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Assessment of spatial and temporal drought in Iraq during the period 1980-2010

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Abstract
This study investigated the frequency of drought for the period 1980 to 2010 in Iraq, based on monthly rainfall data were collected from 39 meteorological stations distributed across the country and digitally encoded into a GIS database. The standardized precipitation index (SPI) is used to evaluated the spatial and temporal characteristics of meteorological drought. The result of SPI analysis reveal that the country faced during the past 30 years frequent non-uniform drought periods in an irregular repetitive manner. the paper suggest the presence of two drought types, local drought and national drought, Drought severity Classes; near normal drought, moderate drought, severe drought and extreme drought increased with time from normal to extreme levels especially at last decade. The result show the year 2008 was the worst dry year during the period, 30% of the area is under extreme drought, 36% under severe drought, 22% of the area is under moderate drought and 12% is near normal.

Keywords: Meteorological drought; Iraq; Standard precipitation index (SPI); Drought magnitude.

1. Introduction

Drought is a natural phenomenon that has significant economic, social, and environmental impacts. Drought differs from other natural hazards in that its onset and end are difficult to determine. It develops slowly, and its impacts may remain for years after termination of the event. most definitions of drought are based on an expression of deficiency of precipitation resulting in water shortage for some activity related to use of water [1]. Consequences of drought are usually defined by the impacts that human use systems place on water supply. Drought impacts are usually first apparent in agriculture but gradually move to other water-dependent sectors. Recovery time for water stored in surface and subsurface systems can be quite long under severe drought conditions .The impacts of drought in the low and variable rainfall regions of the country can be widespread, affecting such diverse sectors as agriculture, irrigation, and energy. There are several indices that measure to what extent precipitation for a given period has deviated from historically established norms. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. The Standardized Precipitation Index (SPI) was designed to quantify the precipitation deficit for multiple time scales, which reflect the impact of drought on the availability of different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short time scale, while groundwater, stream flow, and reservoir storage reflect the longer-term precipitation anomalies as in [2]. For these reasons, McKee et al. [3] originally calculated the SPI for 3-, 6-, 12-, 24-, and 48-month moving average time scales. The SPI is probability-based, as in [4], and was designed to be a spatially invariant indicator of

drought [5-7] which recognizes the importance of time scales in the analysis of water availability and water use [8]. In this study the standardized precipitation index (SPI) is used to analyze meteorological drought. Since agricultural activities and ecological changes are controlled by rainfall, our analysis focuses on drought during the wet seasons. In this study, drought is considered to be a meteorological phenomenon characterized by prolonged periods of abnormal precipitation deficit.

2. Study area

2.1 Location and extent of study area

The republic of Iraq is located in the South - West of Asia, to the North - East of the Arab homeland, bounded on the North by Turkey, on the East by Iran, on the West by Syria, Jordan and Saudi Arabia, on the South by Arab Gulf, Kuwait and Suadi Arabia. Iraq lies between latitudes 29˚ 5´ and 37˚ 22´ North and between longitudes 38˚ 45´ and 48˚ 45´ East. the area of Iraq covers 435052 Sq.Km.

2.2 Topography

Iraq is shaped like a basin, consisting of the Great Mesopotamian alluvial plain of the Tigris and the Euphrates rivers (Mesopotamia means, literally, the land between two rivers). This plain is surrounded by mountains in the north and the east, and by desert areas in the south and west, which account for over 40 percent of the land area.

The Tigris and Euphrates rivers, flowing northwest to southeast before merging into the Shatt-Al-Arab and flowing into the Arabian Gulf. Other significant bodies of water nearby are the Mediterranean Sea, Black Sea, and Caspian Sea.

Altitude ranges from lowest point at Arabian Gulf 0 m (mean sea level) up to highest point 3606 m. The Zagros Mountains extend up to 3000 meters in Iraq and form a natural border between the northeast region of Iraq and western Iran. The Taurus Mountains form the border between northern Iraq and southern Turkey.

2.3 Climate

Iraq lies within the moderate northern region, system similar to that of Mediterranean where rainfall occurs almost in winter, autumn, spring and disappears in summer. The region is often divided into three rainfall zones according to the annual rainfall factor; Northern region, Middle region and Southern region [9]. Rainfall in Iraq varies from 50 mm per year in the SW to 1200 mm per year in the NE. The western desert of Iraq mostly receives <100 mm per year. The Mesopotamian flood plain and Jezira area receive 100-300 mm of precipitation per year. Rainfall in the foothills is 300-700 mm per year; the mountainous region of N and NE Iraq receives >700 mm of rain. Over half of Iraq lies within the arid and semi-arid zones (with<150 mm/year rainfall) [10].The evaporation is very high in the country. the quantity of evaporation varies from one place to the other. Cyclones moving across Iraq are coming from the west; their source is the Atlantic Ocean. They are usually moving east toward the Mediterranean Sea and then in the direction of Cyprus, Lebanon and Jordan finally toward Iraq, or the Arabian Gulf or the Caspian sea. The numbers of cyclones vary with seasons, months and places over which they are passing. Usually they are increasing in the winter, decreasing in the autumn and finally disappear completely in the summer. Also the number of cyclones moving over the south is greater than that moving across both zone of mountains and foothills. For instance, the annual number of cyclones in the south is about 75 while in the north is reaches 40. However, the north and northeast of Iraq usually receive higher amount of rain than the south. This is because the precipitations in the north are orographic as much as it is cyclonic [11].

3. Meteorological data

Historical records of monthly rainfall data for the time period 1980-2010 were acquired from the Iraqi Meteorological Organization and Seismology (IMOS) and Ministry of Agriculture and Water Resources (Kurdistan Region). The long-term data were collected from 39 weather stations, which included; Arbil, Duhook, Dukcan, Emadiyah, Khanqin, Kirkuk, Makmoor, Mosul, Rabiah, Salahaddin, Sinjar, Sulaymaniyah, Sumeel, Taleafer, Tuz, Zakho, Amara, Anah, Baghdad,Basrah, Biji, Fao, Hadithah, Hai, Heet, Kahalis, Kut, Qaim, Ramadi, Samaraa, Tikrit, Diwaniya, Hella, Kerbela, Najaf, Nasiriya, Nukheb, Rutba and Samawa), located at different regions of the country, The database was digitally encoded into a GIS database. as shown in Figure 1.

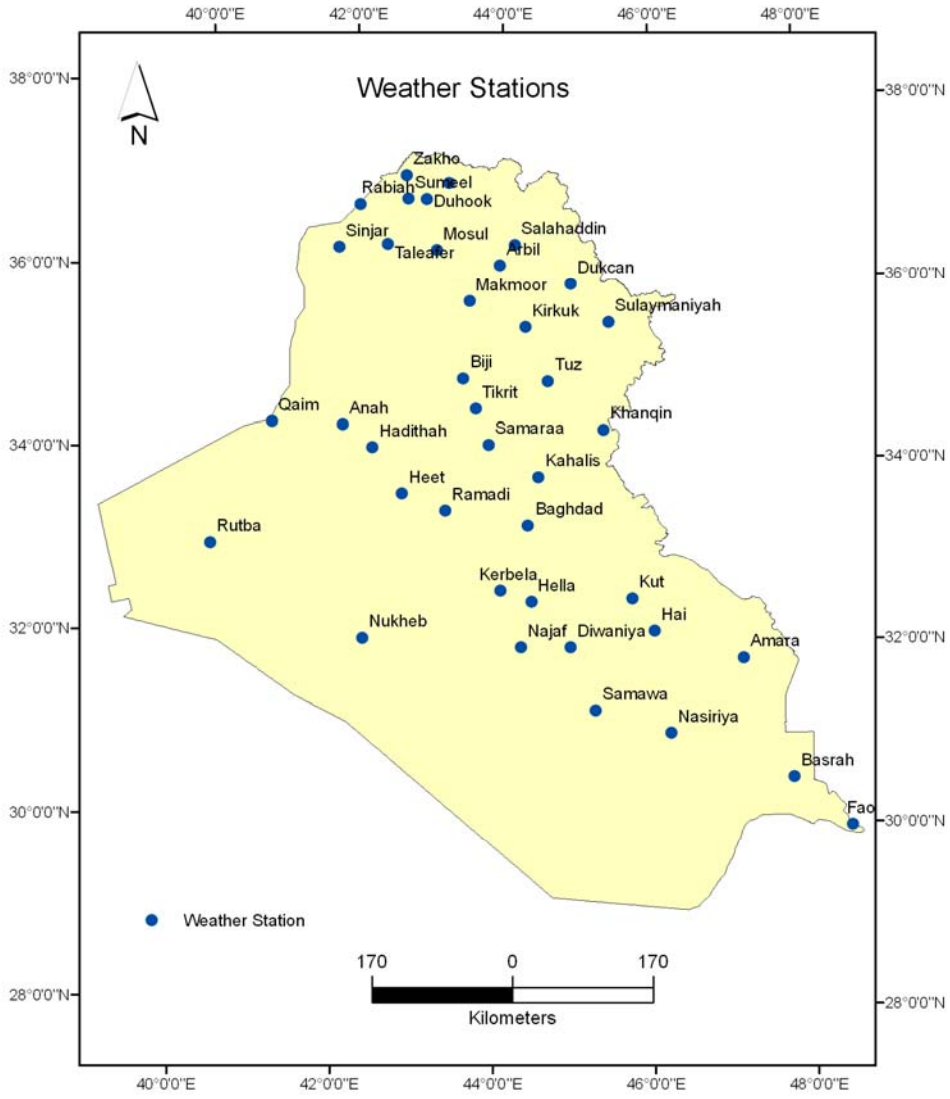


Figure 1. Meteorological stations in Iraq

The identification and assessment of drought severity were done using the SPI. The SPI is calculated from the monthly precipitation record by first fitting the gamma probability distribution function and then transforming that into a normal distribution so the mean SPI is set to zero [3]. In papers by McKee only empirical calculations of drought descriptions such as moderate, severe and extreme drought cases are calculated and accordingly the classifications are done quickly at a single site and correspond to SPI categories as shown in Table 1.

Table 1. Standard precipitation index categories

SPI values	Drought Category
0 to -0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2 or more	Extreme drought

4. The standard precipitation index (SPI)

SPI is calculated by fitting gamma distribution function to given frequency distribution of precipitation totals for a given station, and then transforming the gamma distribution to a normal distribution with mean zero and variance of one. The steps and equations to calculate SPI are as follows:

The precipitation data are calculated using the gamma probability density function which is defined as;

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} \quad \text{for x>0} \tag{1}$$

where $\alpha \succ 0$ is the shape parameter, $\beta \succ 0$ is a scale parameter and $x \succ 0$ is the amount of precipitation. $\Gamma(\alpha)$ defines the gamma function. α and β are parameters to be estimated for each station for each time step of interest. The maximum likelihood solutions are used to optimally estimate the gamma distribution parameters α and β :

$$\overset{\Lambda}{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{2}$$

and

$$\overset{\Lambda}{\alpha} = \frac{\bar{x}}{\overset{\Lambda}{\alpha}} \tag{3}$$

where

$$A = \ln(\bar{x}) - \frac{\sum \ln(\bar{x})}{n} \tag{4}$$

and n is the number of precipitation observations. This allows the rainfall distribution at the station to be effectively represented by a mathematical cumulative probability function given by:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} dx \tag{5}$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q)G(x) \tag{6}$$

where q is the probability of a zero. The cumulative probability H(x) is then transformed to the standard normal distribution to yield SPI [8].

For this study, SPI calculated for 3-months over 30 years period and 39 different meteorological stations. SPI was calculated from total rainy season from Dec to Feb to describe long term drought. SPI values of equal or less then -1.0 were used to determine drought intensity according to Table 1.the frequency of occurrence of drought was determine by looking at the number of dry station (SPI< -1.0) since 1980.

5. Results and discussion

5.1 Temporal drought patterns in Iraq

Meteorological drought indicates the deficiency of rainfall compared to the normal rainfall in given region. The temporal characteristics of drought in Iraq were identified from SPI time series. In our study, SPI for 3-months was computed to examine the characteristics of drought in short time periods. Annual SPI was calculated for the period of 30 hydrological years. Appearance of drought is happening every time when SPI is negative and its intensity comes to -1.0 or lower. Drought stops when SPI is positive. The duration of every drought is determined by negative index value. Accumulated totals of negative values of SPI could also be used as a measure of drought severity. Figure 2 represents the time series of SPI values in Dukcan station (Northern region); the Maximum Magnitude of SPI for 30 years was 46.15, and Maximum duration was from December 1998 to November 2002 (32 months) with intensity 1.44.The worst dry years appear in 1983, 1990, 1998, 1999, 2000, 2001, 2007, 2008, and 2009.

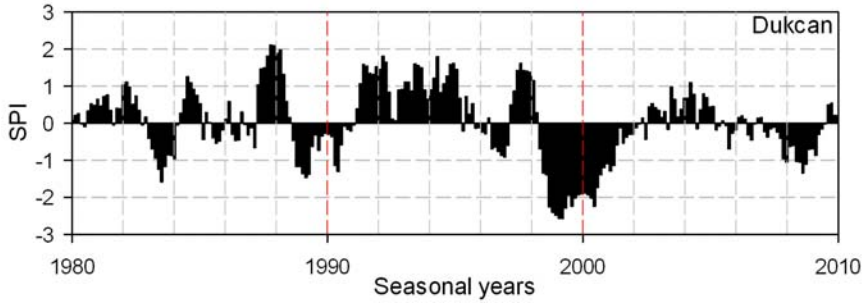


Figure 2. Time series of SPI values for Northern region, Dukcan station

Figure 3 shows the time series of SPI at Baghdad station (middle region), it can clear that the worst dry years were in 1983, 1987, 1989, 1990, 1998, 1999, 2000, 2001, 2002, 2003 2004, 2005, 2007, 2008 and 2009. Figure 3. represents the time series of SPI values in Baghdad station (middle region), The analysis shows that three extreme drought event occurred in Baghdad 1986, 1996, and 2008, The annual precipitation of the years were 35.4mm, 36.6mm, and 52.2mm respectively. The drought occurring in 2008 is the most severe drought ever experienced in Baghdad station. The annual minimum SPI for this drought event occurred in February 2008 with value of SPI - 2.72. the Maximum Magnitude 26.78, Maximum duration from December 2007 to May 2009 (22 months) with intensity 1.22.

Figure 4 shows the time series of SPI at Nukheb station represents the southern region in Iraq, the years 1983, 1987, 1989, 1990, 1998, 1999, 2000, 2001, 2002, 2003 2004,2005,2007,2008 and 2009 were dry. The Maximum Magnitude of SPI during the 30 years was 49.43 and Maximum duration from November 2004 to February 2009 (44 months) with intensity 1.12.

From Figures 2, 3 and 4 a non-uniform cyclic pattern of drought /wet periods were observed during the period 1980 to 2010. The temporal analyses of SPI indicate the presence of two drought types regarding the extent of the event; local and National. National drought having full dry extent at all meteorological stations, occurred more seldom. National drought events on seasonal basis occurred during the historical years of 1983, 1998, 1999, 2000 and 2008.on the other hand, local drought events occurring at one or two regions are more frequent,1987, 1989, 1990, 2001, 2002, 2003, 2004, 2005,2007 and 2009 are local drought seasons.

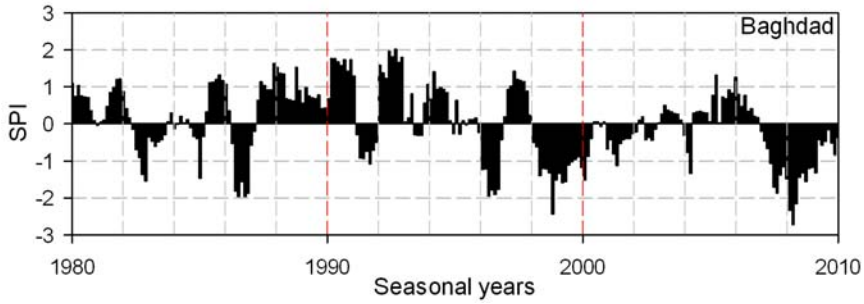


Figure 3. Time series of SPI values for middle region, Baghdad station

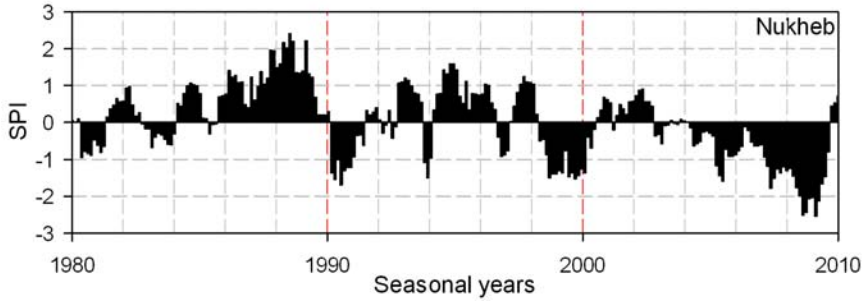


Figure 4. Time series of SPI values for southern region, Nukheb station

5.2 Drought severity

Drought severity was classified to four intervals of SPI values as follows: less than -0.99 is near normal drought (NN), between -1 and -1.49 is moderate drought (MD), between -1.5 and -1.99 is severe drought (SD) and greater than -2 is extreme drought (ED). Table 2 Summarize the frequency of each drought classes in all stations. According to these classifications it was found that near normal has a high values of frequency, Maximum frequency of moderate drought was 37 (15.4%) in Salahaddin station, and Minimum frequency was 12 (5%) in Kerbela, Duhook and Tuz stations, Maximum frequency of severe drought was 24 (10%) in Qaim station, and Minimum frequency was 1 (0.42%) in Basrah station, and Maximum frequency of extreme drought was 12 (5%) in Emadiyah station, Extreme drought did not occur during the last 30 years in Hadithah and Qaim stations. Figure 5 shows the mean of frequency of SPI classes.

Table 2. Frequency of SPI classes during the period 1980-2010

Name of Stations	Extremely drought	Severely drought	Moderately drought	Near normal	Moderately wet	very wet	Extremely wet
Arbil	6	9	24	166	21	8	6
Duhook	9	14	12	157	31	15	2
Dukcan	10	7	21	161	25	14	2
Emadiyah	12	10	17	170	17	11	3
Khanqin	8	10	20	158	31	12	1
Kirkuk	8	11	18	167	20	14	2
Makmoor	6	16	19	165	23	3	8
Mosul	7	17	16	173	9	10	8
Rabiah	6	9	26	174	12	6	7
Salahaddin	3	15	37	147	32	5	1
Sinjar	4	22	16	164	20	8	6
Sulaymaniyah	9	14	17	165	26	6	3
Sumeel	8	9	23	171	18	6	5
Taleafer	7	16	17	168	19	6	7
Tuz	6	20	12	166	25	7	4
Zakho	8	11	15	176	19	5	6
Amara	4	12	26	159	19	19	1
Anah	6	5	20	172	16	9	12
Baghdad	4	16	24	156	26	13	1
Basrah	7	1	22	174	12	16	8
Biji	6	12	19	171	15	8	9
Fao	10	2	14	184	18	8	4
Hadithah	0	9	32	158	25	12	4
Hai	3	13	27	156	24	15	2
Heet	1	8	37	156	16	15	7
Kahalis	8	13	12	167	29	11	0
Kut	5	9	17	166	24	17	2
Qaim	0	24	16	160	20	19	1
Ramadi	1	10	32	165	15	7	10
Samaraa	7	10	14	169	24	10	6
Tikrit	5	13	14	168	22	13	5
Diwaniya	4	13	23	157	25	14	4
Hella	4	9	33	147	30	14	3
Kerbela	7	19	12	161	27	10	4
Najaf	8	5	18	180	12	17	0
Nasiriya	8	6	26	155	30	11	4
Nukheb	6	9	27	158	30	5	5
Rutba	2	9	23	175	6	12	13
Samawa	2	11	20	169	16	13	9

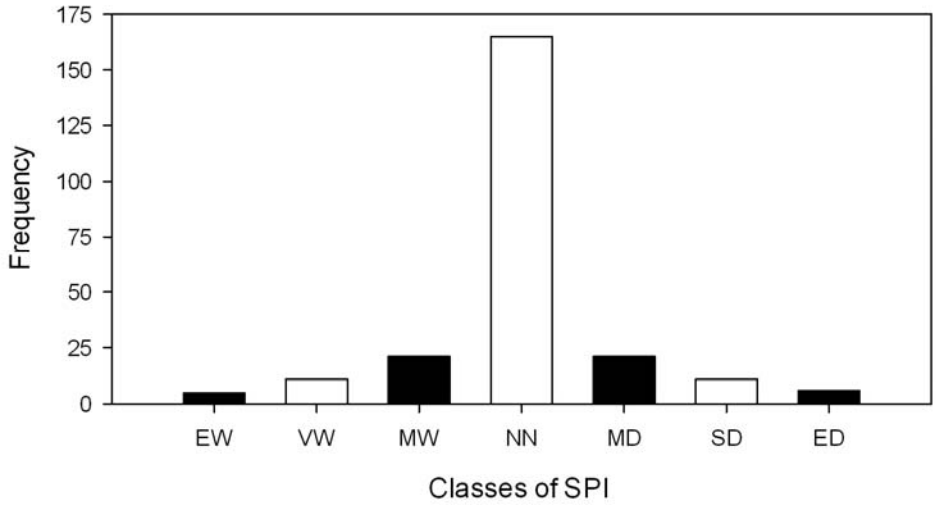


Figure 5. Mean frequency of SPI classes during the period 1980-2010

According to this classifications it was found that near normal drought occurs in 165 out of 240 months, in 21 out of 240 months there was a moderate drought, and in 11 out of 240 months there was a severe drought. Extreme drought occurs in 6 out 240 months during the last 30 years in Iraq.

When dividing the study period, 30 years into three periods each period represents by 10 years (decade). Figure 5 depicts the classes distribution of drought, and wet months for the three periods. For the first decade (1980 -1989) more than 59% of the months were wet months (no drought), 31.7% were slight drought, 6.6%were moderate, 1.7% were severe drought while 0.2% of the months were very severe drought. For the second decade (1990 -1999) the frequency of no drought was 65.9%, slight drought 16.6%, moderate drought 8.7%, severe drought 5.6% and very severe was 3%, the third decade (2000-2009) has get an increase in the frequency of all drought classes, compared with the previous decades, more than 30% of the months were wet months (no drought), 45.6% were slight drought, 11.8%were moderate, 8% were severe drought while 4.4% of the months were very severe drought.

From Figure 6 The results of SPI analysis indicated the increasing trend of drought severity from the year 1980 to 2009 in all stations. It is evident that the drought severity Classes; near normal drought, moderate drought, severe drought and extreme drought increased with time from normal to extreme levels especially at last decade.

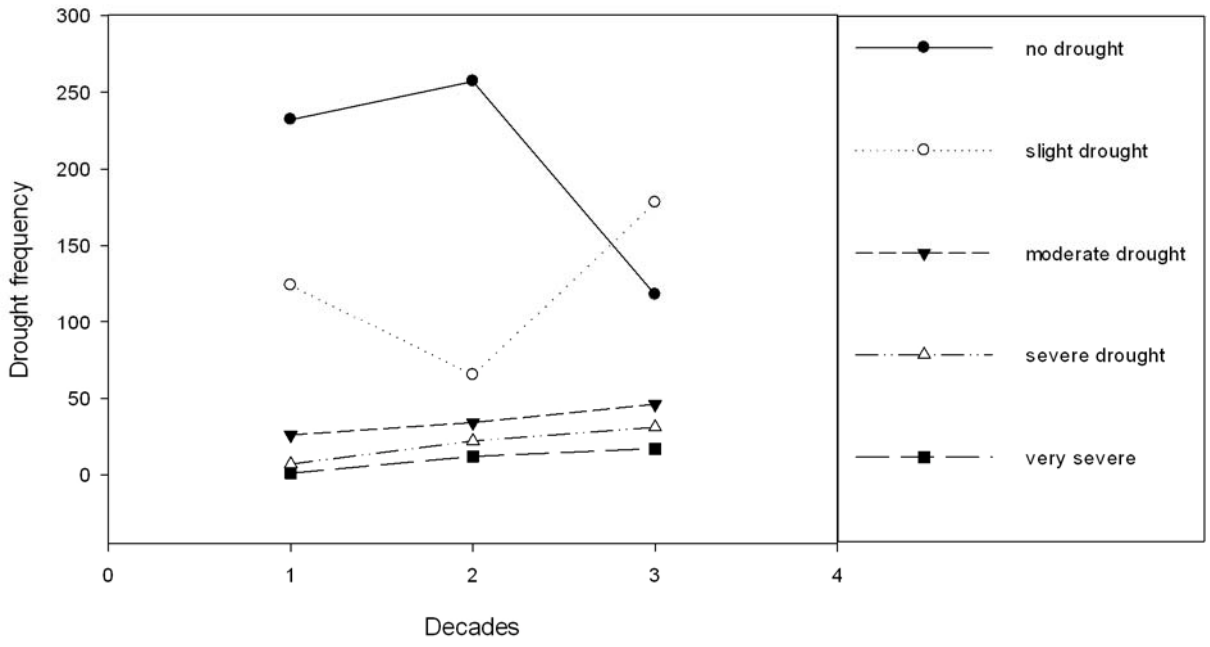


Figure 6. Drought frequency for five classes with three decades

5.3 Spatial drought pattern in Iraq

For the selection of drought years from 1980-2010, SPI was used. The year corresponding to the lowest SPI within the time series was taken and considered as drought year. It can be clearly in last figure that lowest SPI values were observed in the years 1999 and 2008. So years 1999 and 2008 were considered as drought years and similarly, year 1992 was chosen as a wet year. The interpolated maps of SPI, for typical wet 1992 and drought 1999 and 2008 years have been presented to show the spatial pattern of SPI during these years. From Figure 7. It can be seen that during wet year 1992, positive SPI values noticed in the entire study area, which indicated that there was not rainfall deficit in these area.

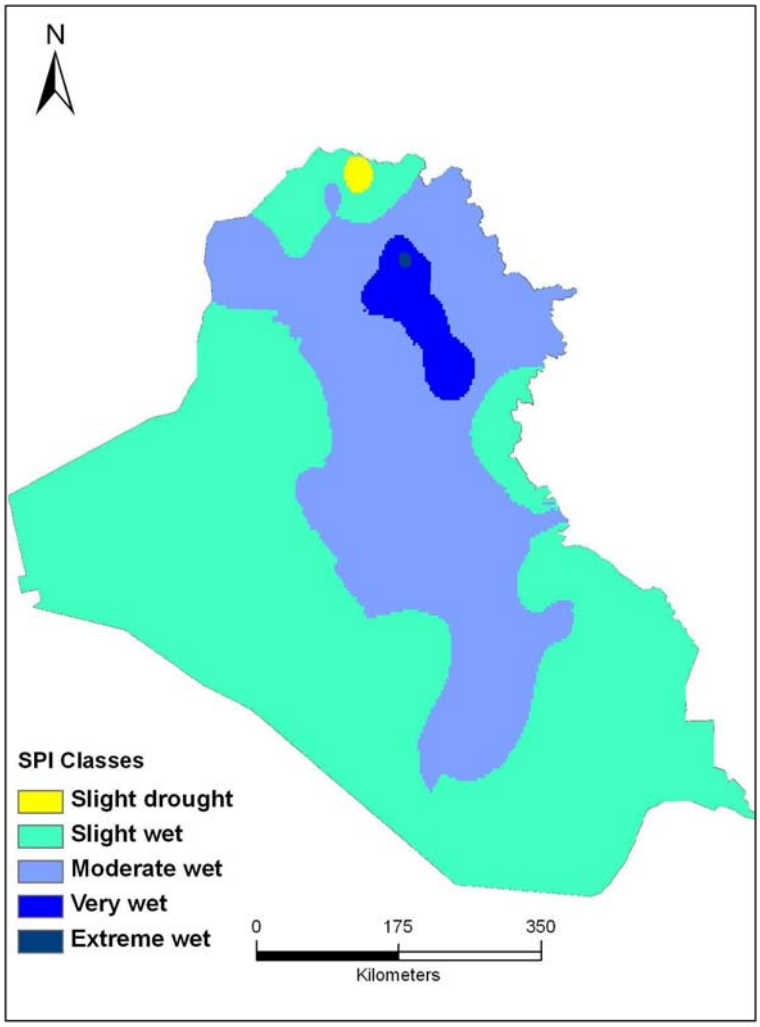


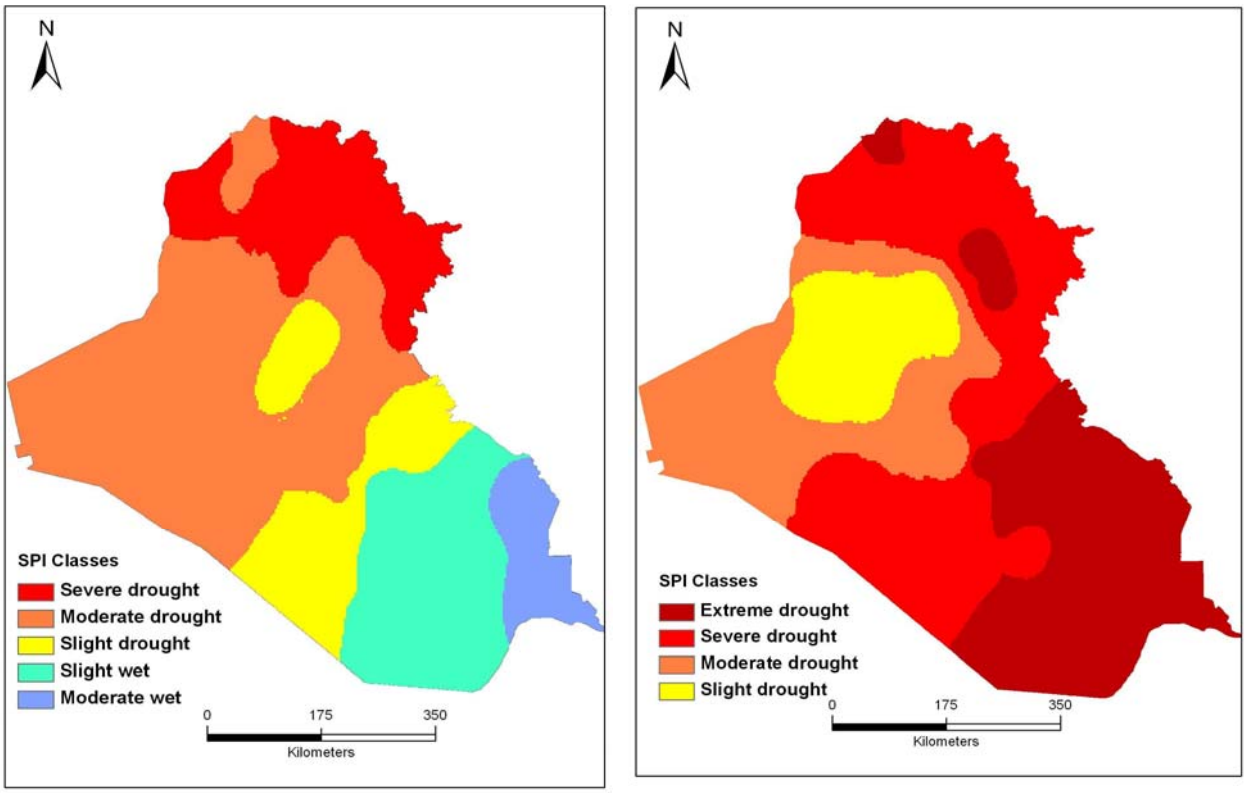
Figure 7. Spatial distributed of SPI for wet year 1992

SPI during selected drought years 1999 and 2008 have been presented to show the spatial pattern of SPI during these years. From Figure 8 it can be clear that during drought of 1999, SPI values are low for the north and north-eastern, which indicates that there has been low rainfall in these areas. SPI in 1999 indicated that 1999 was a severe drought year, where minimum SPI was found to be below -1.9 at Salahaddin station, Whereas SPI in 2008 indicated that it was extreme drought year with minimum SPI -2.6 at Kirkuk station. However during the wet years of 1992 SPI reached up to a value of -0.81 which states that 1992 was wet year.

5.6 The cumulative "or more" curves

A better representation of spatial extent of the drought can be achieved using a type of curves known as cumulative "or more" curves. These curves can be produced by plotting the severity of drought (y-axis) versus the percentage of affected area (x-axis). The severity of drought is presented by a drought index (SPI) and the area refers to that affected by at least the corresponding severity level. The boundaries of

the SPI severity classes were [2<] extreme wet, [2, 1.5]very wet,[1.5, 1] moderate wet, [1, 0] normal to wet, [0,-1] normal to dry, [-1, -1.5] moderate dry, [-1.5, -2] severe dry and [<-2] extreme dry. This type of graphs can be used not only for characterization of drought and determination of its areal extent, but also for comparisons with the critical area percentage (related to severity) directly. Clearly, more than one thresholds referring to the percentage of critical area can be used defining different level of severity. A representative "or more" curve is presented in Figures 9, 10 for the affected area, during a wet and dry year. SPI was calculated for the period of 30 hydrological years. Maps for wet year appear in Figure 9. During wet year (1992) about 64% of the total area is under moderate wet, whereas 97% of the area is under very wet. In other words, 64%, 33%, and 3% are under moderate wet, very wet and extreme wet respectively.



(a) (b)

Figure 8. Spatial distributed of SPI, (a) for drought year 1999; (b) for drought year 2008

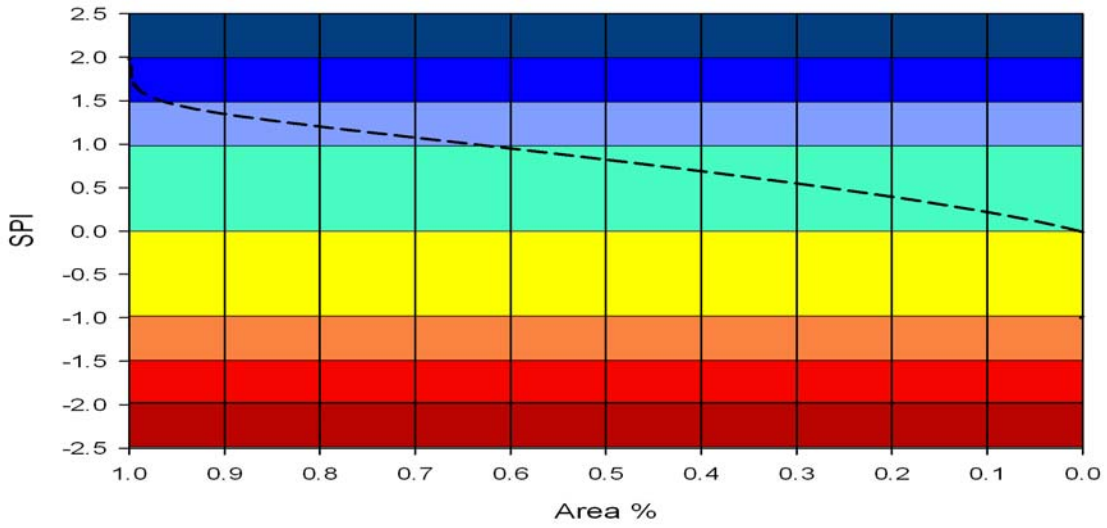
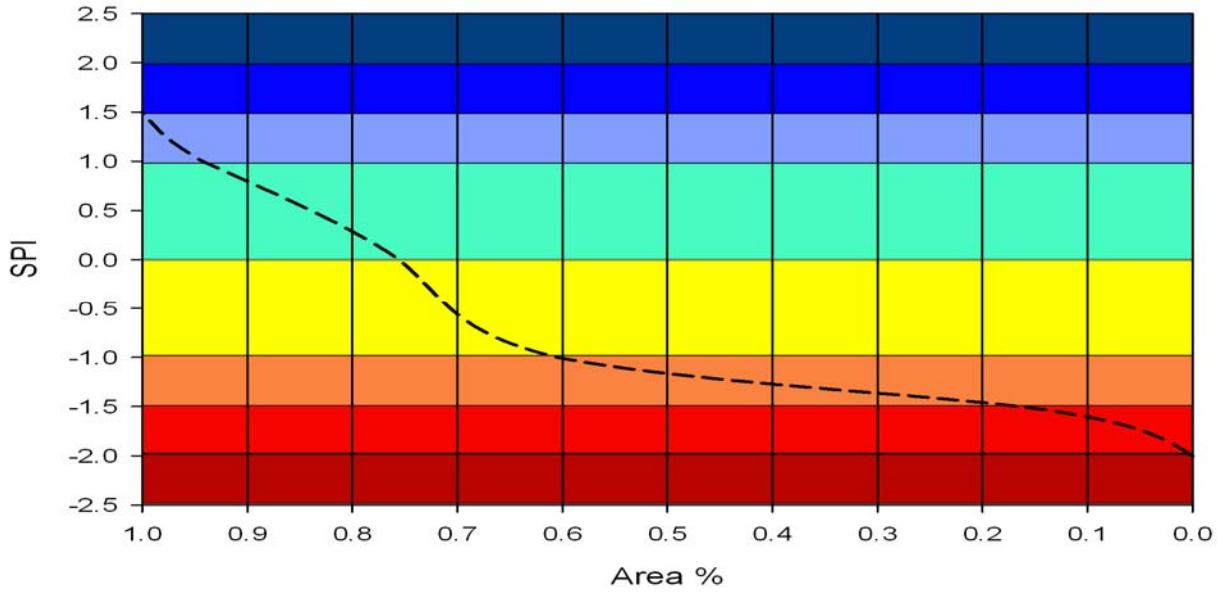


Figure 9. The cumulative "or more" curve for SPI for the wet year 1992

Figure 10 shows spatial extent of the drought years 1999 and 2008.for dry year 1999 it can be seen that about 17% of the total area is under severe drought, 61% of the area is under moderate drought whereas 76% of the area is under near normal and 95% is under at least moderate wet. In other words, 17% of the area is under severe drought, 44% under moderate drought, 15% near normal, 19% moderate wet and 5% very wet. while dry year 2008 have about 30% of the total area is under extreme drought, whereas 66% of the area is under extreme or severe drought and 88% is under moderate drought. So, 30% of the area is under extreme drought, 36% under severe drought, 22% of the area is under moderate drought and 12% is near normal.



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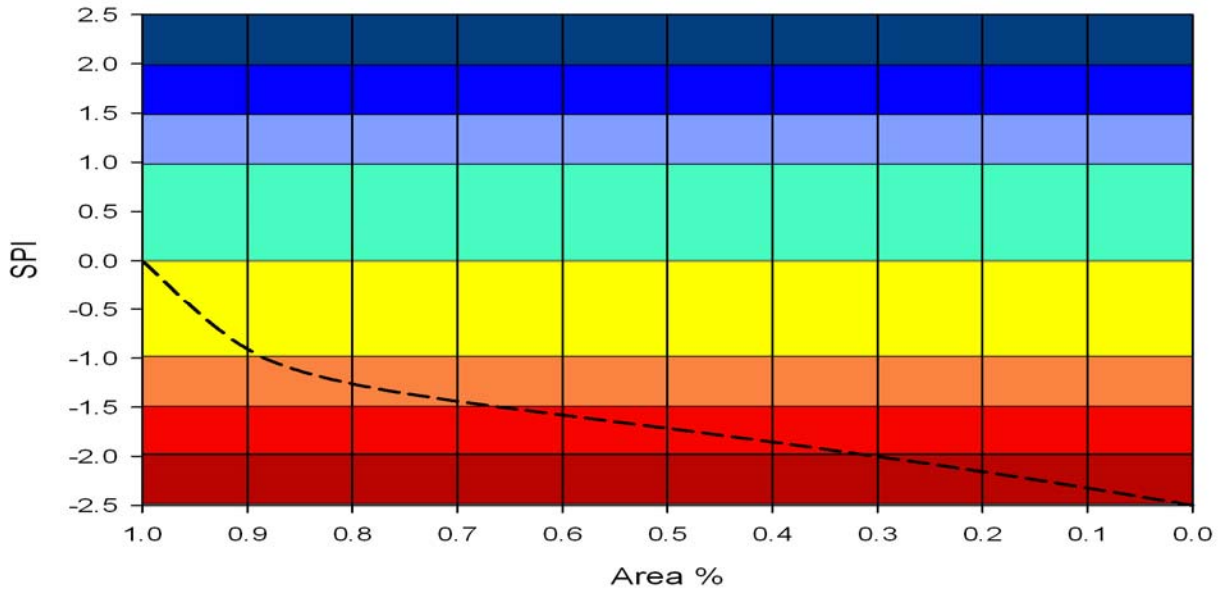

(b)

Figure10. The cumulative curve for SPI, (a) represent dry year 1999 and (b) dry year 2008

6. Conclusion

This study was focused on identification of various drought characteristics, at the 39 meteorological stations in Iraq during the past 30 years. The SPI computed at various time scales was used as an indicator of drought severity. The SPI analysis indicated that the years 1983,1998,1999,2000 and 2008 were the years most affected by drought during the investigation period, Drought maps of SPI was able to quantify the meteorological droughts using long-term rainfall data analyses. Assessment analyses using SPI, during the past 30 years, was facing frequent non-uniform cycles of drought/wet periods in an irregular repetitive manner. The severity of the observed drought incidences increases in both magnitudes and duration by time from normal to moderately severe level and one exceptional extreme drought level, the SPI analyses suggest existence of two drought extents; local droughts acting on one or more geographical climatic subdivisions of the country and national droughts that covered all parts of the country. National droughts are less common but have larger magnitudes and severity levels.

Spatial extent of the drought indicated that 2008 was worst drought year during the period, 30% of the area is under extreme drought, 36% under severe drought, 22% of the area is under moderate drought and 12% is near normal.

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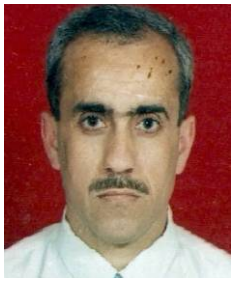

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