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Prevailing and Maximum Drought Intervals in the Iraqi Mesopotamia Plain Region: Index-Based Estimation

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Abstract: Drought indices are an effective tool for evaluating the impact of drought on environments, such as its duration and severity. Here, monitoring and evaluation of meteorological drought were conducted for 3-decades (1984-2014) in the Mesopotamia Plain Region in Iraq using the Drought Indices Calculator DrinC1.7(91) software based on monthly precipitation data recorded by thirteen stations covering the overall study area. The calculations for the standardised precipitation index (SPI), the exceedance probability, the frequency of repetitions of consecutive drought years, and the return period were conducted. Results revealed that the general average drought level was moderately dry, and in most parts of the study region, the percentage of rainy years is less than the dry years, where, on the average annual yearly scale, it is 40% for rainy years and 60% for the dry years. Moreover, the exceedance probability and the frequency decrease when the drought interval increases and the dominant event is a one-year drought and the maximum drought interval occurred within the return period of 3-decades was eight consecutive years (1998-2006), with a 3.33% exceedance probability.

Key words: Mesopotamia plain, meteorological drought, drought indices, gamma SPI, exceedance probability, DrinC program.

Introduction

Drought is classified at the forefront of dangerous natural disasters, because of its severe effects on agriculture, the environment, economy and many other human activities (Wilhite, 2000). In fact, natural disasters are a short time range or of a small spatial scale, except for drought, which accumulates for long periods of time and extends over a large spatial scale. Therefore, studying and assessing the magnitude and severity of drought can be considered very significant for the sustainable management of water resources, the environment, and various human activities (Al-Khafaji and Al-Ameri 2021). The long-term occurrence of the drought season makes it difficult to determine the beginning and end of this event, therefore, the drought is considered an extraordinary hazard. The dry season is defined as a shortage of available water within the hydrological system of a particular region (Barker et al., 2016). Generally, drought can be classified into four types (Dracup et al., 1980; Wilhite and Glantz, 1985):

- Meteorological drought is due to shortages of usual precipitation during a particular period in a specific area.
- Hydrological drought, due to the decline of water levels in rivers, lakes, and reservoirs.
- Agricultural drought, due to the shortage in soil moisture, causes a lack of supply of the crop water demands.
- Groundwater drought is due to deviation of groundwater heads, recharge, and discharge from

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normal (Tallaksen and Van Lanen, 2004; Van Lanen, 2005).

Generally, climate change has accelerated the meteorological and hydrological processes to become quicker and more intense, with many consequences (Mukherjee et al., 2018). The tools that are used to analyse and measure the severity of drought are called drought indices. They refer to the impact of drought on various water resource types. These indices vary depending on the type of drought and its included variables (Svoboda, 2002; Wilhite and Glantz, 1985). Over the past years, climatologists and meteorologists have developed a number of simple and complicated drought indices, such as the precipitation percentiles index and the Palmer Drought Severity Index, respectively (WMO, 2012). The Standard Precipitation Index SPI can be considered as the most communal index. It's a powerful and flexible tool developed by American scientists (McGhee et al., 1993). The SPI index is a simple calculation, where the precipitation variable is the only needed input parameter.

The Mesopotamia Plain is one of the Iraqi regions that has suffered in the last decades from many drought spells. It had severe impacts on the surface water and groundwater resources, which consequently affected the economy of the country. For the Iraqi scale, numerous studies have been presented for understanding and evaluation of drought. Some of these studies focussed on the meteorological drought (Al-Faraj and Al-Dabbag 2015, Jasim and Awchi, 2017, 2020; Rasheed, 2010; Robaa and Al-Barazanji, 2013,). Other studies focused on hydrological and agricultural drought such as (Al-Mohseen, 2010; AL-Timimi et al., 2012; Almamalachy et al., 2020). In this paper, monthly precipitation data were collected from thirteen stations. Data were taken from the Iraqi Meteorological Organization and Seismology (IMOAS). The SPI values were computed for 3 decades (1984-2014) in the Mesopotamia Plain Region in Iraq by using the DrinC1.7(91) software. The exceedance probability, frequency of repetitions of consecutive drought years, and return period were conducted.

Materials and Methods

Study Area

According to the divisions of Iraqi geologists, the Mesopotamia Plain Region is one of main six geological parts as shown in Figure 1. It is a huge lowland located between latitudes 35.118° N and 30.223° N and longitudes 43.00° E and 48.50° E, covers 116000 km^2, and has boundaries in the north and the east with adjacent foothills, particularly Makhoul and Himreen Mountains, respectively, while its boundaries in the west and the southwest is Western and Southern Deserts, respectively. It is considered topographically as a flat region that slopes mildly between Baghdad and Basrah, while gently rippling in its northern boundaries. The highest elevation of the Mesopotamia Plain Region is 140 m above sea level, in the Fatha vicinity, and the lowest elevation is about 1 m above sea level, on the southeastern border of the area along the Arabian Gulf (Yacoub, 2011). The climate conditions in the Mesopotamia Plain region are classified as continental and subtropical, arid to semi-arid. The meteorological information referred to low-scale precipitation depths versus high-scale evaporation depths, the mean yearly rainfall is around 100 mm, the mean yearly evaporation is about 3000 mm, the mean yearly temperature is 22°C, and yearly relative humidity is about 42% (Al-Jiburi and Al-Basrawi, 2011).

Meteorological Data (Precipitation Depth)

In this paper, the monthly precipitation data were collected from a record of 13 meteorological stations for a 30-year historical period. The data were provided by the Iraqi Meteorological Organization and Seismology (IMOAS). In most meteorological stations enclosed by this study, missing data of rainfall records for different periods may be noticed in some stations as long as many years, continuous or intermittent, and vary from one station to another. Missing data values have been assessed by using the Normal Ratio Method or Arithmetic Average Method based on the precipitation data from adjacent stations. Table 1 indicates the geographic and topographic information in addition to other features of the selected meteorological stations for the period (1984-2014). Figure 2 shows the time series of input data that is used to calculate the SPI index.

Theoretical Background of SPI

Generally, drought indices can be described as a quantitative representation of the severity of drought, where it can express the effects of different variables (such as precipitation, temperature, evapotranspiration, stream flow, etc.) for any region and within any chosen time period (Steinemann et al., 2005). SPI is one of the drought monitoring indices, developed by McKee et al. (1993) by using the gamma distribution fitting to give precipitation time series. This index was created based on seasons or limited time periods such as a three-month season, a six-month season, and one year to four years.

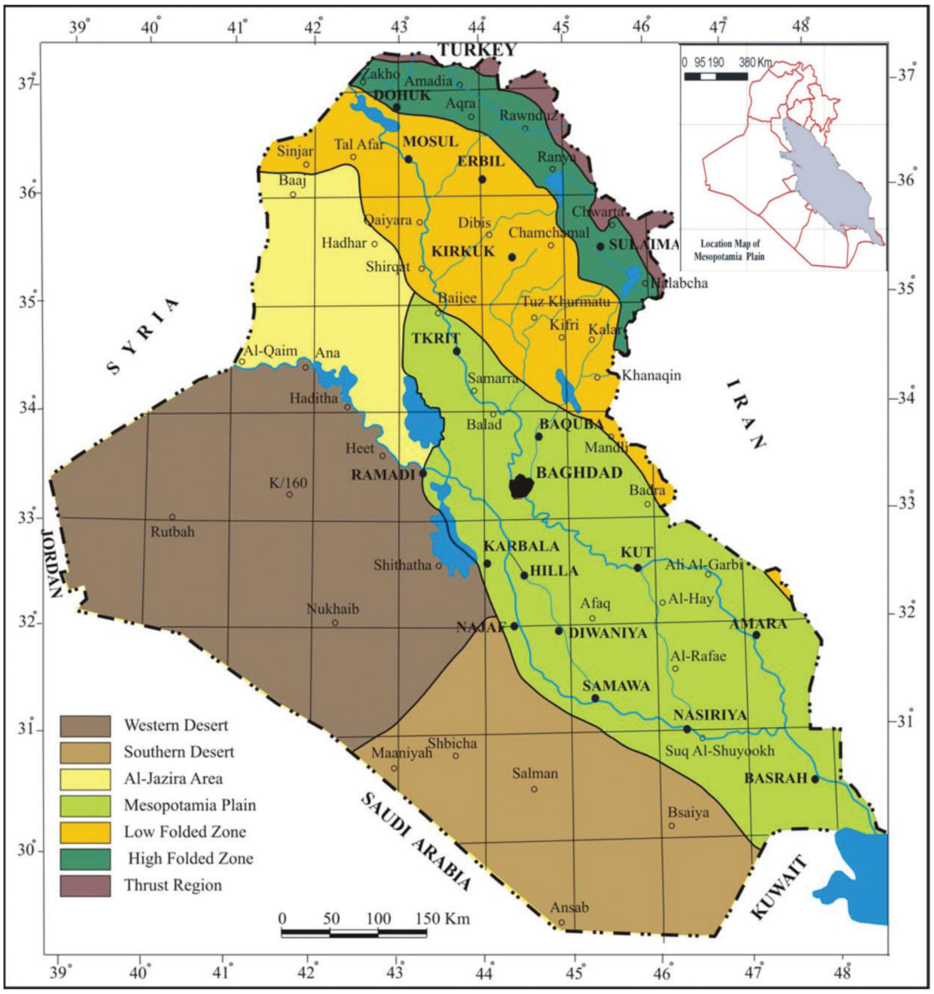

Figure 1: Site map of the Mesopotamia Plain region, (Yacoub, 2011).

Table 1: The geographical, topographical, and statistical information of the selected meteorological stations for the period (1984-2014)

Meteorological Station	*Longitude*	*Latitude*	*Elev. (m)*	*Minimum Yearly Precip. (mm)*	*Maximum Yearly Precip. (mm)*	*Mean Yearly Precip. (mm)*
Samawa	45° 16’	32° 02’	6	33.40	259.10	106.80
Hilla	44° 26’	31° 18’	25	41.00	191.70	101.00
Baghdad	44° 14’	33° 14’	32	49.90	296.70	117.10
Nasiriya	46° 14’	31° 05’	3	34.80	307.80	126.80
Hai	46° 03’	32° 10’	14.9	64.50	233.40	126.60
Basrah	47° 43’	30° 34’	2.4	31.90	296.60	137.10
Baiji	43° 29’	34° 55’	115	113.90	376.70	204.60
Amara	47° 10’	31° 51’	9	60.10	341.10	188.00
Diwanya	44° 58’	31° 58’	20	37.80	223.40	105.90
Karbala	44° 01’	32° 37’	--	34.00	201.00	093.60
Kut	45° 45’	32° 28’	20	44.60	237.70	157.20
Najaf	44° 19’	31° 58’	32	27.00	190.70	091.80
Tikrit	43° 42’	34° 34’	--	83.30	282.10	174.00

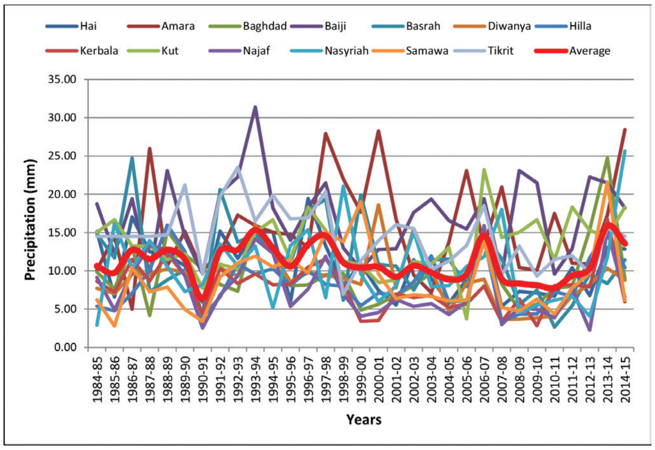

Figure 2: Time series of precipitation depth (mm) for the study area.

Due to this reason, the index is fitting depending on the time period of 3 decades and compared with other areas of different climate conditions, the minimum period of recorded data must be not less than 30 years (Yacoub and Tayfur, 2017). Because of the seasonality in the rainfall data in our study area, the suitability of using the SPI becomes best fitting for us. According to Khan and Gadiwala (2013), short-period rainfall irregularities affect soil moisture, whereas long-period rainfall irregularities affect water resources. The advantage of SPI is applicable to calculating various timescales and providing early warnings of droughts as well as helping evaluate the severity of the droughts. However, the disadvantage of this index depends only on the precipitation. For this index, positive and negative values refer to more than and less than compared with average precipitation. Table 2 indicates the classification of meteorological drought severity depending on the SPI values (McKee et al., 1993).

Table 2: Degrees of meteorological droughts are based on the SPI values (McKee et al., 1993)

SPI values	*Drought type*
0 to 0.99	Mild wet
0 to -0.99	Mild dry
1 to 1.49	Moderately wet
-1 to -1.49	Moderately dry
1.5 to 1.99	Very wet
-1.5 to -1.99	Severely dry
2 or more	Extremely wet
-2 or less	Extremely dry

In this index, the gamma probability function is the essential distribution function used to give a time series of precipitation. It was presented according to the next form (Yacoub and Tayfur, 2017):

$$J(p) = \frac{1}{\beta\alpha\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \text{ for } x,\ \alpha,\ \beta > \text{zero} \tag{1}$$

$$\Gamma\alpha = \int_0^y y^{\alpha-1} e^{-y}\, dy \tag{2}$$

$$\alpha = \frac{1}{4*A}\left(1+\sqrt{1+\frac{44}{3}}\right) \tag{3}$$

$$\beta = \frac{\bar{x}}{a} \tag{4}$$

$$A = \ln(\bar{p}) - \frac{\sum l\,\mathrm{n}(p)}{n} \tag{5}$$

where $J(p)$ is the precipitation quantity in mm, α and β are the shape parameters and Γ (α) is the Gamma function of α, $\bar{p}$ is the average precipitation quantity in mm, n is the number of precipitation data.

$$J(p) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^p p^{\alpha-1} e^{-\frac{p}{\beta}}\, dp \tag{6}$$

$$H(P) = Q + (1 - Q)\, J(p) \tag{7}$$

$$SPI = -\left(t - \frac{2.515517 + 0.802853*t + 0.010328*t^2}{1 + 1.432788*t + 0.189369*t^2 + 0.001308*t^3}\right) \tag{8}$$

If $0 < H(p) \le 0.5$ (9)

$$t = \sqrt{ln\left(\frac{1}{\lfloor H(x) \rfloor^2}\right)} \tag{10}$$

$$SPI = +\left(t - \frac{2.515517 + 0.802853*t + 0.010328*t^2}{1 + 1.432788*t + 0.189369*t^2 + 0.001308*t^3}\right) \tag{11}$$

If $0.5 < H(p) \le 1$

$$t = \sqrt{ln\left(\frac{1}{\lfloor 1 - H(p) \rfloor^2}\right)} \tag{12}$$

$$SPI = \frac{\ln(p_i) - \mu}{\sigma} \tag{13}$$

Arithmetically, standardising the data directly from a fitted natural distribution where possible, then SPI is calculated as follows:

$$SPI = \frac{p_i - \mu}{\sigma} \tag{14}$$

DrinC software

Drought Indices Calculator (DrinC) software was developed by Dimitris et al. (2015) using Visual Basic and can be considered a suitable tool for assessing meteorological, hydrological and agricultural drought indices. The calculation process is performed through a friendly graphical user interface as well as the available options can be adjusted to fit the drought analysis objectives of any certain case. In addition, DrinCsoftware comprises the estimation of potential evapotranspiration (PET) tools, through temperature-based methods (Hargreaves, Thornthwaite, Blaney-Criddle) and the assessment of the aridity index.

Methodology

The first step in the current study began with obtaining the records of precipitation depths from the IMOAS for 13 meteorological stations; Samawa, Hilla, Baghdad, Nasiriya, Hai, Basrah, Baiji, Amara, Diwaniyah, Karbala, Kut, Najaf, and Tikrit. These data were recorded for a 3-decade period from 1984 to 2014. The second step was to estimate missing data values by using the Normal Ratio Method or Arithmetic Average Method based on the precipitation depths of adjacent stations within the same date. The computation of the average monthly SPI was conducted using the (DrinC) software. Finally, statistical calculations were conducted to define drought recurrence periods and the percentage of exceedance probability.

Results and Discussions

At the annual level of the Mesopotamia plain region, the precipitation sometimes begins to fall at the end of the autumn season and is concentrated in the winter and spring, then disappears completely in the summer. Therefore, to study the sequence of drought spells, SPI values were calculated for 12 months in order to enclose the annual precipitations of the meteorological stations during a year, Table 3 indicates the average annual SPI values for the meteorological stations used in this study. As can be noticed from Figure 3 and Table 3, the general average drought level ranges from moderately wet to moderately dry. It is also clear that the percentage of rainy years is less than in the dry years, where it is 40% for rainy years and 60% for the dry years.

The vast majority of meteorological stations referred to moderate droughts in the years 1990 and 2009, while all meteorological stations showed a drought level range between mild wet to extremely wet in the year 1993. The highest level of extremely wet was recorded in Baghdad, Baiji and Diwaniyah stations in the years 2013, 1993 and 2000, respectively. The most severe level of drought was recorded in Kut, Basra and Tikrit stations in the years 2013, 2010 and 1998, respectively. In recent years, all meteorological stations showed continuous spells of drought, contrasting the rest of the years that recorded successive spells of wet and dry years.

The percentage of exceedance probability and frequency of repetitions of consecutive drought years were demonstrated in Figure 4. The most common event is a one-year drought and the maximum drought interval that can occur within the return period of 3-decades was eight consecutive years (1998-2006), with a 3.33% exceedance probability. Also, it is noticed that when the drought interval increases, the exceedance probability and the frequency decrease.

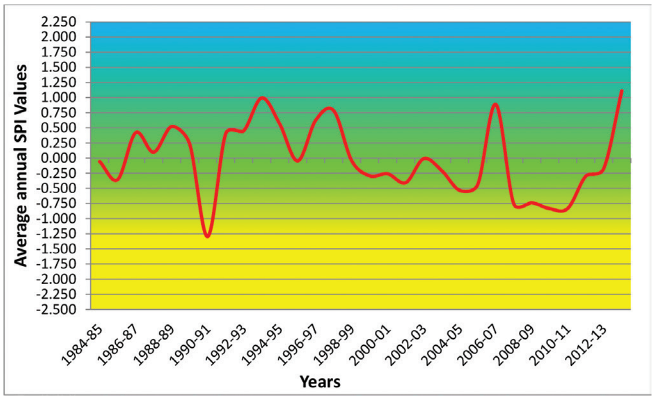

Figure 3: Average annual SPI values for Mesopotamia plain region for the period from 1984 to 2014.

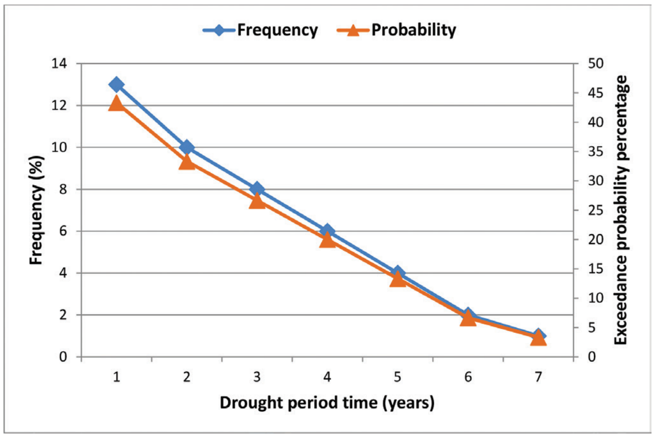

Figure 4: Frequency and exceedance probability of average annual drought versus successive reoccurrence period, for 3-decades (1984 to 2014).

Table 3: Average annual SPI values for all meteorological stations in Mesopotamia plain region for 3-decades from 1984 to 2014

Year	*Hai*	*Amara*	*Baghdad*	*Baiji*	*Basrah*	*Diwanya*	*Hilla*	*Kerbala*	*Kut*	*Najaf*	*Nasyriah*	*Samawa*	*Tikrit*	*Average*
1984-85	1.17	-0.91	0.15	0.42	0.75	-0.19	-0.95	0.38	0.5	0.52	-2.07	-0.59	0.09	-0.056
1985-86	-1.07	-0.06	-0.49	-0.93	0.2	-0.41	-1.21	-0.09	0.86	-0.66	1.12	-1.97	0.09	-0.355
1986-87	1.53	-2.33	0.95	0.54	2.1	0.33	-0.31	1.18	0.09	0.67	0.11	0.5	0.09	0.419
1987-88	0.6	1.55	-1.82	-1.65	-0.78	0.33	0.61	0.39	0.09	1.36	0.77	-0.27	0.09	0.098
1988-89	0.49	-0.79	1.38	1.15	-0.4	0.52	1.97	1.38	-0.38	1.27	0.16	-0.11	0.14	0.522
1989-90	0.16	0.04	0.71	-0.41	-0.11	0.39	1.23	0.61	-0.17	0.57	-0.57	-1.01	1.58	0.232
1990-91	-1.32	-0.94	0.27	-1.63	-1.81	-2.02	-1.59	-1.25	-1.52	-1.7	-0.35	-1.65	-1.33	-1.295
1991-92	1.17	-0.45	-0.3	0.66	1.59	0.55	-0.48	0.87	-0.54	-0.06	0.7	0.23	1.29	0.402
1992-93	0.39	0.38	-0.58	1.02	0.57	0.27	0.83	0.29	-0.71	0.56	0.18	0.64	2.02	0.451
1993-94	1.17	0.17	1.54	2.33	0.75	1.76	0.46	0.67	0.5	1.52	0.65	0.82	0.58	0.994
1994-95	1.15	0.02	0.85	0.32	0.4	1	0.66	0.24	0.86	1.18	-1.18	0.52	1.32	0.565
1995-96	-1.29	-0.03	-0.35	-0.53	0.07	0.07	0.04	0.27	-0.37	-0.51	0.66	0.72	0.64	-0.047
1996-97	1.97	-0.32	-0.32	0.33	1.21	0.39	0.59	0.92	1.2	0.15	0.99	0.34	0.67	0.625
1997-98	0.77	1.77	0.05	0.89	1.43	0.29	0.07	1.2	0.56	1.11	-0.78	1.41	1.41	0.783
1998-99	-0.55	1.05	0.1	-0.75	-1.07	0.19	0	0.28	-0.44	-0.02	1.79	1.18	-2.33	-0.044
1999-00	0.21	0.44	-1.49	-1.44	1.49	-0.04	-0.91	-1.77	-0.54	-0.98	-0.05	2.04	-0.78	-0.294
2000-01	-0.77	1.81	-1.18	-0.8	0.04	2.23	-0.29	-1.71	-1.26	-0.79	-0.93	0.31	-0.05	-0.261
2001-02	-1.46	0.31	-0.74	-0.78	-0.01	-0.17	-0.41	-0.17	-1.15	-0.23	-0.4	-0.54	0.47	-0.406
2002-03	0.34	-1.06	-0.36	0.21	-0.72	1.66	0.17	-0.34	-0.44	-0.51	0.96	-0.38	0.34	-0.010
2003-04	-0.3	-1.65	0.13	0.53	0.15	0.51	1.09	-0.24	-0.53	-0.39	-0.41	-0.45	-1.14	-0.208
2004-05	-1.38	-0.2	-0.04	0.01	0.17	-1.26	-0.72	-0.86	0.04	-0.89	-0.38	-0.63	-0.8	-0.534
2005-06	-0.34	1.19	-0.08	-0.22	-0.6	0.01	-0.65	-0.67	-3.32	-0.32	0.16	-0.61	-0.22	-0.436
2006-07	1.12	-0.3	1.02	0.54	0.7	0.16	1.6	0.19	2.09	1.81	0.4	1.19	1.02	0.888
2007-08	-1.53	0.91	-0.29	-1.65	0.18	-1.76	-1.88	-1.81	0.35	-1.45	1.38	-0.92	-1.37	-0.757
2008-09	-0.82	-0.85	-1.47	1.15	-1.25	-1.74	-1.41	-0.41	0.5	-0.57	-1.39	-1.09	-0.24	-0.738
2009-10	-0.89	-0.93	-1.19	0.89	-0.72	-1.65	-1.39	-2.13	0.86	-0.64	-1.08	-0.56	-1.43	-0.835
2010-11	-1.03	0.42	-0.46	-1.63	-2.44	-1.54	-0.23	0.37	-0.38	-1.05	-0.87	-1.23	-0.73	-0.831
2011-12	0.08	-0.73	-0.37	-0.78	-1.3	-0.48	-0.44	0.24	1.2	0.17	-0.74	-0.14	-0.59	-0.298
2012-13	-1	-0.75	1.4	1.02	-0.22	-0.03	1.02	0.15	0.56	-1.86	-1.57	0.34	-1.27	-0.170
2013-14	0.72	0.38	2.99	0.89	-0.51	0.53	1.82	2.38	0.37	1.71	0.38	2.41	0.36	1.110

Conclusions

In this paper, monitoring and evaluation of meteorological drought were conducted for 3-decades (1984-2014) in the Mesopotamia Plain region in Iraq using the DrinC software based on monthly mean precipitation data recorded in thirteen stations covering the overall study area. In order to achieve this, the calculations for the SPI drought index, the exceedance probability, the frequency of repetitions of consecutive drought years, and the return period were conducted. The important conclusions of this study were:

1. The general average drought level was moderately dry.
2. Severest intervals of drought were recorded in Kut, Basra and Tikrit stations in the years 2013, 2010 and 1998, respectively.
3. In most parts of the study region, the percentage of rainy years is less than the dry years, where, on the average annual scale, it is 40% for rainy years and 60% for the dry years.
4. Most meteorological stations referred to moderate droughts in the years 1990 and 2009, while, all meteorological stations showed a drought level range between mild wet to extremely wet in the year 1993.
5. All parts of the study area showed continuous spells of drought, contrasting the years prior to the study period, which recorded successive spells of wet and dry years.
6. The exceedance probability and the frequency decrease when the drought interval increases. The dominant event was a one-year drought and the maximum drought interval that occurred within the return period of 3-decades was 8 consecutive years (1998 to 2006), with a 3.33% exceedance probability.

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