Forecasting the Future Drought Indices Due to the Effects of Climate Change in Al Najaf City, Iraq.

H H Mahdi¹, T A Musa², Z A A Al-Rammahi³, E J Mahmood⁴

¹,²,³Department of Structures and Water Resources, College of Engineering, University of Kufa, Najaf, Iraq.
⁴Physics Department, College of Education for Girls, University of Kufa, Najaf, Iraq.

Abstract. Drought is a natural disaster associated with a shortage of water availability for specified region within a specific time period. The impacts of drought are significant and extend to damage many important life aspects such as environmental, economic, and social activities. The forecasting of the drought events is an essential element for planning this disaster, reducing its effectiveness and response. The three characteristic frequency, intensity, and time period are the key parts for forecasting and assessment of droughts. Here, two drought indices (The Reconnaissance Drought Index (RDI), standardized precipitation index (SPI)) were used for forecasting of the future drought within Al Najaf city, Iraq. Thirty years meteorological data (average monthly precipitation and temperature) were used for the period (2021–2050) downloaded from the site of the Centre for Environmental Data Analysis (CEDA) for five grid points to cover overall study area. The computation of these indices conducted at a 12-month time scale and included the calculation of potential evapotranspiration by Thorthwaite method. The temporal drought intensity as well as drought frequency configurations were calculated and analyzed for each drought index. The results showed that the general average drought level expected will mildly dry while the maximum drought level expected will extremely dry. The more severe seasons of drought were forecasted in the years 2038, 2034 and 2021, respectively. Also, the prevailing event will be a one year drought and the maximum drought interval occurred within the study period will four consecutive years, with a 3.33% exceedance probability.

1. Introduction and Literature Review
Drought spell is a normal phenomenon that occurs as a result of the lowering values of rainfall depth than the normal limit [1]. Drought can be considered as one of most dangerous natural disasters, as its severe impacts on many human activities such as the agriculture, the environment, and the economy. Drought season developed over the long-term of time, this makes it difficult to define the start and end of this event, therefore, the drought is classified as an extraordinary hazardous. The dry spell within any hydrological system of a specific region is defined as a deficiency of available water [2]. In recent years, water resources have been subjected to increasing stresses as a result of several factors, the most important of which is the increase in population and the accompanying increase in the water demand from various domestically, agricultural, industrial and environmental sectors, in addition to the great shortage in water quantities as a result of climatic changes, and this has led to an increase in the international conflict over water shares. The Intergovernmental Panel on Climate Change (IPCC), 2007 indicated that in the near future, it will be approximately all areas of the world are subjected to negative impact of climate change on water resources, especially freshwater ecosystems. The durable strategic
planning of water resources in any region is necessary in the face of the progressing climate change impacts, it is essential that these impacts be forecasted with a high level of spatial and temporal resolution [3]. A large number of researchers have studied climate change impacts on watersheds, only a few scientists have concentrated on watersheds management adaptation to the impacts of climate variability [4].

Over the previous period, climatologists and meteorologists have investigated the drought problem and developed a number of complex and simple drought indices such as Palmer Drought Severity Index and Precipitation Percentiles Index, respectively (WMO, 2012). The most communal index was the Standard Precipitation Index SPI, it can be considered as powerful and flexible tool established in 1993 by the American researchers, Doesken, McKee, and Kleist [5]. The SPI index is very easy in calculations, because the precipitation parameter is the only needed input independent parameter.

In this study, average monthly precipitation and temperature data were downloaded from the site of the Centre for Environmental Data Analysis (CEDA) for five grid points covered overall study area for thirty year period (2021-2050) to assess the future drought indices. The RDI and SPI indices were computed for the next 30 years (2021-2050) in Al Najaf city, Iraq by using the DrinC software. The analysis of exceedance probability, frequency of spells of successive drought years, as well as reoccurrence period were conducted.

2. Study Region
Al Najaf is one of the important Iraqi cities, it is located southwest of the capital, Baghdad within the geographical coordinates of (29° 50' 00" - 32° 21 00") N and (42° 50' 00" - 45° 44' 00") E, respectively, the Euphrates River passes it only through the eastern border [6-7]. This area is inhabited by more than one million citizens distributed over a number of main areas, the most famous of which are Al-Kufa, Al-Najaf central, Al-Abbasiyah, Al-Haidariyah, Al-Manathirah Al-Hurryah, and others [8]. The climate in Al Najaf is mainly dry to semi dry, its summer season hot with high temperature may be over 45°C in some days, while its winter is semi dry and cold with moderate temperature fluctuated between 8°C and 25°C and may reach to 0°C in some days. The average annual precipitation was assessed as 190.7 mm and 22.8 mm for wet and dry years, respectively. The season of rainfall extends between November (with moderate rainfall) and May (with intermittent rain showers) [9], figure 1 illustrated the geographical location for Al Najaf city.

![Figure 1. Site map of Al Najaf, Iraq.](image-url)
3. Materials and Methodology

The methodology steps of this research focused on three stages are, pre-processing input data, executing DrinC program for calculating PET and drought indices, and post-processing of results, figure 2 explains the details of these steps.

![Flow chart showing methodology steps](image)

**Figure 2.** Flow chart showed the methodology steps.

3.1. Meteorological data (Expected precipitation and temperature)

For this forecasting study, A Representative Concentration Pathway model (RCP4.5) was selected for obtaining data of average monthly precipitation depths as well as average monthly temperature for 5 points were dispersed to covering the study area for the next 30 years (from 2021 to 2050). The site of the Centre for Environmental Data Analysis (CEDA) were used to downloaded these, this site available at: [http://archive.ceda.ac.uk/](http://archive.ceda.ac.uk/). Figure 3 displays the distribution of these 5 points overall study area. Figures 4 and 5 indicate the precipitation and temperature input data which used to calculate the RDI and SPI indices.

![Map of study area with 5 points](image)

**Figure 3.** The distribution of 5 points overall study area.
Figure 4. Expected precipitation data for future periods from 2021 to 2050 which used to compute RDI and SPI values.

Figure 5. Expected temperature data for future periods from 2021 to 2050 which used to compute RDI values.

3.2. Theoretical background of drought indices

3.2.1. Reconnaissance Drought Index (RDI)

RDI is considered as a new meteorological identification and assessment drought index, it was developed by [10] and presented in the MEDROPLAN coordinating meeting project. The computation of RDI based on the ratio between gathered amounts of precipitation and potential evapotranspiration...
There are three types of RDI: initial RDI, normalized RDI, and standardized RDI. These three RDI expressions are calculated by using the following equations:

\[ \text{initial RDI} \ (a_{CM}) = \frac{\sum_{j=1}^{CM} p_j}{\sum_{j=1}^{CM} PET_j} \]  

(1)

\[ \text{normalized RDI} \ (RDI_n(CM)) = \frac{a_{CM}}{\bar{a}_{CM}} - 1 \]  

(2)

\[ \text{standarised RDI} \ (RDI_{st}(CM)) = \frac{y_{CM} - \bar{y}_{CM}}{\hat{\sigma}_{CM}} \]  

(3)

Where: \( a_{CM} \) represents the initial value of the RDI for the certain month, CM represents certain month during a year for a certain period, \( p_j \) and \( PET_j \) represent rainfall and evapotranspiration for the jth month within certain hydrological year, \( \bar{a}_{CM} \) is the average value of a certain month, \( y_{CM} \) is the logarithm of \( a_{CM} \), \( \bar{y}_{CM} \) is the arithmetic mean of \( y_{CM} \), \( \hat{\sigma}_{CM} \) is the standard deviation [11]. Table 1, indicates the of meteorological drought intensity based on the SPI values. Table 2, showed the aridity zones limitation according to UNEP and FAO.

### Table 1. Subdivisions of meteorological drought intensity based on the RDI values.

| Extremely dry | Severely dry | Moderately dry | Mild dry | Near normal | Moderately wet | Very wet | Extremely wet |
|---------------|--------------|----------------|---------|-------------|----------------|---------|---------------|
| Less than -2.00 or -1.99 | -1.99 to -1.5 | -1.49 to -1.00 | -0.99 to 0.00 | 0.00 to 0.69 | 0.70 to 1.00 | 1.01 to 1.49 | 1.50 to 1.99 |
| 2.00 or More | 2.00 or More | 2.00 or More | 2.00 or More | 2.00 or More | 2.00 or More | 2.00 or More | 2.00 or More |

### Table 2. Aridity index according to UNEP, 1992 which used by the Thornthwaite method (Tsakiris and Vangales, 2005).

| Zone limit | P/PET |
|------------|-------|
| Hyper-Arid | < 0.05 |
| Arid       | 0.05-0.20 |
| Semi-Arid  | 0.20-0.50 |
| Sub-Humid  | 0.50-0.65 |
| Humid      | > 0.65 |

3.2.2. Standardized Precipitation Index of drought (SPI).

SPI is one of the quantitative representation of the severity of drought monitoring indices, it was developed by McKee et al., 1993 based on the gamma distribution fitting to generate precipitation time series. SPI index was fitted for a time not less than 30 years and developed based on the principle of limited time periods, for example, four years season, one year season, six month season, and three month season [12]. Previous studies have confirmed that the precipitation of short period irregularities affects the water content of the soil, whereas long period precipitation irregularities impact water resources [13]. SPI is characterized as applicable for evaluation of the severity of the droughts and helps to give early warnings of droughts. But, on the other hand, this index is depended only on the
precipitation, therefore, its results can be considered rather weak. Simply, this index takes average precipitation as a reference line, then positive and negative values refer to up than and less than compared with average precipitation [14]. Table 3, indicates the of meteorological drought intensity based on the SPI values.

**Table 3.** Subdivisions of meteorological drought intensity based on the SPI values [15].

| Extremely dry | Severely dry | Moderately dry | Mild dry | Mild wet | Moderately wet | Very wet | Extremely wet |
|---------------|-------------|----------------|---------|---------|----------------|---------|--------------|
| Less 2.00 or | -2.99       | -1.99          | -1.49   | -1.00   | 0.00           | 0.99    | 1.00         | 1.49         |
| More 2.00     | 1.50        | 1.69           | 1.99    | 2.00    |                |         |              |              |

The main distribution function which used to give a time series of precipitation is the function of gamma probability, it is computed as follows [16]:

If considered that the function \( G(p) \) represent the quantity of precipitation in mm, \( \gamma \) and \( \alpha \) represent the shape parameters, and \( \Gamma(\alpha) \) is the Gamma function of \( \alpha \). \( \bar{p} \) represent the average quantity of precipitation in mm, \( n \) represent data number of precipitation.

\[
G(p) = \frac{1}{\gamma \alpha \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\bar{p}}} \quad \text{for } x, \alpha, \gamma > \text{zero} \tag{4}
\]

\[
\Gamma \alpha = \int_{0}^{y} y^{\alpha-1} e^{-\gamma y} dy \tag{5}
\]

\[
\alpha = \frac{1}{4\bar{x}} \left(1 + \sqrt{1 + \frac{44}{3}} \right) \tag{6}
\]

\[
\gamma = \frac{x}{\alpha} \tag{7}
\]

\[
A = \ln(\bar{p}) - \frac{\sum \ln(p)}{n} \tag{8}
\]

\[
G(p) = \frac{1}{\gamma \alpha \Gamma(\alpha)} \int_{0}^{p} p^{\alpha-1} e^{-\frac{x}{\bar{p}}} dp \tag{9}
\]

\[
H(p) = Q + (1 - Q) \cdot G(p) \tag{10}
\]

\[
SPI = -(t - \frac{2.515517 + 0.802853 \cdot t + 0.010328 \cdot t^2}{1 + 1.432788 \cdot t + 0.0189369 \cdot t^2 + 0.001308 \cdot t^3}) \tag{11}
\]

\[
If \ 0 < H(p) \leq 0.5 \tag{12}
\]

\[
t = \sqrt{\ln \left(\frac{1}{\left[H(\alpha)\right]^2}\right)} \tag{13}
\]

\[
SPI = +\left(t - \frac{2.515517 + 0.802853 \cdot t + 0.010328 \cdot t^2}{1 + 1.432788 \cdot t + 0.0189369 \cdot t^2 + 0.001308 \cdot t^3}\right) \tag{14}
\]

\[
If \ 0.5 < H(\alpha) \leq 1 \tag{15}
\]
\[ t = \sqrt{\frac{1}{\ln(1 - H(p))^2}} \]  

(15)  

\[ SPI = \frac{\ln(p) - \mu}{\sigma} \]  

(16)  

Where possible, in arithmetic standardizing the data directly from a fitted natural distribution, then SPI is considered as the next form:

\[ SPI = \frac{p_i - \mu}{\sigma} \]  

(17)  

3.3. Calculations of potential evapotranspiration (PET)

Using of any potential evapotranspiration calculation method does not give the impression to affect the RDI results. There are many methods to calculate PET such as Penman Monteith, Blaney-Criddle (Doorenbos & Pruitt 1977) [17], Thornthwaite (1948) [18], and Hargreaves and Samani (1982, 1985) [19-20]. The first two methods require minimum and maximum temperature records, whereas the third and fourth method requires only mean temperature records. Here, the PET was calculated based the Thornthwaite Method as follows:

\[ PET = 16 \left( \frac{DS}{360} \right) (10 MN/j)^k \text{ mm/month} \]  

(18)  

\[ k = \left( 6.75 \times 10^{-9} \times j^3 \right) - \left( 771 \times 10^{-7} j^2 \right) + \left( 179 \times 10^{-4} j \right) + 0.492 \]  

(19)  

\[ j = \sum_{i=1}^{12} i \]  

(20)  

\[ i = \left( \frac{MN}{5} \right)^{1.514} \]  

(21)  

Where: M represents the mean monthly temperature in °C units, N represents the number of monthly measurements, j is the index of annual heat (°C), i is the monthly temperature coefficient (°C), D is the number of the days a month, S is the average number of sunshine hours. Figure 6 showed the expected PET for five points within future periods from 2021 to 2050.
4. Result and Discussion

4.1. RDI Results
To obtain clearer representation of spells of wets and droughts, RDI values were implemented for 12 months to cover the yearly precipitations of the points during a year. Figures 7-9, illustrate the three RDI types values for the next 30 years, figure 10, indicates the RDI values for annual average precipitation and temperature data. As can be seen from these figures, the region will suffer for sixteen years of droughts, the ratio of wet years was about 47% while for the dry years about 53%. According to the index divisions in table (1), the RDI levels fluctuated from extremely dry to extremely wet. Generally, the calculations referred to that the average aridity value=0.08, and this means that the climate in this region is arid according to limitations of table (2). The first part of the study period (2021-2035) can be considered a wet period, for the reason that it has nine wet years besides six dry years, while the second part of the period (2036-2050) is a drought period, because it has ten dry years with only five wet years. Compared to the figure 6, the expected PET will increase during the first part of the study period and it reaches its peak in the second part.

Figure 11, expresses the replication of the successive dry years in addition to the exceedance probability percentage with frequency. This figure indicates that the repetition of the two successive dry years happened nine spells and is concentrated in the second part of the study period (2036-2050). Moreover, it can be noticed that the repetition of one drought years was most frequent recurrence, it occurs with exceedance probability of 53%, followed by two successive drought years with an exceedance probability of 30%. The maximum drought period can be occurred within the study period was four successive years, with a 3.33% exceedance probability.

![Figure 7](image-url)

**Figure 7.** RDI (initial type) during future periods from 2021 to 2050 for Al Najaf city, Iraq.
Figure 8. RDI (normalized type) during future periods from 2021 to 2050 for Al Najaf city, Iraq.

Figure 9. RDI (standardized type) during future periods from 2021 to 2050 for Al Najaf city, Iraq.
Figure 10. RDI (for annual average precipitation and temperature data) during future periods from 2021 to 2050 for Al Najaf city, Iraq.

Figure 11. Successive period of drought and exceedance probability percentage versus frequency for the RDI index during future periods from 2021 to 2050 for Al Najaf city, Iraq.

4.2. SPI Results
As in the previous procedure of calculations, SPI values were depended on 12 months to cover the yearly precipitations of the points during a year. Figure 12, illustrates the SPI values for the next 30 years, figure 13, indicates the SPI values for annual average precipitation data. The SPI level for the study
region ranges from extremely wet to extremely dry. There are fourteen dry years as opposed to sixteen wet years, this means that the ratio of dry years is 47% and the ratio of wet years is 53%. As shown in the previous index (RDI), the SPI results indicate that there are two parts, the first part of the study period (2021-2035) can be described as a wet period due to that it has ten wet years besides five dry years, while the second part of the period (2036-2050) is a drought period, because it has six wet years with nine dry years. Figure 13, indicates that strong fluctuations will occur in the period from 2026 to 2041. Figure 14, expresses the repetition of the successive dry years in addition to the exceedance probability percentage with frequency for SPI index. This figure illustrates that the repetition of the two successive dry years occurred nine times and is concentrated in the second part of the study period (2036-2050). In addition, it can be noticed that the repetition of one drought years was most frequent recurrence, it occurs with exceedance probability of 47%, followed by two successive drought years with an exceedance probability of 23%. The maximum drought interval can be occurred within the study period was four consecutive years, with a 3.33% exceedance probability.

**Figure 12.** SPI during future periods from 2021 to 2050 for Al Najaf city, Iraq.
Figure 13. RDI (for annual average precipitation and temperature data) during future periods from 2021 to 2050 for Al Najaf city, Iraq.

Figure 14. Successive period of drought and exceedance probability percentage versus frequency for the RDI index during future periods from 2021 to 2050 for Al Najaf city, Iraq.
5. Conclusions and Recommendations

In this paper, the evaluation of future meteorological drought indices (RDI and SPI indices) was conducted for the next thirty years (2021-2050) in Al Najaf city, Iraq by using the DrinC software. Average monthly precipitation and temperature data were downloaded from the site of the Centre for Environmental Data Analysis (CEDA) for five grid points covered overall study area. The analysis of exceedance probability, frequency of spells of successive drought years, as well as reoccurrence period were conducted. The main conclusions of this research were:

1. The expected values of standardized RDI and SPI showed a significant convergence.
2. The general average drought level expected will mildly dry while the maximum drought level expected will extremely dry.
3. The more severe seasons of drought were forecasted in the years 2038, 2034 and 2021, respectively.
4. The exceedance probability and the frequency decline when drought interval increase, the prevailing event will be a one year drought and the maximum drought interval occurred within study period will four consecutive years, with a 3.33% exceedance probability.

The recommendations for the future studies are dependence on different drought indices that include more meteorological and hydrological parameters in order to reach a high prediction accuracy for future drought.

Acknowledgments

Authors thank the anonymous referees for their useful notes. We would like to give a sincere appreciation to DrinC software team, for providing necessary information.

References

[1] Ogallo L J 1994 Interannual variability of the East African monsoon wind systems and their impact on East African climate. WMO/TD, 619(1), 99-104.
[2] Barker L J, Hannaford J, Chiverton A and Svensson C 2016 From Meteorological to Hydrological Drought Using Standardised Indicators. Hydrology and Earth System Sciences, 20(1) 2483–2505.
[3] Abbaspour K C, Faramarzi M, Ghasemi S S and Yang H 2009 Assessing the impact of climate change on water resources in Iran. Water resources research, 45(10).
[4] Mohammed R and Scholz M 2017 Adaptation strategy to mitigate the impact of climate change on water resources in arid and semi-arid regions: a case study. Water Resources Management, 31(11), 3557-3573.
[5] McKee T B, Doesken N J and Kleist J 1993 The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology, 17(22), 179-183.
[6] Adamo N, Al-Ansari N, Sissakian V K, Knutsson S and Laue J 2018 Climate change: consequences on Iraq’s environment. Journal of earth sciences and geotechnical engineering, 8(3), 43-58.
[7] Mahdi H H 2020 Development of a General Equation for Intensity-Duration-Frequency (IDF): Iraq. Scientific Journal of King Faisal University Basic and Applied Sciences, 22(1), 98-101.
[8] Kareem H 2018 Study of Water Resources by Using 3D Groundwater Modelling in Al-Najaf Region, Iraq. Doctoral dissertation, Cardiff University.
[9] MOTRANS, Ministry of Transportation 2020 Meteorological Data of Al-Najaf Province Station, Iraq: Ministry of Transportation, Iraqi Meteorological Organization and Seismology.

[10] Tsakiris G and Vangelis H J E W 2005 Establishing a drought index incorporating evapotranspiration. European water, 9(10), 3-11.

[11] Tsakiris G, Pangalou D and Vangelis H 2007 Regional drought assessment based on the Reconnaissance Drought Index (RDI). Water resources management, 21(5), 821-833.

[12] Yacoub E and Tayfur G 2017 Evaluation and assessment of meteorological drought by different methods in Trarza region, Mauritania. Water Resources Management, 31(3):825-45.

[13] Robaa S M and Al-Barazanji Z J 2013 Trends of annual mean surface air temperature over Iraq. Nat. Sci., 11(1), 138–145.

[14] Al-Khafaji M S and Al-Ameri R A 2021 Indices-Based Evaluation of Spatiotemporal Distribution of Drought Within Derbendkhan Dam Watershed. Engineering and Technology Journal, 39(6), 893-914.

[15] Shah R, Manekar V L, Christian R A and Mistry N J 2013 Estimation of reconnaissance drought index (RDI) for Bhavnagar District, Gujarat, India. International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering, 7(7), 507-10.

[16] Kumar R, Sagar A and Bist A S 2016 Assessment of Nagina Area of Distt. Bijnor U.P. on the Basis of Standard Precipitation Index (SPI) for drought Intensity. international journal of engineering sciences & research Technology, 5(10), 18 -26.

[17] Doorenbos J and Pruitt W O 1977 Guidelines for predicting crop water requirements. Irrigation and Drainage, FAO, Rome, 24(2), 179.

[18] Thornthwaite C W 1948 An approach towards a rational classification of climates. Geog. Rev. 38(1), 55-94.

[19] Hargraeves G H and Z A Samani 1982 Estimating potential evapotranspiration. ASCE, J. Irrigation and Drainage Division, 108(3), 225-230.

[20] Hargreaves G H and Z A Samani 1985. Reference crop evapotranspiration from temperature. Transaction of ASAE, 1(2), 96-99.