القصوى للجفاف الشديد باستخدام مؤشر RDI والنطاق الزمني لمدة ثلاثة أشهر بنسبة 41٪ و 32٪ و 44٪ في محطات السليمانية ودوكان ودربندخان على التوالي. كشفت النتائج أن الأعوام 1998 و 1999 و 2000 و 2007 و 2008 و 2009 و 2010 شهدت جفافا للمؤشرات المستخدمة ، حيث بلغت شدة محطة دوكان القصوى 112.25 ل SPEI12 للحدث الذي حدث من نوفمبر 2007 إلى سبتمبر 2015. وقد لوحظت الفترات القصوى في محطة دوكان باستخدام SPI و SPEI أيضا ، ومحطة Darbandikhan لديها أعلى تواتر للجفاف. وأظهرت ارتباطات مؤشرات الجفاف، باستخدام معامل التحديد (R ^ 2) أدنى وأعلى اتفاق بين SPI-SPEI و SPI-RDI، على التوالي. وكشفت النتائج أن الموارد المائية في منطقة الدراسة معرضة لخطر النضوب بسبب الجفاف. ولذلك، فإن تقنيات إدارة المياه مطلوبة للتخفيف من حدة الجفاف في منطقة الدراسة.

الكلمات المفتاحية: تغير المناخ ، DrinC، شدة الجفاف ، RDI، SPEI، SPI.