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RESEARCH ARTICLE Open Access

Assessment of Meteorological Drought Indices Using the Reconnaissance Drought Index (RDI) and Standardized Precipitation Index (SPI) in Duhok City, Northern Iraq

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Abstract: Drought is a natural disaster characterized by a deficiency of water resources in a designated territory during a particular period of time. It has a profound effect on several critical facets of life, including environmental, economic, and social activities. Forecasting drought episodes is a crucial component for disaster preparation, mitigating its impact and enhancing efforts to respond. The three parameters, such as frequency, severity, and time period, are essential for the prediction and evaluation of droughts. Two drought indicators, the Reconnaissance Drought Index (RDI) and the Standardized Precipitation Index (SPI), were employed to predict potential drought conditions in Duhok city, Iraq. Forty-three years of climate data (average monthly precipitation and temperature) were utilized over the period from 1980 to 2023, obtained from the Duhok meteorological station. The indices were computed at 3, 6, and 12-month intervals, incorporating the estimation of potential evapotranspiration using the Thornthwaite technique via DrinC tools. The temporal severity and frequency of drought were computed and studied for each drought indicator. Based on SPI indices the moderately droughts have occurred in years (1999 to 2000, 2007 to 2008, 2008 to 2009, and 2017 to 2018) with a 4-year frequency with 9.30% probability of events. Also, according to RDI indices, the moderately droughts have occurred in years (1999 to 2000, 2001 to 2002, 2007 to 2008, 2008 to 2009, and 2017 to 2018) in 5-year frequency with 11.63% probability events. However, from both indices, the severe droughts were shown in years (2010 to 2011 and 2022 to 2023) in a 2-year frequency with a 4.65% probability that events occurred. Moreover, the extremely drought was shown in years (2021 to 2022) in a year frequency with 1% probability from each index. The findings of this study indicate that the RDI is more responsive than the SPI to climatic circumstances, thereby emphasizing the importance of evapotranspiration in drought evaluations. The T-test results indicated that both indices exhibit identical behavior depending on P-value is > 0.05; however, the RDI, mainly due to its incorporation of potential evapotranspiration under comparable climatic situations, demonstrates more sensitivity. This research recommends utilizing the RDI index as the appropriate drought index to evaluate drought conditions in water supply management and planning within the study region.

Keywords: *Precipitation; Evapotranspiration; SPI; RDI; DrinC; Iraq.*

1. Introduction

Drought is a climatic phenomenon that occurs from time to time, and its occurrence is not predictable. According to [1], it is usually understood to be a meteorological phenomenon that comes about as a result of a prolonged period of time in which there is a shortage of precipitation in comparison to a long-term average precipitation situation [2]. According to [3], substantial water shortages are often the outcome of drought. This can be attributed to a number of causes, including insufficient rainfall, excessive evaporation, the exploitation of water resources, or a combination of all of these characteristics. According to [4], drought is caused by a prolonged period of time during which there is insufficient rainfall. [5] and [6]. The duration and severity of precipitation shortage can have a detrimental impact on the soil moisture, groundwater, rivers, ecological systems, and human activities.

As temperatures have increased and precipitation has decreased, the consequences of global warming are being felt in many regions of the world [7]. This is because it has caused temperatures to rise. According to [6]. The effects of climate change might include droughts that are both more frequent and more severe in several nations. The long-term average of the equilibrium between precipitation and evapotranspiration (ET) in an area should be considered while estimating drought situations. Determining what constitutes a drought may be accomplished by considering its frequency, amplitude, intensity, and length [8]. Drought indicators are important in describing and monitoring droughts since they measure the intensity, length, and frequency of climatic abnormalities. This is achieved by streamlining complex meteorological functions. Furthermore, they offer comprehensible knowledge about drought severity to a broader audience [9]. Drought indicators are factors that encompass size, duration, severity, and spatial extent. In recent years, many drought indicators have been developed to identify and assess drought conditions. The Standardized Precipitation Index (SPI), a prominent drought index, was introduced by Mckee and his associates at Colorado State University [10]. The SPI measures precipitation deficits over several time periods and indicates the effects of droughts on the availability of diverse water resources [11]. The SPI offers early detection of drought and its intensity for each region, making it very effective for managing risks.

A newly developed reconnaissance drought finding and evaluation index was initially introduced at the MEDROPLAN coordinating meeting [12] , with a more detailed exposition provided in subsequent publications. The Reconnaissance Drought Index (RDI) employs reference crop evapotranspiration (ET0) and precipitation as the factors for drought evaluation.

The drought index is challenging to compute due to the time required; however, algorithms exist that can calculate it more swiftly and accurately. DrinC is the key program among these algorithms. The primary objective of DrinC is to offer a user-friendly instrument for computing several drought indicators, such as the Reconnaissance Drought Index (RDI) and the Standardized Precipitation Index (SPI). A minimal amount of data is necessary to compute the chosen indices, and the outcomes are straightforward and applicable for operational and strategic planning.

The research region extends approximately from latitudes 36° 50′ N to 36° 00′ N and longitudes 42° 52′ E to 43° 10′ E in northwestern Iraq, situated at an elevation of 430-450 meters amsl, including an area of about 931.26 km² (Fig. 1). The city of Duhok has a linear configuration, bordered by two mountain ranges: Bekhair to the north and northeast, and Zaiwa to the southeast. The city is traversed by two rivers: the Duhok River and the smaller, seasonal Heshkarow River. The two rivers converge in the southwestern part of the city.

This study aimed to estimate drought analysis from two main indices, such as SPI and RDI. Also, using the t-test statistical analysis to correlate these indices.

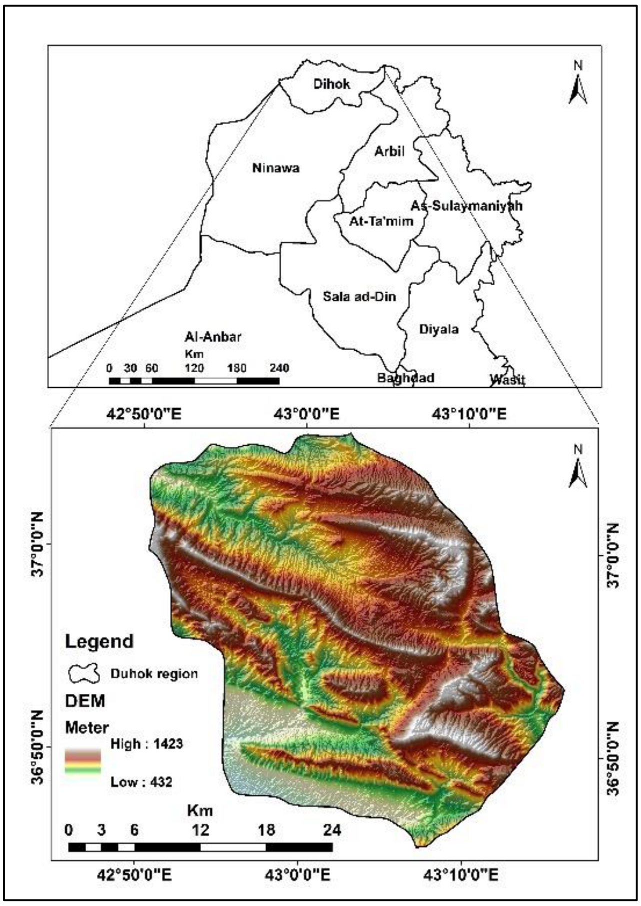

Figure 1: Location of study area.

2. Materials and Methods

The methodology stages of this study concentrated on three stages: pre-processing input data, performing the DrinC program for calculating PET and drought indices, and post-processing of results. Table 1 and the flow chart of Fig. 2 show the description of these stages. Utilizing each of the possible methods for calculating evapotranspiration does not appear to have any impact on the findings of the RDI. Under this situation, the PET was estimated according to the [13]. The comparison of RDI and SPI drought indices is summarized by using a t-test from Origin software version 2024 [2].

Table 1: Data required for calculation of indices.

Indices	Required input data
SPI	Precipitation (mm)
RDI	Precipitation (mm), Temperature or PET (mm)

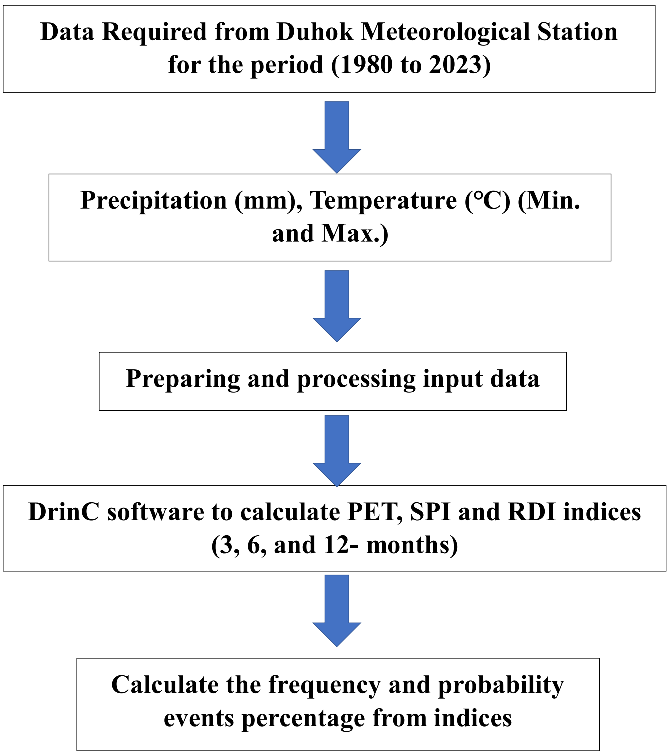

Figure 2: Flow chart methodological process.

3. Meteorological data

Mean monthly precipitation and temperature datasets were obtained from Duhok meteorological station for a period from 1980 to 2023 for calculating PET and drought indices over the study area. The data required was in (Fig. 3).

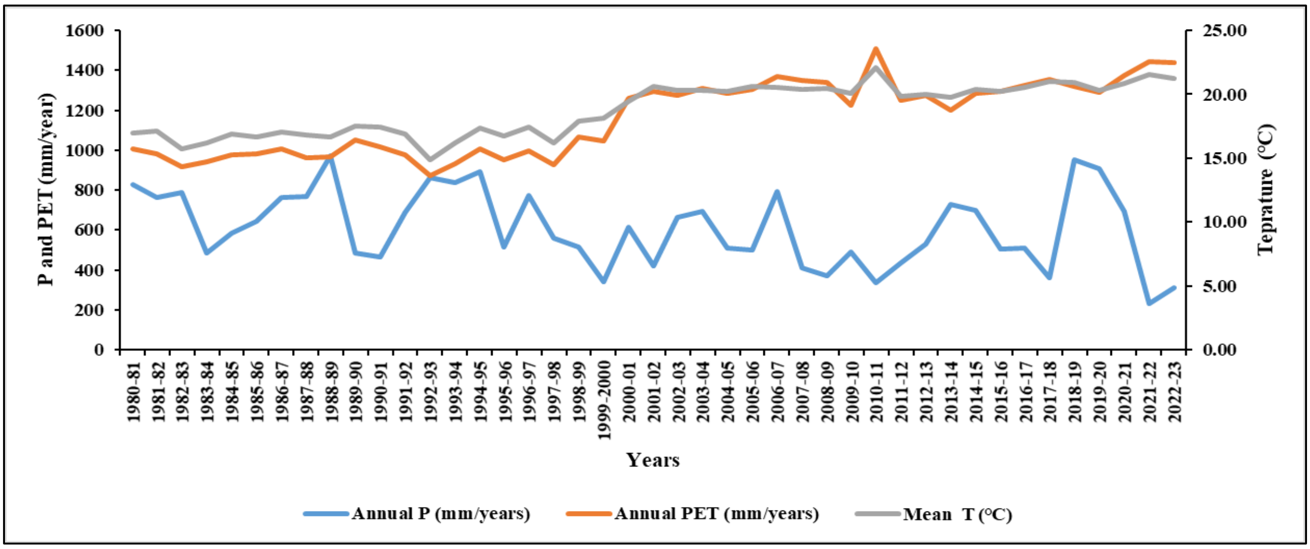

Figure 3: Relationship between annual precipitation and PET recorded at Duhok meteorological station during the period from 1980 to 2023.

3.1 Climate Analysis

Climate type analysis estimated from [14], which calculates annual dryness treatment according to precipitation and temperature values (Table 3). The equations can be expressed as follows:

(1) $$\mathbf{AI-1=\frac{(1*P)}{(11.53*t)}}$$

(2) $$\boldsymbol{AI-2=\frac{\sqrt{P}}{t}}$$

Where P is the mean annual precipitation; t is the mean monthly temperature

Table 2: Classification of the climate according to [14] in the Duhok area for a period (1980-2023)

Type 1	Evaluation	Type 2	Evaluation
AI-1>1.0	Humid to moist	AI-2>4.5	Humid
		2.5 <AI-2< 4.0	Humid to moist
		1.85<AI-2<2.5	Moist
		1.5<AI-2<1.85	Moist to sub-arid
AI-1<1.0	Sub arid to arid	1.0 ≤ AI-2<1.5	Sub arid
		AI-2<1.0	Arid

3.2 Drought Indices

3.2.1 Standardized Precipitation Indices (SPI)

The Standardized Precipitation tool (SPI) is a drought monitoring tool developed by [10], utilizing a gamma distribution to match the frequency distribution of total precipitation (Table 3). [10] devised this index and calculated it across intervals of 3, 6, 12, 24, 36, and 48 months. These times illustrate the impact of moisture and aridity on the accessibility of several water supplies. Short-term precipitation anomalies influence soil moisture, whereas long-term precipitation anomalies impact water resources [15, 16]. Positive values of this indicator signify above-average precipitation, while negative values denote below-average precipitation. The data recording period is mandated to be a minimum of thirty years, as the categories of this index are tailored to this duration and are also similar across various climatic regions [17]. The calculation of this index involves fitting a gamma probability function to the provided precipitation time series, which is obtained as follows [16, 18].

(3) $$\mathbf{SPI= Pi-P^{-}/\ \sigma}$$

Where Pi is annual precipitation, μ is mean, and σ is standard deviation.

3.2.2 Reconnaissance Drought Indices (RDI)

The intensity of a drought can be assessed utilizing the Reconnaissance Drought Index (RDI), with the standard variant yielding more precise outcomes (RDIst). The potential use of PET in identifying drought occurrences has been pivotal in the creation of a novel reconnaissance drought recognition and evaluation index [9]. Drought category classification proposed for the RDI [9] is similar to the SPI [10], as demonstrated in Table 3.

(4) $$\boldsymbol{RDI=\frac{yCM-\bar{y}CM}{\hat{\sigma}CM}-1}$$

where yCM is the logarithm of initial RDI; $\bar{y}$CM is the arithmetic mean of yCM, and $\hat{\sigma}$CM is the standard deviation.

Table 3: quantitative classification of SPI and RDI drought indices [9, 10]

SPI or RDI value Category	Category
2 and above	Extremely Wet
1.5 to 1.99	Severe Wet
1.00 to 1.49	Moderately Wet
- 0.99 to 0.99	Near Normal
- 1.49 to - 1.00	Moderately Drought
- 1.99 to - 1.5	Severe Drought
-2 and less	Extremely Drought

4. Results and Discussions

4.1 Climate type analysis

According to the [14], type of climate results in the study region was shown in the Table 4 which is AI-1= 2.81 which means the climate type is humid to moist and AI-2= 1.31 which is semi-arid.

Table 4: Types of climate depending on the [14] in the study area.

AI-1	Evaluation	AI-2	Evaluation
2.81	Humid to moist	1.31	Semi-arid

4.2 Drought Indices

According to the previous calculations, representing the resulted SPI values at time scales (3, 6, and 12 months) and also, statistically, the minimum, maximum, and standard deviation of 12-month SPI results, which are shown in (Table 5, 6, 7 and Fig. 4, 5, 6) in the study region. The SPI values range from severely wet to extremely dry in the study area. Overall, it has seven wet periods with 11.63% in probability events, and also it has 7 dry periods with 16.28% in probability events, while the frequency of the near normal category is about 29, with a probability of 67.44% in the study area (Table 8 and Figure 7). Depending on SPI results, there are two cycles of drought. The first is the wet period, which is severely wet appeared in years (1988 to 1989 and 2018 to 2019). Also, the dry which are moderately dry in years (1990 to 2000, 2007 to 2008, 2008 to 2009, and 2017 to 2018), severely dry in years (2010 to 2011 and 2022 to 2023) and year (2022 to 2023) represented an extremely drought (Table 7). On the other hand, the obtained RDI result values of the time scale of (3, 6, and 12 months) and the minimum, maximum, and standard deviation of 12-month RDI, which are shown in (Tables 5, 6, 7 and Fig. 4, 5, 6) in the study region. The RDI values range from severely wet to extremely dry in the area. Overall, it has nine wet periods in frequency with a probability of 20.93% events and also 7 dry periods in frequency with 18.61% in probability events, while the frequency of near normal category is about 29 with 67.44% in probability events in the study area (Table 8 and Fig. 7). The DRI results show two periods of drought. The first is the wet period, which is severely wet, which exists in years (1988 to 1989 and 1992 to 1993). Also, the dry periods which are moderately dry in years (1990 to 2000, 2001 to 2002, 2007 to 2008, 2008 to 2009, and 2017 to 2018), severely dry in years (2010 to 2011 and 2022 to 2023) and year (2022 to 2023) represented extremely drought (Table 7) in the study region.

Table 5: 3-month SPI and RDI indices analysis in the study area for the period (1980-2023)

Years	3 months SPI				3 months RDI			
	SPI (October to December)	January to March	April to Jun	July to September	RDI (October to December)	January to March	April to Jun	July to September
1980-81	0.68	0.39	1.39	0.49	0.73	0.81	1.46	0.51
1981-82	0.19	0.97	0.81	0.21	0.17	0.44	1.08	0.24
1982-83	0.41	0.36	1.34	2.33	0.84	1.09	1.43	2.50
1983-84	-0.52	-0.03	-0.27	0.49	-0.44	1.00	-0.12	0.62
1984-85	0.68	-0.71	0.25	-0.15	0.78	-0.45	0.43	-0.15
1985-86	-0.12	0.93	-0.07	-0.15	0.05	1.81	-0.01	-0.15
1986-87	0.93	0.23	0.73	-0.04	1.08	0.17	0.94	-0.03
1987-88	1.31	0.50	-0.39	-0.15	1.49	0.54	-0.26	-0.15
1988-89	0.21	2.06	1.22	0.77	0.30	1.53	1.40	0.82
1989-90	1.02	-1.65	-1.30	0.49	1.04	-0.73	-1.19	0.52
1990-91	-1.18	-0.18	0.39	-0.15	-1.07	0.12	0.48	-0.15
1991-92	0.46	0.74	-0.01	-0.15	0.48	0.60	0.13	-0.15
1992-93	1.22	1.07	0.15	0.49	1.13	2.99	0.45	0.65
1993-94	0.44	-0.13	2.04	0.49	0.43	0.57	2.29	0.57
1994-95	1.48	0.49	0.77	0.77	1.53	0.03	0.81	0.82
1995-96	-1.10	-0.01	0.59	0.77	-0.70	-0.29	0.68	0.91
1996-97	0.33	1.02	0.64	1.95	0.32	0.65	0.76	1.97
1997-98	0.21	-0.34	0.19	0.77	0.22	0.64	0.31	0.95
1998-99	-2.28	0.75	0.20	0.49	-2.07	1.43	0.23	0.49
1999-2000	-0.87	-1.12	-0.58	0.77	-0.75	-0.70	-0.49	0.80
2000-01	0.69	0.25	-0.95	-0.15	0.61	0.70	-0.94	-0.15
2001-02	-0.50	-0.63	-0.28	-0.15	-0.68	-1.09	-0.33	-0.15
2002-03	0.65	0.35	-0.11	-0.15	0.18	-0.55	-0.17	-0.15
2003-04	0.32	1.24	-0.88	-0.15	-0.01	0.69	-0.94	-0.15
2004-05	-0.11	-0.53	0.31	-0.15	-0.35	-0.84	0.21	-0.15
2005-06	-0.76	0.38	-0.40	-0.15	-0.81	-0.12	-0.50	-0.15
2006-07	0.44	1.04	0.76	-0.15	0.34	0.00	0.40	-0.15
2007-08	-2.23	-0.27	0.39	-0.15	-2.09	-0.27	0.15	-0.15
2008-09	0.08	-1.23	-2.74	0.58	-0.07	-1.34	-2.55	0.36
2009-10	1.08	-1.97	-1.01	1.47	0.58	-1.45	-1.03	1.30
2010-11	-1.38	-0.98	-0.18	-0.15	-1.48	-1.15	-0.35	-0.15
2011-12	-1.73	-1.14	1.15	0.03	-1.42	-1.05	0.91	-0.01
2012-13	0.47	-0.07	-1.77	0.05	0.15	0.49	-1.73	0.01
2013-14	0.42	1.26	-0.45	0.26	0.30	-0.03	-0.50	0.22
2014-15	1.25	0.11	-0.69	0.43	2.66	-1.58	-1.18	0.75
2015-16	0.48	-0.85	-0.57	2.54	0.26	-0.82	-0.59	1.97
2016-17	-0.35	0.13	-0.30	-0.15	-0.34	-0.71	-0.43	-0.15
2017-18	-1.37	-1.28	0.38	-0.15	-1.26	-1.30	0.24	-0.15
2018-19	2.03	-0.87	1.51	-0.15	1.40	-1.31	1.21	-0.15
2019-20	0.28	1.53	1.30	0.03	-0.13	0.78	0.94	-0.01
2020-21	-0.96	1.74	0.03	-0.08	-1.12	0.55	-0.10	-0.10
2021-22	-1.61	-1.32	-2.84	-0.15	-1.50	-1.07	-2.72	-0.15
2022-23	-0.51	-2.23	-0.16	-0.15	-0.83	-1.06	-0.37	-0.15

Table 6: 6-month SPI and RDI indices analysis in the study area for the period (1980-2023)

Years	6 months SPI		6 months RDI	
	SPI (October to March)	SPI (April to September)	RDI (October to March)	RDI (April to September)
1980-81	0.64	1.42	0.98	1.47
1981-82	0.68	0.81	0.61	0.97
1982-83	0.42	1.42	1.38	1.61
1983-84	-0.46	-0.28	-0.01	-0.06
1984-85	-0.02	0.21	0.29	0.37
1985-86	0.47	-0.12	1.05	0.02
1986-87	0.74	0.72	1.05	0.81
1987-88	1.21	-0.45	1.61	-0.27
1988-89	1.48	1.25	1.59	1.39
1989-90	-0.15	-1.29	0.23	-1.14
1990-91	-0.91	0.36	-0.67	0.48
1991-92	0.70	-0.06	0.85	0.11
1992-93	1.47	0.15	1.88	0.45
1993-94	0.13	2.09	0.47	2.28
1994-95	1.35	0.79	1.37	0.88
1995-96	-0.74	0.61	-0.24	0.80
1996-97	0.80	0.70	0.83	0.83
1997-98	-0.18	0.20	0.24	0.43
1998-99	-0.47	0.20	-0.33	0.25
1999-2000	-1.44	-0.57	-1.09	-0.44
2000-01	0.55	-1.03	0.74	-1.07
2001-02	-0.87	-0.34	-1.23	-0.43
2002-03	0.59	-0.16	-0.20	-0.25
2003-04	0.95	-0.96	0.44	-1.02
2004-05	-0.54	0.27	-0.87	0.11
2005-06	-0.28	-0.46	-0.49	-0.57
2006-07	0.89	0.74	0.53	0.40
2007-08	-1.35	0.35	-1.35	0.10
2008-09	-0.82	-2.38	-1.02	-2.29
2009-10	-0.22	-0.91	-0.62	-0.90
2010-11	-1.63	-0.24	-1.85	-0.51
2011-12	-1.91	1.15	-1.49	0.89
2012-13	0.19	-1.80	0.05	-1.75
2013-14	1.03	-0.47	0.54	-0.49
2014-15	0.93	-0.69	0.47	-0.77
2015-16	-0.26	-0.40	-0.44	-0.51
2016-17	-0.24	-0.36	-0.49	-0.50
2017-18	-1.84	0.35	-1.73	0.10
2018-19	1.21	1.52	0.26	1.17
2019-20	1.13	1.31	0.42	1.01
2020-21	0.71	-0.01	-0.02	-0.22
2021-22	-1.99	-2.99	-1.79	-2.89
2022-23	-1.89	-0.21	-1.87	-0.45

Table 7: Annual SPI and RDI indices and statistical analysis in the study area for the period (1980-2023)

Years	Annual SPI	Annual RDI	SPI				RDI			
			Min	Max	Mean	SD	Min	Max	Mean	SD
1980-81	1.10	1.19	0.39	1.39	0.74	0.39	0.51	1.46	0.88	0.36
1981-82	0.83	1.03	0.19	0.97	0.55	0.35	0.17	1.08	0.48	0.36
1982-83	0.94	1.32	0.36	2.33	1.11	0.80	0.84	2.50	1.46	0.63
1983-84	-0.58	-0.03	-0.52	0.49	-0.08	0.37	-0.44	1.00	0.27	0.57
1984-85	-0.02	0.36	-0.71	0.68	0.02	0.51	-0.45	0.78	0.15	0.48
1985-86	0.28	0.58	-0.15	0.93	0.15	0.45	-0.15	1.81	0.43	0.80
1986-87	0.83	0.97	-0.04	0.93	0.47	0.39	-0.03	1.08	0.54	0.48
1987-88	0.85	1.10	-0.39	1.31	0.32	0.66	-0.26	1.49	0.41	0.70
1988-89	1.68	1.78	0.21	2.06	1.06	0.67	0.30	1.53	1.01	0.49
1989-90	-0.57	-0.27	-1.65	1.02	-0.36	1.14	-1.19	1.04	-0.09	0.90
1990-91	-0.68	-0.28	-1.18	0.39	-0.28	0.57	-1.07	0.48	-0.15	0.58
1991-92	0.50	0.77	-0.15	0.74	0.26	0.36	-0.15	0.60	0.27	0.30
1992-93	1.25	1.72	0.15	1.22	0.73	0.43	0.45	2.99	1.30	1.00
1993-94	1.14	1.43	-0.13	2.04	0.71	0.81	0.43	2.29	0.97	0.77
1994-95	1.37	1.40	0.49	1.48	0.88	0.37	0.03	1.53	0.80	0.53
1995-96	-0.41	0.09	-1.10	0.77	0.07	0.73	-0.70	0.91	0.15	0.67
1996-97	0.88	1.04	0.33	1.95	0.98	0.61	0.32	1.97	0.93	0.62
1997-98	-0.16	0.36	-0.34	0.77	0.21	0.39	0.22	0.95	0.53	0.29
1998-99	-0.40	-0.18	-2.28	0.75	-0.21	1.21	-2.07	1.43	0.02	1.29
1999-2000	-1.54	-1.03	-1.12	0.77	-0.45	0.73	-0.75	0.80	-0.28	0.63
2000-01	0.13	-0.15	-0.95	0.69	-0.04	0.60	-0.94	0.70	0.06	0.66
2001-02	-0.96	-1.02	-0.63	-0.15	-0.39	0.19	-1.09	-0.15	-0.56	0.36
2002-03	0.38	0.01	-0.15	0.65	0.19	0.33	-0.55	0.18	-0.17	0.26
2003-04	0.51	0.04	-0.88	1.24	0.13	0.77	-0.94	0.69	-0.10	0.58
2004-05	-0.42	-0.61	-0.53	0.31	-0.12	0.30	-0.84	0.21	-0.28	0.38
2005-06	-0.49	-0.69	-0.76	0.38	-0.23	0.41	-0.81	-0.12	-0.39	0.28
2006-07	0.97	0.27	-0.15	1.04	0.52	0.44	-0.15	0.40	0.15	0.23
2007-08	-1.03	-1.16	-2.23	0.39	-0.57	0.99	-2.09	0.15	-0.59	0.88
2008-09	-1.32	-1.36	-2.74	0.58	-0.83	1.29	-2.55	0.36	-0.90	1.14
2009-10	-0.56	-0.60	-1.97	1.47	-0.11	1.43	-1.45	1.30	-0.15	1.13
2010-11	-1.55	-1.76	-1.38	-0.15	-0.67	0.53	-1.48	-0.15	-0.78	0.55
2011-12	-0.89	-0.90	-1.73	1.15	-0.42	1.11	-1.42	0.91	-0.39	0.91
2012-13	-0.32	-0.51	-1.77	0.47	-0.33	0.86	-1.73	0.49	-0.27	0.86
2013-14	0.68	0.39	-0.45	1.26	0.37	0.61	-0.50	0.30	0.00	0.31
2014-15	0.54	0.11	-0.69	1.25	0.28	0.69	-1.58	2.66	0.16	1.69
2015-16	-0.45	-0.65	-0.85	2.54	0.40	1.33	-0.82	1.97	0.21	1.09
2016-17	-0.42	-0.67	-0.35	0.13	-0.17	0.19	-0.71	-0.15	-0.41	0.20
2017-18	-1.40	-1.45	-1.37	0.38	-0.60	0.75	-1.30	0.24	-0.62	0.68
2018-19	1.60	0.83	-0.87	2.03	0.63	1.18	-1.31	1.40	0.29	1.10
2019-20	1.43	0.77	0.03	1.53	0.79	0.64	-0.13	0.94	0.40	0.47
2020-21	0.53	-0.06	-0.96	1.74	0.18	0.98	-1.12	0.55	-0.19	0.60

2021-22	-2.47	-2.35	-2.84	-0.15	-1.48	0.96	-2.72	- 0.15	-1.36	0.92
2022-23	-1.75	-1.82	-2.23	-0.15	-0.76	0.86	-1.06	- 0.15	-0.60	0.36

Table 8: Frequency and probability of SPI and RDI indices analysis over the study area for the period (1980-2023)

Drought range	Categories	Frequency distribution (SPI)	Probability Event (%)	Frequency distribution (RDI)	Probability Event (%)
>2	Extremely Wet	0	0	0	0
1.5 to 1.99	Severe Wet	2	4.65	2	4.65
1.00 to 1.49	Moderately Wet	5	11.63	7	16.28
- 0.99 to 0.99	Near Normal	29	67.44	26	60.47
- 1.49 to - 1.00	Moderately Drought	4	9.30	5	11.63
- 1.99 to - 1.5	Severe Drought	2	4.65	2	4.65
<- 2.0	Extremely Drought	1	2.33	1	2.33

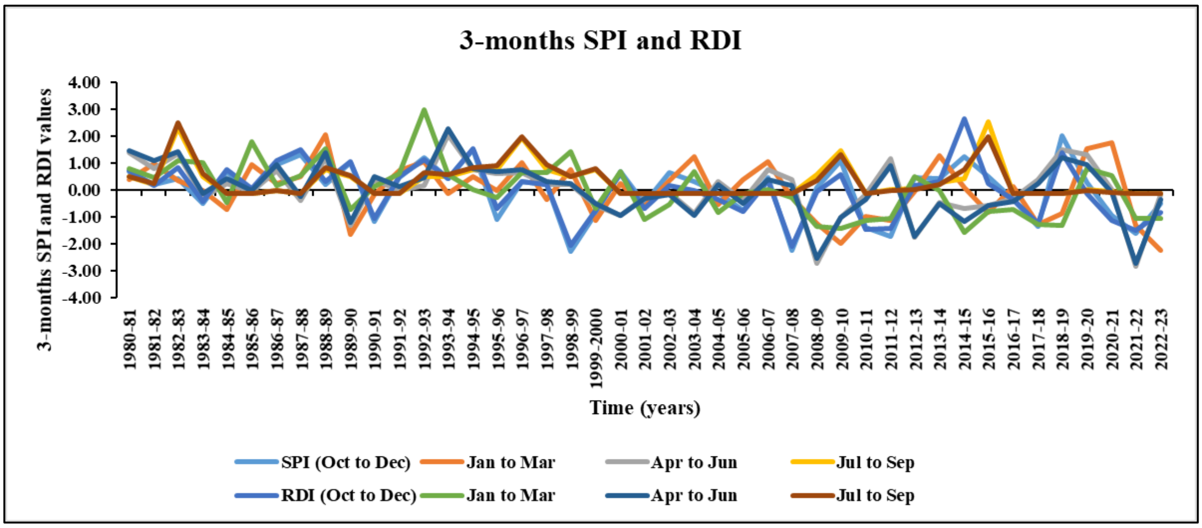

Figure 4: 3-months SPI and RDI indices distributed in the study area for the period (1980-2023)

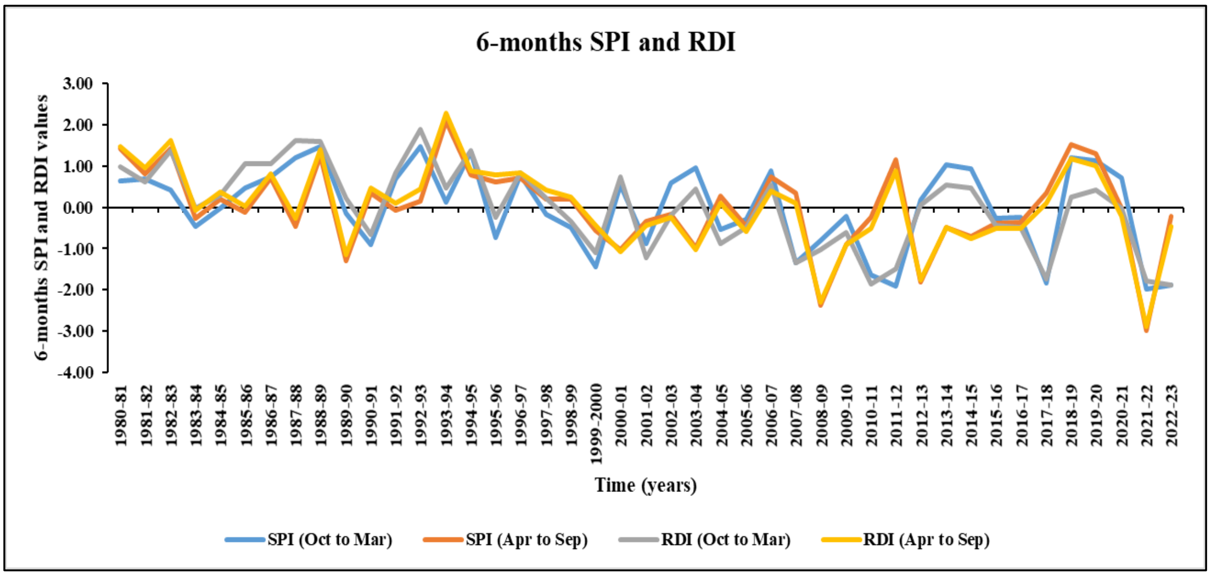

Figure 5: 6 months SPI and RDI indices distributed in the study area for the period (1980-2023)

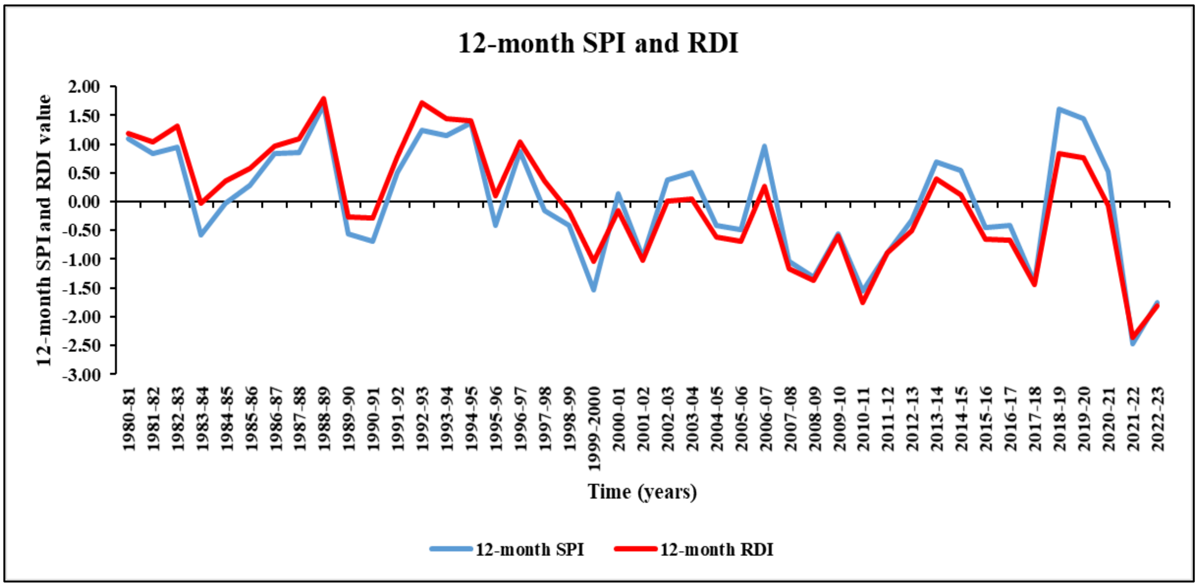

Figure 6: 12-months SPI and RDI indices distributed in the study area for the period (1980-2023)

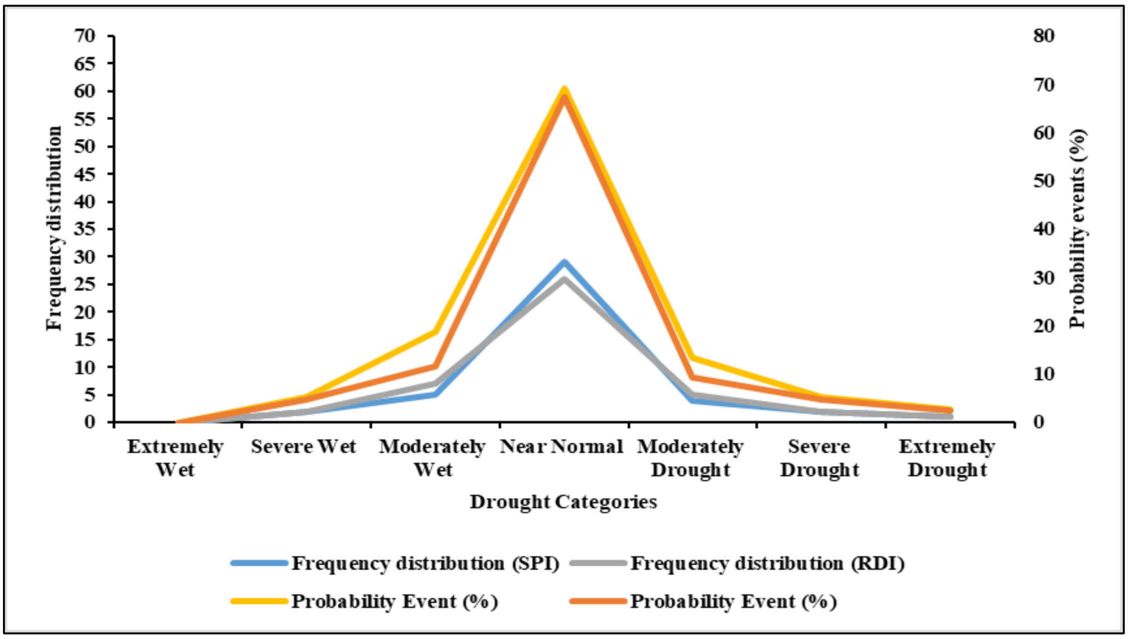

Figure 7: Frequency and probability events of 12-month SPI and RDI indices distributed in the study area for the period (1980-2023).

4.3 Comparison between SPI and RDI

According to the t-test result shown in Table 9. Among these indices, RDI demonstrated the most suitability for replicating SPI, as the T-Test findings revealed that the difference between the two indices was not significant (P value > 0.05). In the meantime, the values of all goodness-of-fit measures indicated that the RDI index is superior for drought estimation due to its higher mean SPI values compared to RDI, which relies entirely on precipitation data. In contrast, RDI incorporates temperature and evapotranspiration in the present study.

Table 9: t-Test analysis of SPI and RDI indices in the study area for the period (1980-2023).

Indices	Mean ± SE	P-value
SPI	0.0006977 ± 0.1542	0.993
RDI	0.0002326 ± 0.1543	0.999

5. Conclusion

In recent decades, a change in the climate has occurred globally, particularly in Iraq. This phenomenon may stem from the rise in greenhouse gases on account of industrial growth. Similarly, human behaviours have caused disruptions in the hydrological cycle. Given the aforementioned parameters, the temporal fluctuation of PET has transpired, resulting in a modified connection between precipitation and PET. Consequently, it is rational to contrast the RDI (incorporating two variables: PET and precipitation) versus the SPI (which includes exclusively precipitation) indices to ascertain the influence of PET in drought assessment. The findings of this study indicate that the RDI is more responsive than the SPI to climatic circumstances, thereby emphasising the importance of evapotranspiration in drought evaluations. The T-test results indicated that both indices exhibit identical behavior depending on whether the P-value is > 0.05; however, as the RDI, incorporates potential evapotranspiration under comparable climatic situations, it demonstrates more sensitivity. Accordingly, it is recommended to utilize the RDI index as the appropriate drought index to evaluate drought conditions, which is of vital importance in water supply management and planning within the study region.

Conflict of Interest: There is no conflict of interest for this paper.

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