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A Standardized Precipitation Index based approach to predict drought and climate change impacts in Najaf, Iraq

Rusul A Al-Ameri[1]

[1]*Civil Engineering, Al-Furat Al-Awsat Technical University, Iraq,*

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ABSTRACT

Drought is a climatic condition resulting from a severe and prolonged deficit in precipitation, accompanied by rising temperatures. This research paper analyses time-series data on average precipitation from 2000 to 2025, sourced from the NASA POWER data. Geographic Information Systems (GIS) were used to analyze and map the data. to visualize the distribution of average precipitation, and the Standardized Precipitation Index (SPI) was calculated for the Najaf Governorate. For future period (2025-2044), DrinC software was utilized to obtain the SPI using data from the global climate model CMIP6 from the NSF National Center for Atmospheric Research website (NCAR), SSP 245-middle of the road scenario. The results showed that the period (2000-2017) recorded lower average precipitation amounts than the period (2018-2025), and it was concentrated towards the north and decreases towards the south, and the SPI values ranged between moderately wet to mild wet. The period from 2025 to 2044 experienced lower amount of average precipitation. SPI results varied from extremely wet to extremely drought, with the (2035–2044) period, in particular, being characterized by dry conditions.

1. Introduction

Water resources, food security, and socioeconomic stability are all severely threatened by drought, one of the worst environmental threats in the world [1]. Therefore, in this larger context, drought may be considered a complicated natural catastrophe that is challenging to identify (including its origin, length, severity, and extent), anticipate, and regulate [2]. Naturally, drought happens during time periods that are continuous and over geographically contiguous locations. Nevertheless, these interconnected spatial-temporal aspects of drought are frequently ignored [3],[4], In particular, focusing solely on the temporal variation of regionally averaged drought variables across a certain spatial extent or the spatial pattern of drought temporal change during a specified time period [5],[6],[7],[8]. These studies may miss crucial information on drought dynamics by arbitrarily separating the closely related spatial and temporal drought trends. [3],[9]. Andreadis et al. (2005) advocated using SAD (a severity-area-duration) strategy based on three-dimensional structures (time, longitude, and latitude), [10] to address this issue. It provides comprehensive assessments of drought spatiotemporal

* Corresponding authors: Civil Engineering, Al-Furat Al-Awsat Technical University,
E-mail addresses: rusulalameri93@gmail.com (Rusul A Al-Ameri)

dynamics while concurrently accounting for drought-related spatiotemporal features [7],[11],[12], [13],[14].
Meteorological indicators are widely used to investigate the drought at both global and regional scales [15],[16]. These indices take into account highly accurate climatological data which often less intertwined with human signals (such as land use alteration), [17]. The standardized precipitation index (SPI; McKee et al. 1993) [18] is one of them.
In recent years, SPI—which measures actual rainfall as a normalized departure from the rainfall probability distribution function—has gained attention as a potential drought indicator that enables cross-temporal and cross-spatial comparisons. The probability distribution function, which is then transformed into a normal distribution with a mean of zero and a standard deviation of one, requires long-term precipitation data.
According to Edwards and McKee (1997) [19], Standard deviations are used to provide SPI values, where positive values indicate precipitation above the median and negative values indicate precipitation below the median. This study analyzed historical average precipitation data for Najaf Governorate from 2000 to 2025 and used GIS10.3 software to map the governorate's average precipitation's geographical distribution. DrinC software was used to construct the Standardized Precipitation Index (SPI). Furthermore, a model of the climate CMIP6 from the NSF National Centre for Atmospheric Research (NCAR) data SSP-245 scenario was used to compute the SPI and analyze average precipitation amounts for the years 2025–2044.

2. Study Area

The research area was the Al-Najaf governorate, which is located in the middle of Iraq. The spatial boundaries of the study area are represented by the area inside the administrative boundaries of the Najaf Governorate. It is located south of Baghdad on the eastern boundary of the alluvial flood basin. The administrative borders of the region are as follows: To the south and southwest sits the Kingdom of Saudi Arabia, with the governorates of Muthanna to the southeast, Babil to the northeast, Qadisiya to the east, Anbar to the northwest, and Karbala to the north. It is located between longitudes 42.0° and 44.45° east and latitudes 29.50° and 32.21° north. Its area on the map is 29346 km² or 435244 km² in Iraq, according to Salih et al. (2024) [20] (4). Figure 1 depicts the Al-Najaf Al-Ashraf governorate's location.

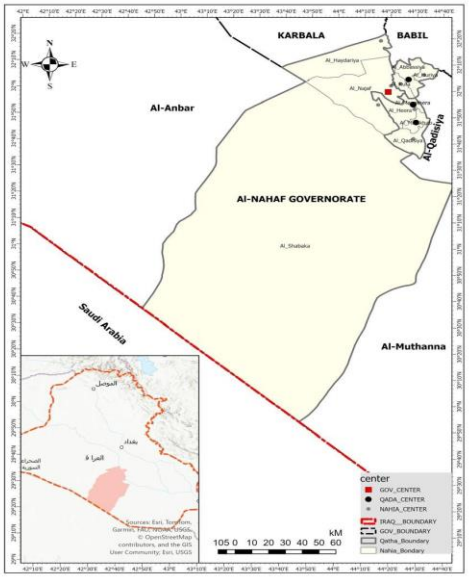


Figure 1. The site of the governorate of Al-Najaf Al-Ashraf (Ministry of Iraqi Planning)

3. Methods and Materials

3.1. Methodology

The website of the NASA Power Data https://power.larc.nasa.gov/data-access-viewer/, provided the yearly mean precipitation data used in this study from 2000 to 2025 [21] were used to analyses average precipitation variability and compute the SPI using the DrinC software. Maps illustrating average precipitation distribution and the SPI distribution were generated by utilizing the GIS 10.3 program. The model of the climate CMIP6 from the NSF National Centre for Atmospheric Research website (NCAR) https://ncar.ucar.edu/, data SSP-245 scenario for the years 2025–2044 [22] were utilized to examine fluctuations in average precipitation amounts and compute the SPI using the DrinC software.

3.2. Standardized Precipitation Index

SPI was introduced by McKee et al. for drought monitoring in 1993. The station frequency distributions of total rain were obtained by fitting gamma distributions. In line with McKee et al. (1993) [18]. Several time periods, including quarter, half, year, two, three, and four years, were used to calculate this index. These times show how dryness and wetness affect the amount of water resources that are accessible. Soil moisture is affected by short-term precipitation deviations, while water availability is affected by long-term precipitation aberrations [23]. Table 1 illustrates the categorization of metrological droughts according to the SPI values.

Table 1. The categorization of metrological droughts according to the SPI values [24].

SPI VALUES	CLASSIFICATION
2.0 or more	Extremely wet
1.5 to1.99	severely wet
1.0 to 1.49	Moderately wet
0.99 to 0	Mild wet
0 to -0.99	Mild drought
-1.0 to -1.49	Moderately drought
-1.5 to -1.99	Severely drought
-2 or less	Extremely drought

4. Results and discussion

4.1 Spatial and temporal distribution for mean precipitation and Standardized Precipitation Index.

This paper utilizes rainfall data from the NASA Power data website covering the period from 2000 to 2025. This timeframe was divided into two distinct periods. The first period (2000–2017) recorded that the years 2001, 2008, 2012, and 2017 had the least significant average precipitation quantities ranging between 26 mm and 90 mm, as shown in Figure 2 illustrated the average precipitation amount for Najaf Governate for the period (2000-2025). In contrast, the second period (2018–2025) experienced higher average precipitation, ranging from 150 mm to 171 mm, within this period, the two years with the greatest averaged precipitation levels were 2018 and 2023, as shown in the figure 2 and table 2 which illustrate the amount of precipitation for each year. The geographical distribution of average precipitation throughout the Najaf Governorate was also mapped using the software Geographic Information System (GIS). The distribution of the average yearly precipitation for the period 2000–2025 is illustrated in Figure 3. A spatial distribution map for the period was created by computing the average precipitation over the entire period for six stations with the coordinates for each station distributed across the study area, were taken from the NASA Power Data, and GIS program was used to create the map. The governorate's northern and northeastern regions saw the highest average yearly precipitation, while the south, southeast, and southwest saw lower average rainfall quantities.



Figure 2. The Najaf Governorate's average yearly precipitation from 2000 to 2025.

Table 2. Average precipitation amounts for the period (2000-2025).

YEAR	AVERAGE PRECIPITATION
2000	33.27167
2001	26.03833
2002	40.685
2003	43.26
2004	34.42333
2005	39.76167
2006	47.79833
2007	35.21833
2008	30.24
2009	54.43167
2010	45.22333
2011	73.72333
2012	45.165
2013	69.825
2014	68.13333
2015	90.41833
2016	65.285
2017	26.94333
2018	149.5467
2019	84.655
2020	134.5917
2021	95.57
2022	85.50167

2023	171.695
2024	122.005
2025	64.62333

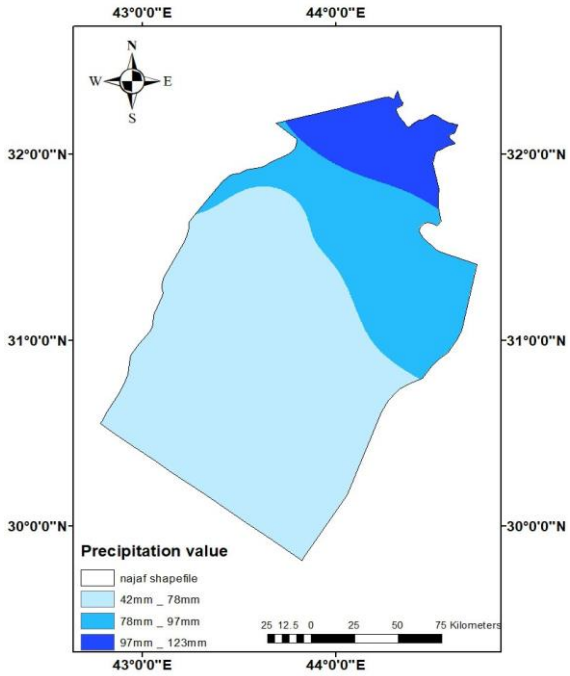


Figure 3. The distribution of the Najaf Governorate's average yearly precipitation from 2000 to 2025.

The SPI index was computed for the years from 2000 to 2025 using the DrinC software, the results indicated conditions ranging from moderately wet to mild wet throughout the period, as illustrated in Figure 4, which shows the average SPI values for Najaf Governorate from 2000 to 2025. The years from 2000 to 2012 were characterized by mild wet, with index values ranging from 0.5 to 0.85, for the period from 2013 to 2019, values ranged from 1.1 to 0.26. In 2020, the index value was 0.26, while for the period from 2021 to 2025, values ranged from 0.9 to 0.56. Although the first period recorded lower average precipitation amount levels than the second which is considered to have the highest average precipitation, the index results classified it as mild wet. This reflects the alarming acceleration of climate change, the noticeable rise in temperatures, and the intensifying global warming the world has been witnessing recently.

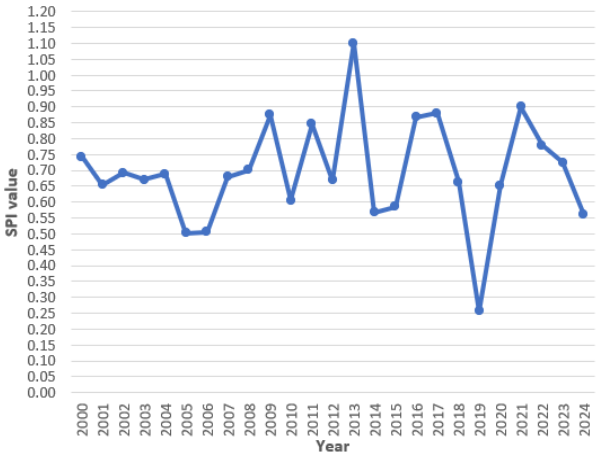


Figure 4. The average annual SPI values for the period (2000-2025) for Najaf Governorate.

A spatial distribution map of the SPI values was generated using GIS10.3 software, it was also mapped using average precipitation data from six stations distributed across the study area, the index was calculated for each station, and a spatial distribution map was generated based on the index values and coordinates of the stations. Figure 5 illustrates the distribution of average SPI values for Najaf Governorate during the period (2000–2025). As shown in the figure, the index values indicate mild wet conditions in the northern parts of the governorate, with values increasing towards the south; specifically, they ranged from 0 to 0.41 in the north and from 0.48 to 0.56 in the eastern and western areas, while ranging from 0.56 to 0.64 in the south.

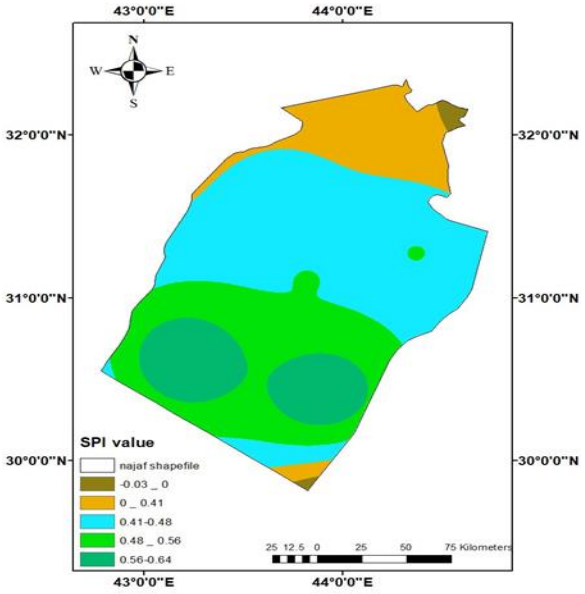


Figure 5. The distribution of average annual SPI for the period (2000-2025) for Najaf Governorate.

4.2. Climate Change Model for Future Period

The model of the climate CMIP6 from NCAR, SSP-245 results indicated that average precipitation for the future period of 2026–2044 was lower than that of the 2000–2025 period, within the future timeframe, peak average precipitation was recorded in 2027, 2030, and 2035, with values of 117 mm, 118 mm, and 114 mm, respectively. Conversely, the lowest average rainfall levels occurred in the years 2026, 2031, 2036, 2041, and 2044, with recorded averages of 49 mm, 63 mm, 70 mm, 63.6 mm, and 60 mm, respectively, as shown in the figure 6 which illustrate the average annual precipitation for the period (2025-2044) for Najaf Governorate.

The SPI values ranged from severely wet to extreme drought, with dry years occurring in 2026, 2031, 2032, 2036, 2038, 2041, and 2044, the corresponding index values were -2.31, -0.05, -1.23, -0.05, -0.79, -1.18, and -1.35, according to the index classifications as shown in Table 1, previously presented in Section 3.2.

As for the wet years, the index values ranged from moderately wet to mild wet. These years were 2027, 2029, 2030, 2033, 2034, 2035, 2037, 2040, 2042, and 2043, with corresponding index values of 1.27, 0.63, 1.34, 0.11, 0.54, 1.16, 0.10, 0.02, 0.46, and 0.33, according to the classifications of the index, mild wet (0.99 to 0), and moderately wet (1 to 1.49). The period from 2035 to 2044 was characterized as dry, given that 60 percent of the years within this period were dry. As shown in figure 7 which illustrate the average annual SPI values for the period (2025-2044) for Najaf Governorate.

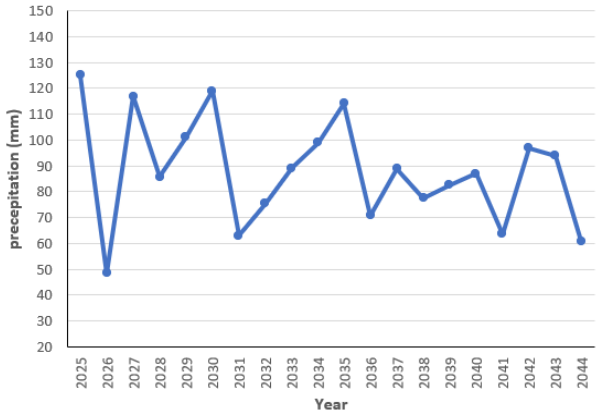


Figure 6. The average yearly precipitation for the Najaf Governorate from 2025 to 2044.

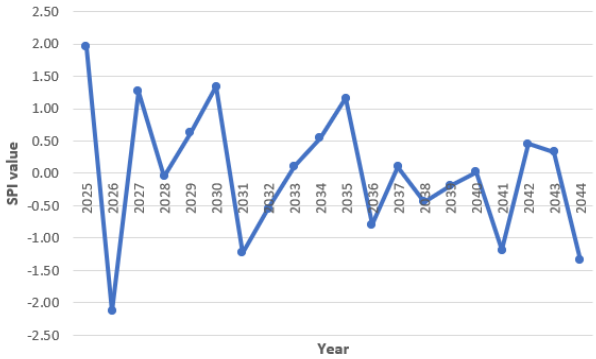


Figure 7. The average annual SPI values for the period (2025-2044) for Najaf Governorate.

Some previous studies have addressed the use of the SPI index, among these studies are: [25] This study was conducted in western Iraq, and the SPI results indicated that the period from 2013 to 2023 was a wet period. [26] This study focused on changes in drought conditions in Iraq over a period of more than 70 years, from 1950 to 2022. The index results revealed a significant increase in drought severity following the 1980s, accompanied by a marked decline in rainfall. [27] This study focused on the period from 1951 to 2021. The results revealed a decrease in spring rainfall, an increase in instances of severe drought, and a reduction in the number of wet years. [28] In this study, the index was used as a predictive input serving as a reference indicator for drought and the LSTM model demonstrated the best performance. [29] The results of this study indicated that the period following the year 2000 was the driest. Three drought indices SPI, RDI, and SDI were compared, and the results of the SPI index were very similar to those of the other indices.

5 Conclusion

Low atmospheric humidity and a scarcity of precipitation are hallmarks of atmospheric drought a condition described as a "silent killer" that inflicts severe damage. Its most significant adverse effects include crop failure, water shortages, increased wildfires, and harm to human health (such as respiratory ailments and skin dryness), alongside environmental degradation. This paper focuses on analyzing the time series of the quantities of precipitation for the years from 2000 to 2025 and calculating the Standardized Precipitation Index (SPI) for this timeframe. The findings show that precipitation was lower between 2000 and 2017 than it was between 2018 and 2025, Precipitation ranged from 26 mm to 90 mm, with the lowest quantities recorded in 2001 and 2017 and the greatest in 2015 (90 mm). In contrast, the period from 2018 to 2025 recorded higher amounts, with 2023 marking the highest recorded precipitation at 171 mm. The drought index SPI values for this entire period ranged from moderately wet to mild wet. Regarding future projections, climate model CMIP6

SSP-245 results indicated fluctuating and generally declining precipitation levels, particularly between 2035 and 2044. Drought index values for this period ranged from extremely wet (in 2025) to extremely drought (in 2026) and severely drought (in 2044), while the remaining years fell within the range of moderately wet to moderately drought.

Based on the obtained results, this study recommends that the future research and studies incorporate climate models, drought indices, and additional scenarios to formulate effective strategies for mitigating climate change in Iraq.

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