

Research Article

The Analysis of Socio-economic Drought in Iraq Using the Standardized Precipitation Index and GIS

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Article Info	Abstract
Article History	Drought is a significant natural hazard that poses a significant threat to many countries, including Iraq. It occurs frequently over short and long periods, severely impacting the nation's economic and social sectors. This study presents a comprehensive assessment of drought risk in Iraq by calculating the Drought Hazard Index (DHI) using the Standardized Precipitation Index (SPI) to estimate the probability of meteorological drought. The Drought Vulnerability Index (DVI) was derived from five socio-economic factors: water withdrawal, irrigated land area, population, and agricultural and municipal water use. The Drought Risk Index (DRI) was determined by combining hazard and vulnerability scores. ArcGIS software created spatial maps and applied inverse distance weighting (IDW) for rating calculations. The findings reveal that the Nasiriyah station in the south faces the highest drought risk, while five other stations show moderate risk. Sixteen stations experience low risk, and most northern stations exhibit no drought risk. The elevated risk in the south is linked to limited water resources and overreliance on groundwater. Conversely, low rainfall and limited irrigated farmland have led to lower risk in the north. The study's maps and findings offer valuable tools for guiding drought preparedness and promoting sustainable water resource management in Iraq.
Received Nov 17, 2024	
Revised Dec 23, 2024	
Accepted Jan 18, 2025	
Keywords	
Drought Hazard Index	
Drought Risk Index	
Drought Vulnerability Index	
Socio-economic drought	
Standardized Precipitation Index	



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1. Introduction

Drought is recognized as a significant natural hazard, characterized by a marked reduction in water availability relative to average regional conditions. Due to its profound and enduring impacts on the economy, society, and natural environments, drought ranks among the costliest global disasters [1]. Unlike other natural hazards such as earthquakes, floods, and storms, the detrimental effects of drought persist even after its cessation. Climate change exacerbates drought through sustained high temperatures, decreased precipitation, and increased evaporation associated with global warming [2]. Historical data indicates that drought-related events between 1900 and 2019 caused global economic losses estimated at approximately \$1.75 billion and were responsible for more than 11 million fatalities [3].

These severe consequences make effective drought monitoring, analysis, and the risk management

strategies critical. Prolonged drought episodes can lead to significant land degradation, desertification, and extensive damage to crops, forests, and water resources [4]. Consequently, drought profoundly influences economic stability and societal well-being, particularly when the demand for essential commodities intensifies due to limited water availability [5].

Drought risk assessments typically encompass hazard evaluation and vulnerability analysis, integrating hydrological, meteorological, and socio-economic data. Such comprehensive assessments are vital for developing sustainable strategies to ensure water resource management and regional food security [6]. For Iraq, a country experiencing rapid urbanization and significant land-use changes, clear and accurate information on drought is essential for effective policymaking and preparedness [7]. This study addresses these specific challenges, providing critical insights for water resource management decision-makers in Iraq.

Despite considerable research efforts globally, coherent integration of hydrological, meteorological, and socio-economic dimensions remains a notable gap. Addressing this, the current research develops an integrated drought risk assessment model tailored specifically for application in Iraq, offering a robust decision-support framework for sustainable drought preparedness and mitigation strategies.

2. Literature Review

Numerous studies have explored drought risk assessment methodologies, emphasizing various indices to quantify drought severity and assess associated vulnerabilities. For example, Dabanli [8] used the Standardized Precipitation Index (SPI) to study the vulnerability to drought in Turkish provinces. He used four socio-economic factors to calculate the Drought Vulnerability Index. To represent the provinces, he drew a map using ArcGIS to show the results of these indices.

In another regional study, Ahmed et al. [9] conducted drought vulnerability modeling for the Mandawa watershed in northern Iraq, employing Geographic Information Systems combined with the Analytical Hierarchy Process (GIS-AHP) and reverse weighting methods. Their approach incorporated seven critical factors, including land characteristics, to derive a detailed drought vulnerability index.

Dunne and Kuleshov [10] conducted a drought risk assessment and mapping of the Murray–Darling Basin in Australia, using agricultural, economic, and social factors as indicators of drought vulnerability. They used the Standardized Precipitation Index (SPI) to calculate drought severity and produce maps using ArcGIS.

Further demonstrating the applicability of GIS-based assessments, Dunne and Kuleshov [10] performed drought risk mapping in Australia's Murray–Darling Basin. They employed agricultural, economic, and social indicators, alongside the Standardized Precipitation Index (SPI), to measure drought severity and produce insightful spatial representations using ArcGIS.

Adnan and Ullah [11] expanded drought vulnerability research by integrating soil moisture anomalies

with SPI for comprehensive drought hazard assessment in Pakistan. Their innovative approach provided a robust vulnerability index tailored to regional drought analysis.

Moreover, Nasrollahi et al. [12] advanced drought risk assessment by calculating drought hazard and vulnerability indices using SPI and eight socio-economic parameters. Their study utilized natural break methods in ArcGIS for efficient data classification and visualization.

Further studies, such as those by Mishra and Singh [13], have extensively reviewed various drought indices and underscored the need for comprehensive frameworks that incorporate multiple environmental and socio-economic dimensions. Similarly, Vicente-Serrano, et al. [14] introduced the Standardized Precipitation Evapotranspiration Index (SPEI), which integrates temperature data to improve drought monitoring accuracy and has been widely adopted for drought characterization globally.

Research by Wilhite [15] highlights the importance of proactive drought management policies, emphasizing preparedness and mitigation strategies rather than reactive crisis management. Their findings underscore the role of integrated water resource management (IWRM) in addressing drought challenges effectively.

Studies conducted by Wardlow, et al. [16] further support using satellite remote sensing techniques to enhance drought monitoring accuracy and real-time data acquisition. These techniques provide valuable spatial and temporal information for decision-making and resource management during drought conditions.

Despite these advances, existing studies predominantly emphasize localized or region-specific assessments. There remains a critical need for integrated drought assessment frameworks to bridge hydro-meteorological data with broader socio-economic vulnerabilities, particularly in regions facing rapid urbanization and resource management challenges, such as Iraq. Addressing this research gap, the current study aims to develop a comprehensive and transferable drought risk assessment model that integrates multiple indices and vulnerability factors, offering a robust decision-support tool for sustainable water resource management and effective drought preparedness.

3. Methodology

This study employs an integrated approach combining meteorological and socio-economic analyses to assess drought risks across Iraq. The methodological framework involves defining the study area, applying standardized drought indices (SPI), calculating drought hazard and vulnerability indices, and integrating these to develop a comprehensive drought risk assessment using GIS mapping techniques. The detailed methodology consists of clearly defined sequential steps described in the following subsections.

3.1. Study Area

Iraq is located between 38.45° and 48.45° east longitudes and 29.5° and 37.5° north latitudes. Six countries border it, and the Tigris and Euphrates rivers run through it. The northern and eastern parts of

Iraq are mountainous areas with heavy rainfall in winter and spring, whereas the southern and western regions are predominantly desert areas. The Iraqi Meteorological and Seismological Organization provided rainfall data for this study. Table 1 shows the location data for the stations adopted in the study and the annual rainfall rates. Annual statistical data, including economic and social data, were obtained from the Central Statistical Organization of the Iraqi Ministry of Planning. Figure 1 shows the location of the different meteorological stations in Iraq considered in this study and the distribution of mean annual rainfall rates over 43 years.

Table 1. Location and rainfall characteristics of the stations adopted in the study

No	Station	Longitude (°)	Latitude (°)	Altitude (m)	Mean annual rainfall (mm)
1	Kirkuk	44.35	35.47	331	332.62
2	Erbil	44.00	36.15	420	428.52
3	Sulaymaniyah	45.45	35.53	843	689.08
4	Zakho	42.72	37.13	433	605.22
5	Duhok	43.00	36.87	554	561.98
6	Emadiyah	43.30	37.05	1236	808.73
7	Dukan	44.95	35.95	490	626.51
8	Baghdad	44.40	33.30	32	122.34
9	Mosul	43.15	36.31	223	355.76
10	Basra	47.78	30.52	2	133.86
11	Karbala	44.05	32.57	29	95.66
12	Najaf	44.32	31.95	53	96.55
13	Tikrit	43.70	34.57	123	176.11
14	Nasiriyah	46.23	31.02	5	122.56
15	Nukhaib	42.28	32.08	305	78.96
16	Hilla	44.45	32.45	27	105.69
17	Hai	46.03	32.13	15	134.02
18	Ramadi	43.32	33.45	48	96.11
19	Haditha	42.35	34.13	140	111.11
20	Rutba	40.28	33.03	615	110.18
21	Amara	47.17	31.83	9	180.11
22	Samawah	45.27	31.27	11.4	102.82
23	Khanaqin	45.35	34.39	202.2	280.37
24	Baiji	43.53	34.90	116	196.06
25	Tuz	44.65	34.88	220	154.57
26	Tel-Afer	42.48	36.37	373	316.46
27	Salahaddin	44.20	36.38	1075	597.73

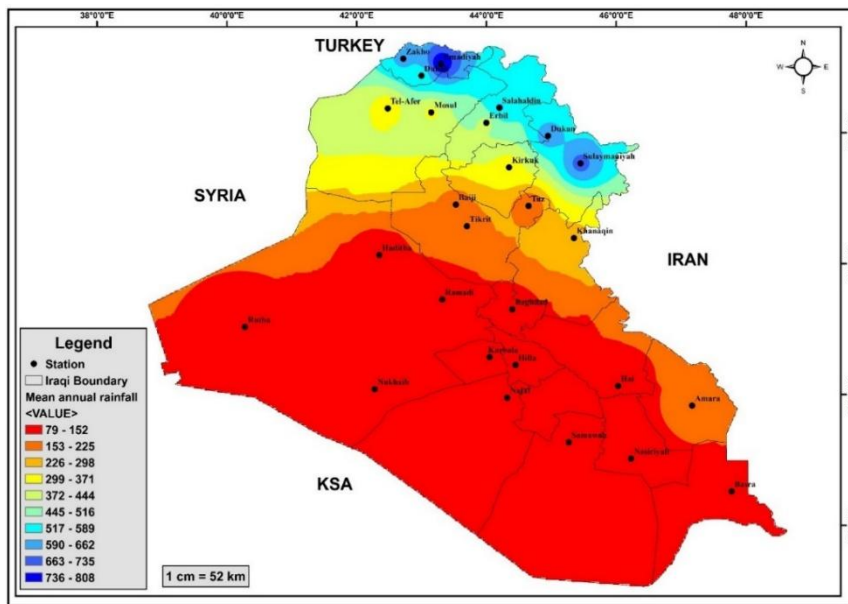


Figure 1. The mean annual rainfall rate distribution and the location of meteorological stations considered for the study area

3.2. Mapping Methods

Mapping is essential to clarifying and comparing the distribution of droughts in the study area. For this study, the ArcGIS 10.8 program was utilized, which relies upon three techniques: the inverse distance weighted interpolation method (IDW), the Thiessen polygon method, and the natural breaks method (NBM) to create drought maps that illustrate its risk assessment and vulnerability analysis. Hydrological studies use IDW for interpolation and spatial analysis. It is a useful spatial statistical technique used to represent and display data better [17]. The natural breaks method (NBM) is a categorization technique that optimally organizes data into distinct categories [18]. The NBM approach works through an iterative procedure. NBM can generate a precise classification [19] by creating a range according to an algorithm and then averaging each range to distribute the data evenly across the ranges. The values are very close within each range [20]. To estimate the effective area of each rain measuring station, the Thiessen polygon method was used [21] to represent drought distribution maps and risk calculations [22].

3.3. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was employed to investigate the severity of drought occurrences in the study area [23]. This index depends on the probability of rainfall on multiple time scales and is widely used worldwide. Numerous studies have confirmed that the SPI effectively detects and monitors drought events [24]. The drought analysis with SPI can be conducted with different time scales, e.g., 3, 6, 9, 12, 24, and 48 months. The SPI-12 has been adapted in this work because drought and its socio-economic impact evolve over a longer time, which is relied upon to identify drought hazards. Table 2 shows the classification of drought severity based on the Standardized Precipitation Index (SPI) [25]. The SPI

index is calculated using the following formula:

$$SPI = \frac{R_{ij} - \bar{R}}{\sigma} \quad (1)$$

where R_{ij} represents the designated rainfall values for a certain time within the year, whereas $\bar{R}$ and σ denotes the average and standard deviation of rainfall values for that period.

Table 2. Standard Precipitation Index (SPI) Categories

Category	SPI Value
Very severely wet	$2.0 \leq$
Severely wet	$1.5 - 1.99$
Moderately wet	$1.0 - 1.49$
Mildly wet	$0.99 - 0$
Mild drought	$0 - -0.99$
Moderate drought	$-1.49 - -1.0$
Severe drought	$-1.99 - -1.5$
Very severe drought	-2.0 and less

3.4. Drought Hazard Index (DHI)

This study assessed drought hazards based on a 12-month SPI time scale. Monthly SPI values were assigned weights (W) and ratings (R). As shown in Table 3, weights ranging from 1 to 4 were assigned to the categories that negatively affect the drought event, which correspond to values with an $SPI < 0$. A weight of 1, 2, 3, and 4 were given to the mild, moderate, severe, and very severe drought categories, respectively [26]. After that, each of the four weights was divided into four ratings. The natural break method assigned ratings from 1 to 4 based on the probability of each drought event, as determined by SPI-12 values. The drought class with the lowest likelihood of drought hazard was assigned a rate of 1, while the class with the highest percentage probability was assigned a rate of 4. Table 3 shows the distribution of weights and ratings [27].

After determining the weights and ratings, the degree of drought hazard (DHS) was determined by the following equation [28]:

$$DHS = \sum_{i=1}^{SPI,i} W_i \times R_i \quad (2)$$

where SPI_i is the SPI values for the specified time period, W_i is the weight assigned to the drought classifications, and R_i is the rating assigned to each drought class.

Thiessen polygons were created by ArcGIS 10.8 for the meteorological stations to determine the area of influence for each station relative to the total area of Iraq. The drought risk index for each station was computed using the following method:

$$DHI = \sum_{i=1}^n A(\%)_i \times DHS_i \quad (3)$$

where $A\%$ is the ratio of the station's area of influence.

Table 3. Weight and rate classification of drought categories according to SPI-12

Severity	Weight	Occurrence Probability %		Rating	Area %
Mild Drought	1	29.91	$\geq$	1	24.41
		29.92	— 32.98	2	30.21
		32.99	— 37.04	3	34.87
		37.05	$\leq$	4	10.50
Moderate Drought	2	8.09	$\geq$	1	23.48
		8.10	— 8.74	2	24.09
		8.75	— 9.39	3	18.05
		9.40	$\leq$	4	34.38
Severe Drought	3	3.93	$\geq$	1	39.25
		3.94	— 4.65	2	10.74
		4.66	— 5.45	3	17.95
		5.46	$\leq$	4	32.06
Very Severe Drought	4	1.91	$\geq$	1	52.64
		1.92	— 2.47	2	10.13
		2.48	— 3.11	3	8.37
		3.12	$\leq$	4	28.86

A normalization method scaled the DHI values from Equation 4 between 0 and 1 to arrive at DHI, as follows:

$$DHI = \frac{DHI_i - DHI_{min}}{DHI_{max} - DHI_{min}} \quad (4)$$

The results were then divided into four categories: low ($0 < DHI < 0.25$), moderate ($0.25 < DHI < 0.50$), high ($0.5 < DHI < 0.75$), very high ($0.75 < DHI < 1.0$), and $DHI = 0$, which indicates no hazard of a drought event [29].

3.5. Drought Vulnerability Index (DVI)

Drought vulnerability is being studied because of its importance in reducing population exposure to risks and its close connection to economic and social conditions. It is challenging to identify vulnerability factors, as their nature and circumstances vary from region to region [30]. Exposure to drought poses a significant danger and threat to livelihoods in developing countries, as it affects the ability to maintain productivity levels [31]. Indicators are identified based on the local context, the area's specific risks, and the availability of measurable data [32]. Five indicators were selected to study exposure to drought in Iraq; these indicators were used to measure the maximum possible damage during the event.

The specified indicators were: Withdrawn Water, Irrigated Lands, Population, Agricultural Water, and Municipal Water. The parameters were set as follows:

- **Withdrawn Water (WW):** This shows the rate of raw water withdrawals for water supply stations. Water

supply stations are closely linked to the raw water supply, which includes both surface and groundwater. Drought negatively impacts water resources, and the more water is withdrawn, the more it affects the area that utilizes the water.

- **Irrigated Lands (IL):** This refers to the percentage of irrigated land to the total land area. Irrigated land areas depend on the amount of groundwater and surface water for irrigation. Their availability is directly related to meteorological droughts. A lack of rainfall leads to a decline in groundwater and river water levels, which increases the cost of irrigation and sometimes makes it impossible to implement it.
- **Population (P):** This factor represents the number of residents in each area. Drought affects a region with a larger population more significantly than one with a smaller population. As a result, the degree of risk will increase with an area's population growth.
- **Agricultural Water (AW) and Municipal Water (MW):** These factors represent the amount of water consumed by the agricultural and municipal sectors. These sectors consume water daily because of its important role in human life. The scarcity of agricultural water affects crop productivity, and agricultural areas increasingly depend on water are more at risk. These areas rely on municipal water from rivers and groundwater, and fluctuations in water levels exacerbate the risk of drought in these areas. Therefore, increasing reliance on water consumption leads to increased exposure to drought.

For each indicator, four ratings from 1 to 4 were chosen. These ratings were obtained using the natural break method and ArcGIS 10.8 software. Higher ratings have higher values because they are more susceptible to drought. The Drought Vulnerability Index (DVI) can be calculated using the following formula [33]:

$$DVI = \frac{WW_n + IL_n + P_n + AW_n + MW_n}{N} \quad (5)$$

where WW_n , IL_n , P_n , AW_n and MW_n are ratings assigned to Withdrawn Water, Irrigated Lands, Population, Agricultural Water, and Municipal Water, respectively. N is the number of parameters. A map was plotted to show the evaluation of each station by IDW after reclassification using the previously mentioned normalization method and with the same comparison values.

3.6. Drought Risk Index (DRI)

To assess the risk of drought in Iraq and mitigate the impacts resulting from its occurrence, the drought risk index was calculated using Equation 6 by multiplying the drought hazard and drought vulnerability indices [27]. A region is not at drought risk if one of the indices is zero. The risk of drought increases with the severity of drought hazards or vulnerability indices. Drought risk is classified into four categories: low ($0 < DRI < 0.25$), moderate ($0.25 < DRI < 0.50$), high ($0.5 < DRI < 0.75$), and very high ($0.75 < DRI < 1.0$) [34]. The IDW method employs a map to represent it. The DRI is calculated as follows:

$$DRI = DHI \times DVI \quad (6)$$

4. Results and Discussion

Previous research processed missing data from monthly rainfall records, conducted homogeneity and consistency tests, and then used the results to measure SPI in this study [35]. Drought values were calculated using the SPI on a 12-month time scale for 27 stations. The calculated SPI values indicate the drought class for each month of the year and for the 43 years, as classified in Table 2. For example, Figure 2 shows the drought values calculated for the four stations. Iraq is prone to major droughts, such as those in 1998–1999, 2008–2010, and 2021. The frequency of drought categories with values less than or equal to -0.99 was calculated to estimate the drought hazard.

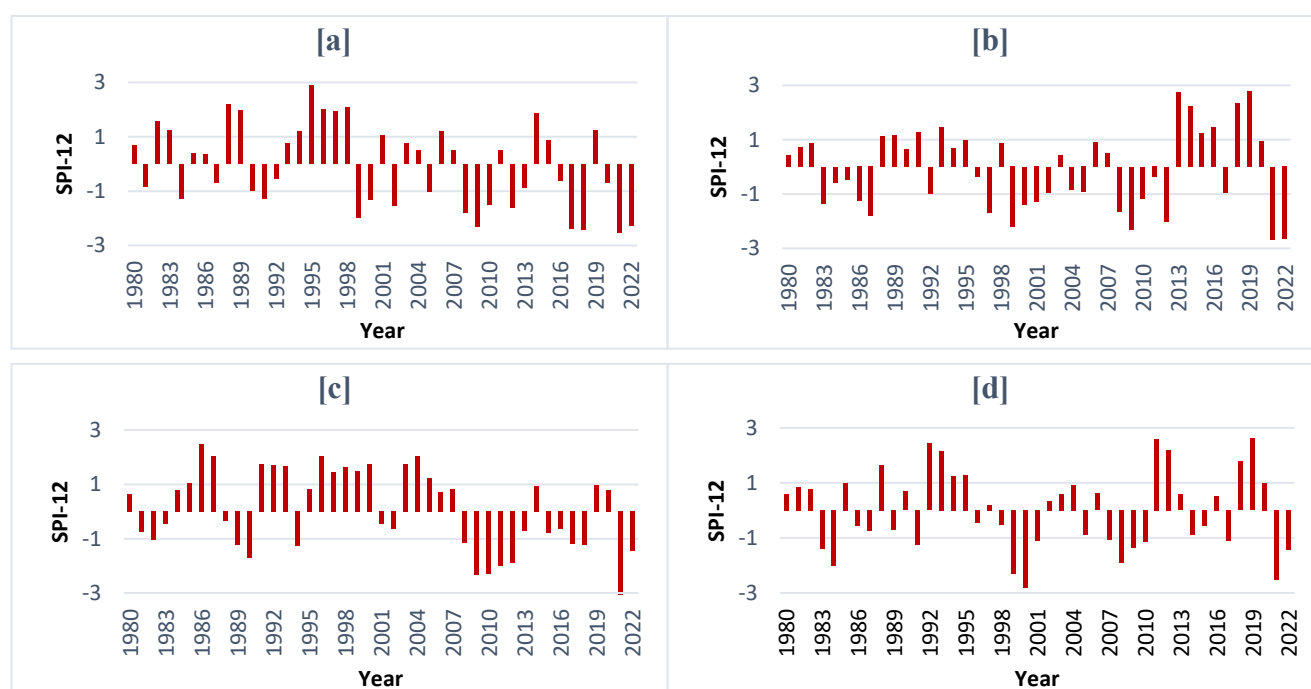


Figure 2. Annual SPI values for (a) Rutba, (b) Baghdad, (c) Basra, and (d) Erbil stations

Table 3 shows the weights assigned to each category, from 1 to 4. The probability of drought occurrence for each category was calculated by dividing the frequency of occurrence of any drought category by all expected probabilities. The probability of drought occurrence was calculated by sorting each category for all stations involved separately. Therefore, ratings from 1 to 4 for each category were assigned using the natural break method (NBM) in ArcGIS software (see Table 3). Equation 2 was used to calculate the drought hazard score for the stations. The inverse distance weighting (IDW) method was used to draw the probability distribution maps of the four ratings for each station category, as shown in Figure 3. The maps indicate that Iraq's southern and western regions are predominantly affected by mild to moderate droughts, whereas the northern and central regions experience severe to very severe droughts. The northern stations, which experienced high drought intensity, suffered from a rainfall shortage compared to the mean rainfall rates over the entire period. Short- and long-term droughts plague the southern stations. The analysis also showed that the drought pattern in Iraq is volatile and undefined. The area of influence of each station was found using the Thiessen polygon method in order to find the drought hazard index according to Equation

3. The drought hazard map (see Figure 4) shows that 52% of the stations experienced low drought hazard, while 26% suffered from medium drought hazard. Three stations showed a high drought hazard index, namely Najaf, Haditha, and Nasiriyah, while Rutba and Nukhaib recorded the highest. On the other hand, Duhok station did not record any significant hazards.

The data on the five vulnerability factors were collected from the annual statistics of the Iraqi Ministry of Planning. Then, each factor was classified into four ratings, ranging from 1 to 4, using the natural breaks method. The value 1 represents the smallest vulnerability factor, and 4 represents the largest vulnerability factor, in ascending order. Figure 5 shows the maps of economic and social factors in all stations based on the four ratings. Eq (5) combines the factor maps to determine drought vulnerability index for each station.

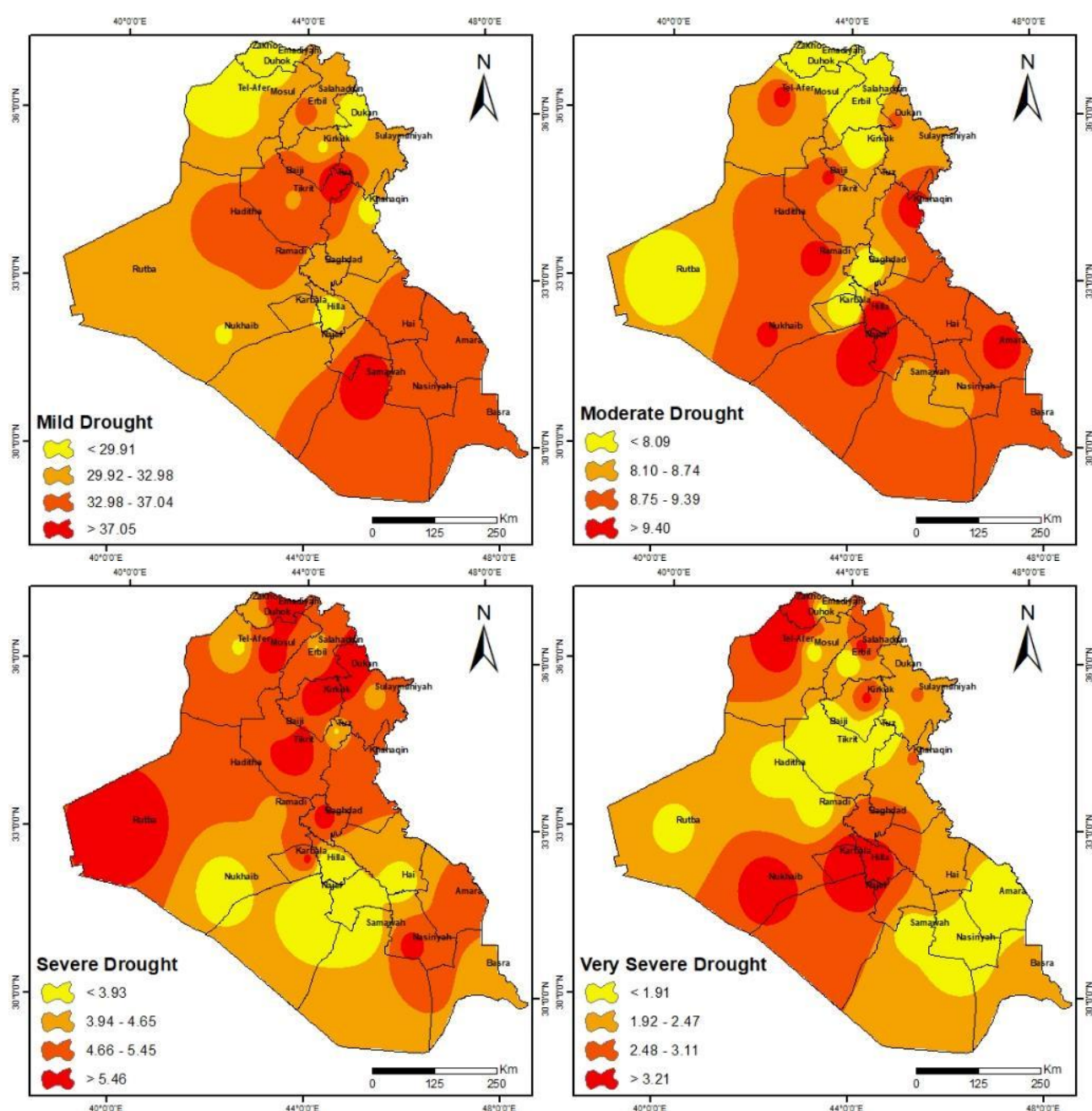


Figure 3. Drought probability distribution for the four drought categories according to SPI classification

Figure 6 shows the distribution of the drought vulnerability index, in which 49% of the stations with high and very high vulnerability categories are located in Iraq's southern, eastern, and central regions. In comparison, 22% of the stations with low categories are concentrated in the western and northwestern regions. Most stations in the northern regions, including Salahaddin, Zakho, Emadiyah, and Dukan, did not record any drought vulnerability index value, except for Kirkuk, Sulaymaniyah, and Baiji, which recorded a medium category. Most stations in the northern regions, including Salahaddin, Zakho, Emadiyah, and Dukan, did not record any drought vulnerability index value, except for Kirkuk, Sulaymaniyah, and Baiji, which recorded a medium category. The southern regions have experienced long-term drought, significantly impacting the economic and social sectors. For example, withdrawing large quantities of raw water from the southern and central regions has led to a shortage of water for agricultural land irrigation and for the population. Drought is directly linked to the scarcity of agricultural and municipal water. The western regions also recorded the lowest ratings in all five factors, which contributed to their placement in a lower category of the drought vulnerability index classification due to the small agricultural lands and the scarcity of agricultural and municipal water. The pattern of drought vulnerability may be linked to the elevation of some northern areas that did not record any vulnerability index, as they have a lower reliance on irrigated agricultural areas compared to other areas.

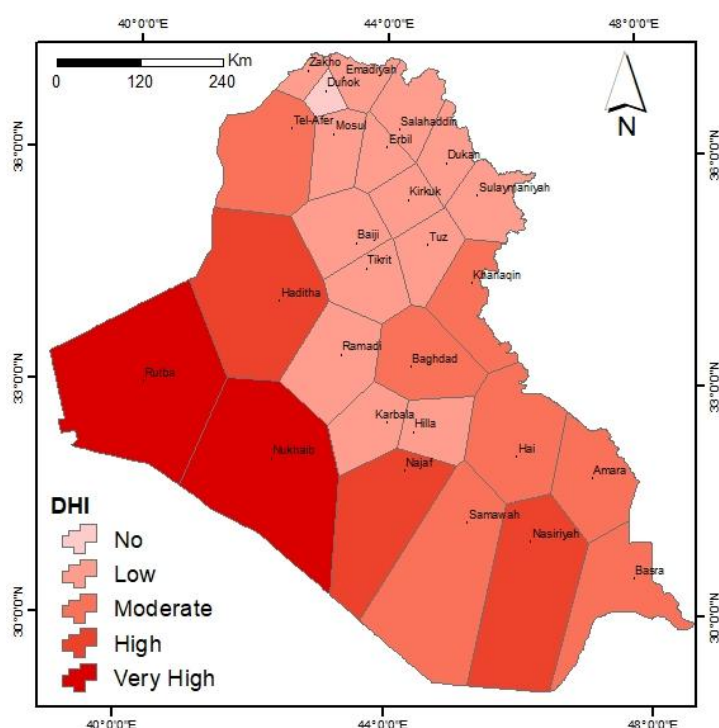


Figure 4. Drought Hazard Index distribution for Iraq using DHI

The drought risk index was calculated according to Equation 6. The drought hazard and vulnerability indices play a fundamental role in assessing drought risk, as the relationship is directly proportional to the risk index; with any increase in either of them, the risk increases. ArcGIS combined the maps to create a drought risk index map, as illustrated in Figure 7.

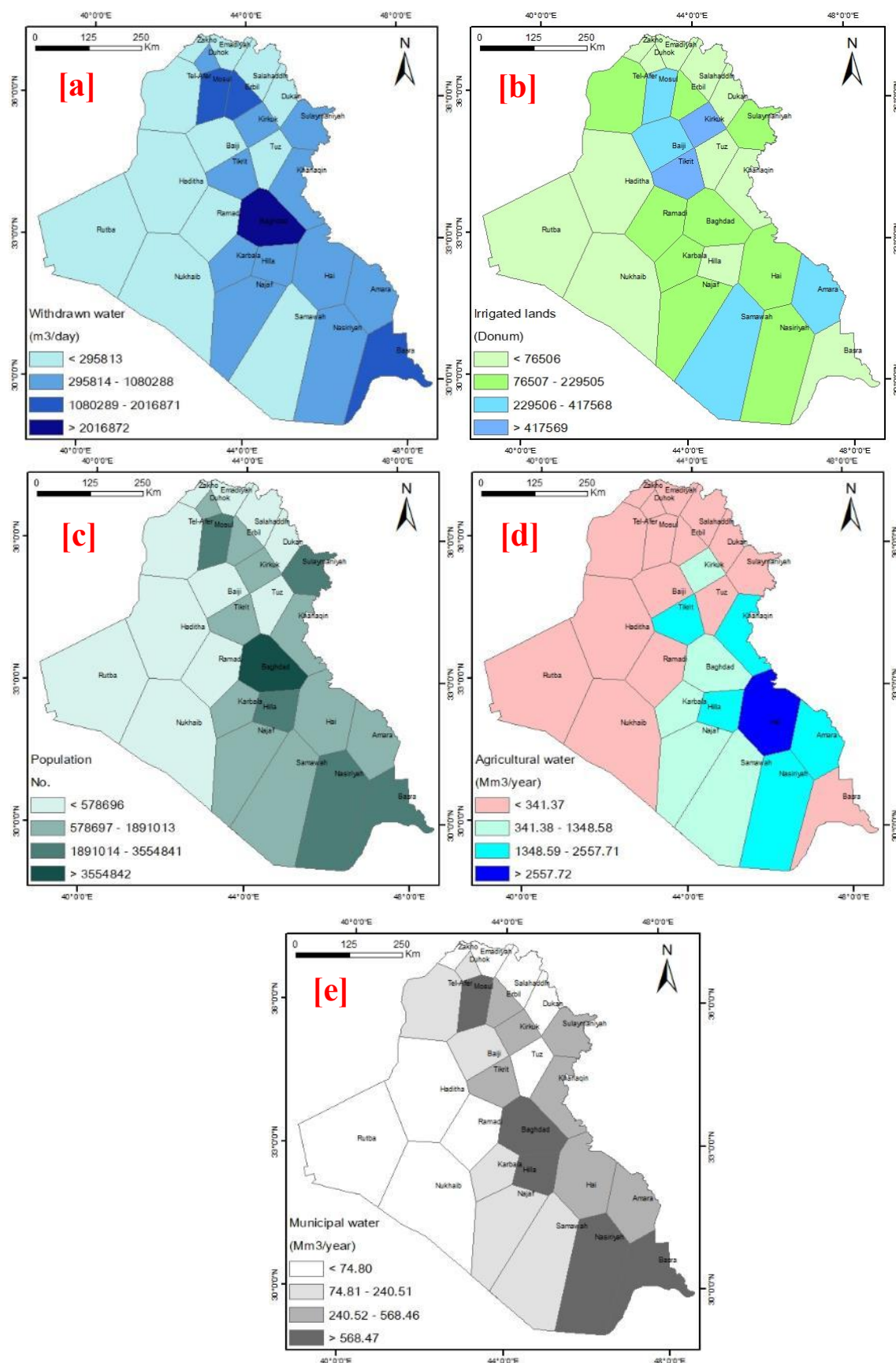


Figure 5. Distribution maps for the five economic and social indicators at the considered stations a- Withdrawn water. b- Irrigated lands. c- Population. d- Agricultural water. e- Municipal water

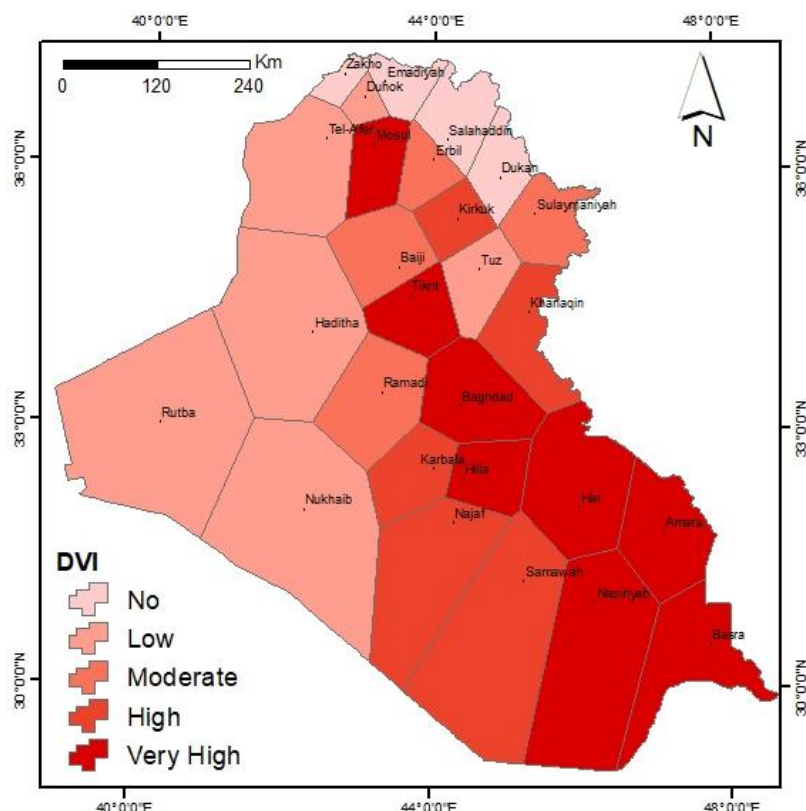


Figure 6. Drought Vulnerability Index distribution for Iraq using DVI

The DRI was calculated according to Equation 6. The drought hazard and vulnerability indices play a fundamental role in assessing drought risk, as the relationship is directly proportional to the risk index; with any increase in either of them, the risk increases. ArcGIS combined the maps to create a drought risk index map, as illustrated in Figure 7.

The results showed that 59% of the stations recorded low drought risk, while Baghdad, Najaf, Samawah, Amara, and Hai stations recorded moderate drought risk. Most of the northern stations, namely Emadiyah, Zakho, Dohuk, Salahaddin, and Dukan, did not record a drought risk index, and their values were zero. This pattern indicates that the impact of agricultural lands, population, and raw water withdrawals was low in these areas, in addition to the low DHI values, which significantly contributed to the risk assessment.

The Dohuk station, with a DHI value of zero, likewise carried no risk. However, Al-Nasiriyah station was the most exposed to drought risks and was classified in a high category. This is because the region has experienced long-term drought periods and low annual rainfall and river discharge, resulting in a high DHI value. Additionally, the irrigated lands and the amount of agricultural and municipal water allocated to them are of high value, which results in a higher risk category. Large amounts of raw water withdrawals, reliance on irrigation, population growth, agricultural and municipal water consumption, and variability in annual rainfall have made the southern regions of Iraq more vulnerable to drought than other parts of the country. Therefore, water conservation is particularly important in these areas.

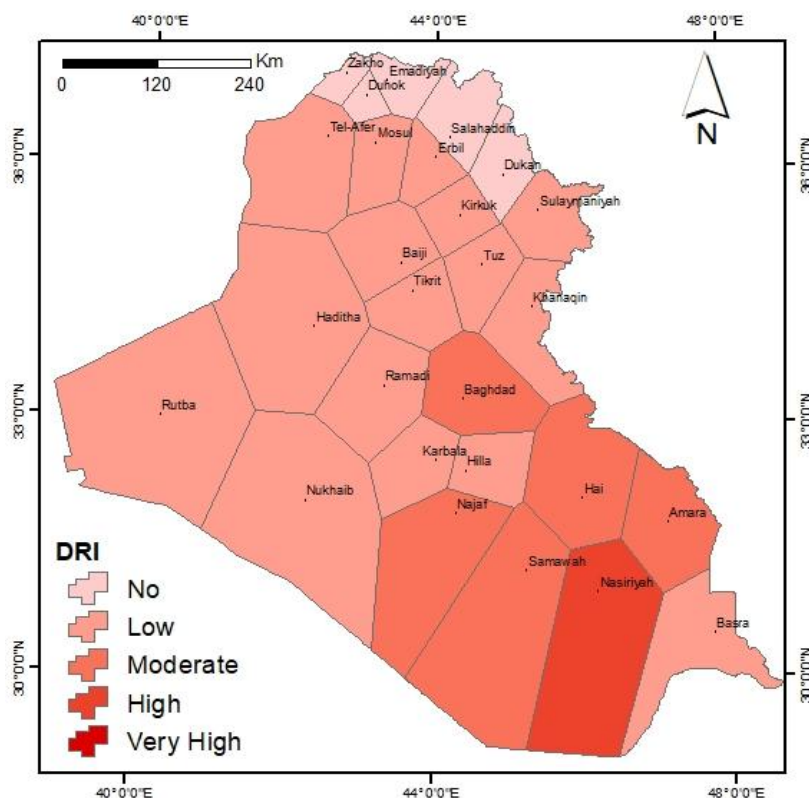


Figure 7. Drought Risk Index distribution for Iraq using DRI

5. Conclusions

In this paper, the detection and analysis of drought vulnerability and hazard indices were conducted to calculate the Drought Risk Index (DRI). To calculate the Drought Hazard Index (DHI), the Standard Precipitation Index (SPI) was used, and five socio-economic factors were utilized in calculating the Drought Vulnerability Index (DVI).

The results showed that vulnerability and hazard indices combined in overall drought risk assessment. The DHI calculation revealed a severe drought risk in the northern regions; however, the low drought vulnerability index prevented the recording of any drought risk index. Due to limited water resources in the southern regions, the decline in groundwater levels has increased the drought vulnerability index, rendering the area more susceptible to risks. The control of neighboring countries over the quantities of water entering Iraq has impacted the country's droughts, leading to a reduction in cultivated land area and a decline in water resource levels.

The drought risk map for 27 stations shows that 16 stations have a low drought risk, five stations have a moderate drought risk, and 1 station has a high drought risk. The remaining five stations did not record any drought risk. This study helps to identify areas that need to be prioritized for the comprehensive management of drought occurrences. Wet areas have a larger population than desert and dry areas. The Baghdad, Nasiriyah, Amara, and Samawah stations demonstrate the importance of combining human resources

and management to mitigate the risk of drought. Developing drought monitoring systems is crucial, especially in southern regions with high drought risks, and educating individuals to reduce water consumption in both the domestic and agricultural sectors is essential. Reducing the cultivation of high-water consumption crops and utilizing modern irrigation methods are crucial in mitigating the impact of droughts.

This research is the first study to cover drought risk assessment in all regions of Iraq. Therefore, it is recommended that more economic and social indicators be used and compared with those presented in this study. Research on drought risk management in Iraq and the development of drought mitigation strategies by decision-makers can benefit from this study.

Funding: The authors declare that no funding was received for this research.

Declaration of Competing Interest: The authors declare they have no known competing interests.

Research Involving Human/Animal Participants: This article does not involve any studies conducted by authors on animals or human participants.

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