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Research paper

Assessment of agricultural and meteorological drought in Southern Iraq's wetlands using Vegetation condition and Drought indices

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ABSTRACT

The southern Iraq's wetlands face many challenges that affect their environment and the livelihoods of local communities, including the problem of drought. This study aims to evaluate both meteorological and agricultural drought conditions within the marshland regions over a four-decade span (1984, 1994, 2004, 2014, and 2024). Satellite imagery from the Landsat multispectral scanner (MSS), Thematic mapper (TM), Enhanced thematic mapper (ETM), Landsat 8 and Sentinel-2 was employed to derive the vegetation condition index (VCI) to assess agricultural drought and climatic data were used to derive reconnaissance drought index (RDI) to assess meteorological drought. The result showed that the severity of the meteorological droughts increased over the period. In 1984, most of areas were under no drought condition while in 2024, most of the areas were under moderate to severe drought condition. The study also revealed that there was mild meteorological drought in 1994, but the agricultural drought conditions was severe and extreme. Overall, it suggests that the climate change and water scarcity have exacerbated agricultural drought condition in the region.

Keyword: Drought, Iraq's wetlands, Reconnaissance drought index (RDI), Remote sensing, Vegetation condition index (VCI).

The Mesopotamian Marshes of Iraq, spanning an area of approximately 20,000 square kilometers, are a unique wetland ecosystem of exceptional ecological importance. They constitute a rich biodiverse habitat, containing endemic plant and animal species, and have played a pivotal role in shaping the cultural and economic identity of the Arab Marsh Arabs for thousands of years. (Al-Maarofi, 2015). The Mesopotamian marshes have been subjected to severe environmental degradation due to a combination of natural factors and human interventions. The construction of dams and the implementation of extensive drainage projects during the late 20th century significantly reduced water flow, resulting in the destruction of ecological habitats, a decline in biodiversity, and a direct threat to traditional livelihoods in the region. (Al-Quraishi & Kaplan, 2021) these marshes served as the floodplains of the Tigris and Euphrates rivers, and they are currently connected to these rivers via surface water feeder canals. Historically, the Mesopotamian marshes received consistent flood pulses during the spring season from

March to May. In recent decades, however, several large dams have been constructed in the Tigris and Euphrates basins for irrigation purposes and power generation, severely altering the flow regime, which along with other direct anthropogenic activities, has severely degraded the marsh ecosystem. This work quantifies changes in the riverine flow regime and how they have affected the hydro-pattern of the western Mesopotamian marshes (focusing on the western Al-Hammar marsh. In the face of climate change, scarce water resources, and political instability, Iraq's marshes face significant challenges that hinder their rehabilitation. This requires concerted efforts at the local, national, and international levels to ensure their sustainable management. (Jabbar *et al.*, 2010). Data recorded by the MODIS satellite between 2000 and 2012 show the extent of the degradation of the Mesopotamian marshes over the past twelve years, confirming the harmful effects caused by human activities. (Abdullah & Abduljabbar, 2020).

Drought is a natural phenomenon that can occur in various

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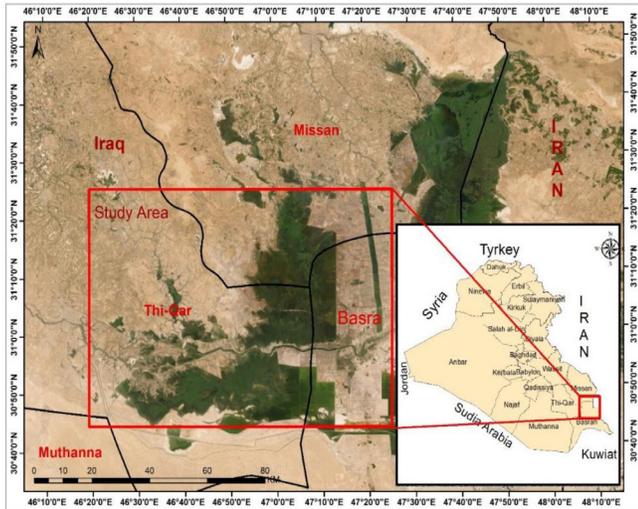


Fig. 1: Map of the study area (Iraqi marshes)

climates, and its characteristics vary depending on geographic location. Drought occurs when rainfall amounts fall below normal levels over a specific period of time, resulting in multiple negative effects. (Mansoor & Chung, 2024). A long-term lack of rainfall that results in a decline in vegetation and a shortage of groundwater is referred to as a drought from the perspective of cause and effect. It is typically associated with meteorological variables such as high temperature, high wind, and low relative humidity. These elements have the potential to exacerbate drought in many parts of the planet (Coco, 2007). It's also critical to distinguish between dryness and drought. Drought is a transient phenomenon linked to a decrease in precipitation. Water and plant resources are frequently lost as a result of it. An arid region's constant characteristic—dryness—is a product of its climate (Chopra, 2006). Remote sensing employs satellite or aerial imagery to generate diverse spatial data, providing valuable information on metropolitan areas, land use patterns, vegetation cover, water bodies, and various regional utilities (Abood *et al.*, 2024). Numerous studies worldwide have examined drought and environmental changes, focusing on issues such as shifting rainfall patterns, increasing temperatures, soil moisture decline, and the resulting effects on agriculture, ecosystems, and water availability, such as (Abbood *et al.*, 2025; Patil *et al.*, 2024 ; Pandya *et al.*, 2022; Khalaf & Mohammed, 2024). This study aims to evaluate both meteorological and agricultural drought conditions within the southern marshland regions of Iraq over a four-decade span (1984-2024).

MATERIALS AND METHODS

Study area

The study area is the southern marshes of Iraq; It is located between (46° 20' 0" E to 47° 25' 0" E) longitude and (30° 45' 0" to 31° 25' 0") latitude. They are located in the governorates including Basra, Missan and Thi Qar with an approximate area of 10.000 km² (Fig. 1). The marshes are generally bordered to the east by the borders of the Islamic Republic of Iran (via Hawizeh Marsh) and to the south by Eastern Hammar Marsh and the Arabian Gulf. The climate of the marshlands in southern Iraq is characterized by

Table 1: Monthly rainfall and temperature of the study area (1984-2024)

Month	Average rainfall (mm)	Average temperature (°C)
January	22.3	12.2
February	15.2	15.1
March	20.4	21.2
April	11.1	26.3
May	4.2	32.1
June	0.0	37.2
July	0.0	38.1
August	0.0	38.4
September	0.5	34.3
October	5.3	28.2
November	21.1	20.1
December	21.4	14.3

a semi-arid to arid climate, with long, extremely hot summers and short, mild winters. Summer temperature values range between 37 and 38 °C (Table 1).

Data and methodology

Satellite imagery from the Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper (ETM), and Landsat 8 was acquired from (<http://earthexplorer.usgs.gov>) and Sentinel-2 image was acquired from (<https://dataspace.copernicus.eu>). The study area is covered by four Landsat scenes, corresponding to Path/Row combinations: 167/38, 166/38, 167/39, and 166/39. Multispectral Landsat imagery was acquired during four-time scale: 1984, 1994, 2004, and 2014, for MSS, TM, ETM, and Landsat 8, respectively. While Sentinel-2 image was acquired during 2024. All images were captured between January and December for each year. A total of 240 images were collected and utilized. The climatic data comprised of monthly mean temperature, rainfall, and evaporation were acquired from the Iraqi Meteorological and Seismology Organization (IMSO) and NASA's climate archives (<https://power.larc.nasa.gov>) for four meteorological stations (Samawah, Thi Qar, Missan, and Basra) over a 40-year period spanning from 1984 to 2024.

Agricultural drought characterization

The vegetation condition index (VCI) was used to categorize the agricultural drought as described by Gaikwad (2015). Satellite imagery was utilized to derive the normalized difference vegetation index (NDVI) for five discrete years (1984, 1994, 2004, 2014, and 2024), representing decadal intervals within the 40-year study period, as given in following equation;

$$NDVI = (\rho. NIR - \rho. RED) / (\rho. NIR + \rho. RED)$$

Where: $\rho. RED$ and $\rho. NIR$ are the red and near infrared reflectance band respectively. The value of NDVI ranges between -1 and +1. Using NDVI values vegetation condition index (VCI) were computed.

Table 2: Classes of VCI and RDI drought indices

Agricultural/ meteorological drought classes	Vegetation condition index (VCI)	Reconnaissance drought index (RDI)
Extremely	<10	<= -2
Severely	<20	-1.5 to -1.99
Moderately	<30	-1 to -1.49
Mild	<40	0 to -0.99
No drought	>=40	> 0

Table 3: Percentage distributions of area under agricultural drought severity classes in different years

Agricultural drought	1984	1994	2004	2014	2024
Extreme	2.8	68.7	5.5	8.5	16.9
Severe	1.5	17.6	51.7	34.8	55.6
Moderate	9.9	6.1	25.4	29.5	17.9
Mild	18.1	3.7	12.7	19.8	7.5
No drought	67.6	3.9	4.8	7.3	2.1

$$VCI = ((NDVI - NDVI_{min.}) / (NDVI_{max.} - NDVI_{min.})) \times 100$$

Where, NDVI_{max} and NDVI_{min} stand for the maximum and minimum NDVI values of each pixel. The VCI value ranges from 0 to 100, representing the maximum and minimum dynamics of vegetation phenology (Uttaruk & Laosuwan, 2017). Relative variations in moisture condition from very poor to ideal are reflected in the VCI index. Vegetation that is healthy and not under stress has high VCI values. The different classes of agricultural drought based on VCI are presented in Table 2. Consequently, the computed VCI values represent vegetation condition relative to the selected years and are suitable for comparative inter-decadal analysis of vegetation condition among the chosen periods.

Meteorological drought characterization

The meteorological drought was categorized using reconnaissance drought index (RDI) as described by Shah *et al.* (2013). This index depends on the proportion between accumulated amounts of precipitation and potential evapotranspiration (ET). To compute RDI index, it is first necessary to compute the RDI initial value ($\alpha_k^{(i)}$) as following formula:

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^k R_{ij}}{\sum_{j=1}^k ET_{ij}}, \quad i=1 \dots N \text{ and } j=1 \dots K$$

Where: R_{ij} and ET_{ij} are precipitation and potential evapotranspiration of the jth month of the ith year. Also, N as the number of years and k as 1 to 12 months.

After that, the Standardized RDI (RDIST) is calculated, using the following equation for each year.

$$RDIST^i = \frac{y_k^i - A(y^k)}{\sigma y^k}$$

Where, y_k^i is the ln ($\alpha_k^{(i)}$), $A(y^k)$, is the average and σy^k is the standardized deviation. The Thornthwaite method was used

to estimate ET (Saleh *et al.*, 2020) the spatial distribution of the precipitation in Iraq were reviewed, as it is considered as one of the most important parameters that controls groundwater recharging. In addition, the physiographical divisions of Iraq had been assessed as it is contributing in determining the groundwater aquifers, as well as a review of the division of the main groundwater aquifers. Subsequently, a review of the level and depths of groundwater, the regional trends of its flow, the variation of its specific quality (especially salinity). The RDI index classes were categorized as indicated in the Table 2 (Tsakiris *et al.*, 2007).

The spatial drought profiles were developed using geographic information system (GIS) techniques. The Inverse Distance Weighted (IDW) interpolation method by ArcGIS 10.8 software was applied to generate continuous spatial maps, allowing for effective visualization and analysis of meteorological drought distribution patterns across the study region. The percent area under each category of drought were computed and presented.

RESULTS AND DISCUSSION

Spatial and temporal variation in agricultural drought

The temporal assessment of agricultural drought severity across five selected years (1984, 1994, 2004, 2014, and 2024) reveals significant spatial and temporal variability (Fig. 2). Table 3 present the percentage drought areas classified by severity. The area affected by extreme drought showed significant fluctuation, starting at 2.8% in 1984, peaking dramatically at 68.7 % in 1994, then decreasing to 5.5 % in 2004, and subsequently rising again to 16.9 % by 2024. Severe drought area increased substantially from 1.5 % in 1984 to 55.6% in 2024, with notable peaks in 2004 and 2014. Moderate drought areas varied over the years, with a high of 29.5% in 2014 and a low of 6.1% in 1994. Mild drought showed a decreasing trend overall, peaking at 19.8% in 2014 but dropping to 7.5% in 2024. The area with no drought conditions shrank drastically from 67.6 % in 1984 to only 2.1% in 2024, indicating an overall increase in drought prevalence across the study period. The extent of agricultural drought showed significant variation over the decades. In 1984, the area affected by drought was relatively small, reflecting more stable water availability. However, by 1994, there was a dramatic increase in drought-affected lands, largely attributed to political decisions that led to the deliberate reduction of water flow from the Tigris and Euphrates rivers into the study area. This disruption severely limited the natural replenishment of soil moisture and nutrients, exacerbating drought conditions and negatively impacting agricultural productivity.

Spatial and temporal variation in meteorological drought

The spatial distribution of reconnaissance drought index (RDI) based meteorological drought classified under different categories for different years are presented in Fig. 3. The results reveal a significant increase in atmospheric drought over the past two decades. The findings indicate a pronounced intensification of meteorological drought in 2024, when drought severity reached its peak, directly impacting the region. In 1984, 80.4% area was under no drought condition, in 1994 it reduced to 40.2% and in

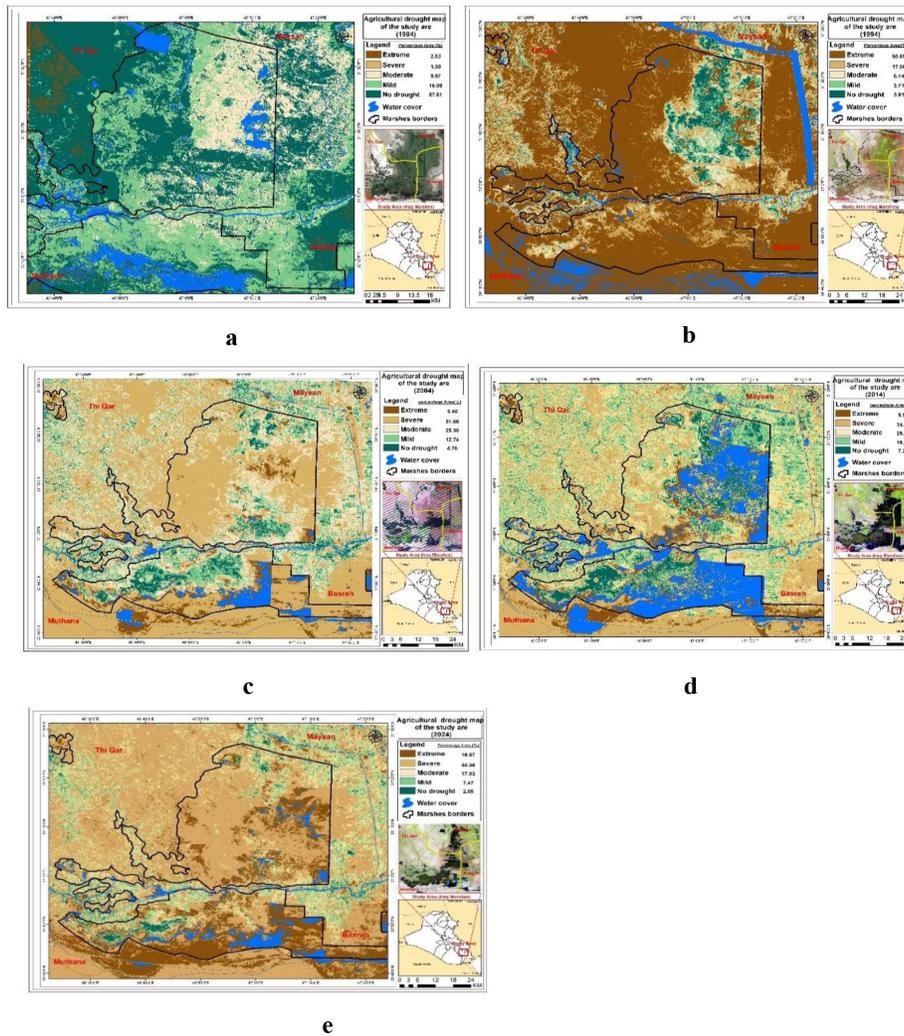


Fig. 2: VCI based agricultural drought maps of the study area (a) 1984, (b) 1994, (c) 2004, (d) 2014, and (e) 2024

Table 4: Percentage distributions of area under meteorological drought severity classes in different years

Meteorological drought	1984	1994	2004	2014	2024
Extreme	0.0	0.0	0.0	0.0	0.0
Severe	0.0	0.0	0.0	22.3	76.1
Moderate	0.0	0.0	45.4	78.2	24.3
Mild	20.1	60.3	55.1	0.0	0.0
No drought	80.4	40.2	0.0	0.0	0.0

subsequent years drought classes shifted to moderate and severe conditions as shown in Table 4. This escalation is strongly linked to observable climate change trends in the area. The results show that both meteorological and agricultural droughts are happening, which need serious action to stop further damage. These droughts threaten food security for people in the region. The study also points out how important it is to use remote sensing, GIS, and environmental models to understand Iraq’s southern wetlands. Without action and better water management, these marshes will keep getting worse, harming the environment and the people who depend on them.

CONCLUSION

The temporal analysis of drought severity from 1984 to 2024 revealed marked spatial and temporal variability in the study area. Severe and extreme agricultural drought conditions expanded significantly. While regions of no drought declined from 67.6% in 1984 to only 2.1% in 2024, reflecting an overall intensification of aridity. The exceptional drought recorded in 1994 was primarily driven by political actions that reduced the inflow of water from the Tigris and Euphrates rivers, leading to soil moisture depletion and reduced agricultural productivity. Meteorological drought assessment using the RDI index indicated a continuous rise in meteorological drought, particularly evident in 2024, consistent with ongoing climatic changes. The concurrent occurrence of meteorological and agricultural drought highlights growing environmental pressure and the urgent need for adaptive water management. The 1994 event illustrates how human-induced factors can intensify drought conditions beyond natural climatic influences, threatening ecological balance and food security.

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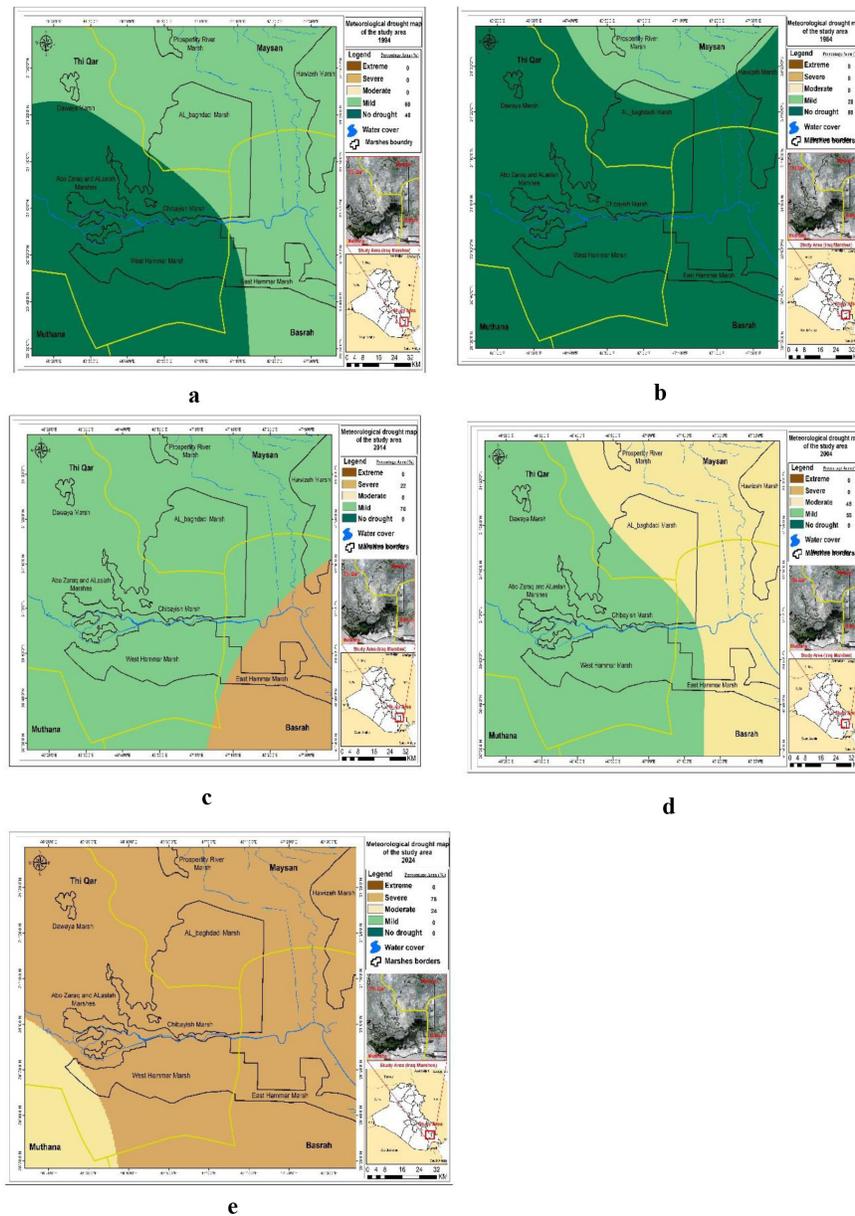


Fig. 3: RDI based meteorological drought maps of the study area (a) 1984, (b) 1994, (c) 2004, (d) 2014, and (e) 2024

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Authors' contribution: **F. T. Dakhil:** Data curation, Formal analysis, and Writing-original draft, Methodology; **N. B. Sabtu:** Methodology, Investigation, review, editing, and Supervision; **A. G. Khalaf:** Investigation, Writing-review and editing, Formal analysis, Supervision.

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