Evaluation of dryness conditions in Babylon governorate

Using the Standardized Precipitation Index (SPI) and the Normalized Difference Water Index (NDWI)

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Abstract: Drought is an anomaly from normal climatic conditions, which affects most of the climatic zones worldwide. Drought monitoring is a very crucial step to detect drought vulnerable zones and to raise awareness about the future of development. The present study aimed to investigate the efficiency of drought monitoring indicators: the standardized precipitation index (SPI) and the Normalized Difference Water Index (NDWI) to spatially description of drought conditions of Babylon governorate for the period 1980-2016. On the basis of SPI values, the season 1995-1996 was classified as a rainy season with the highest positive SPI value of 1.83 among 17 wet seasons represented by the positive values of the SPI. The season 2010-2011 was classified as a very drought season with the highest negative SPI value of -2.25 among 14 dry seasons with negative values of the SPI. The results of NDWI showed that the year 2000 was classified as a dry with the highest negative deviation from the average of the period from 2000 to 2016, while 2014 was classified as a wet with the highest positive deviation from the average of the mentioned period. The results confirmed that the use of plant indices was supportive of the meteorological indices in detecting and monitoring the intensity and severity of the effect of the drought. The study established that the intensity and impact of the drought could be extended to the years after the dry year. That confirms the necessity of adopting the condition of moisture in the plant as a sensitive and effective indicator to assess the severity of drought and the extent of negative effects. The integration of satellite and rainfall derived indices has contributed to provide an effective representation of drought conditions in the study area.

Keywords: Drought; NDWI; SPI

Subject classification codes: water efficiency
1. Introduction

The world has been suffering from drought for a long time. Drought is a severe shortage of water resources due to lack of rainfall or falling below the normal range over a given period of time. Agriculture is the first sector that affected by the drought, which leads to famine and adversely affected the economic, social sectors. Iraq is one of the most vulnerable to drought and desertification due to its repeated exposure to drought, according to the Tunis conference of 1986 on environmental considerations in development. Drought is one of the most serious natural phenomena in terms of economic costs and social problems such as famine, migration and loss of life. The negative effects of the drought from 1900 to 2010 damaged nearly 2 billion people and killed 10 million people (EM-DAT, 2012; EEA, 2012). There is a raising awareness of drought and related hazards such as heat waves and fires, which has led to increased interest in research and studies on drought (Mishra and Singh, 2010), as well as increasing efforts to monitor droughts (Svoboda et al., 2002). Although drought occurs everywhere, the most severe consequences for humans occur especially in arid and semi-arid regions where there is a decline in water even under normal conditions. The communities in these regions often lack the capacity to adapt to the drought risk or at least reduce its negative impacts. Drought management is critical to adapting to drought conditions (Dai, 2011). Drought is a regionally different in frequency and intensity from one place to another, therefore it is difficult to identify, leading to multiple drought monitoring indicators (Marengo and Bernasconi, 2015).

In order to understand the phenomenon of drought and determine its effects, it is necessary to study and analyze the characteristics of drought in terms of frequency and intensity, as well as their spatial dimension (Panu and Sharma, 2002; Seneviratne et al., 2012). Standardized Precipitation Index (SPI) is a tool developed primarily to identify and monitor drought. It allows for determination of the state of drought at a given time.
(time resolution) by analyzing historical rainfall data for different periods: 1, 3, 6 and 12 months anomalies in both droughts and extreme humidity (Mckee et al., 1993; Wanders et al., 2010). The Standardized Precipitation Index (SPI) is one of the recommended climate guides, as recommended by a WMO drought workshop in 2009 to describe droughts in meteorological regions around the world. One of the main disadvantages of the SPI is that it only depends on rainfall values and neglects all other climatic data, which may not be less important than rainfall (Dai, 2011; Masante et al., 2018), as well as the length of time for approved data (not less than 30 years). The another disadvantage is the relative expression of drought severity, while resource management requires absolute values to determine water deficit (Sheffield and Wood, 2011). To overcome the impact of these defects, modern drought indicators that depend on satellite data and focus on vegetation have emerged as a measure of drought level. The main advantage of these indicators is that satellites provide data with a large spatial coverage and high accuracy. While the main disadvantage is that it is difficult to distinguish other effects on phytosanitary, but by combining them with the SPI index for periods 1, 3 and 12 months, it was easy to update the assessment of the state of agricultural drought for 10 days in Europe (Sepulcre-Cato et al., 2012).

Spectral indicators emerged in the 20th century as one of the most effective techniques for investigating and combating drought stress, as well as their effectiveness in providing a database and maps for measures to mitigate drought and achieve sustainable development (Kogan, 2002). The most recent evidence used here is the Normalized Difference Water Index (NDWI). Which was recently used to monitor the moisture conditions of vegetation over large areas (Jackson et al., 2004; Chen et al., 2005). It was considered an effective criterion for monitoring and assessing drought in vegetation, providing accurate information to decision makers and in a timely manner for planning,
effectively mitigating the effects of drought and reducing economic losses. For this reason, continuous assessment of NDWI is needed to better understand how these indicators respond to soil moisture fluctuations, which are ultimately linked to the drought stress on plants (Wang et al., 2007). Al-hedny and Aati (2017) emphasised the efficiency of the NDVI and NDWI indices for drought monitoring and classification, as well as providing a database and maps to monitor the drought and desertification situation. They pointed out the importance of combining more than one indicator to increase the efficiency of indices in the classification of drought.

This study aims to:

1- Studying the general trend of rainfall of Babylon Governorate
2- Determining dry periods to maintain using of the standardized precipitation index (SPI) and the Normalized Difference Water Index (NDWI)
3. Comparison of the efficiency of drought monitoring evidence in determining the time periods for dry seasons.

2. Materials and Methods

2.1. Area of study

Babylon governorate is located in the central part of Iraq within the sedimentary plain, bordered by Baghdad governorate to the north, Anbar and Karbala to the west. It is also bordered by the province of Wasit and the south by Qadisiya and Najaf. Babylon Governorate is located between 33° and 32° North latitude and 45° and 44° east latitude. It rises about 35 m above sea level. Babylon is characterized by a flat topography with a desert climate of between 50 and 200 mm per a year. Summer temperatures may reach 50 °C, the prevailing winds in Babylon are north-westerly or western.

The Euphrates River is the main source of irrigation. Babylon is famous for its cultivation of wheat, barley, maize, cotton and sesame crops, as well as vegetable crops. The
governorate occupies 1.3% of the total area of Iraq. Its total area is 5739 km², which comprises four districts of Hilla, Mahaweel, Musayyib, Hashimiyah and Al-Qasim.

2.2. Standardized Precipitation Index (SPI)

SPI is a function of climate factors such as rainfall, temperature, etc. In general, the SPI is the conversion of monthly or annual rainfall measurements to the Z-distribution, which is calculated as in the equation below (Borg, 2009).

\[
\text{SPI} (i, k) = \frac{(W - W)}{S (wk)} \tag{eq.1}
\]

whereas:

- \( i = 2, 1, \ldots \) represents the year
- \( k = 4, 3, 2, 1 \) represents the reference period
- \( W = \) total rain for the studied year
- \( W = \) the arithmetic mean and \( S \) is the standard deviation. The positive values of the SPI according to the above equation represent the wet periods, while the negative values of the index represent the dry periods. Table 1 is used to classified the drought categories within the study period (Mckee, 1993).

Table 1: Drought severity classification based on SPI values.

| SPI            | Classification            |
|----------------|---------------------------|
| 2 or more      | Extremely wet             |
| 1.5 to 1.99    | Very wet                  |
| 1 to 1.49      | Moderately wet            |
| 0.99 to -0.99  | Near normal               |
| -1 to -1.49    | Moderately dry            |
| -1.5 to -1.99  | Severely dry              |
| -2 and less    | Extremely dry             |
2.3. Normalized Difference Water Index (NDWI)

The current study adopted the analytical approach for digital data from MODIS for the period from 2000 to 2017. The drought status and severity of Babylon governorate was assessed by tracking the change in moisture content of the vegetation cover using the Normalized Difference Water Index (NDWI). Using ArcGIS 10.1, as follows:

2.3.1. Pre-Processing of satellite images

The study used a set of MODIS images, which were obtained from https://earthexplorer.usgs.gov. All images taken in GIS format (TIFF) were re-stored using the MODIS Re-projection tool in the USGS, the images taken accurately at 250 m every 16 days. The total number of uploaded images was 16 years x (12 months) × (2 weeks) = 384, where the visuals were at least 10% cloud cover. Visualizations taken from the MODIS sensor have been performed by all digital processors in advance, and geo-referencing has been performed where the column and grade coordinates in the image are identical to the WGS84 coordinate system that was made through the ground control points.

2.3.2. Calculation of Normalized Difference Water Index (NDWI)

The data obtained after the above treatments were used to calculate the values of NDWI, which is one of the useful methods in plant control, which is based on the equation based on the relationship between the near infrared NIR and mid infrared SWIR, as shown in the equation below:

\[
\text{NDWI} = \frac{\text{NIR-SWIR}}{\text{NIR} + \text{SWIR}}
\] .......................... (eq.2)

The NDWI values were then processed in ArcGIS 10.1 by calculating the Raster Calculator from the Spatial Analyst Tool toolbar.

\[
\text{NDWI}_y = \frac{(\text{NDWI}_1 + \text{NDWI}_2 + \ldots + \text{NDWI}_{17})}{18}
\] .......................... (eq.3)

NDWI_y represents the NDWI rate during the period 2000 to 2017.
NDWI Anomaly $i = \frac{(\text{NDWI}_i - \text{Mean NDWI})}{\text{Mean NDWI}} \times 100 \; \text{.................. (eq.4)}$

NDWI Anomaly represents the standard deviation of the years adopted in the study from the average values of the study period from 2000 to 2017.

3: Results and Discussion

Figure (1) shows the rainfall of Babylon Governorate for the period 1980-2012, which showed a general decreasing in the trend of rainfall. The highest rainfall value was in the rainy season 1995-1996 with value of 193.3 mm, while the lowest rainfall values for the seasons 2008-2009 and 2010-2011 with value of 37.1 and 32 mm, respectively.

Fig 1: Annual rainfall of Babylon governorate for the period 1980-2012

It is also evident from the figure that rainfall values gave a description of the decrease in the precipitation values and the general trend of precipitation amounts, but they do not clearly reflect the condition and severity of drought and their recurrence over the period of study.

Figure (2) shows the values of the SPI for Babil governorate for the period 1980-2012. According to the Positive values (above zero) of SPI, 17 seasons were wet seasons of 17 values. While the negative values (below zero) showed increasing in the period of the 2000s. The highest values of the standardized precipitation index (SPI) were 1.83 for the very wet category for season 1995-1996. The lowest values were in seasons 2008-2009.
and 2010-2011 with value of -1.92 and -2.25 respectively, which classified as a severely dry and extremely dry. The other seasons ranged from dry to wet and classified as a normal seasons.

![SPI Value Graph](image)

Fig 2: Values of the SPI for Babylon governorate for the period 1980-2012.

Table (2) shows the percentages of the frequency of different dry and wet category. The most frequent category is Near normal of 66%, very wet and severely dry of 10%, moderately dry and extremely dry of 3% with the least frequent compared to other drought categories during 31 season.

Table 2: The frequency of drought categories for the period 1980-2012

| Drought Category | Frequent percentage % |
|------------------|------------------------|
| Near Normal      | 66                     |
| Moderately dry   | 3                      |
| Moderately wet   | 6                      |
| Very wet         | 10                     |
| Severly dry      | 10                     |
| Extemely dry     | 3                      |

The values of the NDWI range from -1 and +1, where the standard deviation values are shown. Figure 3 shows the values of the NDWI for Babylon Governorate for the period.
2000-2012. It is clear that only 2000 was (NDWI = -0.82), which represents a decrease in the moisture content of the plant from zero, while the values of the index for the rest of years of the study positive, and in 2014 was characterized by higher values of moisture content index (NDWI = 0.042) compared to the rest of the positive years. As shown by the figure, the NDWI values were low in 2000 despite higher rainfall values this year compared to the 2008-2009 and 2010-10 rainy seasons, while the NDWI values did not show any decrease in response to the lower rainfall values in the two seasons. As shown by the figure, the moisture content index values and rainfall values were consistent in the rain seasons 2004-2003 and 2010-2009. These results confirm the importance of using NDWI in plant drought control. The NDWI provides information on the spatial distribution of stress and its temporal development over longer periods of time, as well as the ability to collect data easily, allowing for a qualitative and quantitative comparison of the intensity and duration of water stress presented to the plant during the growing season (Ceccato et al., 2002; Gu et al., 2007).

Fig 3: Values of NDWI and annual rainfall for Babylon for the period 2000-2012

Figure 4 shows the extent to which the moisture content index values of the plant in each of the study years deviate from the average years of study (2000-2012). The figure shows
that the 2000, 2001, 2003, 2005, 2008, 2009, 2010, and 2012 years had NDWI values below the average for the studied period with highest deviation in 2000, while years 2004, 2006, 2011, 2013, 2014 and 2016 are higher than the average value of the study period with the highest value in 2014. The calculation of anomalies of NDWI values from their mean values for the study period gave a clear representation of the deviation of the moisture content of the plant, whether higher or lower than their content for the study period. Therefore, by reference to the NDWI values in Fig. 3, it is clear that only in 2000 was negative and indicating the prevalence of drought conditions. Figure 5 shows that the period from 2000 to 2003 has suffered a significant reduction in the moisture content of the plant. The results of this study confirm that the adoption of the method of calculating the deviation rate of the values of the guide provides support for the description of the state and intensity of moisture stress in the plant. These results confirmed previous studies in the effectiveness of plant evidence for the drought monitoring (Gu et al., 2008; Khudair and Aati, 2017).

Fig 4: NDWI anomaly for Babylon governorate for the period 2000 - 2016

As for the compatibility of the drought control evidence used in the current study, Figure 5 shows the standard rainfall index (SPI) and the NDWI (soil moisture content index).
The values of the drought control index were consistent in the 1999-2000 season with values below zero. The values of the evidence did not match the description of the drought situation. Table 6 shows the correlation values between the values of the evidence and the rainfall values for the years of study. The index of the standard rainfall was highly correlated with $r = 0.97$, while there was no correlation between rainfall and NDWI values. The importance of the moisture content guide for plants in the evaluation of plant droughts especially in irrigation areas such as Babil province.

Fig 5: SPI and NDWI for Babylon for the period 2000 - 2011

4. Conclusions

This study concluded that the values of the SPI are directly related to the variability of the annual precipitation with correlation coefficient value of $R = 0.97$, while the variations of the NDWI values were not associated with precipitation amounts for the study period. The response of vegetation to drought can be spatially characterized by changes in NDWI values for the study period. adoption of more than one index identify the variations in the
incidence and severity of droughts. The results showed also that the values of the used indices were not identical in the variance for all years of the study period.

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Figure 3. Values of NDWI and annual rainfall for Babylon for the period 2000-2012.

Figure 4. NDWI anomaly for Babylon governorate for the period 2000 - 2016.

Figure 5. SPI and NDWI for Babylon for the period 2000 - 2011.