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# Spatial and Temporal Analysis of Droughts in Iraq Using the Standardized Precipitation Index

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***Abstract:****The aim of this study is to analyze the drought characteristics and draw a spatial pattern maps for drought by using the ordinary kriging interpolating method within a GIS environment. The Standardized Precipitation Index (SPI) was used to analyze the drought, based on the historical data for ten meteorological stations during the years from 1980 to 2011in the Iraq region. The result shows that the maximum severity of drought (Smax) value was identified during the periods 2007-2011 for most of the stations and the highest value of average severity of drought (Savg) was found in the north (central) region of Iraq for SPI 9 month (SPI 12 month), respectively. The results showed that the 1999, 2008 and 2009 years were the worst drought years have passed in all parts of Iraq at SPI 9, and 12-month time scale.*
***Keywords:****Standardized Precipitation Index (SPI); Drought; Iraq.*

## I. Introduction

Assessment and studying the drought characteristics helpsin the management of water resource because it will provide insight into the possible impacts of future climate changes [1]. For this reason, several studies have been submitted indices for drought analysis, such as the Palmer Drought Severity Index [2] that is widely used in the United States, the decile index [3] that is operational in Australia, Z-Index [4] that is used by the National Metrological Center of China, the Standardized Precipitation Index (SPI) [5], the Reconnaissance Drought Index (RDI)[6], and the Standardized Precipitation Evapotranspiration Index (SPEI) [7], where the SPI, RDI, and SPEI indices have gained world popularity. Among these indices, the Standardized Precipitation Index (SPI) was used in this study, which is known its simplicity and the limited data needed for analysis.

The previous studies conducted with drought indices in different parts of the world can be summarized as follows: [8] evaluated the SPI, China-Z index (CZI) and Z-score index for 1-, 3-, 6-, 9- and 12-time scales using monthly precipitation data for four stations in China during 1951- 1988. They found that the results of CZI and Z-score indices were similar to SPI index. [9] compared the SPI index at different time scales with surface hydrological variables in a big closed basin located in the central Spanish Pyrenees. They indicated that the SPI time scales greater than 12 months were not useful for drought quantification in this region. Moreover, short SPI time scales were more effect on the surface flows, whereas longer SPI time scales (7–10 months) were more effect on the reservoir storages. [10] conducted a comparison between the Standardized Precipitation Index SPI and the Standardized Precipitation-Evapotranspiration Index SPEI at 9- and 12-month time scales for the same stations located among semi-arid, sub-humid, and humid locations in Portugal. They found that the two indices had similar results for the same time scales concerning drought occurrence and severity.

The main purpose of this study is to analyze the drought characteristics by SPI 9, and 12-month for ten stations in Iraq. A MATLAB software code was written by M-File Programming to calculate the frequency, intensity, and duration of drought at different time scales.

## II. Data and methodology

Iraq is located in south-west Asia at the crossroads of the Middle East. It covers an area of 435,052 km2, which lies between the latitudes of 29° 5′ and 37° 22′ north and the longitudes of 38° 45′ and 48° 45 east. Historical records of precipitation for 32 years (1980-2011) from 10 climate stations was acquired from the Iraqi Meteorological Organization and Seismology (IMOS). The location of the Meteorological stations and their geographical coordinates are indicated in Fig.1.

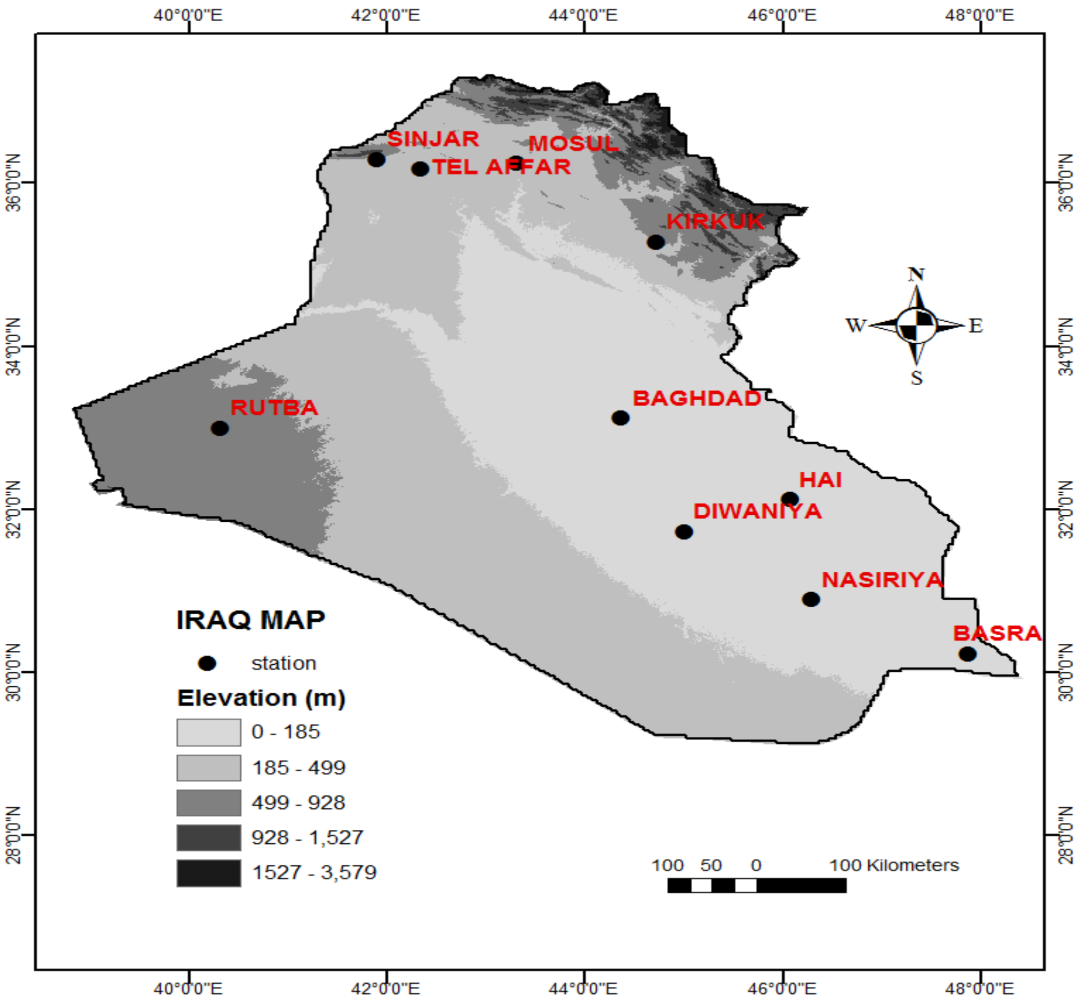


**Fig.1:** locations of meteorological stations in Iraq

## III. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is the widely used indices for the purpose of monitoring and revealing drought, this index submitted by [5]. The SPI is calculated from the accumulated precipitation series for a fixed time scale of interest. The mean (SPI) equal to zero for the location and desired period because of the time series fitting to a probability distribution, which the probability density function is transformed into a normal distribution [1]. The gamma distribution has been calculated for each station by its probability density function as

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

$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1}\, e^{-y}$ (2)

where: α, β are the shape and scale parameters respectively, x is the precipitation amount, and $\Gamma(\alpha)$ is the gamma function.

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

$\beta = \frac{\bar{x}}{\alpha}$ (4)

$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n}$ (5)

The parameters are compensated in gamma distribution function, becoming as shown in the equation below.

$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx$ (6)

Assuming the value of x/β is equal to t, so it can formulate gamma distribution function as shown in the following equation.

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-1} dt \qquad (7)$$

If the gamma distribution function is undefined at zero values (x=0) and rainfall records may be contained zero, so the cumulative probability H (x) is applied as follows:

$$H(x) = q + (1 - q)G(x) \qquad (8)$$

where q represents the probability of a zero, and G(x) the cumulative probability of the incomplete gamma function. The probability of a zero (q) is computed by m/n, where m represents the number of zeros in a precipitation time series.The equations below are used to convert the cumulative probability into the standard normal random variable z, which represents SPI [5].

$$SPI = -\left(t - \frac{2.515517 + 0.802853\,t + 0.010328\,t^2}{1 + 1.432788\,t + 0.189269\,t^2 + 0.001308\,t^3}\right) \text{for } 0 < H(\text{x}) \le 0.5 \quad (9)$$

$$SPI = +\left(t - \frac{2.515517 + 0.802853\,t + 0.010328\,t^2}{1 + 1.432788\,t + 0.189269\,t^2 + 0.001308\,t^3}\right) \text{for } 0.5 < H(\text{x}) < 1 \quad (10)$$

*where*

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \text{for } 0<\text{H(x)}\le 0.5 \qquad (11)$$

$$t = \sqrt{\ln\left(\frac{1}{(1-H(x))^2}\right)} \text{for } 0.5 < H(\text{x}) < 1 \qquad (12)$$

Drought category classification suggested for the SPI [5] as illustrated in Table-1.In this study, a drought event occurs in the case of the value of SPI is less than this zero.

**Table-1**Drought classification for SPI value and corresponding event probabilities.

| SPI | Classification | Probability (%) |
|---|---|---|
| 0 to -0.99 | Mild drought (Mi.D) | 34.1 |
| -1 to -1.49 | Moderately drought (Mo.D) | 9.2 |
| -1.5 to -1.99 | Very drought (S.D) | 4.4 |
| -2< | Extremely drought (E.D) | 2.3 |

## IV. Results and Discussion

The drought characteristics for the SPI 9, and12-month time scale was summarized in Table-2. The severity of peak drought (Sp) for 9-month SPI was calculated for all stations and obtained that the values of Sp were greater than −3 for all stations except for Rutba station. The periods 2007-2010 was very severe and dominated on all parts of Iraq. Northern Iraq exposed to the strongest drought than other regions through the period of 32 years. In fact, the maximum severity of drought (Smax) ranged between -39 and -56 for the stations located in the north of Iraq, while in other stations ranged between -23 and -38. The time series of SPI-9 month at Mosul, Bagdad, Rutba and Basra stations were presented in Fig.2.The longer drought duration was detected from Sep 2007 to April 2010 (32 months) with theintensity of 1.33 at Mosul station. Also, the worst drought years were observed in most of the study period especially during the period from 1998 to 2011. At Bagdad station, the longest duration of drought was obtained between Oct 1998 and Feb 2001 (29 months), with theintensity of 0.83. The worst drought years were observed in 1987, 1997, 2007, and 2008. Rutba (Basra) station having the longer duration from Nov 2007 to Feb 2010 (Nov 2007 to March 2010), with theintensity of 0.67 (0.77), respectively. At Basra station, the worst drought years were in 2009, 2010and 2011.

Based on SPI 12-month, the values of Sp ranged between (-3.3 - -1.4), and the highest value observed at the Rutba station during December in 2004 with a value of -12.3. The value of Smax was identified during the periods 2007-2011 for most of the stations. The highest value of Smax was observed in Tel Affar station, where the duration of drought began in Jan-2007 and ended in Mar-2011, lasted 51 months. Also, it was found that the relative frequencies (RF) of Diwaniya (53%), Basra (50%), and Sinjar (50%) were higher than the rest of the regions as shown in Table-2. The time series of SPI-12 month for Mosul, Baghdad, Rutba and Basra representing Northern, Central, Western and Southern Iraq are presented in Fig.3. It was seen that the longest duration of drought obtained between April 2007- April 2010 (32months) with theintensity of 0.57 at Mosul station. Whilst, the Baghdad (Rutba) station experienced the longer duration of drought between Dec 2007-Dec 2010 (Jan 2004-Mar2007) with theintensity of 1.27 (1.13). In Basra station, the longest duration of drought was determined between Feb 2008- Dec2011 with intensity 1.22. The worst dry years were obtained in 1999, 2000, 2008, and 2009; 1987, 1997 , 1999, 2000, 2001, 2008, 2009, and 2010; 1999, 2002, 2004, 2006, and 2008; and 1989, 1994, 2003, 2008, 2009, 2010 and 2011 for Mosul, Baghdad, Rutba and Basra regions, respectively.

**Table-2** Drought characteristics for the SPI 12-month time scale from 1980 to 2011 periods

| Stations | SPI 9-month | | | | | SPI 12-month | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sp | RF | Smin | Smax | NO.of month for Smax | Sp | RF | Smin | Smax | NO.of month for Smax |
| MOSUL | -4.0 | 60 | -1.2 | -41.6 | 32 | -1.4 | 32 | -0.03 | -21.2 | 37 |
| SINJAR | -3.1 | 40 | 0.0 | -38.6 | 28 | -2.8 | 50 | -0.04 | -59.6 | 51 |
| TEL AFFAR | -3.1 | 42 | -0.3 | -51.6 | 34 | -2.8 | 43 | -0.55 | -72.9 | 51 |
| KIRKUK | -4.3 | 43 | -0.1 | -55.7 | 32 | -3.3 | 44 | -0.07 | -63.8 | 39 |
| BAGHDAD | -3.7 | 44 | 0.0 | -26.9 | 28 | -2.9 | 46 | -0.01 | -46.9 | 37 |
| RUTBA | -2.9 | 39 | 0.0 | -18.8 | 28 | -3.3 | 46 | -0.003 | -43.9 | 39 |
| HAI | -4.8 | 41 | -0.1 | -38.3 | 26 | -3.3 | 49 | -0.04 | -50.0 | 31 |
| DIWANIYA | -3.2 | 46 | -0.2 | -35.5 | 42 | -2.7 | 53 | -0.02 | -69.4 | 60 |
| NASIRIYA | -3.1 | 44 | -0.7 | -25.2 | 29 | -2.3 | 49 | -0.01 | -53.8 | 46 |
| BASRA | -3.9 | 42 | -0.1 | -22.5 | 29 | -2.3 | 50 | -0.004 | -57.4 | 47 |

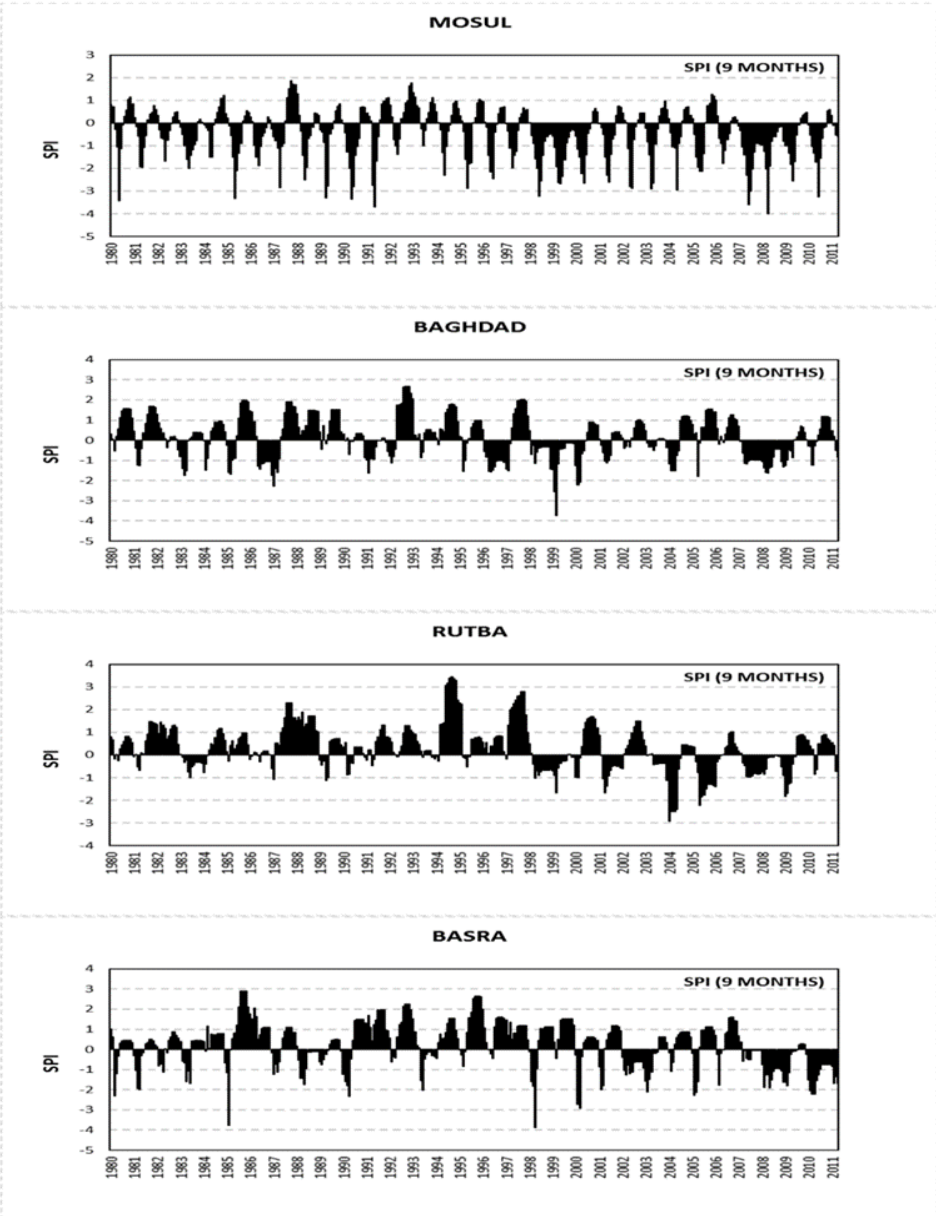


**Fig.2** the time series of SPI-9 month for some stations (Mosul, Baghdad, Rutba, and Basra)

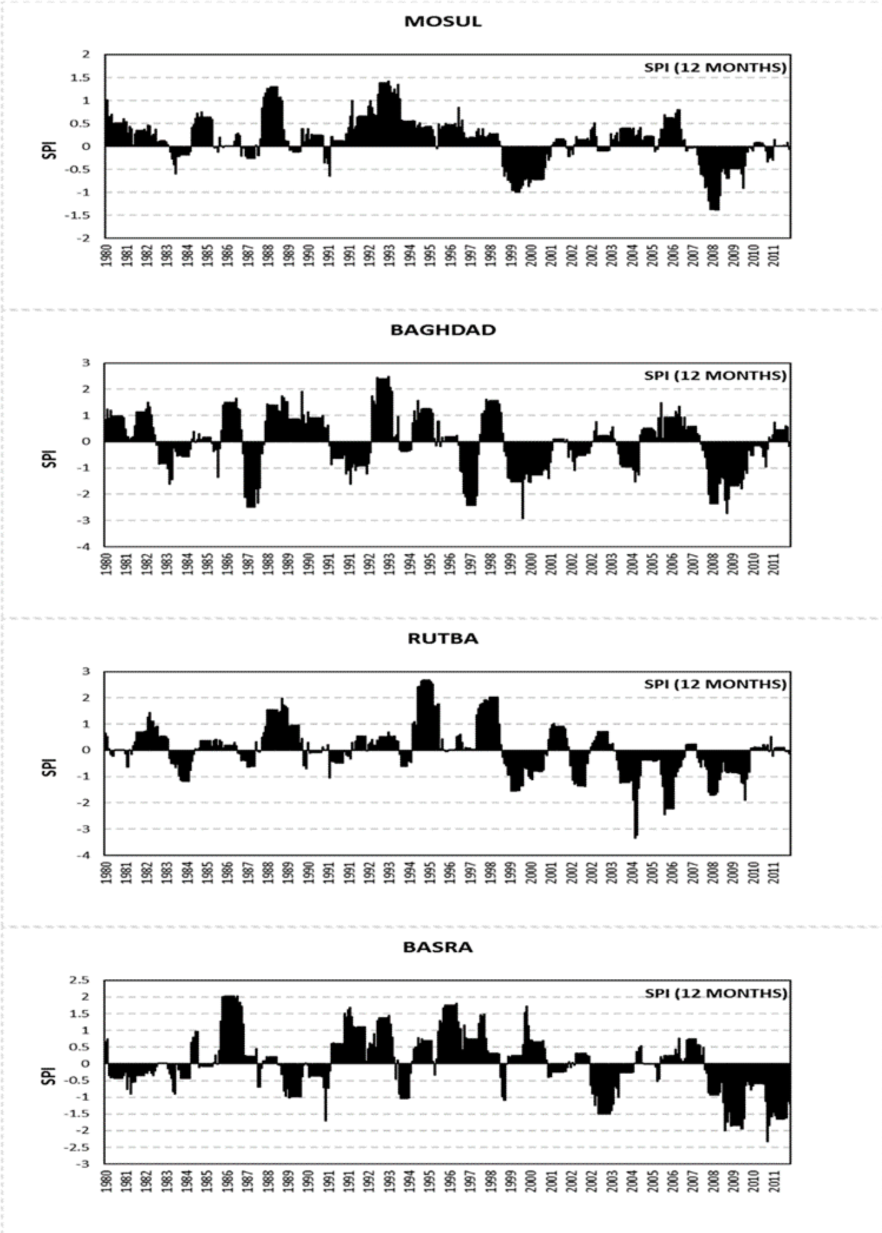


**Fig.3** the time series of SPI-12 month for some stations (Mosul, Baghdad, Rutba, and Basra).

Table-3summarize the frequency of each drought conditions for all stations. It is observed that the numbers of drought event results for SPI 9, and12-month time scales showed that the Mild drought conditions are the highest number of drought event than other conditions for all stations. As the 9-month SPI analysis shows, the highest (lowest) number of drought events occurred in Diwaniya and Nasiriya (Sinjar and Rutba). Baghdad (Sinjar) recorded the highest numbers of moderately (severely) drought events, while the highest number of extremely drought events existed in the Kirkuk, Mosul and Tel Affar. Based on 12-month SPI, Basra (Baghdad) recorded the highest (lowest) number of total mild drought events over the study periods. In addition, Diwaniya, (Baghdad) region located in the southern (central) Iraq has faced more frequently of moderately (extremely) drought as compared with other regions.Based on SPI 12-month,Basra (Baghdad) regions recorded the highest (lowest) numbers of total mild drought events over the study periods.Diwaniya, (Baghdad) region located in the southern (central) Iraq has faced more frequently of moderately (extremely) drought as compared with other regions.

**Table-3** the numbers of drought event results for the SPI 12-month time scale.

| Stations | SPI 9-month | | | | SPI 12-month | | | |
|---|---|---|---|---|---|---|---|---|
| | Mi.D | Mo.D | S.D | E.D | Mi.D | Mo.D | S.D | E.D |
| MOSUL | 91 | 29 | 22 | 16 | 129 | 17 | 21 | 18 |
| SINJAR | 84 | 28 | 29 | 10 | 126 | 21 | 28 | 12 |
| TEL AFFAR | 89 | 26 | 23 | 20 | 96 | 19 | 33 | 12 |
| KIRKUK | 83 | 34 | 24 | 23 | 97 | 26 | 20 | 23 |
| BAGHDAD | 101 | 42 | 17 | 5 | 94 | 33 | 22 | 24 |
| RUTBA | 118 | 16 | 7 | 6 | 118 | 32 | 13 | 8 |
| HAI | 83 | 40 | 23 | 10 | 121 | 18 | 30 | 12 |
| DIWANIYA | 133 | 24 | 10 | 7 | 112 | 46 | 28 | 10 |
| NASIRIYA | 105 | 39 | 13 | 9 | 116 | 39 | 12 | 15 |
| BASRA | 96 | 23 | 25 | 14 | 136 | 22 | 27 | 1 |

The spatial variability of the average severity of drought (Savg) and the average duration of drought (Davg) based on SPI 9and 12- months were plotted by using the ordinary kriging interpolating method within a GIS environment as shown in Fig.4. The 9-month SPI maps show that the Northern of Iraq (Mosul and Kirkuk regions) experienced the highest severity of drought (Savg) with the longest duration of drought (Davg) as compared with other parts of the study region. The Savg (Davg) values are ranged between -6.4 - -9.6 (6.1-8.4), respectively. Although, the southern part of the study region exposed to the lowest severity of drought (Savg) with the longest duration of drought (Davg) as compared with central of Iraq. Spatial distributions of (Savg) and (Davg) for SPI 12- month had a rising trend from northern parts to the southern and southwestern of Iraq region, the Davg and Savg maps indicate that the northern and western regions have lower values of Savg (Davg) than other regions, ranged from -4.1 to -13.7 (from 7 to 12.4), respectively.

It was observed that the highest value of Savg obtained in the northern regions of Iraq for 9-month time scale, while the central and southern regions of Iraq exposed to the highest degree of drought severity according to SPI 12-month. Because of the change in the time series reflect the impact of drought on the meteorological, agricultural, or hydrological sectors. Where [5] stated that the SPI-9 time scale gives a very good indicator of agriculture and the SPI-12 month time scale is related to hydrological. Consequently, the drought in these regions reached to a big stage of agriculture (hydrology) drought according to SPI 9-month (SPI 12-month) results, respectively.

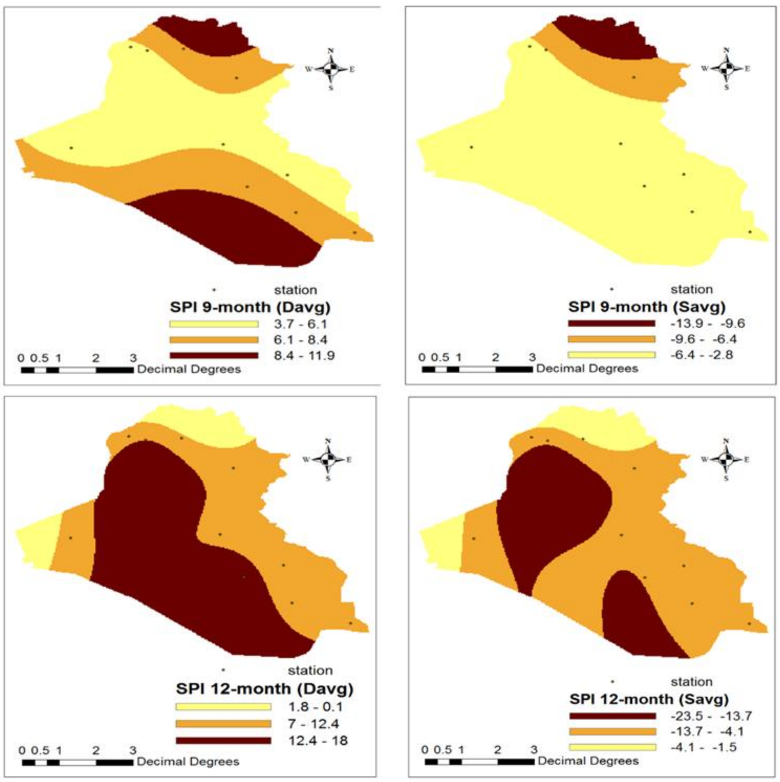


**Fig.4** The Davg and Savg drought using 9-, and 12 month SPI.

## V. Conclusion

The drought characteristics were analyzed in Iraq dependent on the observed climate data from 10 meteorological stations during 1980-2011. In this study, the SPI method for 9, 12-month time scales was used to studying and analyzing of droughts. The results showed that the 1999, 2008 and 2009 years were the worst drought years have passed in all parts of Iraq at different time scale. The SPI 9-month results found that the Mosul station experienced the worst drought years than other stations. It was found that the Northern of Iraq exposed to the severe drought for SPI 9- month during the study period as compared with other parts of the region. Whilst, the Baghdad, and Diwaniya regions experienced the highest degree of drought according to SPI 12-month, thus the drought in these regions reached to a big stage of agriculture (hydrology) drought, respectively.

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