Iraqi National Journal of Earth Science
www.earth.mosuljournals.com

Drought Analysis in The Kurdistan Region-Iraq Using Standardized Precipitation Indices (SPI): A Case Study with in Duhok, Erbil and Sulaimaniyah Regions.

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Article information

Received: 11-Jul-2024

Revised: 18-Aug-2024

Accepted: 22-Sep-2024

Available online: 01-Oct-2025

Keywords:
SPI Drought indices
PET
Duhok, Erbil, and Sulaimaniyah
Meteorological Station
Kurdistan Region.

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ABSTRACT

Drought indices are frequently utilized to identify, observe, and assess drought occurrences. The Standardized Precipitation Index (SPI) represents one of the most commonly utilized drought measures. This article analyzes drought occurrences for three chosen meteorological stations in the Kurdistan region, including Duhok, Erbil, and Sulaimaniyah governorates, and analyzes the impact of theoretical distribution choices on SPI values. The annual time-scale SPI formula was calculated for the period (1980-2023) in the governorates. Analysis with SPI method results showed that the extremely wet represents only in Erbil governorate in frequency 2 years with probability events (4.55%). Drought ranged from mild drought to severe drought in each governorate. Mild drought shows in Erbil governorate in a 16-year frequency with a 36.36% probability of events. Also, in Sulaimaniyah governorate, in a 13-year frequency with a 30.23% probability of events. However, in Duhok governorate, in a 15-year frequency with a (34.09%) probability of events. The moderate drought shows in governorates such as 7-year frequency with (15.91%) probability events, 4-year frequency with (90.30%) probability events, and 6-year frequency with (13.64) probability events, respectively. The severe drought also shows in governorates such as 1-year frequency with (2.27%) probability events, 3-year frequency with (6.98%) probability events, and 2-year frequency with (4.55%) probability events, respectively.

DOI: 10.33899/earth.2024.151762.1319, ©Authors, 2025, College of Science, University of Mosul.

تحليل الجفاف في محافظات إقليم كردستان العراق (دهوك وأربيل والسليمانية) باستخدام المؤشرات القياسية لهطول الأمطار (SPI)

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معلومات الارشفة

تاريخ الاستلام: 11- يوليو-2024

تاريخ المراجعة: 18- أغسطس-2024

تاريخ القبـول: 22- سبتمبر-2024

تاريخ النشر الالكتروني: 01- يناير-2025

الكلمات المفتاحية:

مؤشرات الجفافSPI

PET

محطة المناخية دهوك وأربيل والسليمانية

إقليم كردستان

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الملخص

تُستخدم مؤشرات الجفاف بشكل واسع في تحديد حالات الجفاف ومراقبتها وتقييمها بحيث يمثل دليل المطر القياسي (SPI) أحد مقاييس الجفاف الأكثر استخدامًا وفعالية. في هذه الدراسة تم دراسة حالات الجفاف لثلاث محافظات مختارة في إقليم كردستان وهو دهوك وأربيل والسليمانية اذكر عدد المحطات، وتم تحليل تأثير خيارات التوزيع النظرية على قيم المؤشر المعياري للسواقط. معادلة المؤشر الزمني السنوي المحسوب للفترة (1980-2023) في المحافظات المذكورة. أظهرت النتائج من خلال استخدام طريقة SPI أن الرطوبة الشديدة تمثل فقط في محافظة أربيل بتكرار 2 سنة مع أحداث احتمالية (4.55٪). ويتراوح الجفاف من جفاف خفيف إلى جفاف شديد في كل محافظة. يظهر الجفاف المعتدل في محافظة أربيل بتكرار 16 سنة مع نسبة احتمالية حدوثها (36.36%). وأيضاً في محافظة السليمانية بتكرار 13 سنة وبنسبة احتمالية (30.23%). أما في محافظة دهوك فشهدت تكرار 15 سنة مع احتمالية (34.09%). ويظهر الجفاف المعتدل في المحافظات مثل تكرار 7 سنوات باحتمالية (15.91%)، وتكرار 4 سنوات باحتمالية (90.30%)، وتكرار 6 سنوات باحتمالية (13.64%)، على التوالي. يظهر الجفاف الشديد أيضًا في المحافظات مثل تكرار السنة الواحدة بأحداث احتمالية (2.27%)، وتكرار 3 سنوات بأحداث احتمالية (6.98%)، وتكرار سنتين بأحداث احتمالية (4.55%)، على التوالي.

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Introduction

A drought is an occurrence led by a prolonged period of low water availability. It generally happens when rainfall is below normal in a particular region or area. Insufficient precipitation, whether in the form of snow or rain, may lead to a decrease in the moisture content of soil or groundwater, a reduction in the flow of streams, a harmful impact on industrial, agricultural, and ecological situations too, and a greater shortage of water (Al-Quraishi et al., 2021; Daniel, 2008; Danshvar et al., 2006). The phenomenon of drought differs from other types of natural disasters. Because these phenomena have developed gradually over a considerable amount of time and sometimes over years, they have persisted. Furthermore, these phenomena may spread across dry regions without being influenced by morphological or geological causes (Smith, 2001). When it comes to modifying designs that resist drought management, the monitoring system is essential. For this reason, the phenomena have been shown quantitatively using the drought indices. Standardized precipitation indices have been used to analyze precipitation over various time intervals ranging from 1 to 48 months (McKee, 1995; Jirjees et al., 2023; Hamed, 2023). A positive SPI value indicated that the precipitation was above the mean, while a negative value indicated that the quantity of rainfall dropped short of the mean. According to the previous study (Akhtari, 2006; Jirjees et al., 2023), the SPI technique indicates that a drought phase begins when the SPI is consistently negative, reaches

-1 or below, and ends when the SPI is positive (Ekwezuo and Madu, 2020; Nedham and Hassan, 2019).

Aim of the study

The main goals of current research are to evaluate the climate types and determine the drought status in Northern Iraq (Erbil, Duhok, and Sulaimaniyah). Using the Standardized Precipitation Index (SPI) during the period 1980-2023.

Description of study area

The provinces of Erbil, Duhok, and Sulaimaniyah are situated in the northeast of Iraq (Fig. 1). They cover an area of approximately (2728, 6641, and 17564 km²), respectively.

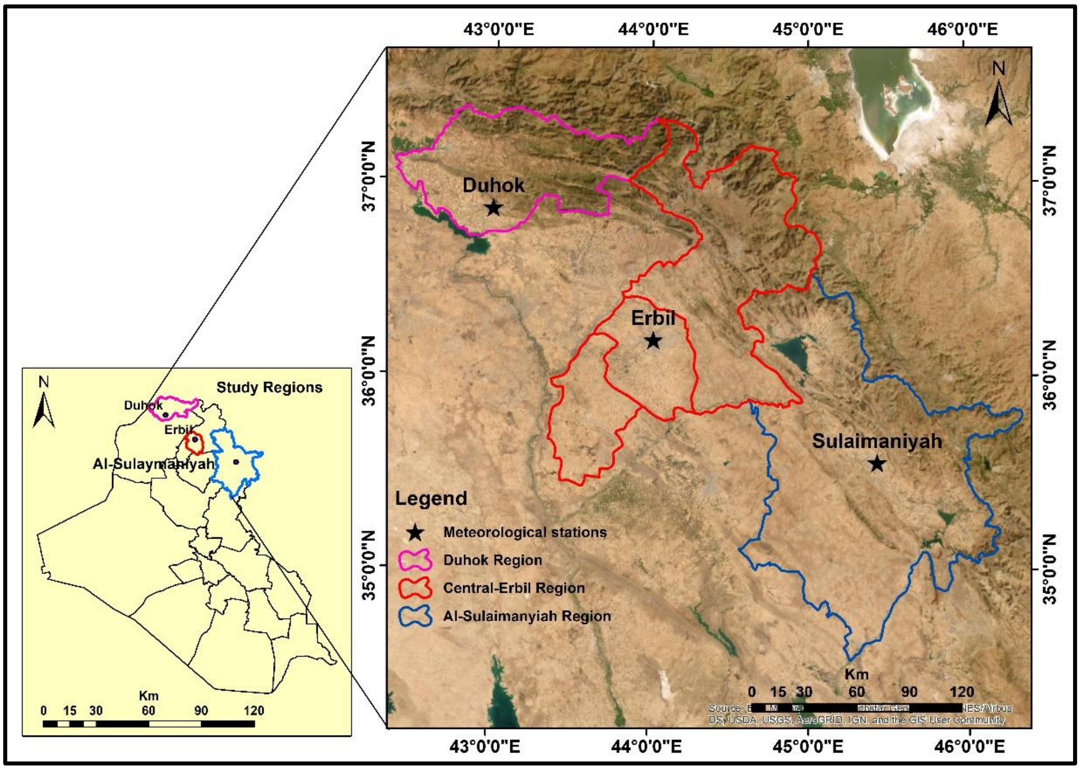

Fig.1. Location map of study area.

Materials and Methods

The climate data, which include rainfall and temperature such as mean monthly rainfall, annual rainfall, and mean monthly temperature from Erbil, Duhok, and Sulaimaniyah metrological stations, about (43-years) for a period (1980 to 2023), are used. All meteorological stations are situated at these locations (Table 1). Thornthwaite's (1944) method was used to estimate the potential evapotranspiration (PET) dependent on the temperature variable. Climate data were used to determine the types of climates in the study areas. In addition, the main classification was proposed such as (Al-Kubaisi, 2004). Moreover, the Standardized Precipitation Index (SPI) was used to calculate the drought analysis in the long term (12 months). According to the SPI drought severity categorization, the state of drought is considered to begin when the SPI continuously falls below zero. While the level of severity values became positive, the SPI stopped (McKee et al., 1993; Hayes et al., 1999). The flow chart below shows the methodological process of data obtaining and calculation (Fig. 2). The SPI indices were calculated from the equation below (Jirjees et al., 2020; Dara et al., 2021; Jirjees et al., 2022):

$$SPI = \frac{\mathrm{Pi} - \mathrm{P(Average)}}{\mathrm{S}} \qquad 1$$

Where Pi is annual rainfall in given years; P (average) is the mean annual rainfall for 43 years of annual rainfall data for each Meteorological Station (Duhok, Erbil, and Sulaimaniyah); S is the standard deviation.

According to a previous study (McKee et al., 1993), SPI was classified into different classes, which are summarized in Table 2.

Table 1: Geographical location of meteorological stations in the studied regions.

Regions	Easting (E)	Northing (N)	Altitude (m a.s.l)
Erbil	411729.66	4005018.72	420
Duhok	320684.52	4080843.71	583
Sulaimaniyah	539438.96	3934781.31	885

Table 2: The drought classification using SPI, according to (McKee et al., 1993).

SPI values	Category SPI values
≥ 2	Extremely wet
1.50 to 1.99	Severely wet
1 to 1.49	Moderately wet
0 to 0.99	Mildly wet
-0.99 to 0	Mildly drought
-1.49 to -1	Moderate drought
-1.99 to -1.50	Severe drought
>-2	Extremely drought

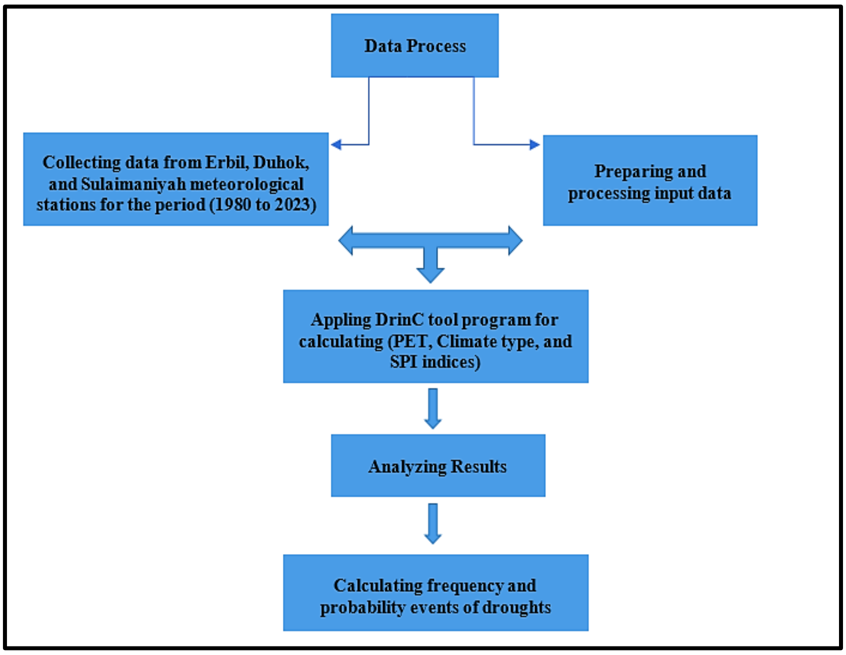

Fig. 2. Flow chart representing the methodology process.

Results and Discussion

Meteorological data (Precipitation and Temperature)

This study represents the results of potential evapotranspiration (PET) and the climate type for each region shown in Table 3 and Fig. 3. Also, the correlation of annual rainfall for the period (1980 to 2023) is shown in Fig. 4.

Table 3: Estimation of PET and climate type for each region.

Regions	P (mm)	Mean T (°C)	Al-Khubaisi (2004) AI-1	Climate Types	Al-Khubaisi (2004) AI-2	Climate Types
Erbil	410.29	20.66	1.7	Humid to moist	2.0	Humid to moist
Duhok	604.75	18.86	2.8	Humid to moist	2.6	Humid to moist
Sulaimaniyah	686.31	19.53	3.0	Humid to moist	2.7	Humid to moist

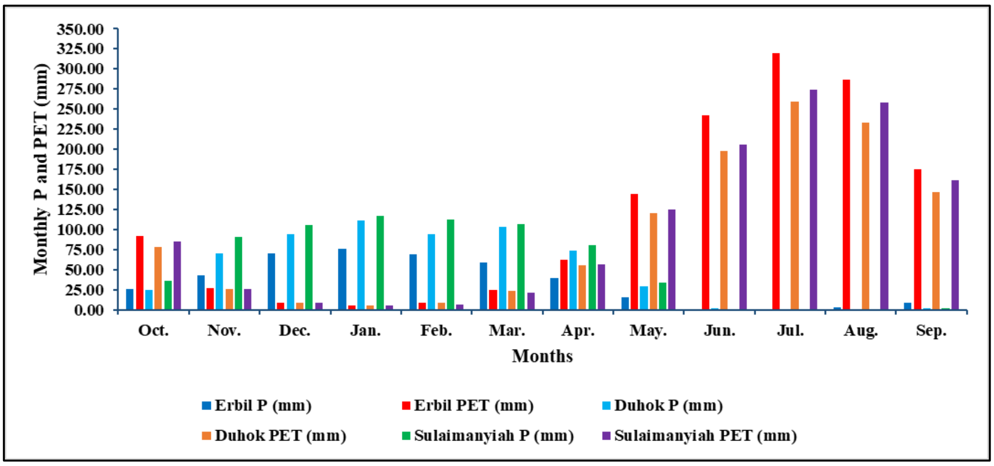

Fig. 3. Relationship between mean monthly rainfall and PET during the period (1980 to 2023) for each region (Ministry of Communication and transportation in Kurdistan Region-Iraq).

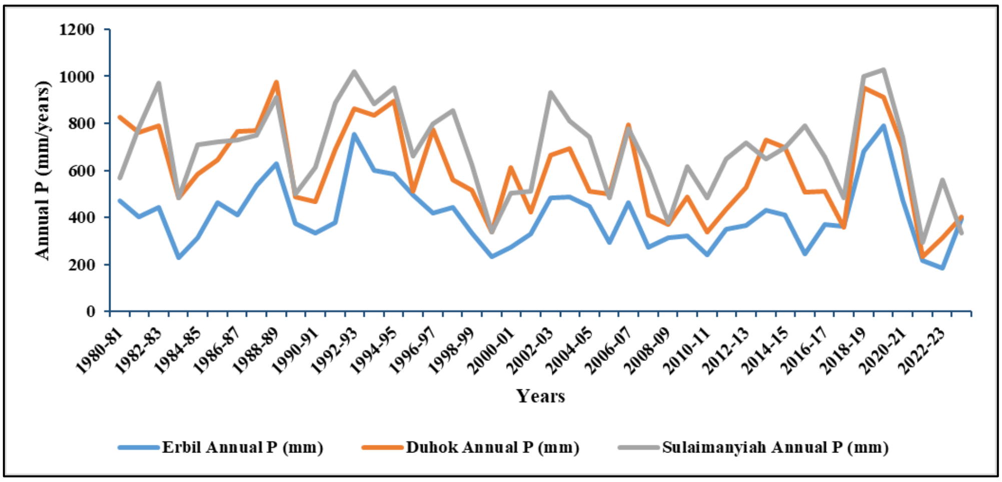

Fig. 4. Annual rainfall data used to estimate SPI indices during the period (1980 to 2023) for each region (Ministry of Communication and transportation in Kurdistan Region-Iraq).

Meteorological drought indices (Standardized Precipitation Indices (SPI))

Standardized Precipitation Indices in Duhok Region

The SPI drought analysis, frequency, and probability event happen results values were summarized in Tables 4, 5, and Fig. 5. Accordingly, severe wet with 4-frequency and 9.09% probability of 9.09% were shown in the years (1988, 1994, 2018, and 2019). On the other hand, severe drought with 2-frequency and 4.55% probability events was happening in the years 2021 and 2022.

Table 4: Frequency and probability of events happening during (1980-2023) in the Duhok region.

SPI value	Category	Frequency	Probability event (%)
≥ 2	Extremely wet	0	0
1.50 to 1.99	Severely wet	4	9.09
1 to 1.49	Moderately wet	4	9.09
0 to 0.99	Mildly wet	13	29.55
0 to -0.99	Mildly drought	15	34.09
-1 to -1.49	Moderate drought	6	13.64
-1.50 to -1.99	Severe drought	2	4.55
≤ -2	Extreme drought	0	0

Table 5: Annual SPI drought analysis for the period (1980-2023) in Duhok region.

Years	Rainfall (mm)	SPI	SPI Categories	Years	Rainfall (mm)	SPI	SPI Categories
1980	826	1.168	Moderately wet	2002	664	0.312	Mildly wet

1981	763	0.836	Mildly wet	2003	693	0.463	Mildly wet
1982	788	0.968	Mildly wet	2004	511	-0.495	Mild drought
1983	483	-0.643	Mild drought	2005	499	-0.557	Mild drought
1984	585	-0.104	Mild drought	2006	795	1.006	Moderately wet
1985	644	0.207	Mildly wet	2007	412	-1.017	Moderately drought
1986	764	0.841	Mildly wet	2008	370	-1.239	Moderately drought
1987	768	0.862	Mildly wet	2009	488	-0.617	Mild drought
1988	974	1.950	Severely wet	2010	338	-1.409	Moderately drought
1989	486	-0.627	Mild drought	2011	434	-0.902	Mild drought
1990	467	-0.727	Mild drought	2012	529	-0.399	Mild drought
1991	691	0.455	Mildly wet	2013	729	0.658	Mildly wet
1992	862	1.358	Moderately wet	2014	699	0.498	Mildly wet
1993	836	1.221	Moderately wet	2015	506	-0.522	Mild drought
1994	894	1.527	Severely wet	2016	511	-0.494	Mild drought
1995	513	-0.484	Mild drought	2017	358	-1.301	Moderately drought
1996	774	0.894	Mildly wet	2018	953	1.839	Severely wet
1997	559	-0.242	Mild drought	2019	909	1.609	Severely wet
1998	514	-0.479	Mild drought	2020	696	0.482	Mildly wet
1999	340	-1.398	Moderately drought	2021	232	-1.97	Severe drought
2000	614	0.049	Mildly wet	2022	313	-1.542	Severe drought
2001	423	-0.962	Mild drought	2023	402	-1.072	Moderately drought

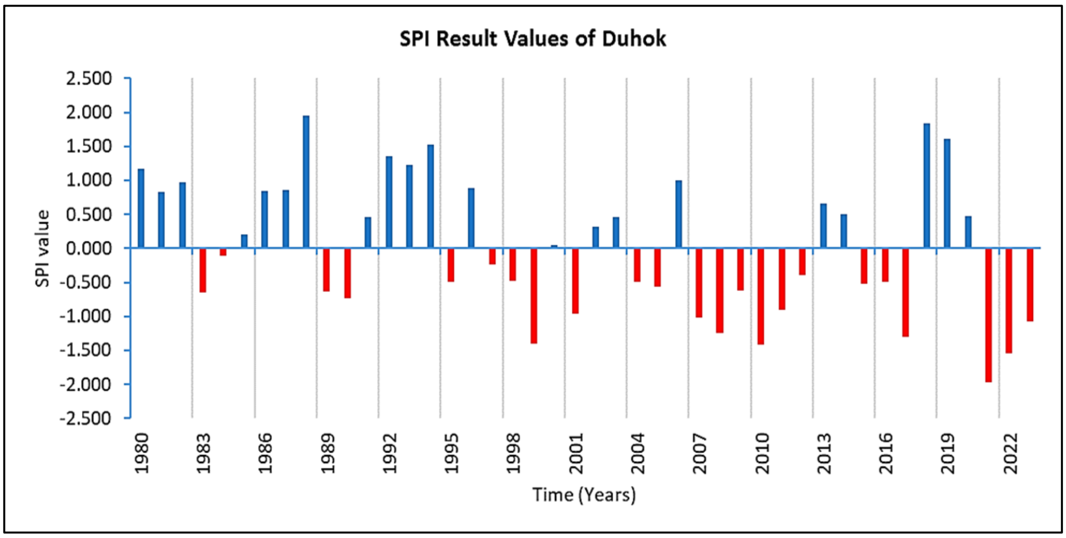

Fig. 5. SPI drought indices analysis in Duhok region.

Standardized Precipitation Indices in Erbil Region

The SPI drought analysis, frequency, and probability event results values were summarized in Tables 6, 7, and Fig. 6. Accordingly, extremely wet conditions were obtained with 2-frequency and 4.55% probability events in the years (1992 and 2019). However, severe drought shows with a 2.27% probability of events in the year 2022.

Table 6: Frequency and probability of events happening during (1980-2023) in the Erbil region.

SPI value	Category	Frequency	Probability event (%)
≥ 2	Extremely wet	2	4.55
1.50 to 1.99	Severely wet	2	4.55
1 to 1.49	Moderately wet	2	4.55
0 to 0.99	Mildly wet	14	31.82
0 to -0.99	Mildly drought	16	36.36
-1 to -1.49	Moderate drought	7	15.91
-1.50 to -1.99	Severe drought	1	2.27
≤ -2	Extreme drought	0	0.00

Table 7: Annual SPI drought analysis for the period (1980-2023) in the Erbil region.

Years	Rainfall (mm)	SPI	SPI Categories	Years	Rainfall (mm)	SPI	SPI Categories

1980	472	0.45	Mildly wet	2002	481	0.52	Mildly wet
1981	404	-0.04	Mild drought	2003	487	0.57	Mildly wet
1982	444	0.25	Mildly wet	2004	449	0.28	Mildly wet
1983	230	-1.32	Moderately drought	2005	295	-0.85	Mild drought
1984	316	-0.69	Mild drought	2006	462	0.38	Mildly wet
1985	464	0.39	Mildly wet	2007	274	-1.00	Moderately drought
1986	412	0.01	Mildly wet	2008	315	-0.70	Mild drought
1987	537	0.93	Mildly wet	2009	321	-0.65	Mild drought
1988	627	1.59	Severely wet	2010	241	-1.24	Moderately drought
1989	373	-0.27	Mild drought	2011	352	-0.43	Mild drought
1990	335	-0.55	Mild drought	2012	366	-0.32	Mild drought
1991	377	-0.25	Mild drought	2013	432	0.16	Mildly wet
1992	752	2.51	Extremely wet	2014	410	-0.001	Mild drought
1993	602	1.41	Moderately wet	2015	244	-1.22	Moderately drought
1994	583	1.27	Moderately wet	2016	370	-0.30	Mild drought
1995	494	0.62	Mildly wet	2017	364	-0.34	Mild drought
1996	419	0.06	Mildly wet	2018	682	1.99	Severely wet
1997	442	0.23	Mildly wet	2019	789	2.78	Extremely wet
1998	334	-0.56	Mild drought	2020	474	0.47	Mildly wet
1999	233	-1.31	Moderately drought	2021	216	-1.43	Moderately drought
2000	272	-1.01	Moderately drought	2022	184	-1.66	Severe drought
2001	329	-0.60	Mild drought	2023	394	-0.12	Mild drought

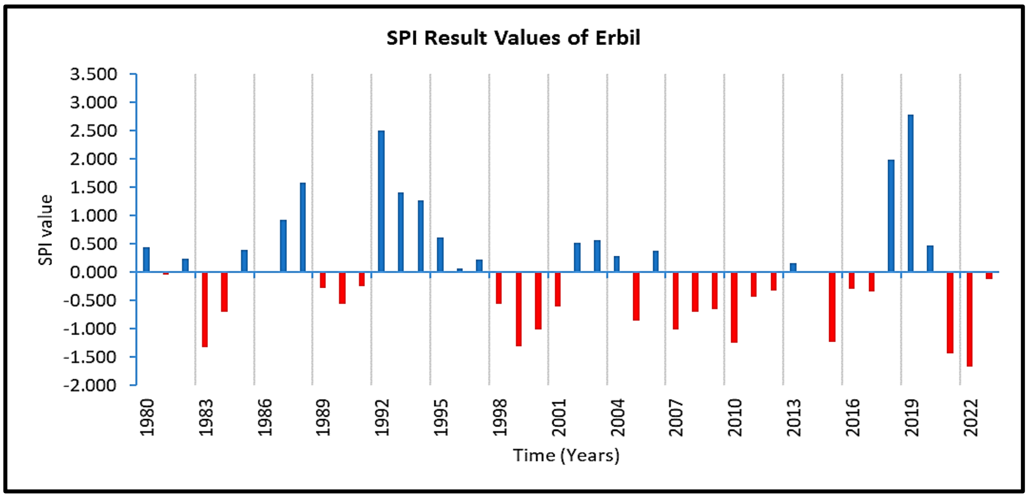

Fig. 6. SPI drought analysis in the Erbil region.

Standardized Precipitation Indices in Sulaimaniyah Region

The SPI drought analysis, frequency, and probability event happen results values were summarized in Tables 8, 9, and Fig. 7. Accordingly, severe wet events occurred with a 4-frequency and 9.30% probability events in the years (1982, 1992, 2018, and 2019). However, severe drought showed in 3-year frequency with 6.98% probability events in years (1999, 2008, and 2023). According to Bety (2013), the topography has a great influence on the rainfall distribution. The rainy season starts in October and ends by the end of May, and the absence of precipitation during the summer is the main characteristic of rainfall distribution in the area.

Table 8: Frequency and probability of events happening during (1980-2023) in the Sulaimaniyah region.

SPI value	Category	Frequency	Probability event (%)
≥ 2	Extremely wet	0	0.00
1.50 to 1.99	Severely wet	4	9.30
1 to 1.49	Moderately wet	5	11.63
0 to 0.99	Mildly wet	14	32.56
0 to -0.99	Mildly drought	13	30.23
-1 to -1.49	Moderate drought	4	9.30
-1.50 to -1.99	Severe drought	3	6.98
≤ -2	Extreme drought	0	0.00

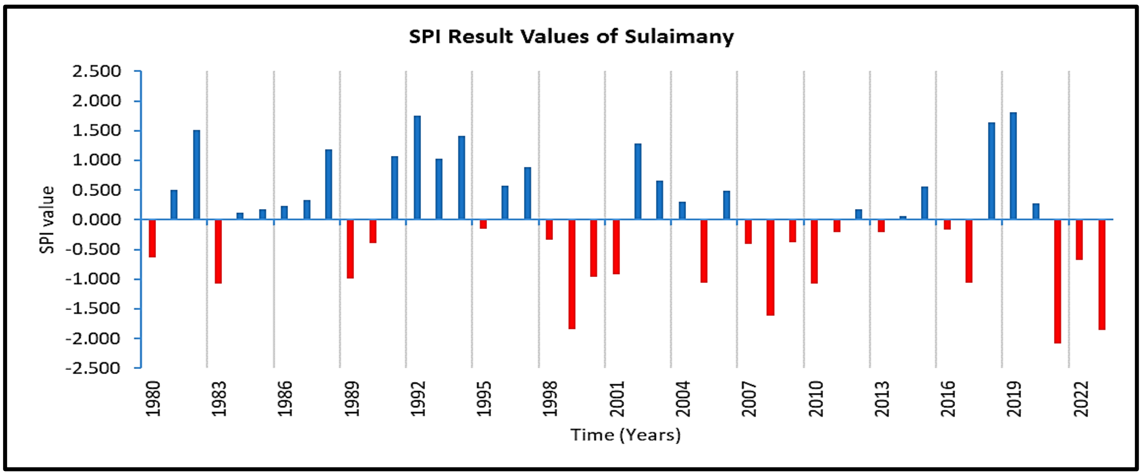

Fig. 7. SPI drought analysis in the Erbil region.

Table 9: Annual SPI drought analysis for the period (1980-2023) in the Sulaimaniyah region.

Years	Rainfall (mm)	SPI	SPI Categories	Years	Rainfall (mm)	SPI	SPI Categories
1980	566	-0.63	Mild drought	2002	930	1.29	Moderately wet
1981	782	0.50	Mildly wet	2003	811	0.66	Mildly wet
1982	973	1.51	Severely wet	2004	743	0.30	Mildly wet
1983	484	-1.07	Moderately drought	2005	485	-1.07	Moderately drought
1984	710	0.13	Mildly wet	2006	779	0.49	Mildly wet
1985	721	0.18	Mildly wet	2007	609	-0.41	Mild drought
1986	729	0.23	Mildly wet	2008	380	-1.62	Severe drought
1987	749	0.33	Mildly wet	2009	615	-0.38	Mild drought
1988	911	1.19	Moderately wet	2010	484	-1.07	Moderately drought
1989	498	-0.99	Mild drought	2011	648	-0.20	Mild drought
1990	613	-0.39	Mild drought	2012	719	0.17	Mildly wet
1991	888	1.07	Moderately wet	2013	647	-0.21	Mild drought
1992	1018	1.75	Severely wet	2014	698	0.06	Mildly wet
1993	881	1.03	Moderately wet	2015	791	0.55	Mildly wet
1994	953	1.41	Moderately wet	2016	655	-0.16	Mild drought
1995	659	-0.14	Mild drought	2017	485	-1.06	Moderately drought
1996	796	0.58	Mildly wet	2018	998	1.65	Severely wet
1997	855	0.89	Mildly wet	2019	1028	1.81	Severely wet
1998	624	-0.33	Mild drought	2020	740	0.28	Mildly wet
1999	339	-1.84	Severe drought	2021	292	-2.08	Extreme drought
2000	505	-0.96	Mild drought	2022	559	-0.67	Mild drought
2001	513	-0.92	Mild drought	2023	334	-1.86	Severe drought

The Erbil governorate has been significantly impacted by drought, experiencing 23 instances of drought between the years 1980 and 2023. In comparison, the Sulaymaniyah governorate has faced slightly fewer droughts, with 22 occurrences, but it remains more affected than the Duhok governorate, which experienced drought 21 times during the same period. When analyzing the Standardized Precipitation Index (SPI) results, it is evident that 1998 marks a pivotal year for the increasing frequency of droughts across Erbil, Sulaymaniyah, and Duhok. Before 1998, drought events were relatively infrequent, but following this year, the frequency of droughts in these regions noticeably escalated. The findings of this study align with expectations and are consistent with the broader impacts of climate change, which have had severe consequences for Iraq as a whole, including these three governorates. The increasing drought occurrences underscore the vulnerability of these areas to shifting climatic patterns, highlighting the urgent need for adaptive measures to mitigate the effects of climate change on water resources.

Conclusion

Based on the information presented, it is possible to conclude that, as the Kurdistan region consists of both dry and semi-arid places, it is essential for the management of water resources to determine the trends in drought and the factors that have reduced precipitation in recent years.

The SPI result for Duhok province represented 52.28% of the probability event evaluated was in the Mild to Severe drought ranges. Also, in Erbil province, the SPI results show the probability event with 54.55% in the Mild drought to Severe drought ranges. However, the SPI result in Sulaimaniyah province was 46.51% of a probability event in the Mildly drought to Severely drought ranges. According to the significant results of this investigation, the drought pattern that has been happening in Kurdistan Governorate recently, compared to its previous forms, is concerning; as a result, plans for decreasing risks and managing the region's water resources are necessary.

Acknowledgements

The authors expressed their appreciation to the Ministry of Transportation and Communication, Metrology and Seismology Directorate in Kurdistan Region for supplying the necessary metrological data to carry out and effectively execute this study.

Conflict of Interest

The authors declare that there is no conflict of interest related to the publication of this work.

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