DROUGHT HAZARD ASSESSMENT IN IRAQ USING SPI AND GIS SYSTEMS

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ABSTRACT

The aim of this research is to find out drought periods, percent of occurrence and spatial distribution of drought in the whole of Iraq in order to reduce it and take the necessary precautions to face it. The study utilizes the standardized precipitation index (SPI) to determine drought depending on monthly rainfall data that were collected from 24 stations during the period 1950-2016. Short term drought represents agricultural drought taken for six months (SPI 6) and long term drought represents hydrological drought taken for twelve months (SPI 12). The results showed that the study area (Iraq) was exposed to varied drought especially in the last decades (1997-2016) for both long and short terms. To represent the results of SPI for April and October of 2015, the Geographic information system (GIS) was used with the aid of Inverse distance weighted (IDW). It can be seen that these months suffered from varied drought levels in different regions of Iraq ranging from mild to extreme drought.

Keywords: drought, standardized precipitation index, SPI, GIS.


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1. INTRODUCTION

Drought is a normal phenomenon that happens when precipitation is less than the normal limit [1]. The deficiency in precipitation may also cause lower yields of the crop to agriculture; flows will reduce for water systems, loss in environmental diversity and many problems for biodiversity. Adding to the disadvantages of drought, it also causes a shortage of water supply for drinking that will affect negatively on local life [2]. The drought of meteorological maybe follows by hydrology drought that will affect flows of river, lakes level, and aquifer storage [3]. The long period of drought cause changes in socioeconomic may lead to famine and cause immigration and many situations of refugee [4]. Drought and its impact appeared to increase in many countries of the world due to changes in the atmosphere, including the phenomenon of global warming and other problems. The phenomenon of global warming and
expansion especially in recent decades has affected the climate dramatically, leading to an increase in the risk of drought and floods alike [5]. Little predicts of drought characteristics like frequency, termination, and initiation can make it both hazard and catastrophic. Drought can be considered a hazard cause its natural phenomenon it’s occurrence unpredictable, but by following it, studying its characteristics and using modern methods, it’s occurrence can be predicted.

Drought is considered as catastrophic because of the failure in precipitation system, affecting the water that supplies all of the natural and agricultural systems as well as effect on the various human activities [6].

Iraq is one of the countries in Asia, specifically in the Middle East that suffered from the recent periodic drought due to the great weather fluctuations [7]. High temperature and lack of rain, which negatively affected on the water resources, vegetation in Iraq and expansion of the desert area in the whole country, which will cause in the future on lands desertification and migration for people who live in areas that exposed to the impact of drought [8].

The aims of this study are to make a knowledge of the drought periods and its spatial distribution to make the necessary precautions to minimize its impact by following appropriate methods.

2. MATERIALS AND METHODS
2.1. Study Area
The study area is Iraq, which is located in a region of semi-arid between 29° 5’ and 37° 22’ latitudes and 38° 45’ and 48° 45’ longitudes, The total area of Iraq is 437,049 km2 [9]. Iraq location map with adjacent countries shown in figure (1).

Figure 1 Iraq location map with adjacent countries.

The terrain of Iraq has different types including the mountainous in the eastern north and north regions, desert in the western and western south regions. In the southern region, marshlands abound [10]. Iraq can be divided into three main regions: the north, middle, and south. Climate conditions are different with respect to the place. Iraq in terms of weather can be described as hot and dry at summers, and cold wet at winters. Iraq climatic conditions are influenced by Mediterranean and low-pressure region that focuses on the Arabian Gulf in the summer. The daily temperature records in summer were mostly high; they sometimes exceed 45°C in different locations of Iraq, especially in the south region. Seventy percent of
precipitation falls from October to April, while from June to August it is predominately rainless. Precipitation season also changes from a year to another, sometimes rainfall is within the normal limit and does not represent a serious threat, whereas in some seasons it’s severe and causes erosion for some soft-land in addition to many damages in the social and agricultural reality [11].

2.2. Data used
The monthly rainfall data used in this study were collected from twenty-four meteorological stations in Iraq which are (Basrah, Nasiriya, Amara, Samawa, Diwaniya, AL_hai, Hilla, Kut, Najaf, Kerbala, Nukhaib, Baghdad, Rutba, Ramadi, AL_khalis, Heet, Samarra, Tikrit, Anah, Baiji, Tuz, Mosul, Kirkuk and Sinjar) these provinces and cities are cover all the area under study. Rainfall records are extended from 1950-2016 for 24 meteorological station. The locations of the stations (longitude and latitude) are shown in table (1).

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of Station</th>
<th>Longitude</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Baghdad</td>
<td>44.24</td>
<td>33.2</td>
</tr>
<tr>
<td>2</td>
<td>Nasiriya</td>
<td>46.14</td>
<td>31.01</td>
</tr>
<tr>
<td>3</td>
<td>Basrah</td>
<td>47.78</td>
<td>30.5</td>
</tr>
<tr>
<td>4</td>
<td>AL_hai</td>
<td>46.03</td>
<td>32.1</td>
</tr>
<tr>
<td>5</td>
<td>Kirkuk</td>
<td>44.24</td>
<td>34.28</td>
</tr>
<tr>
<td>6</td>
<td>Rutba</td>
<td>40.17</td>
<td>33.02</td>
</tr>
<tr>
<td>7</td>
<td>Diwaniya</td>
<td>44.59</td>
<td>31.59</td>
</tr>
<tr>
<td>8</td>
<td>Mosul</td>
<td>43.09</td>
<td>36.19</td>
</tr>
<tr>
<td>9</td>
<td>Najaf</td>
<td>44.32</td>
<td>32.03</td>
</tr>
<tr>
<td>10</td>
<td>Nukhaib</td>
<td>42.27</td>
<td>32.03</td>
</tr>
<tr>
<td>11</td>
<td>Samawa</td>
<td>44.16</td>
<td>31.18</td>
</tr>
<tr>
<td>12</td>
<td>Hilla</td>
<td>44.26</td>
<td>32.29</td>
</tr>
<tr>
<td>13</td>
<td>Kut</td>
<td>45.45</td>
<td>32.3</td>
</tr>
<tr>
<td>14</td>
<td>Kerbala</td>
<td>44.01</td>
<td>32.37</td>
</tr>
<tr>
<td>15</td>
<td>Amara</td>
<td>47.1</td>
<td>31.51</td>
</tr>
<tr>
<td>16</td>
<td>AL_khalis</td>
<td>44.53</td>
<td>33.84</td>
</tr>
<tr>
<td>17</td>
<td>Samarra</td>
<td>43.9</td>
<td>34.11</td>
</tr>
<tr>
<td>18</td>
<td>Ramadi</td>
<td>43.2</td>
<td>33.45</td>
</tr>
<tr>
<td>19</td>
<td>Heet</td>
<td>42.83</td>
<td>33.64</td>
</tr>
<tr>
<td>20</td>
<td>Anah</td>
<td>41.98</td>
<td>34.37</td>
</tr>
<tr>
<td>21</td>
<td>Tuz</td>
<td>44.64</td>
<td>34.89</td>
</tr>
<tr>
<td>22</td>
<td>Tikrit</td>
<td>43.63</td>
<td>34.65</td>
</tr>
<tr>
<td>23</td>
<td>Baiji</td>
<td>43.49</td>
<td>34.94</td>
</tr>
<tr>
<td>24</td>
<td>Sinjar</td>
<td>41.87</td>
<td>36.33</td>
</tr>
</tbody>
</table>

3. ESTIMATION OF MISSING RAINFALL DATA
Rainfall is an essential part of studies related to hydrology research. Before beginning the steps, it must ensure that the meteorological and hydrological are dependable data. However, rainfall data is incomplete frequently. Many causes that lead to data loss: measuring instruments damages, errors of measurement, paucity geographical data (gaps of data) or changes due to overtime instrumentation, collectors of data, the measurement irregularity or topical severe changes in the hydrological of the region [12]. Simple Arithmetic Method and Normal Ratio Method are the most popular methods used to estimate missing rainfall data [13].
4. CONSISTENCY TEST FOR RAINFALL RECORDS

It is a practical, visual and simple method, used widely as a test for long term records and hydrological consistency data [14]. The theory for the DMC method provides that the plot between two quantities of cumulative records at the same duration must be a straight line and not change at different periods. If the line exposure to a break at a certain period, it must find a change point and divide a correcting slope on an original slope for it and multiply a result by a cumulative value before change for a records station that wants to modify it. The relation graph between two stations shown in figure (2) [15], the equation is:

\[ P_{cx} = P_x \cdot (M_c/M_a) \]  \hspace{1cm} (1)

Where,

- \( P_{cx} \): correcting rainfall at a period time \( t_1 \) of station \( x \).
- \( P_x \): originally rainfall recorded at period time \( t_1 \) of station \( x \).
- \( M_c \): correcting slope.
- \( M_a \): originally slope.

![Figure 2](image.png)

**Figure 2** Consistency for annual rainfall data test [15].

5. STANDARDIZED PRECIPITATION INDEX (SPI)

SPI is a normal index used for drought monitoring depending on the amount of precipitation data. SPI development in the year 1993 by McKee et al [16], using SPI will provide some important advantages for researchers. First, it relies on precipitation only for data entry and doesn’t require any other variables to describe drought. Secondly, drought can be described by SPI for different time scales. Third, SPI can be used effectively to compare different conditions of drought between regions and different time periods. When extracting SPI values for different time scales, negative values indicate dry periods and positive values indicate wet periods [17]. Table (2) shows the classification of drought based on the range of SPI values.

<table>
<thead>
<tr>
<th>Value of spi</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥2</td>
<td>Extremely wet</td>
</tr>
<tr>
<td>1.5 to 1.99</td>
<td>Severely wet</td>
</tr>
<tr>
<td>1 to 1.49</td>
<td>Moderately wet</td>
</tr>
<tr>
<td>0 to 0.99</td>
<td>Mild wet</td>
</tr>
<tr>
<td>−0.99 to 0</td>
<td>Mild drought</td>
</tr>
<tr>
<td>−1.49 to −1</td>
<td>Moderately drought</td>
</tr>
<tr>
<td>−1.99 to −1.5</td>
<td>Severely drought</td>
</tr>
<tr>
<td>−2 ≥</td>
<td>Extremely drought</td>
</tr>
</tbody>
</table>

Table 2: Classification of drought based on values of SPI [16].
Drought Hazard Assessment in Iraq using SPI and GIS Systems

Determination of SPI depends on the fitting of the probability distribution to assembly monthly series precipitation (3, 6, 12, 24, and 48) months. The probability function density transformed into a standardized index which its values are represented classification for the drought. The SPI computed only when there are long and continuous records of data (30 years at least). Gamma distribution is the best observational model for precipitation data to represent probability distribution. The equation shown below represents the Gamma distribution [18].

\[ g(x) = \frac{1}{\beta \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \quad \text{for } x > 0 \] \hspace{1cm} (2)

Where;
\[ \alpha > 0 \text{ (parameter of shape)}, \beta > 0 \text{ (parameter of scale)}, x > 0 \text{ (precipitation amount)} \] and \( \Gamma(\alpha) \) is a value that taken by standard function mathematical which known as Gamma function, it is described as integral as shown in the equation (3)[18].

\[ \Gamma(\alpha) = \int_0^\infty x^{\alpha-1} e^{-x} dx \] \hspace{1cm} (3)

For modeling observed data with density function gamma distributed, it’s important to estimate \( \beta \) and \( \alpha \) parameters. Different ways to estimation these parameters. The approximation for Thom (1958) was used for probability in McKee (1997) [16].

\[ \alpha = \frac{1}{4A} \left( 1 + \sqrt{1 + \frac{4A}{3}} \right) \] \hspace{1cm} (4)

\[ \beta = \frac{\bar{x}}{\alpha} \] \hspace{1cm} (5)

Where for observations \( n \);
\[ A = \sum_{i=1}^{n} \ln(x_i) \] \hspace{1cm} (6)

After coefficients \( \beta \) and \( \alpha \) are estimating, the probability function density \( g(x) \) is integrated due to \( x \) then it can be finding the probability cumulative \( G(x) \) that a certain quantity of rain observed for a specific month and a specific scale time [18].

\[ G(x) = \int_0^x g(x)dx = \frac{1}{\beta \Gamma(\alpha)} = \int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx \] \hspace{1cm} (7)

The function of Gamma, not a definition at \( x=0 \) (There is no precipitation), so the probability cumulative becomes [18]:

\[ H(x) = q + (1-q)G(x) \] \hspace{1cm} (8)

Where, \( q \) meaning no precipitation, \( H(x) \) refers to the probability cumulative of observed precipitation. The probability cumulative convert into standardized normal distribution \( Z \) with variance unit and null average then get SPI index [18].

\[ Z = SPI = -\left( t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad \text{for } 0 < H(x) \leq 0.5 \] \hspace{1cm} (9)

\[ Z = SPI = +\left( t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad \text{for } 0.5 < H(x) < 1 \] \hspace{1cm} (10)
Where;

\[ t = \sqrt{\ln \left( \frac{1}{H(x)} \right)} \quad \text{for} \quad 0 < H(x) \leq 0.5 \quad \ldots (11) \]

And,

\[ t = \sqrt{\ln \left( \frac{1}{1-(H(x))} \right)} \quad \text{for} \quad 0.5 < H(x) < 1 \quad \ldots (12) \]

Where,

\[ H(x) : \text{the probability cumulative of observed precipitation.} \]

\[ x: \text{precipitation.} \]

\[ c_0, d_0, c_1, d_1, c_2, d_2: \text{constants values, the magnitude of these constants} \]

\[ c_0 = 2.515517 \quad c_1 = 0.802853 \quad c_2 = 0.010328 \]

\[ d_0 = 1.432788 \quad d_1 = 0.189269 \quad d_2 = 0.001308 \]

6. DATA REPRESENTATION BY GEOGRAPHIC INFORMATION SYSTEM (GIS)

GIS is a designer system used to store, capture, manipulate, manage, analyze and shows all geographical types of data, it’s a new strong system used to simplify spatial information data [19]. Inverse distance weighted (IDW) (built in GIS software) used as interpolation’s method in this study, which considers noneostatistical method f or interpolation. This method assumed that the influence mapping variable decreases with distance with the location of the original sample, this method will give high weight value for the points that are close to original data [20].

7. RESULTS AND DISCUSSION

For the SPI, Basrah, Baghdad, and Sinjar were chosen to represent the south, middle and north of Iraq, the time series of SPI 6 for them for the period 1950-2016 are shown in Figs. 3 to 5.

Figure (3) shows the SPI 6 time series for Basrah province. The period 1950-1954 was dry despite having little wet months, also the years 1959-1967 considered a very dry period that ranging from mild to extreme, the periods 1980-1991 were varied drought, for the last years 2000-2013, it dominated by the character of drought ranging from mild to extreme drought through different months.

Figure (4), show that the time series of drought SPI 6 for Baghdad province for the period 1951-1954 were dry period and the drought varied from mild to moderate. It noticed another dry period during 1963-1967 where the drought varied from mild to moderate, the periods 1976-1992 and 1994-1997 suffered from varied drought as shown in figure (4), while for the last year’s 1999-2012, it is considered as dry period and the drought ranging from mild to extreme despite having a few wet months.

The time series of SPI 6 time series for Sinjar city shown in Figure (5). The figure shows that the periods 1954-1963, 1964-1967, 1977-1980, 1988-1992 and 1998-2000 suffered from drought at different classes during different months, while for last times 2001-2013 exposed to dry periods ranging from mild to extreme drought despite some exist wet months.
Drought Hazard Assessment in Iraq using SPI and GIS Systems

Figure 3 SPI 6 for Basrah province (south region of Iraq).

Figure 4 SPI 6 for Baghdad province (middle region of Iraq).

Figure 5 SPI 6 for Sinjar city (north region of Iraq)

Basrah, Baghdad and Sinjar time series of SPI-12 for the period 1950-2016 are shown in Figs. 6 to 8.

Figure (6) shows the SPI 12 time series of drought for Basrah province. The periods 1951-1952, 1956-1961, 1964-1968, 1976-1978 and 1988-1991 were suffered from drought which ranging from mild to extreme despite having a few wet months in these periods. Also the last years 1997-2014, it can be seen that the presence of dryness varies intensity ranging from mild to extreme.
Figure (7) shows the SPI 12 time series of drought for Baghdad province. From the figure, it can be seen that the period 1951-1954 drought was ranging from mild to moderate, while the period 1976-1992 the drought was wobbling and ranging from mild to extreme overlapping with a little wet months. The last years 1999-2013 drought was higher than other years as well as its intensity was ranging from mild to extreme.

Figure (8) shows SPI 12 time series for Singer city. The drought was varying from mild to extreme for the periods 1958-1967, 1977-1980 and 1983-1988. The drought for last years was extreme mostly, especially in the years 1998-2013, while varying from mild to moderate for the period 2015-2016.
After extracting values of SPI for both short and long terms by using the SPI program during period 1950-2016, GIS has been used to show the spatial distribution of SPI 6 and SPI 12 over the study area. SPI 6 for April and October months for the year 2015 represented on Iraq map to show the differences between cities and provinces in drought levels for the same month.

Figures (9 and 10) represent the spatial distribution of SPI 6 on the Iraq map for April and October months of 2015 respectively.

Figure (9) show that the southern, middle and west regions of Iraq varied between mild dry and dry level, whereas the northern region ranged between mild dry and mild wet at longest north.

Figure (10) shows that the southern, west and middle regions of Iraq were range between mild wet and wet, whereas the northern region exposed to mild wet except Sinjar city was wet level of drought.

SPI 12 for April and October months for the year 2015 represented on Iraq map to show the differences between cities and provinces drought levels for the same month. Figures (11 and 12) represent the spatial distribution of SPI 12 on Iraq map for April and October months of 2015 respectively.

Figure (11) shows that the study area (Iraq) varied between mild dry and dry except Rutba and Sinjar cities had the mild wet and wet class of drought.

Figure (12) shows that the southern, west and large parts of the middle region of Iraq were mild dry except for Basrah and the other part of the middle region was mild wet. Whereas the northern region of Iraq varied from dry till wet at Sinjar city.

Figure 9 Spatial drought distribution of Iraq for SPI 6 at April 2015.
Figure 10 Spatial drought distribution of Iraq for SPI 6 at October 2015.

Figure 11 Spatial drought distribution of Iraq for SPI 12 at April 2015.
8. CONCLUSIONS

1- Results for short term drought (SPI 6) shows presence of droughts of different intensities during the period 1950-2016, where the period 2000-2015 was the worst because the drought was extreme class mostly and continues in all regions of Iraq.

2- Results for long-term drought (SPI 12) during the period 1950-2016 show that there was a difference in drought happened in the first decades of this period. However, the worst period for drought in all regions of Iraq shown in the last years especially for the period 1999-2014, the drought was extreme at most months and extends for long period.

3- The study showed that more all the years for the period under the study was in a drought and most drought events were of the class “extreme drought” according to SPI 6 and 12, the reason for extreme drought in the last years because it ascribed to the global warming and climate change phenomenon.

4- Drought distribution on the map of Iraq for April of 2015 for short term (SPI 6) was ranging from dry at some southern and middle regions of Iraq to mild wet at the northern region of Iraq, but it can be seen from Fig.9 that about 75% of total area of Iraq was mild dry. Whereas for October of 2015, the drought distribution on the map of Iraq was ranging from mild wet (largest part of Iraq map) to wet class, but it can be seen from Fig.10 that about 75% of total area of Iraq was mild wet.

5- Drought distribution on the map of Iraq for April of 2015 for long term (SPI 12) highest part of Iraq map was mild dry with the presence of dry at middle region and mild wet of Sinjar city, but it can be seen from Fig.11 that about 75% of total area of Iraq was mild wet. Whereas for October 2015, the drought distribution on the map of Iraq was ranging from mild dry to mild wet for most pars of Iraq, but it can be seen from Fig.12 that about 75% of total area of Iraq was mild dry.

Figure 12 Spatial drought distribution of Iraq for SPI 12 at October 2015.
REFERENCES


Drought Hazard Assessment in Iraq using SPI and GIS Systems


