Drought assessment in Iraq using analysis
of Standardized precipitation index (SPI)

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Abstract

The Present study investigated the drought in Iraq, by using the rainfall data which obtained from 39 meteorological stations for the past 30 years (1980-2010). The drought coefficient calculated on basis of the standard precipitation index (SPI) and then characteristics of drought magnitude, duration and intensity were analyzed. The correlation and regression between magnitude and duration of drought were obtained according the (SPI) index. The result shows that drought magnitude values were greater in the northeast region of Iraq.

تقييم الجفاف بالعراق باستعمـال تحليل دليل المطر القياسي

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الخلاصة

تتناول الدراسة الحالية الجفاف في العراق، حيث تم دراسة ظاهرة الجفاف من خلال جمع بيانات الامطار الشهرية والتي تغطي 39 محطة انواء جوية خلال 30 سنة الماضية 1980 الى 2010، بعد حساب دليل المطر القياسي لكل محطة تم تحليل خصائص الجفاف مقداراً، استدامة وشدة، حيث تم حساب معامل الارتباط والانحدار بين قيمة الجفاف واستدامته، نتائج الدراسة توضح بان اكبر مقدار من الجفاف كان في المنطقة الشمالية الشرقية من العراق.

Introduction

Drought is an insidious natural hazard that is generally perceived to be a prolonged period with significantly lower precipitations relative to normal levels [1]. The reasons for the occurrence of droughts are complex because they depend not only on atmosphere, but also on the hydrologic processes [2]. Further, drought was ranked first followed by tropical cyclones, regional floods, earthquakes, and volcanoes based on most of the hazard characteristics and impacts [3].

Droughts are extreme hydrological events which may adversely affect social, economic, cultural, political and other functions of a region during dry periods [4]. 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 [4]. In order to understand that a deficit of precipitation has

different impacts on the groundwater, reservoir storage, soil moisture, snow cover, and streamflow [4]. McKee et al. [5] developed the standardized precipitation index (SPI); it was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short time scale, while groundwater, streamflow, and reservoir storage reflect the longer-term precipitation anomalies[5]. McKee et al. used a classification system which is based on the water and dry climates and can be represented in the same way by means of SPI. In addition, wet periods can also be monitored using the SPI McKee et al., [6]. McKee also defined the criteria for a "drought event" for any time scale. A deficit occurs any time that the SPI is continuously negative. The accumulated magnitude of deficits is referred to as drought magnitude, and it is the positive sum of the SPI for all the months within a drought event.

The main purpose of this study is to identify various drought properties on the basis of SPI analysis for 39 stations in Iraq. Empirical relationships are provided through scatter diagrams between the drought magnitude and duration during the period from 1980 to 2010.

Study Area

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 [7].

Methodology

1. Rainfall data collection and analysis

The monthly rainfall data of 39 meteorological stations for the time period 19^0-2010 were acquired from the Iraqi Meteorological Organization and Seismology (ministry of transportation) and Ministry of Agriculture and Water Resources (Kurdistan Region), which covered Iraq from the north to the south as shown in Fig.1. The identification and assessment of drought severity were done using the SPI. The SPI is calculated from the monthly precipitation record. The 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.

2. 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 [7]:

The precipitation data are calculated using the gamma probability density function which is defined as [8] ;

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

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 :

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad (2)$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \qquad (3)$$

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

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[9]:

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

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

$$H(x) = q + (1-q)G(x) \qquad (6)$$

where q is the probability of a zero. The cumulative probability H(x) is then transformed to the standard normal distribution to yield SPI [6].
The 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 than -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.
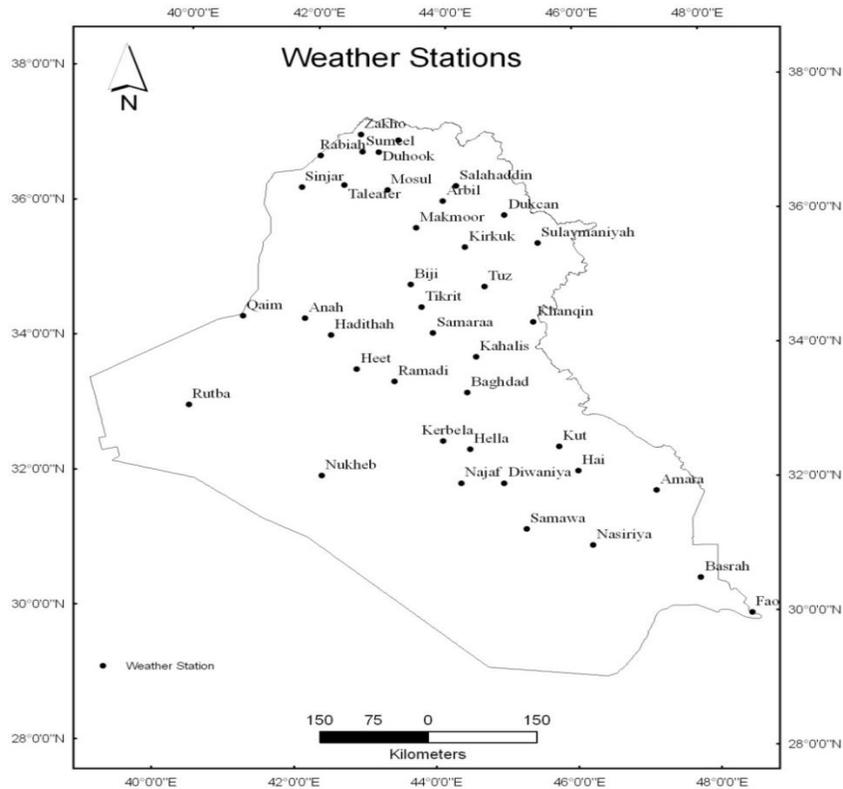

Fig. 1: Meteorological stations in Iraq.

Table 1: Standard precipitation index categories [5].

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

3. Drought parameters

Temporal drought characters are determined using SPI analysis. Drought magnitude, M_j, is defined as the average negative deviation from the truncation level x_o. The drought intensity I_j of the jth dry period is defined as the ratio of drought magnitude to drought duration, L_j.

Results and Discussion

The SPI values were calculate to observe anomalous dry and wet years over the study period. The 3 month SPI values for six stations in the north selected (Dukcan and Mosul), middle selected (Baghdad and Basrah) and south selected (Rutba and Nukheb) regions of the study area are shown in Figs.2 and 3. Appearance of drought is happening every time when SPI is negative and it is intensity comes to -1.0 or lower. Drought stops when SPI is positive. The duration of every drought appearance is determined by negative index values. Accumulated totals of negative values of SPI could also be used as a measure of drought severity. The analysis shows that a non-uniform cyclic pattern of drought /wet periods were observed during the period 1980 to 2010 Fig.2. Drought on seasonal basis were observed to exist more often during the historical years, especially at the years 1983, 1998, 1999, 2007, and 2008. The SPI analysis indicate the presence of two drought types regarding the extent of event; local(regional) and national. National drought having full dry extent at all meteorological stations, occur 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 (1990, 2000, 2001, 2004, 2005, 2006 and 2009 are local drought seasons).
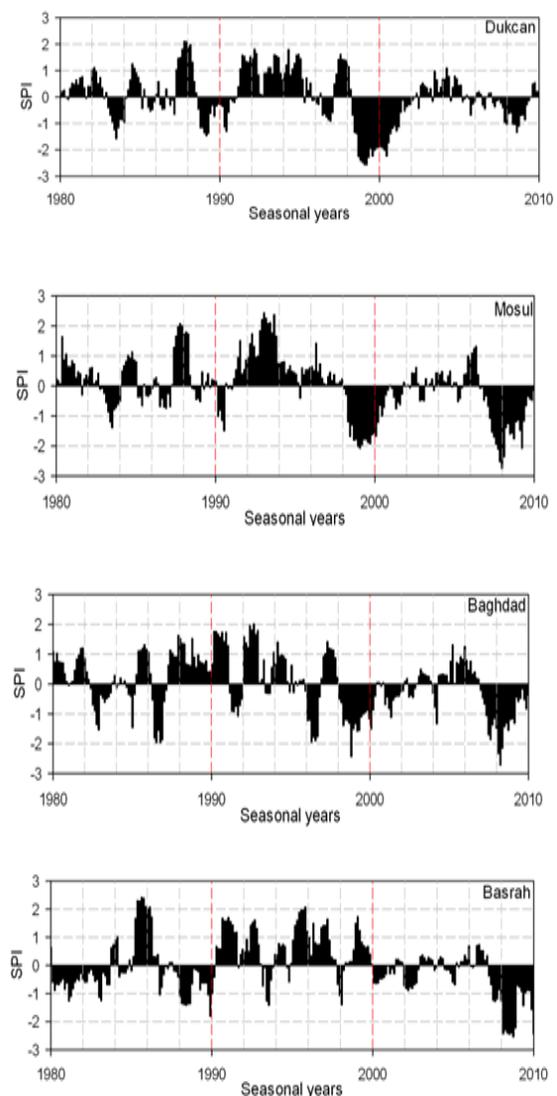

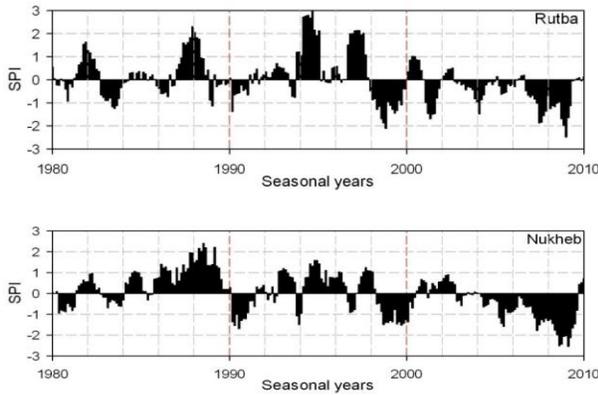*Fig. 2: SPI time series for Dukcan, Mosul, Baghdad and Basrah stations.*

Fig. 3: SPI time series Rutba and Nukheb stations.

Table 2, shows various statistical parameters concerning drought duration, magnitude and intensity based on SPI analysis values at standard truncation levels of zero. These drought features refer to past observations, but their statistical parameters are useful for what-if analysis, conditionally valid also for the future. For instance, one can find drought magnitude, which corresponds to a given drought duration, as shown in Fig. 3.

Table 2: Statistical values of drought magnitude (M), duration (L), and intensity (I).

statistical parameters	Dukan Station			Mosul Station		
	Magnitude M (mm)	duration L(month)	intensity I (mm)	Magnitude M (mm)	duration L(month)	intensity I (mm)
Max	17.40	8	2.18	14.59	8	1.82
Min	0.04	1	0.04	0.03	1	0.03
Average	3.45	4.48	0.77	3.75	4.46	0.84
statistical parameters	Baghdad Station			Rutba Station		
	Magnitude M (mm)	duration L(month)	intensity I (mm)	Magnitude M (mm)	duration L(month)	intensity I (mm)
Max	13.95	8	1.74	10.97	8	1.37
Min	0.03	1	0.03	0.02	1	0.02
Average	3.32	3.69	0.90	3.32	4.78	0.69
statistical parameters	Nukheb Station			Basrah Station		
	Magnitude M (mm)	duration L(month)	intensity I (mm)	Magnitude M (mm)	duration L(month)	intensity I (mm)
Max	12.65	8	1.58	15.31	8	1.91
Min	0.20	1	0.2	0.07	1	0.07
Average	3.76	4.56	0.82	3.58	5.08	0.70

It is clear from Fig.4 that increases in the drought duration result in increased drought magnitude. Similar graphs can be obtained for   other truncation levels. The only expected difference will be in the slopes of the relationships, which are almost equivalent to straight lines that pass almost through the origins.
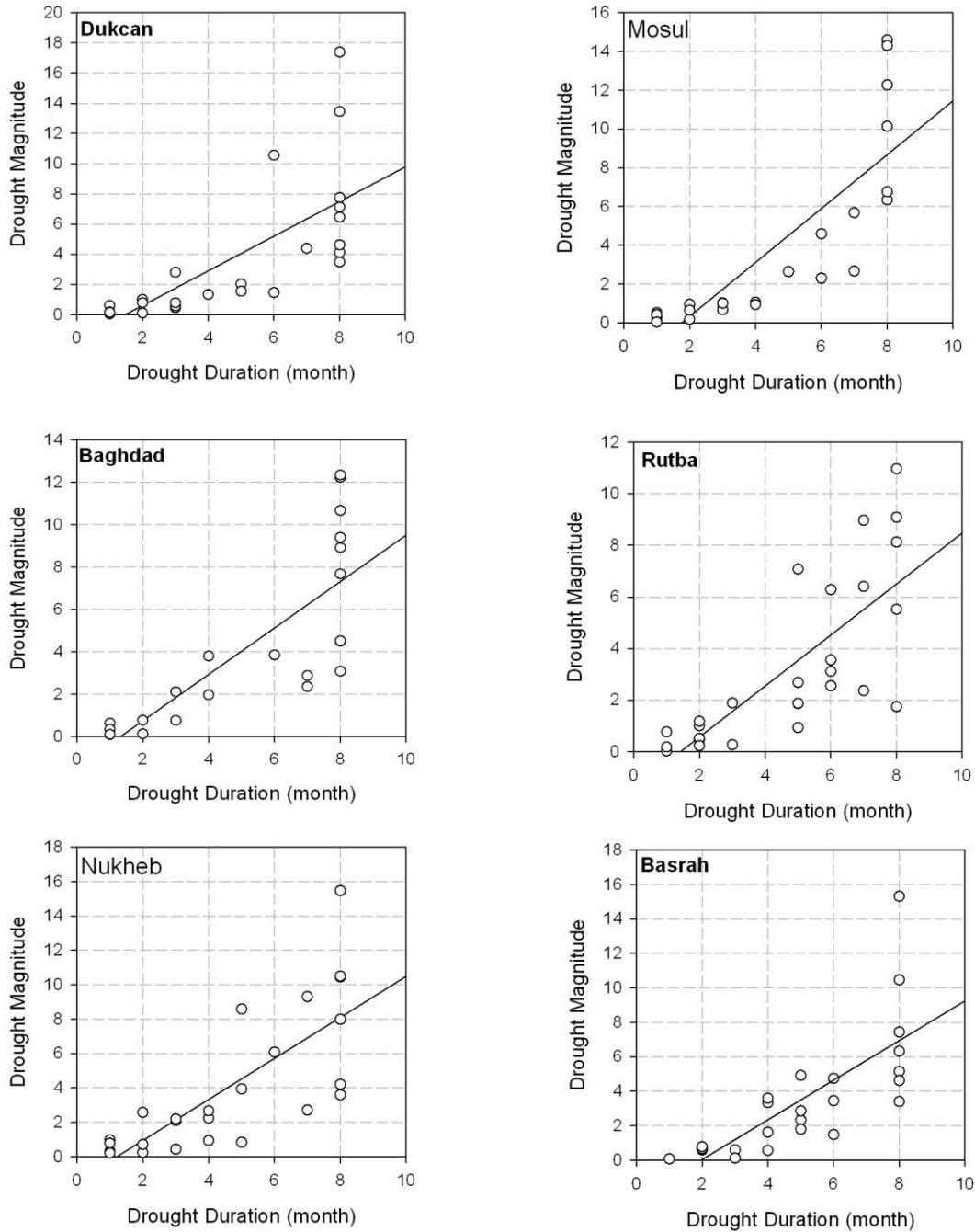
Fig. 4: Scatter diagrams of Magnitude and Duration.

The SPI is used for the identification of various drought characteristics such as the duration, magnitude, and intensity at different standard truncation levels. Basic formulations are given for these drought features and their applications are presented for 39 meteorological stations in Iraq. The relationships between the drought duration and magnitude are provided in the form of scatter diagrams with the best straight-line fits. These are obtained for truncation levels zero.

Table 3: Statistical values of drought for 39 stations.

Station	Max Magnitude	Max Intensity	correlation coefficient	Regression	Year of Max Magnitude
Duhook	12.3	1.5	0.78	Y=-1.45+1.09X	2008-2009
Kirkuk	18.4	2.3	0.77	Y=-4.09+1.65X	2008-2009
Emadiyah	18.0	2.0	0.75	Y=-2.21+1.32X	1999-2000
Khanqin	16.7	2.1	0.76	Y=-1.82+1.24X	1999-2000
Makmoor	15.1	1.9	0.87	Y=-2.34+1.38X	1999-2000
Mosul	14.6	1.8	0.83	Y=-2.45+1.39X	1999-2000
Rabiah	16.5	2.1	0.76	Y=-3.24+1.38	1999-2000
Salahaddin	11.8	1.5	0.9	Y=-2.87+1.46X	2000-2001
Sinjar	14.3	1.8	0.89	Y=-2.78+1.5X	1999-2000
Sulaymaniyah	18.1	2.3	0.75	Y=-1.53+1.14X	1999-2000
Sumeel	15.6	2.0	0.81	Y=-3.26+1.54X	1999-2000
Taleafer	14.8	1.8	0.83	Y=-3.2+1.56X	1999-2000
Tuz	15.0	1.9	0.77	Y=-1.81+1.27X	2008-2009
Zakho	13.7	1.7	0.8	Y=-1.79+1.23X	2007-2008
Dukcan	17.4	2.2	0.73	Y=-1.69+1.14X	1999-2000
Arbil	17.5	2.2	0.82	Y=-1.52+1.13X	1999-2000
Qaim	12.6	1.6	0.86	Y=-2.05+1.24X	1999-2000
Basrah	15.3	1.9	0.74	Y=-2.26+1.15X	2008-2009
Fao	16.0	2.0	0.67	Y=-0.94+0.93X	2008-2009
Hai	11.7	1.5	0.87	Y=-0.85+1.09X	2008-2009
Amara	11.7	1.5	0.87	Y=-1.63+1.16X	2008-2009
Kut	12.2	1.5	0.81	Y=-0.79+0.95X	2008-2009
Biji	14.5	1.8	0.75	Y=-1.4+1.14X	2000-2001
Tikrit	13.5	1.7	0.74	Y=-1.24+1.05X	1998-1999
Samaraa	13.8	1.7	0.82	Y=-1.72+1.16X	2007-2008
Baghdad	14.0	1.7	0.78	Y=-1.45+1.09X	2008-2009
Kahalis	15.3	1.9	0.69	Y=-1.18+1.24X	1999-2000
Ramadi	9.7	1.2	0.86	Y=-0.95+X	2008-2009
Heet	9.5	1.2	0.79	Y=-1.03+0.94X	2008-2009
Hadithah	13.1	1.6	0.86	Y=-1.58+1.15X	2007-2008
Anah	11.1	1.4	0.73	Y=-0.93+0.95X	1999-2000
Rutba	11.0	1.4	0.76	Y=-1.41+0.98X	1999-2000
Kerbela	14.3	1.8	0.67	Y=-1.02+1.05X	1999-2000
Najaf	8.5	1.1	0.73	Y=-2.46+1.35X	2008-2009
Nukheb	12.7	1.6	0.76	Y=-1.45+1.19X	2008-2009
Diwaniya	14.6	1.8	0.81	Y=-1.82+1.24X	2008-2009
Samawa	10.1	1.3	0.82	Y=-1.45+0.93X	2008-2009
Nasiriya	14.4	1.8	0.71	Y=-1.05+1.02X	2008-2009
Hella	12.2	1.5	0.88	Y=-0.78+1.08X	2008-2009

Tables 3 summarize correlation coefficient between magnitude and duration of drought in all stations with range (0.67-0.9). Fig.5 was plotted by using Arc GIS 9.3,it is shows that the stations Kirkuk, Sulaymaniyah, Dukcan and Arbil have a high values of magnitude drought ranged from (18.4 to 17.4) mm during the seasonal years 1999-2000,this mean the northeast region of Iraq faced high drought during the period 1980-2012.
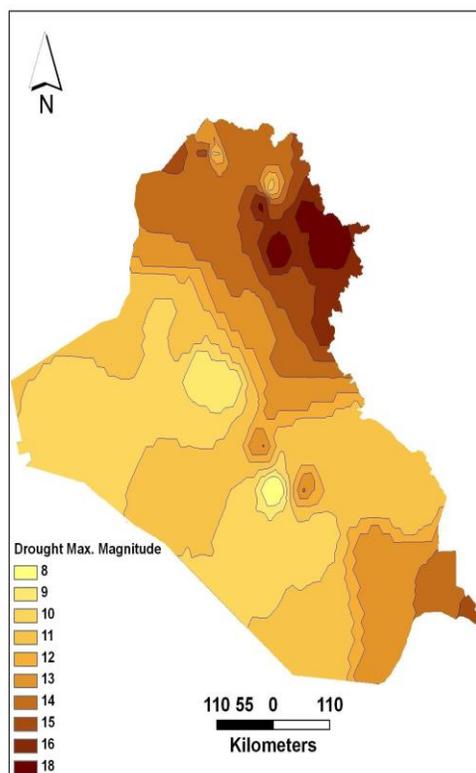

Fig. 5: Map of drought Magnitude for 30 years (1980-2010).

Conclusion

This study was focused on identification of various drought characteristics, such as magnitude, duration and intensity 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 year's most affected by drought during the investigation period, the northeast region of Iraq during the driest year 1999 faced high drought. The relationships between drought duration and magnitude are provided in the form of scatter diagrams with the best straight line fits. The drought magnitude can be obtained corresponding to a given drought duration from the magnitude-duration graphs, which gives an idea about the water need in a critical period in a watershed for different purposes.

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