Drought Monitoring using Remote Sensing-Based Indices in the Southern Region of Iraq

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Abstract

Drought considers a general risk that can have considerable effects on ecosystem stability and functioning, biodiversity, and the habitat of wildlife, particularly in arid regions. The study aims to use remote sensing dataset to evaluate the drought situation in the southern region of Iraq. Various indices were used, including the Land Surface Temperature (LST,) the Soil-Adjusted Vegetation Index (SAVI), the Normalized Difference Moisture Index (NDMI), the Normalized Difference Water Index (NDWI), and Normalized Difference Vegetation Index (NDVI) for this purpose using Landsat data for the years 2014 and 2024. Also, the annual precipitation from climatic remote sensing data for the years 2014 and 2024 was used to access the hydrological drought. Then, to produce the drought risk map, all these layers were normalizing and overlaid using ArcGIS 10.3 software. Finally, the study area was classified into three categories; high drought, low drought, and no drought according to the indices. The result showed that, for the year 2014, the area of the class high drought, low drought, no drought is 10090 km^2, 8791 km^2, and 8486 km^2 respectively. This research study could help researchers work on drought monitoring, especially in arid and semi-arid regions. Remote sensing-based indices can provide significant benefits in assessing the time stage and severity of the drought.

Keywords: Climatic, Drought, GIS, Vegetation

1. Introduction

Drought is considered one of the greatest severe natural disasters on Earth, which can occur in a variety of climatic zones and at different frequencies and intensities [1]. Drought has a major effect on the security of food and water [2], then its effects depend on the ability to mitigate its negative social, economic, ecological and environmental effects [3]. The probability and extent of the warming climate pattern will increase, making climate extremes like droughts and periods of heavy rainfall more common and severe [4] and [5].

Drought is an important natural disaster that has many detrimental impacts on agriculture, water resources, and other sectors. Remote sensing provides a valuable tool for monitoring drought, as it supplies various meteorological and vegetative parameters over large and inaccessible areas using different indices. One of the most important tenders of remote sensing technology is monitoring environmental changes and vegetation growth [6]. It can be used to monitor large and inaccessible areas in order to assess land cover changes over distance and to study vegetation growth pattern and changes over time [7]. Drought is a complex environmental phenomenon that has devastated immense regions around the globe, particularly in semi-arid and arid countries. Drought is individual of the most dangerous climate-related hazards. It is a gradual phenomenon, and its effects on agriculture are often caused by a combination of other factors rather than solely by a deficit of rainfall. Since the 1980s, drought-related problems associated with the recurring drought pattern have been major constraints on the development of deserts, semi-deserts, and arid regions. It is a slow-onset disaster with long-term effects on ecosystems and human activities, including agriculture, biodiversity, energy, food security, health, infrastructure, land degradation, population displacement, water resources, and economic development [8]. The occurrence and severity of drought are closely related to the climatic setting of the region.

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Drought leads to a considerable decrease in the soil moisture content, which in turn has a direct impact on agriculture [9]. Arabic countries with arid and semi-arid climates face many issues, including rainfall variability and droughts. Owing to the dry climate, erosion, desertification, and dune movements, in addition to its effect on the economy, agriculture, and life in general, drought is considered one of the most serious phenomena globally [10]. Drought is defined differently by different disciplines depending on its impact on social, economic, or environmental bases. In semi-arid and arid regions, agriculture poses a paramount problem because of high dependence on rain-fed agriculture [11]. As the Arab world has a dry climate, climate changes, especially rainfall variability and drought, can hinder agricultural progress in the region, so a detailed study of droughts and their effects on agriculture is needed. Iraqi agriculture is heavily reliant on a delicate rainfall regime, which makes it vulnerable to climate variability and weather-related events. Such situations change from year to year, with a potential drought pattern forming across southern Iraq, rendering many agricultural areas prone to high levels of drought [12].

Remote sensing data has the benefit of providing surface information for a large area with good temporal resolution. The satellite images provide wide coverage and unique snapshots of land surface phenomena. These data have an important role to play for drought quantification. Drought monitoring using remote sensing satellite imagery and different indices is a complex issue. While meteorological parameters such as precipitation are required for drought assessment, vegetative parameters are always associated with water supply deficit and environmental stress [13]. In recent years, Iraq has witnessed a significant deterioration in drought conditions, threatening the country's water and food security, and negatively affecting the daily lives of citizens and various economic sectors. The reasons for the exacerbation of this phenomenon are due to a group of natural and human factors that require urgent and sustainable solutions to address them. Among these important factors are climate change, population growth, increased demand for water, and poor water management. Climate change is one of the main reasons of the exacerbation of drought in Iraq. Increased temperatures and decreased rainfall have led to a severe shortage of water resources. According to United Nations reports, Iraq is among the countries most affected by climate change in the Middle East, as the country is experiencing longer and more severe droughts compared to previous decades. Iraq is also witnessing rapid population growth, which increases pressure on limited water resources. The increased demand for water for drinking, agriculture, and industry exceeds the country's ability to provide it, especially in light of the difficult climatic conditions. In addition to the excessive use of water in agriculture and industry without taking into account future needs, the absence of long-term strategic plans, and the failure to modernize the water infrastructure, relying on traditional irrigation methods in agriculture increases the depletion of available water resources. Iraq has around 670 kilometers of desert, which accounts for more than 38% of the country's territory [14].

Factors contributing to the increased desertification include random deforestation, expansion of settlement areas, population growth, reduction in vegetation cover, intensive agriculture, and water scarcity. From a health perspective, drought leads to a decrease in the quality and quantity of water, which in turn increases illness and death, negatively impacts mental health and livelihood challenges [15]. The southern part of Iraq has an extremely dry climate that is subject to droughts because of its geographical location. Not much has been done to alleviate the drought in this area, despite growing evidence of its effects on ecosystem functioning and food security. Remote sensing-based indices can provide significant benefits in assessing the time stage and severity of the drought. In this study, the methodology outlined can be re-established for future application to different regions and other timeframes, being adaptable to diverse datasets. Furthermore, the detected drought indices are particularly useful for planning measures to fight drought in future years, extensive datasets, reanalysis datasets for full access for consideration globally, and satellite datasets ensuring a continual record of droughts and ability to compare past, present, and future droughts.

This study aims to monitor the drought condition using the spectral index based on Landsat data and the precipitation data, Southern Iraq, for the current situation (2024) and compere the result with the last decade (2014). The results could be helpful for the researchers work on drought monitoring, especially in semi-arid and arid regions to develop a drought mitigation strategy.

2. Study Area

This study focused on the analysis of remote sensing-based indices in the southern part of Iraq, which is known as the Middle Euphrates region, includes the provinces of Babylon, Karbala and Diwaniyah, and the northern parts of the provinces of Najaf and Muthanna. The area located between latitudes 31° and 34° N and longitudes 44° and 46° E, as shown in Figure 1.

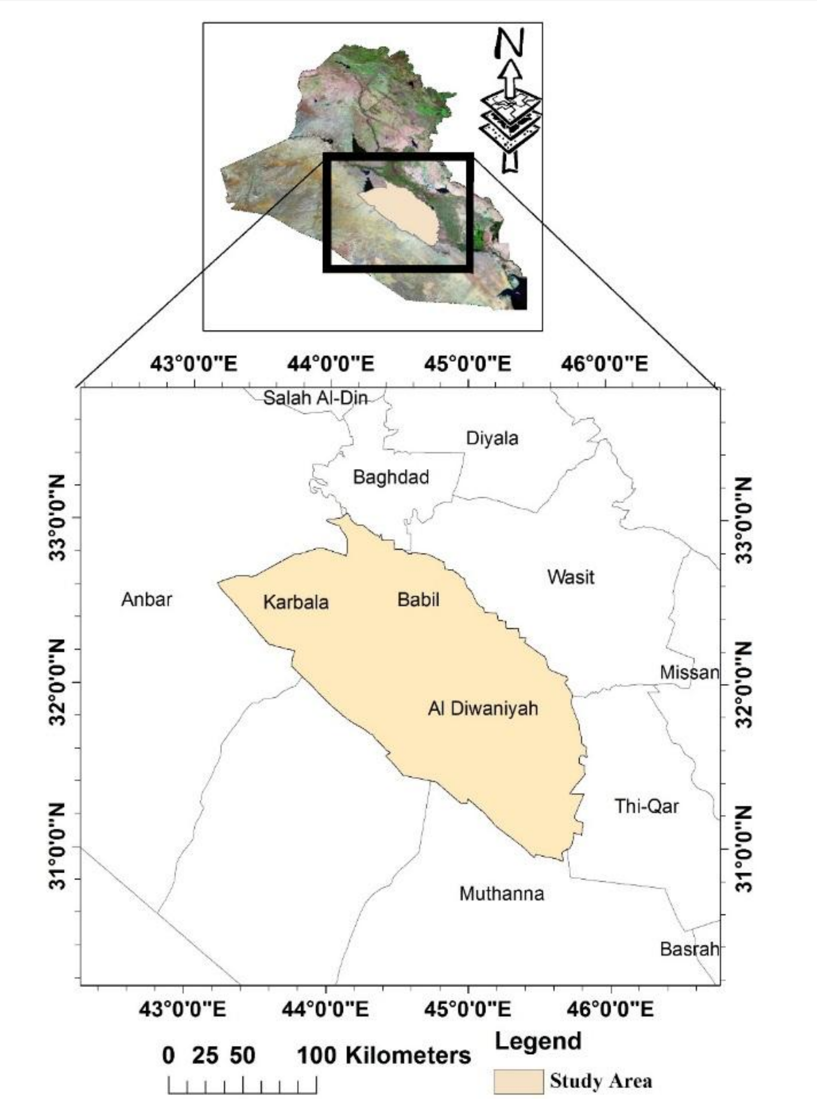

Figure 1: Middle Euphrates region, southern Iraq

It possesses a desert climate with very hot summers, pleasant winters, and limited rainfall concentrated between November and May. The Tigris and Euphrates rivers are crucial for the country's water supply, but dams constructed by Turkey and Syria have diminished the rivers' annual flow by over 90%. On the other hand, salinity and sedimentation are problematic for the agriculture sector due to the basin's low gradient and high evaporation. However, the topic of remote sensing-based drought assessment and monitoring techniques, particularly within Iraq, has not received adequate attention despite its significance.

3. Materials and Methods

The concept of remote sensing entails obtaining data about a formation without direct contact therewith. Non-contact data collecting methods and instrumentation are generally used in remote sensing [16]. Consequently, remote sensing techniques have gained considerable acceptance during the last three decades for a diverse range of agronomic, land surface, and meteorological tenders. This broad acceptance is most noticeably apparent in drought monitoring and assessment through the complementary use of satellite remote sensing observations with ground-based weather and surface data, either visible or infrared, for studying aridity or drought situations. The study area is composed of agricultural and wetlands land in the southern region of Iraq. The precipitation data for the years 2014 and 2024 are obtained from NASA website (https://giovanni.gsfc.nasa.gov/giovanni/).

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Global Precipitation Measurement (GPM) data were used to map the annual average rainfall in the region for the years 2014 and 2024. The data downloaded in NetCDF form then it converted to point shapefile with about 261 grid data point, then the data interpolated using ordinary Kriging method to convert it to Raster form. Then the maps were created by ArcGIS 10.3 software. The LST and spectral indices data to compute NDVI, SAVI, NDMI, and NDWI were acquired from Landsat images in 2014, and 2024.The methodology flow chart was shown in Figure 2. The image specification shown in Table 1. The Fuzzy Linear membership (FLM) function Remote Sensing has become an important technology to monitor drought due to its cumulative advantages such as wide coverage, rapid acquiring of data, and multiple spectral bands [17]. With Remote sensing datasets, a number of indices have been applies a linear function between the user-specified minimum and maximum values based on the likelihood of belonging to a certain set, the Fuzzy Membership tool reclassifies or converts the input data to a 0–1 scale. Locations that are unquestionably not part of the specified set are assigned a value of 0, values that are unquestionably part of the specified set are assigned a value of 1, and all potential membership levels are assigned a value between 0 and 1. In this study FLM was used to normalized the criteria layers.

3.1 Spectral Indices

developed as alternative data sources to detect the occurrence of drought. Given the fact that drought adversely affects vegetation growth and development, it is reasonable to try to assess drought through monitoring vegetation activity [18].

Table 1: Dataset collection specification

Image	Date	Spatial Resolution	Used band
Landsat 8	24 April 2014	30 m	B3, B4, B5, B6, B10, B11
Landsat 9	19 April 2024	30 m	B3, B4, B5, B6, B10, B11
Precipitation GPM	Annual average 2014	0.1 x 0.1 Degree	
Precipitation GPM	Annual average 2024	0.1 x 0.1 Degree	

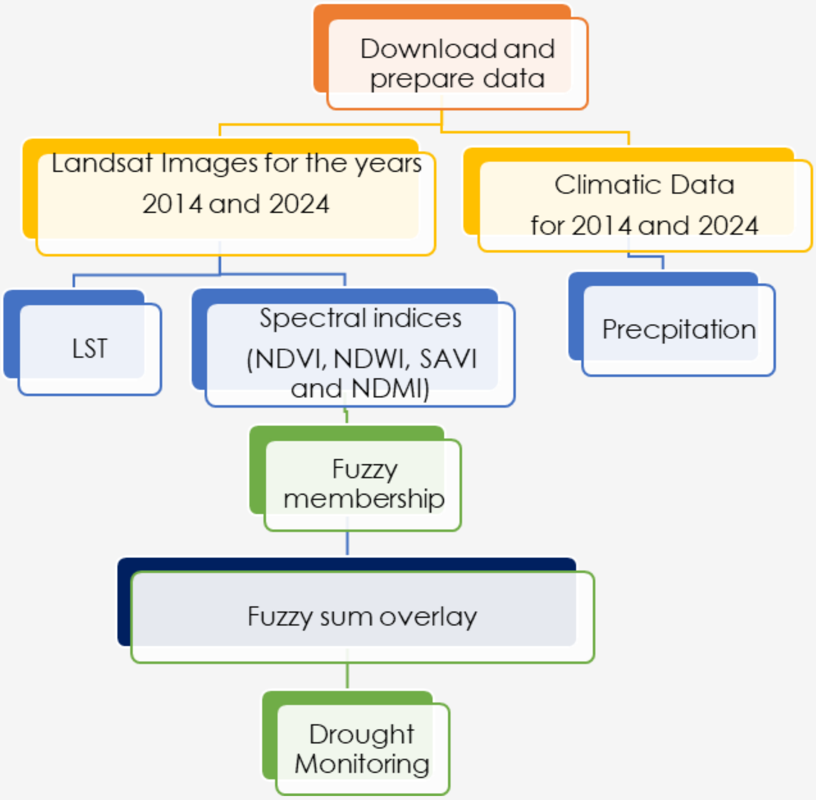

Figure 2: Drought monitoring using fuzzy membership technique

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A comparison of drought indices is conducted by using the spectral indices in the region. The drought indices used in the comparison consist of NDVI, NDMI based on band 1 and band 4, SAVI, NDMI based on band 3 and band 4.

3.1.1 Normalized Difference Vegetation Index (NDVI)

NDVI has been commonly used as Vegetation health indices to evaluate drought situations. It is a simple ratio vegetation index based on the reflectance measurement in the near-infrared and red wavelengths. It operates on the principle that healthy green vegetation absorbs a large amount of red light due to chlorophyll activity and reflects a large amount of near-infrared light due to its cellular structure. The NDVI measures the vigor and greenness of plants and can detect stress on it caused by drought. The NDVI takes values between -1 and +1, where low values correspond to water, barren areas, snow, or clouds while higher values indicate shrub and grasslands, and very high values correspond to temperate or tropical forests. NDVI images were calculated using satellite data from Landsat 8 by Equation 1 [19].

$$NDVI = \frac{Band5 - Band4}{Band5 + Band4}$$

Equation 1

3.1.2 Normalized Difference Water Index (NDWI)

Through NDWI be analyzed the water bodies. NDWI is a stress detection technique used to evaluate drought's effects on agriculture. It has excellent spatial coverage across all terrains and great resolution. Green and near-infrared bands from remote sensing images are used in the index. In most circumstances, the NDWI can effectively improve water information. For Landsat 8 the Equation 2 is used [20]:

$$NDWI = \frac{Band3 - Band5}{Band3 + Band5}$$

Equation 2

Values description: Index values greater than 0.5 are frequently used to indicate water bodies. Vegetation usually corresponds to significantly smaller values, whereas built-up areas often correspond to values between zero and 0.2.

3.1.3 Normalized Difference Moisture Index (NDMI)

NDMI uses a mixture of the short-wave infrared (SWIR) and near-infrared (NIR) spectral bands to determine the amount of moisture in vegetation. It is a trusted sign of agricultural water stress. Extreme drought conditions might ruin the total output in addition to stressing the crops. The temporal evolution of the NDMI during dry years shows that dry years can be easily detected and the NDMI relative value index falls below the reference value. The vegetation water content is ascertained using the NDMI. In the conventional manner, it is computed as a ratio between the NIR and SWIR readings [21]. In Landsat 8, NDMI can calculated by Equation 3:

$$NDMI = \frac{Band5 - Band6}{Band5 + Band6}$$

Equation 3

3.1.4 Soil-Adjusted Vegetation Index (SAVI)

SAVI is especially helpful in regions that are prone to drought since it offers a more precise assessment of vegetation strength [22]. SAVI can be used to separate between the grassland areas with different characteristics depending on the soil types [23]. The SAVI describes the vegetation cover and gives better results in areas with a few vegetation cover and a high spectral soil influence. SAVI can be calculated from Landsat 8 by Equation 4 [24]:

$$SAVI = 1.5\left[\frac{Band5 - Band4}{Band5 + Band4}\right]$$

Equation 4

3.2 Estimation Land Surface Temperature (LST)

Understanding Earth's surface energy balance is essential for predicting climate, weather, and hydrology, and LST is a key indicator in this regard. Remotely sensed data can be used to correctly predict LST. The LST is calculated in Celsius using the Landsat 8 thermal band with a spatial resolution of 100m and the following algorithm [25]. The satellite geometric model is established first. Finally, LST is calculated using the modified mono-window algorithm. As a physical model, there are many factors affecting LST, such as acquisition time, satellite orbit, and view geometry, below are the formulas used to determine land surface temperature. In Landsat 8 LST calculated by Equation 9 [26]:

$$L_\lambda = M_L Q_{cal} + A_L$$

Equation 5

$$BT = \left[\frac{K2}{\ln\left(\frac{K1}{L_\lambda}\right) + 1}\right] - 273.15$$

Equation 6

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$$P_v = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right]^2$$
Equation 7

$$\varepsilon = 0.004P_v + 0.986$$
Equation 8

$$LST = \frac{BT}{1 + 0.00115 \frac{BT}{1.4388} \ln(\varepsilon)}$$
Equation 9

Where: Q_{cal} is digital number of band 10, A_L is the band-specific additive rescaling factor, M_L is the band-specific multiplicative rescaling factor, L_λ is the reflectance at the top of atmosphere. *K1* and *K2* constants, ε is the emissivity, *BT* is the brightness temperature and P_V is the percentage of vegetation.

4. Results and Discussion

4.1 Spatiotemporal Patterns of Indices-Based Drought Conditions

There are two ways that global warming is raising the mean sea level. First, the world's ice sheets and glaciers are melting, filling the seas with water. Second, as the water heats, the ocean's volume is growing [27]. In this study, six layers were used to mapping the drought in Southern Iraq, which is NDVI, NDMI, SAVI, NDWI, LST, and precipitation. All these layers were prepared using ArcGIS 10.3 software. Figure 3 shows the criteria layer for the year 2014, and Figure 4 shows the criteria layer for 2024.

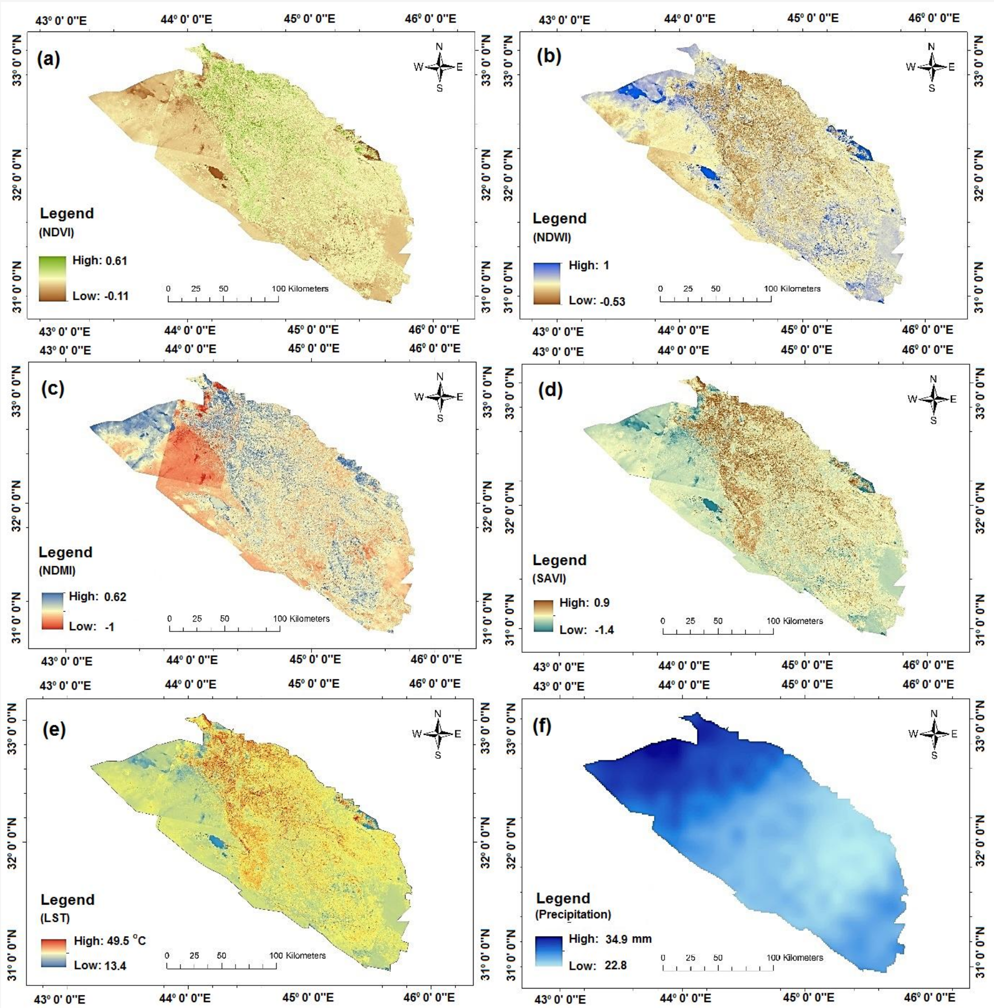

Figure 3: Spectral indices of 2014: (a) NDVI, (b) NDWI, (c) NDMI, (d) SAVI, (e) LST and (f) precipitation

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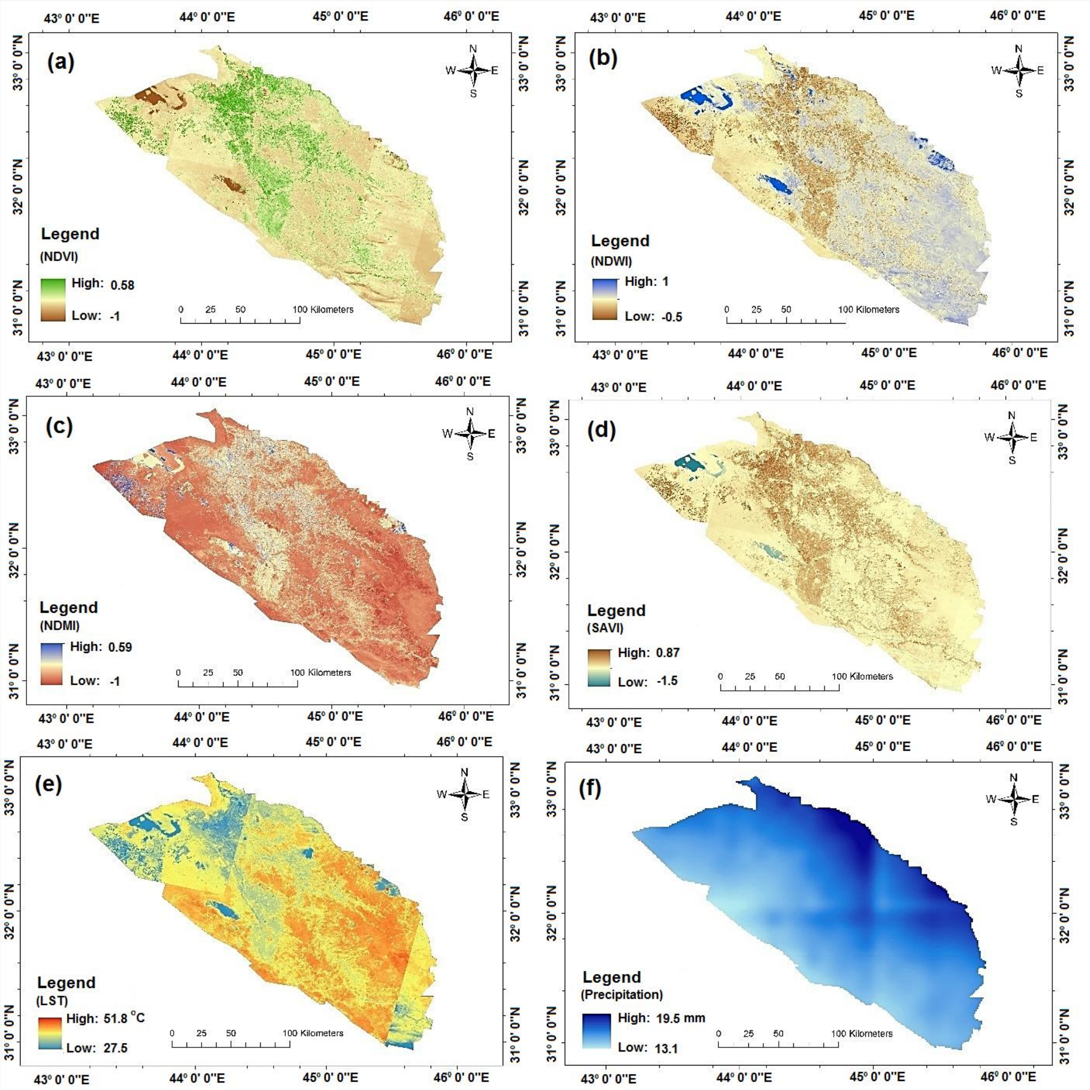

Figure 4: Spectral indices of 2024: (a) NDVI, (b) NDWI, (c) NDMI, (d) SAVI, (e) LST and (f) precipitation

It is notice that the LST in 2014 ranges between 13°C to 49 °C, while in 2024 ranges between 27 °C to 51°C for the same month. Which may be because the climatic change and indicated increased the drought area. Additionally, the monthly seasonal precipitation rate in 2014 is range between 22 mm to 34 mm, while in 2024 ranges between 13 mm to 19 mm, this decrease in the precipitation rate could be affected the vegetation in the study area. The Standardized Precipitation Index (SPI) is widely used because it standardizes precipitation data over time and space, making it easier to compare drought severity across different regions and periods. It provides a statistically robust method by transforming precipitation data into probabilities, which is useful for identifying drought conditions based on historical trends. However, using raw rainfall data alone can still give insights into drought conditions, especially when comparing observed precipitation to long-term averages or thresholds that signal dry periods. Advances in remote sensing have transformed drought monitoring by enabling the use of satellite-derived indices derived from thermal and optical bands and precipitation data [28].

4.2 Drought Map

After preparing the associated factor, all these layers' uniform to a scale between 1 to 0 using Fuzzy Membership function [29], then combined together using Fuzzy overlay function in ArcGIS 10.3 software. The region separated into three categories according to the drought condition, high drought, low drought, no drought.

Table 2: The area and percentage for each drought category

Class	2014		2024		Chanage	
	Area	**%**	**Area**	**%**	**Area**	**%**
High Drought	10,090	36	14,791	54	4,701	+18
Low Drought	8,791	33	10,931	39	220	+6
No Drought	8,486	31	1,645	7	6,841	-24

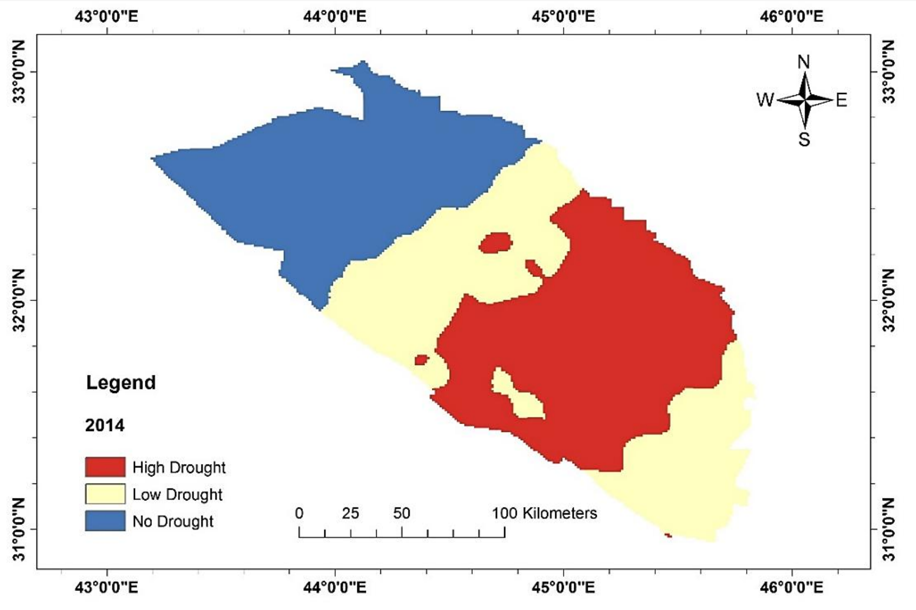

Figure 5: Drought map for the year 2014

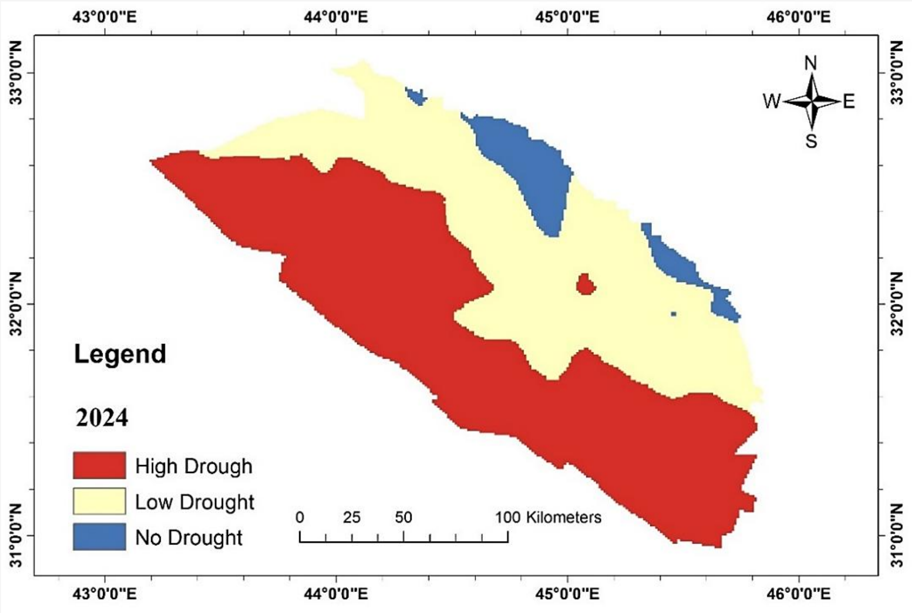

Figure 6: Drought map for the year 2024

Where a value from 0 to 0.3 was given for no drought, from greater than 0.3 to 0.7 for moderate drought, and values ranging from 0.7 to 1 for high drought [30]. The area and percentage for each category were computed as presented in Table 2. Figure 5 shows the drought map for 2014, and Figure 6 shows the drought map for 2024.

For the year 2014, the area of the class high drought, low drought, no drought is 10090 km^2, 8791 km^2, and 8486 km^2 respectively. For the year 2024, the area of the class high drought, low drought, no drought is 14791 km^2, 10931 km^2, and 1645 km^2 respectively. From Table 2 it can be notice that the class high drought increased in 2024 by 18% than 2014. The class low drought increased in 2024 by 6% than 2014. Additionally, the class no drought decreased in 2024 by 24% than 2014. Overall, the research study successfully assessed the effectiveness of remote sensing-based indices in monitoring the drought condition in the southern region of Iraq. Furthermore, the results of the research have important implications for future research and practical applications. Further research should examine potential modifications in the methods of remote sensing-based indices to improve their drought monitoring effectiveness.

Drought is an extended period of months or years when an area experiences a shortage of its water supply. This generally occurs when an area consistently receives below-average precipitation. It can have a significant impact on the ecosystem and agriculture in the affected area. Although droughts can last for several years, severe and short-lived droughts can cause significant damage to the local economy. According to rainfall maps, the study area is considered to be severely arid, based on the amount of seasonal and annual rainfall. The study area falls within the arid zone according to the classification [31], which relied on annual rainfall and temperature. The drought maps for the two years were consistent with the rainfall maps for the region. The northern and northwestern parts of the 2014 drought map were classified as non-drought, while the central and southern parts were classified as either highly or lowly drought (Figure 5), due to the increased rainfall in that area. While a clear decrease in rainfall was observed in the southern parts in 2024, resulting in high drought (Figure 6), on the other hand, a significant increase in rainfall in the central parts of the region, on the basis of which the region was classified as low drought, and a small part of the upper region as non-drought.

5. Conclusions

Drought represents one of the most severe natural hazards, exerting profound impacts on ecosystems, agriculture, and socio-economic systems. This study assessed the effectiveness of remote sensing-based indices in detecting drought conditions in the southern region of Iraq. The indices examined included the Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), Normalized Difference Moisture Index (NDMI), and Normalized Difference Water Index (NDWI), as well as Land Surface Temperature (LST) and precipitation data. The findings revealed that, in 2014, the areas classified as experiencing high drought, low drought, and no drought spanned 10,090 km^2, 8,791 km^2, and 8,486 km^2, respectively. By 2024, these figures shifted to 14,791 km^2, 10,931 km^2, and 1,645 km^2, respectively. Notably, the area experiencing high drought increased by 18% from 2014 to 2024, while low drought areas expanded by 6%, and regions without drought decreased by 24%. These results highlight the growing severity of drought conditions over the decade, emphasizing the value of satellite-based indices in drought monitoring, particularly in semi-arid and arid regions. The demonstrated effectiveness of these indices provides researchers, managers, and decision-makers with reliable tools for assessing and managing drought severity. Remote sensing-based approaches offer substantial advantages in evaluating the temporal dynamics and intensity of droughts, where traditional ground-based data may be limited or unavailable.

6. Limitations and Suggestions

Drought maps are an essential tool for understanding drought dynamics and its impact on the environment and communities. However, limitations related to the lack of sufficient data points in affected areas can reduce the accuracy of these maps and impact the decisions based on them. These limitations include the low spatial density of measuring stations, leading to data gaps in remote areas and the inability to continuously monitor drought developments due to the lack of periodic data. Furthermore, rapid climate changes make it difficult to develop long-term models based on intermittent or limited data. Proposals for future research include increasing the density of measuring points and developing and increasing the number of ground stations in remote or critical areas. Improving data integration and creating more advanced models that integrate satellite and ground station data are also recommended. Relying on artificial intelligence and machine learning to estimate missing data and analyze patterns.

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