Utilization of reconnaissance drought index (RDI) for monitoring of meteorological drought over middle Euphrates region during the period from 1988 to 2017

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Abstract. This study was conducted to monitor of meteorological drought over middle Euphrates region based on Reconnaissance Drought Index (RDI) during the period from 1988 to 2017. Average monthly of rainfall, temperature and sunshine hours data were used to calculate this Index. These data were acquired from Iraqi Meteorological Organization and Seismology at known five stations called Hilla, Diwaniya, Karbala, Semawa, and Najaf. The final results illustrated that the highest frequencies of drought, higher values of drought magnitude and intensity are recorded in the Hilla and Karbala stations followed by Najaf, Diwaniyah and Semawa stations respectively. Drought values ranged from moderate to severe in all stations of the study area. There is a high correlation between magnitude and intensity of drought in the study area. There are variations of drought over years between stations because of the difference of climate conditions for each station in the study area.

1. Introduction
Drought differs from other normal threats because drought season develops gradually, making it difficult to pinpoint the start and end of an event [1]. Drought is one of the normal threats affecting the environment and economy and worldwide sustainable development [2]. Drought is a part of natural climate changes, which occurs in all climate zones. Meteorological drought occurs at a reduced rainfall compared to the average rainfall for several years [3]. Meteorological drought is usually defined on the basis of the degree of dryness [4].

The understanding of the temporal and spatial growth of drought events are important for planning drought response and decreasing its impact. Drought severity, spatial extent and its duration are some of the important characteristics for understanding of drought. Severity of meteorological drought is usually assessed by the negative deviation of rainfall from its normal. The development of an active drought monitoring system is usually depend on drought indices and drought triggers which are its essential elements. Drought indices are indicators used to characterize drought to assist decision makers for taking measures for decreasing its impacts [5].

Traditionally drought indices have been used for drought severity assessment. Many indices have been used in the last four decades [6]. Recently, a modern index for drought assessment and monitoring is presented called Reconnaissance Drought Index. It is computed depend on rainfall and potential evapotranspiration. Rainfall alone cannot illustrate the effect of drought on vegetation and agricultural production. Applying both of the rainfall and evapotranspiration in drought severity calculation and monitoring can increase the validity of the results [7]. In this research, RDI index has been used for monitoring of meteorological drought in middle Euphrates region from 1988 to 2017.
2. Materials and Methods

2.1. Location of the study

The study area is located in the middle Euphrates region. It whose area about 26611 km² and located between 31° 0' and 33° 0' N latitudes and 43° 30' and 45° 30' E longitudes. The study area consists of five governorates are Qadisiya, Babel, Karbala, Najaf, and Semawa as illustrated in Figure 1. The climate of the region is arid to semi-arid with dry hot in summer season and cool in winter season. Rainfall in the region starts in October and ends in June and the average of rainfall differs from station to another as illustrated in figure 2. On the other hand, the rainfall rates ranged from 91 mm to 113 mm in the area during the period from 1988 to 2017 as shown in figure 3. There are variations of rain values between stations because of the difference of climate conditions for each station in the study area. The rainfall is in decreasing trend in all stations of study area as illustrated in figures 4 - 8. The highest value of the average temperature is recorded in August month and the lowest value is recorded in January month as illustrated in Figure 9. The average temperature is in increasing trend in all stations of study area as shown in figures 10-14.

![Iraq Map](image1.jpg)

**Figure 1.** Iraq map with a map represents the study area (Modified by authors based on Iraq administrative map scale 1:1000000, Ministry of water resources/General Directorate for Survey 2006).
Figure 2. Average rainfall mm in the study area (1988-2017)

Figure 3. Rainfall rates mm in the study area (1988-2017)

Figure 4. Annual rainfall trend at Diwaniya station (1988-2017)
Figure 5. Annual rainfall trend at Hilla station (1988-2017)

Figure 6. Annual rainfall trend at Karbala station (1988-2017)

Figure 7. Annual rainfall trend at Najaf station (1988-2017)
Figure 8. Annual rainfall trend at Semawa station (1988-2017)

Figure 9. Average temperature °C in the study area (1988-2017)

Figure 10. Average temperature trend at Diwaniya station (1988-2017)
**Figure 11.** Average temperature trend at Hilla station (1988-2017)

**Figure 12.** Average temperature trend at Karbala station (1988-2017)

**Figure 13.** Average temperature trend at Najaf station (1988-2017)
2.2. Data collection

In this research, three types of meteorological data were used to compute the RDI index. These data are monthly average rainfall, average temperature, and sunshine hour's data. These data were collected from Iraqi Meteorological Organization and Seismology. All data which mentioned above were collected from known five stations called Hilla, Diwaniya, Karbala, Semawa, and Najaf for 30 years from 1988 to 2017.

2.3. Reconnaissance drought index (RDI)

This index is based both on cumulative rainfall and potential evapotranspiration. Positive values of this index refer to wet periods and negative values refer to drought periods compared with the normal conditions of the region [8]. Two parameters need to be computed, these parameters are initial $\alpha_0$ and standardized RDI. The initial $\alpha_0$ for year $i$ and reference period of $m$ is calculated using a monthly time scale as follow [5]:

$$\alpha_0 = \frac{\sum_{j=1}^{m} P_{ij}}{\sum_{j=1}^{m} PET0_{ij}}$$

Where: $P_{ij}$ and $PET0_{ij}$ are the rainfall and potential evapotranspiration of month $j$ of year $i$.

The standardized form of this index is calculated by fitting a log-normal probability density function to the given frequency distribution of $\alpha_0$. The formula for the Standardized RDI is as given [5]:

$$RDI_{Stmi} = \frac{ym_i - Av (ym_i)}{\sigma_{ym_i}}$$

Where, $ym_i$ is the ln ($\alpha_0$), $Av (ym)$ is the mean and $\sigma_{ym_i}$ is the standard deviation. The categorization of RDI index is illustrated in Table 1 [9]. This research depended on Thornthwait 1948 method for estimating PET0 according to follow equations [10]:

$$PET0 = 16 \left(\frac{D \times S}{360}\right) (10 \times tn/K)^2 \text{ mm/month}$$

$$\sum_{i=1}^{12} P$$

$$P = [tn/5]^{1.514}$$

$$Z = (0.675 \times 0.00000001) K^3 - (0.771 \times 0.000001) K^2 + (0.179 \times 0.001) K + 0.492$$
Where, PETO is potential evapotranspiration (mm/month), t is mean monthly temperature (°C), n is number of month measurement, K is annual heat index, P is monthly temperature parameter (°C), S is average number of sunshine hours, and D is number of the days a month.

**Table 1.** The classes of RDI index

| No. | Classes of drought       | RDI          |
|-----|--------------------------|--------------|
| 1   | Extremely wet            | >=2          |
| 2   | Severely wet             | 1.5 to 1.99  |
| 3   | Moderately wet           | 1 to 1.49    |
| 4   | Near normal              | -0.99 to 0.99|
| 5   | Moderately drought       | -1 to -1.49  |
| 6   | Severely drought         | -1.5 to -1.99|
| 7   | Extremely drought        | <= -2        |

**2.4. Drought magnitude and intensity**

Sum of the drought periods only represents its magnitude. The ranges of drought are negative values (-1 and less), therefore the drought magnitude should be the absolute sum of the RDI. The magnitude (M) and intensity (DI) of drought computed as follow [11]:

\[ M_{ij} = \sum_{i=1}^{n} |RDI_i| \]  

(7)

Where: n is the total number of drought

Drought Intensity (DI) is used to represent the drought severity. The drought intensity of a site within a certain period is usually reflected by the RDI value. Higher RDI absolute value is more serious of drought. Drought Intensity is computed as follow:

\[ DI_{ij} = \frac{1}{m} \sum_{i=1}^{n} |RDI_i| \]  

(8)

Where: m is the number of drought years of the site.

**3. Results and Discussions**

Middle Euphrates region is one of the agricultural areas in Iraq, which is characterized by its economic importance in the country. This area suffers from several problems, the most important ones are drought especially in the last years. Therefore this research focused on monitoring of meteorological drought over this area based on RDI index during the period from 1988 to 2017. This area consists of five stations are Diwaniya, Hilla, Karbala, Najaf, and Semawa. ArcGIS 10.4 program has been used to draw maps for the study area depending on the Inverse Distance Weight (IDW) interpolation method.

The final results of analysis shown that the region of study suffered from periods of drought during the period from 1988 to 2017 and these periods ranged between moderate drought and severe drought according to each station in the region as illustrated in table 2. The Hilla and Karbala stations have been recorded higher frequencies of drought, higher values of drought magnitude and intensity followed by Najaf, Diwaniya and Semawa stations respectively as illustrated in Table 2 and Figs. 15 - 21. The reason of variation of drought years between stations due to the difference of climate conditions for each station in the study area. There is a high correlation between magnitude and intensity of drought for the study area, where the correlation reached to 0.82 as shown in Fig. 22.
Table 2. Severity and duration of drought during the period 1988-2017 at each station

| Station   | Duration            | Severity of Drought   |
|-----------|---------------------|-----------------------|
| Diwaniya  | 2007, 2008, and 2010| Moderately Drought    |
|           | 2009 and 2017       | Severely Drought      |
| Hilla     | 1991, 1999, 2004, and 2017 | Moderately Drought |
|           | 2007, 2008, and 2009 | Severely Drought      |
| Karbala   | 1990, 1999, 2000, 2007, and 2012 | Moderately Drought |
|           | 2009, and 2017      | Severely Drought      |
| Najaf     | 1991, 1999, 2004, 2007, and 2012 | Moderately Drought   |
|           | 2017                | Severely Drought      |
| Semawa    | 2008, 2009, and 2010 | Moderately Drought    |
|           | 1990 and 2017       | Severely Drought      |

Figure 15. RDI index results at Diwaniya station (1988-2017)

Figure 16. RDI index results at Hilla station (1988-2017)
Figure 17. RDI index results at Karbala station (1988-2017)

Figure 18. RDI index results at Najaf station (1988-2017)

Figure 19. RDI index results at Semawa station (1988-2017)
Figure 20. Magnitude of drought map in the study area (1988-2017)
Figure 21. Intensity of drought map in the study area (1988-2017)

Figure 22. Scatter plot of magnitude and intensity of drought
4. Conclusions

1. The study area suffered from drought ranged between moderate and severe according to each station in it.
2. The Hilla and Karbala stations recorded higher frequencies of drought, higher values of drought magnitude and intensity followed by Najaf, Diwaniya and Semawa stations respectively.
3. Inequality of drought years between stations of the study area is due to different climatic conditions (rain rates, average temperature or potential evapotranspiration) between these stations.
4. There is a high correlation between magnitude and intensity of drought in the study area, where the correlation reached to 0.82.

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