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Assessment of Vegetation Cover Quality and Health Using Spectral Drought Indices

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ABSTRACT

This study aims to assess the quality and health of vegetation cover in Thi-Qar Governorate using spectral drought indices (NDVI, VCI, TCI, and VHI) derived from satellite imagery for the period 1990–2023. The objective is to diagnose the dynamics of vegetation condition and to monitor the intensity of water and thermal stress in arid and semi-arid environments. Remote sensing data were analyzed using Landsat satellite images (TM, ETM+, and OLI) within a Geographic Information Systems (GIS) environment to identify the spatial and temporal changes in the spectral indices. The results showed that vegetation indices (NDVI) indicated the dominance of very severe and severe degradation levels over large areas, reaching a peak in 1990 with an area of 98.77 km² (99.64%), reflecting the region's exposure to recurrent drought events and weak vegetation regeneration. The Vegetation Condition Index (VCI) revealed the prevalence of very severe drought classes in most years, reaching 54.66% in 1990 and 92.62% in 2018. Meanwhile, the Thermal Condition Index (TCI) showed a marked increase in thermal stress, peaking in the years 1990, 1996, and 2023, with an affected area exceeding 60 km² (>60%) of the total study area. The Vegetation Health Index (VHI) reflected clear environmental degradation, as the area classified as very severe drought reached 59.34 km² (59.86%) in 2023. These findings indicate that Thi-Qar Governorate suffers from high environmental fragility and extreme sensitivity to climatic variations. The dynamics of vegetation cover are directly affected by thermal and moisture drought factors and by fluctuations in rainfall. The study recommends the implementation of rehabilitation and integrated management programs based on increasing permanent vegetation cover, rainwater harvesting, and improving soil properties to limit vegetation degradation and enhance its sustainability.

Keywords: Spectral drought indices, vegetation health, NDVI, VCI, TCI, VHI, Thi-Qar, Geographic Information Systems (GIS).

INTRODUCTION

Vegetation cover is one of the most vital components of the terrestrial ecosystem, serving as a visible indicator of the health and stability of ecological systems across various environments, particularly in arid and semi-arid regions. It reflects the interactive relationship among key environmental elements—soil, climate, and water—and contributes to their equilibrium by regulating the hydrological cycle, fixing carbon, reducing wind and water erosion, and maintaining soil fertility and sustainability.

Soil, in turn, represents the fundamental substrate upon which vegetation develops, as its physical, chemical, and fertility characteristics determine the plant's capacity for water and nutrient uptake. Soils rich in organic matter, with medium texture and stable structure, enhance the plant's resilience to climatic stress. In contrast, sandy or saline soils inhibit vegetation growth and increase its susceptibility to degradation (FAO, 2022; Mohammed et al., 2023). Disturbance of the balance between soil and climate often leads to vegetation loss and its replacement by impoverished desert forms, which is a key indicator of the onset of environmental desertification processes (Al-Timimi et al., 2025).

Arid and semi-arid regions—such as Thi-Qar Governorate in southern Iraq—are increasingly exposed to environmental pressures stemming from climate change, rainfall variability, rising temperatures, and frequent dust storms. These factors have negatively affected soil quality and fertility, leading to a decline in both natural and agricultural vegetation cover. The soils of these regions are characterized by high salinity, weak structural aggregation, and low organic matter content—conditions that reduce plant biological efficiency and heighten its sensitivity to agricultural drought. These environmental constraints are further compounded by anthropogenic pressures such as overgrazing, poor water management, and unregulated agricultural expansion, all of which contribute to accelerated land degradation and desertification (IPCC, 2021; Al-Mashhadani et al., 2023).

Given these complex environmental conditions, remote sensing (RS) and Geographic Information Systems (GIS) have become indispensable tools for evaluating the interactions between soil, vegetation, and climate. Spectral indices allow for monitoring spatial and temporal variations in vegetation growth and its response to environmental stress. Among the most widely utilized indices are the Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI), which serve as precise quantitative tools for assessing agricultural drought and vegetation health (Kogan, 1995; Rhee et al., 2010).

Notably, the VHI integrates vegetation moisture response (VCI) with thermal stress (TCI), thereby providing a comprehensive assessment of vegetation stress resulting from climatic variability and soil conditions. Recent studies have demonstrated that applying these indices in arid and semi-arid environments allows for accurate assessment of vegetation degradation processes, supports the prediction of future stress hotspots, and informs sustainable land management programs (Zeng et al., 2023; Susila et al., 2024; Adewuyi et al., 2025).

Accordingly, this research aims to assess the quality and health of vegetation cover in Thi-Qar Governorate using NDVI, VCI, TCI, and VHI derived from remote sensing and spatiotemporal analyses. Particular emphasis is placed on examining the role of soil physical and chemical properties in shaping vegetation responses to thermal and moisture stress. The study further seeks to identify high-sensitivity agricultural drought zones and propose sustainable soil and vegetation management strategies that can mitigate desertification and enhance environmental stability in the region.

MATERIALS AND METHODS

The study area is located in the northern part of Thi-Qar Governorate in southern Iraq, between latitudes 31°47'30"–31°53'30" N and longitudes 45°34'00"–45°50'30" E, with a total area of 99.12 km². The region is characterized by an arid to semi-arid climate, with annual rainfall ranging between 27–245 mm, and a mean annual temperature of 26°C. Summer temperatures frequently exceed 40°C, particularly during July and August. The dominant soil textures are sandy and sandy-loam, accompanied by extensive salinization and surface exposure—conditions that make the area suitable for studying vegetation dynamics under continuous drought stress.

The climate of the study area exhibits a dry continental desert nature with pronounced seasonal variation and extreme thermal fluctuations. Climate data (Table 1) indicate the presence of two major climatic cycles: a short, cool, wet winter and a long, hot, dry summer.

1. Rainfall

Rainfall is concentrated in the winter season, particularly in November (99.5 mm) and December (74.7 mm), which represent the peak of the rainy period. Rain is nearly absent during the summer months (May–September), indicating a dominant dry-summer pattern that limits natural vegetation regeneration. The annual average rainfall in the early wet months is approximately 20 mm, with minimum values reaching 0.0 mm during complete drought months—classifying the region as semi-arid to extremely arid.

2. Temperature

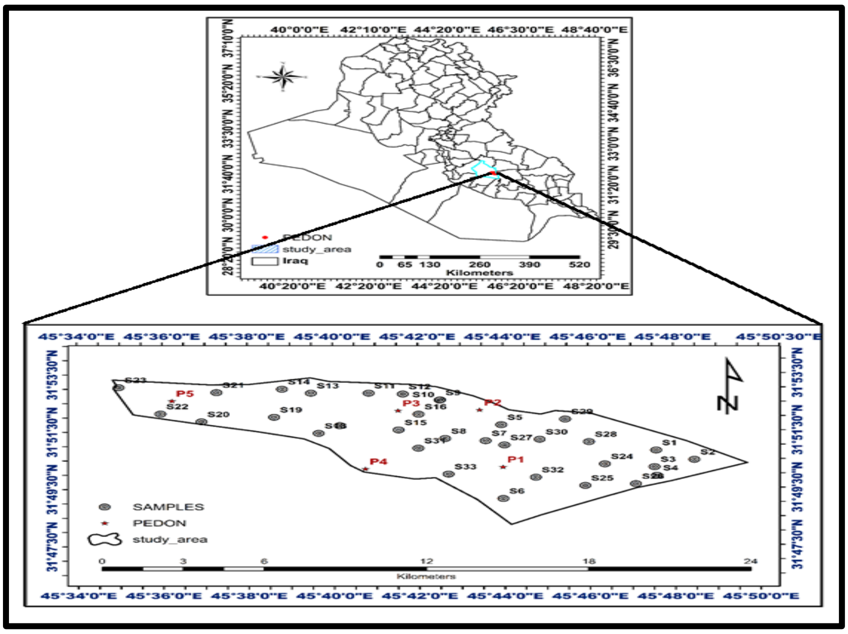
Monthly values show a wide thermal range: minimum temperatures vary between –5.0°C in January and 25.0°C in July, demonstrating severe winter cold that occasionally falls below freezing, contrasted with persistent summer heat with little nocturnal cooling. Such conditions typify continental climates lacking moderating marine influences.

Maximum temperatures (Tmax) reach exceptionally high values in July and August (up to 52.4°C), exceeding 45°C in most summer months. These represent extreme levels capable of generating substantial environmental and agricultural thermal stress. Winter maximum temperatures are relatively moderate, ranging between 23–27°C.

3. Mean Temperature (Tmean)

The mean temperature ranges from 11.1°C in January to 38.7°C in July and August, reflecting strong thermal seasonality. This results in high evaporation rates, reduced atmospheric moisture efficiency, and increased likelihood of climatic drought and desertification.

Collectively, these climatic characteristics demonstrate that the study area is exposed to severe environmental pressures resulting from low rainfall, high temperatures, and fluctuating relative humidity. These conditions contribute to high ecological sensitivity, environmental degradation, and instability in both natural and agricultural vegetation cover.



الشكل (1) خريطة موقع الدراسة بالنسبة للعراق واحداثيات النمذجة

جدول (1) البيانات المناخية لمنطقة الدراسة للفترة (1992– 2024)

		JAN	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des
Rainfall	Min	1.3	1.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Max	64.6	47.6	48.7	43.6	46.2	4.4	7.3	0.2	6.7	62.0	99.5	74.7
	Mean	22.8	15.3	16.3	12.4	6.9	0.2	0.3	0.0	0.4	6.6	18.9	17.3
Tmin	Min	-5.0	-3.9	0.0	4.6	14.1	21.8	25.0	24.4	18.7	11.0	0.9	-3.9
	Max	3.9	5.3	8.9	14.1	22.2	26.9	30.1	30.1	25.8	20.3	12.4	6.7
	Mean	-0.8	0.8	5.3	10.8	18.2	24.4	27.5	27.3	22.1	15.6	6.2	1.3
Tmax	Min	18.1	23.4	28.1	35.4	42.7	45.7	46.9	47.8	44.4	38.9	29.2	19.7
	Max	27.7	31.4	42.3	43.5	49.0	51.3	52.4	51.8	49.7	44.7	36.7	28.6
	Mean	23.0	27.1	33.7	40.4	46.0	48.7	50.0	50.1	47.3	41.6	32.8	24.8
Tmean	Min	7.0	10.9	14.3	21.6	29.2	34.6	36.2	36.1	32.3	26.1	15.7	8.0
	Max	15.8	17.7	25.6	27.7	34.6	38.8	40.9	40.5	37.1	31.7	23.2	17.6
	Mean	11.1	14.0	19.5	25.6	32.1	36.5	38.7	38.7	34.7	28.6	19.5	13.0
Wind Velocity	Min	2.5	2.8	3.0	3.0	3.3	3.5	3.4	3.1	2.8	2.7	2.6	2.3
	Max	3.6	4.0	4.0	4.1	4.3	4.8	4.6	4.2	4.0	3.7	3.5	3.2
	Mean	3.1	3.3	3.5	3.6	3.8	4.0	4.0	3.6	3.4	3.1	3.0	2.9
Humidity %	Min	41.8	37.3	26.6	20.5	13.3	11.2	10.3	11.6	11.7	17.1	23.9	33.7
	Max	69.4	60.4	51.9	45.7	37.7	17.1	15.6	16.6	19.7	36.6	71.2	69.6
	Mean	57.8	50.5	39.3	31.0	21.2	13.7	13.1	13.6	15.7	24.0	43.2	55.2

Satellite Imagery: There are numerous spectral indices related to assessing soil conditions, vegetation cover, and the influence of climatic factors on the expansion of desertified lands and the monitoring of recurring drought episodes. Several of these indicators were employed in the present study, supported by a set of satellite images that served the study's objectives. A number of satellite scenes were used, as shown in **Table (3)**.

Table (3): Satellite imagery used in the study.

Satellite	Sensor	Date	Satellite	Sensor	Date
Landsat-5	TM*	1990-05-17	Landsat-5	TM*	2003-05-13
Landsat-5	TM	1991-05-04	Landsat-5	TM	2014-05-03
Landsat-5	TM*	1993-05-25	Landsat-5	TM*	2016-04-22
Landsat-5	TM	1995-05-12	Landsat-5	TM	2018-04-28
Landsat-5	TM*	1996-05-17	Landsat- 8	OLI*	2020-05-03
Landsat-5	TM	1997-05-20	Landsat- 8	OLI	2021-05-06
Landsat-7	ETM*	1998-05-07	Landsat- 8	OLI*	2022-05-13
Landsat-7	ETM	2000-05-4	Landsat- 8	OLI	2023-05-12
Landsat-5	TM*	2002-02-26	Landsat- 9	OLI*	2024-05-14

Spectral Drought Indices

Spectral indices are among the most important tools used for monitoring vegetation conditions and assessing agricultural drought severity based on satellite data. The Normalized Difference Vegetation Index (NDVI), developed by NASA (Tucker, 1979), is one of the earliest and most widely applied indices for evaluating vegetation vigor through the spectral contrast between the red (RED) and near-infrared (NIR) bands. NDVI values range from –1 to +1, where higher values indicate dense, healthy vegetation, whereas low or negative values represent bare soil, degraded land, or water bodies.

1. Normalized Difference Vegetation Index (NDVI)

Equation (20):

NDVI=(NIR−RED)(NIR+RED)\text{NDVI} = \frac{(NIR - RED)}{(NIR + RED)}NDVI=(NIR+RED)(NIR−RED)

2. Vegetation Condition Index (VCI)

The VCI is widely used to determine vegetation stress by comparing current NDVI values to long-term historical minima and maxima for the same period. This comparative approach allows for identifying drought severity relative to previous years (Kogan, 1995). The index ranges from 0 to 100, where values below 40% indicate severe drought conditions, while higher values reflect healthier vegetation.

Equation (21):

VCI=100×(NDVI−NDVImin)(NDVImax−NDVImin)\text{VCI} = 100 \times \frac{(NDVI - NDVI_{\min})}{(NDVI_{\max} - NDVI_{\min})}VCI=100×(NDVImax−NDVImin)(NDVI−NDVImin)

3. Land Surface Temperature (LST)

Land Surface Temperature is a key parameter for drought estimation because it is inversely related to soil and vegetation moisture—decreasing moisture levels typically result in elevated surface temperatures. LST derived from satellite thermal bands enables detection of spatial and temporal thermal variations and supports composite drought assessments (Sandholt et al., 2002).

Equation (22):

(Generalized single-channel LST formula)
LST=TB1+(Lλ×TB14380)ln(ε)−273.15\text{LST} = \frac{TB}{1 + \left(\frac{L_\lambda \times TB}{14380}\right) \ln(\varepsilon)} - 273.15LST=1+(14380Lλ×TB)ln(ε)TB−273.15
Where:

- **TB** = at-sensor brightness temperature (Kelvin)
- **LλL_\lambdaLλ** = spectral radiance
- **ε\varepsilonε** = surface emissivity

4. Temperature Condition Index (TCI)

The TCI is employed to detect thermal stress by comparing the current LST to the historical maximum and minimum temperatures for the same period. Low TCI values indicate high thermal stress, whereas high values signify more favorable thermal conditions for vegetation (Kogan, 1995).

Equation (24):

TCI=100×(LSTmax⁡−LST)(LSTmax⁡−LSTmin⁡)\text{TCI} = 100 \times \frac{(LST_{\max} - LST)}{(LST_{\max} - LST_{\min})}TCI=100×(LSTmax−LSTmin)(LSTmax−LST)

5. Vegetation Health Index (VHI)

The VHI is a composite index that integrates both VCI (moisture-related stress) and TCI (thermal stress), providing a comprehensive assessment of vegetation health under combined climatic pressures (Kogan, 1997; Guttman, 1998). VHI values range from 0 to 100, where values below 40 indicate varying degrees of drought severity, while higher values represent healthier vegetation.

Equation (25):

VHI=a(VCI)+(1−a)(TCI)\text{VHI} = a(\text{VCI}) + (1 - a)(\text{TCI})VHI=a(VCI)+(1−a)(TCI)

The parameter **a** ranges from 0 to 1 and is commonly set to 0.5 to ensure equal weighting of thermal and moisture components (Kogan, 2000).

$$VHI = a\,VCI + (1 - a)\,TCI \qquad \dots\dots\dots\dots\dots\dots (25)$$

Table (2): Classification of Drought (VHI)

DROUGHT CLASSES	VHI values
Very sever	**<10**
Sever	**10-20**
moderate	**20-30**
Slightly	**30-40**
No drought	>40

Calculation of the Environmental Sensitivity to Desertification (ESA) Index

The Environmental Sensitivity to Desertification (ESA) index is an assessment tool used to identify areas most susceptible to desertification by combining multiple environmental, geological, and climatic factors. The approach integrates spatial data such as soil type and quality, slope, vegetation cover, and climatic indicators using Geographic Information Systems (GIS) to produce maps that classify land according to its susceptibility (e.g., low, moderate, high). This method supports evidence-based natural-resource management and targeted desertification mitigation strategies (Giordano & Sirangelo, 2011).

In this study, the ESA index was computed from three sub-indices representing the main drivers of sensitivity:

- **SQI** — Soil Quality Index (e.g., texture, salinity, organic matter, structure)
- **CQI** — Climate Quality Index (e.g., rainfall, rainfall variability, temperature extremes)
- **VQI** — Vegetation Quality Index (e.g., vegetation cover, NDVI-derived condition)

The composite ESA index is calculated as the geometric mean of these three sub-indices, according to the following equation (see Tables 13 and 14 for scoring and class boundaries):

Equation (35):

ESA_index=(SQI×CQI×VQI)13\text{ESA_index} = \bigl(SQI \times CQI \times VQI\bigr)^{\tfrac{1}{3}}ESA_index=(SQI×CQI×VQI)31

Using the geometric mean ensures that a low score in any one component (soil, climate, or vegetation) has a proportionate effect on the overall sensitivity score, which is appropriate given the multiplicative interactions among these factors.

After computing the ESA index for each spatial unit, values are classified into sensitivity categories (for example: Low, Moderate, High, Very High) using the thresholds defined in Tables 13 and 14. The resulting map of ESA classes is produced in a GIS environment to visualize spatial patterns of desertification risk and to prioritize areas for mitigation and restoration interventions.

Table (3): Ranges of Soil, Vegetation, and Climate Quality Indicators in the Environmental Sensitivity to Desertification Index (ESAI)

الدليل	الصنف	المدى	الوصف
دليل نوعية الغطاء النباتي VQI	1	أقل من 1.13	نوعية عالية
	2	1.45_1.13	معتدلة النوعية
	3	أكبر من 1.45	نوعية منخفضة

RESULTS AND DISCUSSION

Spectral Drought Indices

Vegetation Condition Index (VCI)

The Vegetation Condition Index (VCI) is one of the advanced spectral indicators that reflects relative changes in vegetation conditions based on normalized difference vegetation index (NDVI) values over a defined time period. This indicator converts NDVI values into a relative scale ranging between 0 and 100, where lower values indicate moisture stress and drought conditions, while higher values reflect healthy and stable vegetation (Kogan, 1995; Kogan et al., 2019).

The results for Dhi Qar Governorate (the study area) show that the region has experienced a clear decline in vegetation vitality, with very severe and severe drought classes dominating during multiple periods across the study timeline. This indicates high environmental sensitivity to climatic fluctuations and changes in surface moisture.

The largest area classified as very severe drought was recorded in 1990, reaching about 54.18 km² (54.66%), as shown in Figures (95–96). Meanwhile, the area classified under severe drought expanded during the years 1990, 1994, 1996, 2016, 2018, and 2020, reaching (42.31, 78.95, 46.40, 53.94, 91.63, 40.41) km² with percentages of (42.69, 46.40, 46.81, 54.42, 92.62, 41.23)%, respectively, as illustrated in Figures (96, 98, 100, 106, 108, 110). These values suggest that recurring drought waves—linked to reduced rainfall and increasing evapotranspiration—were the dominant factor shaping vegetation dynamics during most study years.

The moderate drought class recorded fluctuating areas during 1994, 1996, 1998, 2014, 2016, and 2020, ranging between 19.23–92.12 km² (39.47–92.94%), indicating temporary improvement in vegetation conditions due to limited seasonal rainfall or localized increases in surface soil moisture, as shown in Figures (98, 100, 102, 104, 106, 110). In contrast, the mild drought class remained marginal, with areas of (8.92, 6.17, 6.67) km² and percentages of (9.00, 6.22, 6.73)% recorded in 1998, 2014, and 2023 (Figures 102, 104, 112). Areas with almost no drought appeared only as very small patches during 2014 and 2020, totaling (0.44, 0.48) km² (0.44, 0.48)%, demonstrating the scarcity of areas with truly healthy vegetation in the study environment (Figures 104, 110).

This spatiotemporal pattern can be explained by low rainfall effectiveness, high reference evapotranspiration (ET_0), elevated land surface temperatures (LST), and recurrent dust storms that reduce net solar radiation and limit photosynthetic efficiency (Nemani et al., 2003; Eziz et al., 2017). In addition, the physical and chemical properties of soils in Dhi Qar—characterized by sandy to sandy-loam textures, high salinity and carbonates, and low organic matter—reduce water-holding capacity and rooting depth, diminishing plant vigor and lowering VCI values. Human activities such as overgrazing, unsustainable shallow tillage, and rangeland degradation further contribute to expanding bare surfaces and continuous decline in VCI (FAO, 2022; Borrelli et al., 2020).

This trend indicates that vegetation in Dhi Qar responds rapidly to any changes in the water balance: VCI values rise significantly with improved moisture conditions or more regular rainfall, and drop sharply during periods of drought and high temperatures. Therefore, VCI is considered an effective operational tool for monitoring the development of agricultural drought and desertification in arid and semi-arid regions. It can also be integrated with NDVI, temperature, and rainfall data to assess long-term drought dynamics (Son et al., 2012; Rhee et al., 2010; Meroni et al., 2021).

The findings confirm that Dhi Qar Governorate exhibits high environmental sensitivity to climatic variations, and that any improvement in water management or increase in permanent vegetation cover can directly enhance VCI values and improve the ecological performance of the land system. Accordingly, the study recommends adopting reclamation programs based on rainwater harvesting, improving soil quality and organic matter content, and establishing biological windbreaks to reduce climatic stress and enhance vegetation sustainability in the governorate.

جدول() مديات ومساحات أصناف دليل حالة الغطاء النباتي VCI .

النسبة المئوية	المساحة	المدى		الصنف	التاريخ
		الى	من		
54.66	54.18	20	0	1	1990
42.68	42.31	40	21	2	
2.50	2.48	60	41	3	
0.14	0.14	80	61	4	
0.01	0.01	100	81	5	
0.26	0.25	20	0	1	1994
79.65	78.95	40	21	2	
19.40	19.23	60	41	3	
0.64	0.63	80	61	4	
0.06	0.06	100	81	5	
0.79	0.79	20	0	1	

46.81	46.40	40	21	2	1996
50.95	50.50	60	41	3	
1.29	1.28	80	61	4	
0.15	0.15	100	81	5	
0.72	0.72	20	0	1	1998
1.44	1.43	40	21	2	
88.73	87.96	60	41	3	
9.00	8.92	80	61	4	
0.10	0.10	100	81	5	
0.15	0.15	20	0	1	2014
0.24	0.24	40	21	2	
92.94	92.12	60	41	3	
6.22	6.17	80	61	4	
0.44	0.44	100	81	5	
0.02	0.02	20	0	1	2016
54.42	53.94	40	21	2	
39.47	39.12	60	41	3	
5.93	5.87	80	61	4	
0.17	0.17	100	81	5	
0.14	0.13	20	0	1	2018
92.44	91.63	40	21	2	
5.72	5.67	60	41	3	
1.29	1.28	80	61	4	
0.23	0.22	100	81	5	
0.53	0.52	20	0	1	2020
41.23	40.87	40	21	2	
55.19	54.71	60	41	3	
2.56	2.54	80	61	4	
0.48	0.48	100	81	5	
0.18	0.18	20	0	1	2023
0.94	0.93	40	21	2	
91.91	91.11	60	41	3	
6.73	6.67	80	61	4	
0.24	0.24	100	81	5	

Temperature Condition Index (TCI)

The Temperature Condition Index (TCI) is one of the advanced spectral indicators used to measure the thermal response of the land surface and to estimate heat stress associated with soil dryness and reduced moisture content. Low TCI values indicate elevated land surface temperatures (LST) and diminished soil moisture, conditions that ultimately weaken vegetation activity and reduce photosynthetic efficiency (Kogan, 1995; Kogan et al., 2019).

The results for the study area reveal a clear spatial and temporal dominance of high thermal drought levels. The highest recorded area of the *very severe* thermal drought class occurred in 1990, reaching **62.28 km²** (62.84%), indicating an intense heatwave accompanied by pronounced surface dryness and reduced vegetation performance, as shown in Figures (113–114). The *severe* drought class also expanded notably in the years 1994, 1996, 2014, 2016, 2020, and 2023, covering areas of **56.08, 68.77, 59.65, 57.02, 59.01, and 74.63 km²**, respectively, with percentages of **68.77%, 69.38%, 60.18%, 57.53%, 59.53%, and 75.30%**, as shown in Figures (116–118–122–124–128–130). This pattern reflects a series of recurrent and varying-intensity heatwaves that adversely impacted vegetation vigor.

In contrast, the *moderate* drought class appeared in 1998, 2014, 2016, and 2018, with areas ranging between **19.48–38.34 km²** (19.48–38.81%), as illustrated in Figures (120–122–124–126). These patterns indicate periods of relative thermal moderation without reaching optimal conditions for vegetation growth. The *mild* drought class remained limited in 2016 and 2018, with areas of **8.35 and 8.01 km²** (8.42% and 8.08%), as shown in Figures (124–126). Small pockets of *no drought* were recorded only in 2018, covering **1.29 km²** (1.30%), as shown in Figure (126). Overall, the spatial–temporal distribution demonstrates a predominance of thermal stress and energy imbalance at the land surface, resulting in a gradual degradation in vegetation condition.

These findings can be explained in relation to the climatic and soil characteristics of the region, where sandy and sandy-loam textures dominate, with low water-holding capacity, high salinity and carbonate content, and low organic matter. These properties increase surface heating rates and reduce the soil's ability to retain moisture (Nemani et al., 2003; Eziz et al., 2017). Consequently, land surface temperature (LST) rises, leading to a reduction in TCI values. Recurrent dust storms and the scarcity of permanent vegetation further enhance surface reflectance and reduce latent heat fluxes, accelerating soil temperature rise and intensifying thermal stress (Peng et al., 2019; Ghazaryan et al., 2022).

Scientifically, the TCI reflects the inverse relationship between land surface temperature and soil moisture. When integrated with the Vegetation Condition Index (VCI), the two indicators collectively capture both the thermal and vegetative dimensions of plant–climate interactions. Their integration enables highly accurate detection of agricultural drought severity (Singh et al., 2003; Rhee et al., 2010; Meroni et al., 2021). The low values of both indices in the years 1990, 1996, 2018, and 2023 indicate simultaneous thermal and moisture stress, whereas relative increases in TCI in other years may be attributed to seasonal thermal moderation even when moisture levels remain limited.

The results confirm that thermal stress is a primary climatic driver of vegetation degradation in the study area. Any improvements in the surface water–energy balance—such as increasing permanent vegetation cover, establishing biological windbreaks, improving soil structure, and implementing water-harvesting techniques—will likely lead to rapid enhancements in TCI values and reductions in agricultural drought risk. Thus, monitoring TCI represents an effective operational tool within early-warning systems for desertification and drought in arid and semi-arid environments due to its strong association with land-surface biophysical properties and energy dynamics.

جدول ( ) مديات ومساحات أصناف دليل الظروف الحراري Soil codition index

التاريخ	الصنف	المدى		المساحة	النسبة المئوية
		من	الى		
1990	1	0	20	62.28	62.83
	2	21	40	30.68	30.95
	3	41	60	5.17	5.22
	4	61	80	0.68	0.69
	5	81	100	0.30	0.30
1994	1	0	20	22.95	23.15
	2	21	40	56.08	56.58
	3	41	60	17.67	17.83
	4	61	80	1.93	1.95
	5	81	100	0.48	0.48
1996	1	0	20	15.37	15.51
	2	21	40	68.77	69.38
	3	41	60	12.75	12.86
	4	61	80	1.74	1.76
	5	81	100	0.49	0.49
1998	1	0	20	9.39	9.47
	2	21	40	47.81	48.23
	3	41	60	38.34	38.68
	4	61	80	2.78	2.80
	5	81	100	0.80	0.81
2014	1	0	20	13.35	13.47
	2	21	40	59.65	60.18
	3	41	60	19.48	19.65
	4	61	80	6.25	6.31
	5	81	100	0.39	0.39
2016	1	0	20	2.52	2.54
	2	21	40	57.02	57.53
	3	41	60	30.68	30.95
	4	61	80	8.35	8.42
	5	81	100	0.55	0.55
2018	1	0	20	16.99	17.14
	2	21	40	36.34	36.66
	3	41	60	36.48	36.80
	4	61	80	8.01	8.08
	5	81	100	1.29	1.30
2020	1	0	20	32.43	32.72
	2	21	40	59.01	59.53
	3	41	60	6.99	7.05

0.32	0.32	80	61	4	
0.37	0.37	100	81	5	
7.64	7.57	20	0	1	2023
75.29	74.63	40	21	2	
15.98	15.84	60	41	3	
1.02	1.01	80	61	4	
0.07	0.065	100	81	5	

دليل صحة النبات (Vegetation Health Index - VHI)

Vegetation Health Index (VHI)

The Vegetation Health Index (VHI) is an advanced composite indicator that integrates both the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI), with nearly equal weighting, to represent the combined interaction between moisture and thermal stress within the plant ecosystem. Low VHI values reflect reduced soil moisture and elevated land surface temperatures, which collectively lead to the deterioration of plant vitality and reduced ability of vegetation to grow and regenerate (Kogan, 2001).

The results for the study area show that the upper drought classes dominated large portions of the region, indicating clear environmental fragility and a decline in vegetation performance, as illustrated in Figure (131). The highest area of the "extreme drought" class was recorded in 2014 and 2023, reaching about 50.02 km² and 59.34 km², respectively, representing 50.47% and 59.86%. This indicates a sharp decline in available moisture and an increase in surface temperatures, which in turn led to reduced VCI and TCI values simultaneously.

The "severe drought" class also expanded in 1996, 2014, 2016, 2020, and 2024, covering areas of 52.31, 47.99, 45.12, 42.61, and 59.12 km² with percentages of 52.31%, 48.41%, 45.53%, 42.99%, and 59.64%, respectively. This pattern reflects the persistence of intense and recurring drought waves accompanied by notable thermal stress in the study environment.

Conversely, the "moderate drought" class appeared more clearly in 1994, 1998, 2018, 2020, and 2024, with areas ranging from 22.68 to 39.25 km² and percentages between 19.32% and 37.22%. These indicate periods of relative improvement in vegetation conditions as a result of limited increases in rainfall or local rises in soil moisture. The "mild drought" class, however, remained very limited in 1990 and 1998, with areas of 59.56 km² and 25.24 km² and percentages of 60.08% and 25.47%, respectively. Small pockets free of drought appeared in 1990 and 2016, covering only 0.51 km² and 0.01 km², representing 0.52% and 0.01%, which reflects the scarcity of dense and stable vegetation within the study area, as shown in Figure (132).

The decline in VHI values is attributed to a combination of natural and human-induced factors. Dominant sandy and gypsiferous soil textures with limited water-holding capacity, high carbonate and salinity content, and low organic matter reduce the roots' ability to absorb water and nutrients, making soils more prone to rapid heating and moisture loss. Human activities such as overgrazing and shallow tillage also increase soil exposure to wind erosion, expand bare surfaces, and lower vegetation efficiency (Li et al., 2017; Eziz et al., 2017; Borrelli et al., 2020; FAO, 2022).

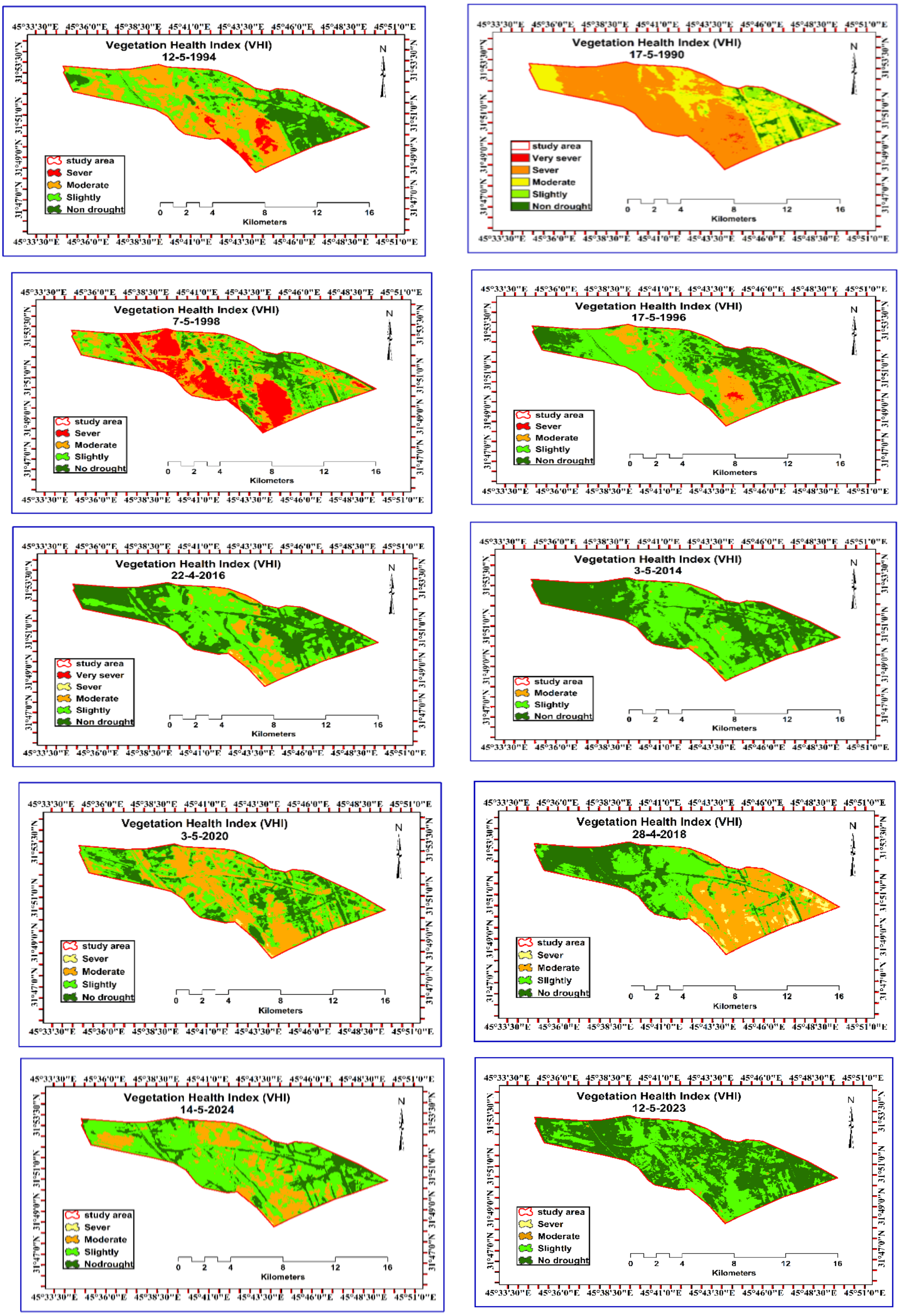
Additionally, the prevailing climatic conditions in Thi-Qar Province—characterized by high temperatures and low rainfall—enhance evaporation rates and exacerbate plant heat stress, resulting in a continuous decline in VHI values.

Areas near the Tigris River exhibited relatively higher VHI values due to improved local moisture and the fertility of alluvial soils with loam to clay-loam textures and granular to blocky structure. These areas also support perennial species such as willow (Salix spp.), tamarisk (Tamarix spp.), and thistles (Cirsium spp.), which contribute to more stable vegetation cover year-round. Local increases in VHI during some years may also be attributed to improved rainfall patterns, supporting the growth of annual plants and seasonal rangeland species.

In conclusion, the study area is experiencing recurring drought cycles influenced by combined thermal and moisture stress, making it highly sensitive to desertification and land degradation. Improving VHI values requires adopting integrated land management strategies that enhance permanent vegetation cover through planting drought-resistant native species, improving irrigation and rainwater harvesting practices, increasing organic matter in soils to enhance water retention capacity, and reducing surface disturbance and wind erosion by stabilizing sand dunes and using biological windbreaks. Any improvement in soil-water-energy balance will be quickly reflected in higher VHI values and greater ecosystem stability in the region (Peng et al., 2019; Ghazaryan et al., 2022; Meroni et al., 2021).

دليل صحة النبات جدول ( ) مديات ومساحات (VHI)

		المدى			
النسبة المئوية	المساحة	الى	من	الصنف	التاريخ
3.75	3.72	10	0	1	
8.97	8.89	20	10	2	
26.68	26.45	30	20	3	
60.08	59.56	40	30	4	
0.52	0.51	100	40	5	1990
19.49	19.32	10	0	1	
36.56	36.23	20	10	2	
39.60	39.25	30	20	3	
4.36	4.32	40	30	4	
0.00	0.00	100	40	5	1994
27.14	26.90	10	0	1	
52.77	52.31	20	10	2	
19.49	19.32	30	20	3	
0.60	0.59	40	30	4	
0.00	0.00	100	40	5	1996
13.25	13.14	10	0	1	
32.48	32.19	20	10	2	
28.80	28.55	30	20	3	
25.47	25.24	40	30	4	
0.00	0.00	100	40	5	1998
50.47	50.02	10	0	1	
48.41	47.99	20	10	2	
1.12	1.11	30	20	3	
0.00	0.00	40	30	4	
0.00	0.00	100	40	5	2014
42.29	41.92	10	0	1	
45.52	45.12	20	10	2	
11.84	11.73	30	20	3	
0.35	0.34	40	30	4	
0.01	0.01	100	40	5	2016
25.57	25.34	10	0	1	
33.20	32.91	20	10	2	
37.22	36.89	30	20	3	
4.01	3.97	40	30	4	
0.00	0.00	100	40	5	2018
22.99	22.79	10	0	1	
42.99	42.61	20	10	2	
33.61	33.32	30	20	3	
0.41	0.41	40	30	4	
0.00	0.00	100	40	5	2020
59.86	59.34	10	0	1	
39.63	39.28	20	10	2	
0.50	0.50	30	20	3	
0.00	0.00	40	30	4	
0.00	0.00	100	40	5	2023



الشكل (131): خرائط دليل صحة الغطاء النباتي VHI في منطقة الدراسة.

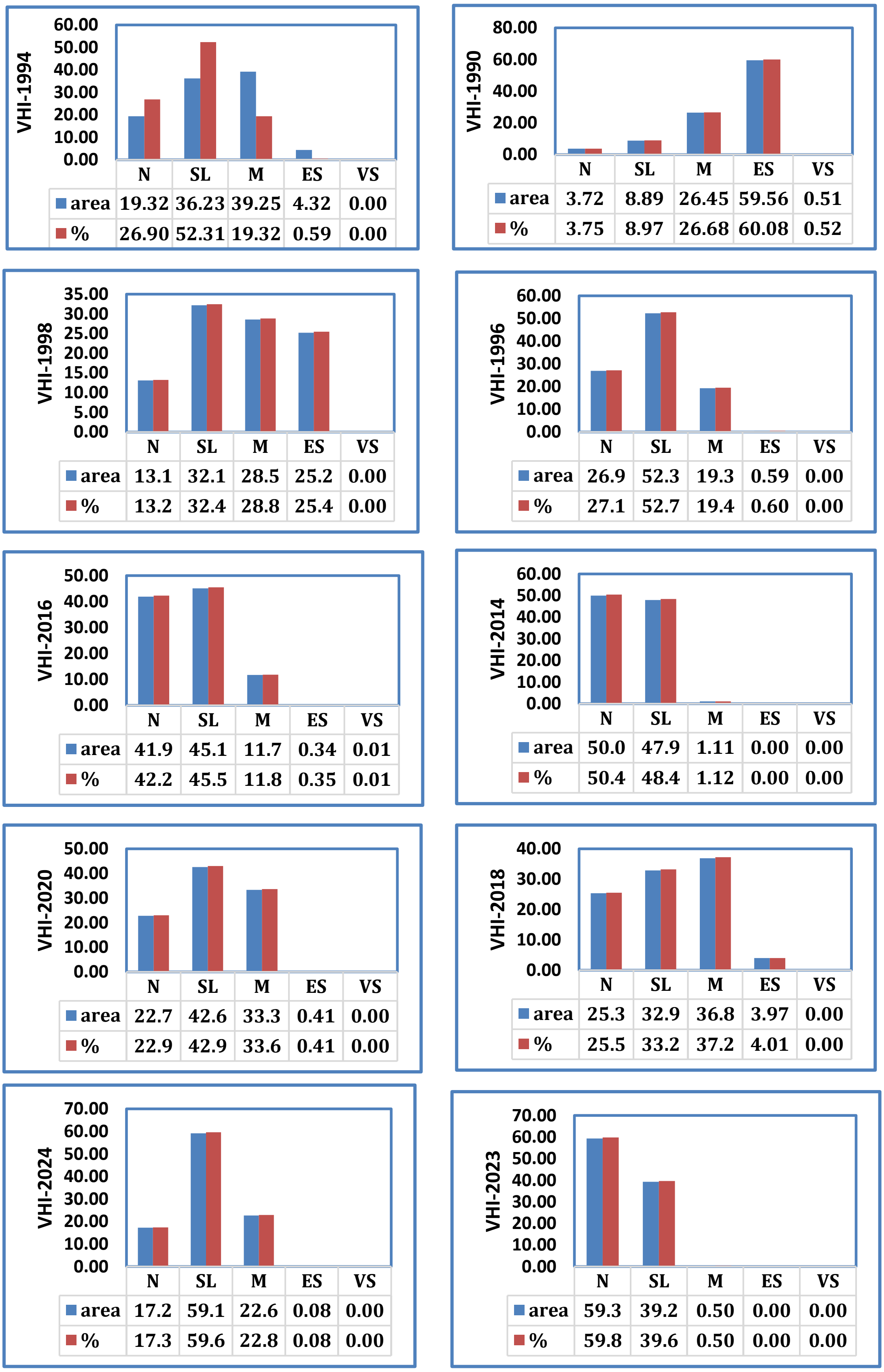


Figure (132): Distribution Curves of Vegetation Health Index (VHI) Classes.

Calculation of the Vegetation Quality Index (VQI) in the Study Sites

The results presented in Figure (80) for the calculation of the Vegetation Quality Index (VQI) in the soils of Dhi Qar Governorate (study sites) indicate a clear variation in the index values, reflecting differences in soil properties and the environmental conditions influencing them. The VQI values ranged between **1.339–2.000**, with an average of **1.605**, a standard deviation of **0.200**, and a coefficient of variation of **0.125**. This indicates a moderate level of variability in the response of the different sites to erosion sensitivity and drought conditions.

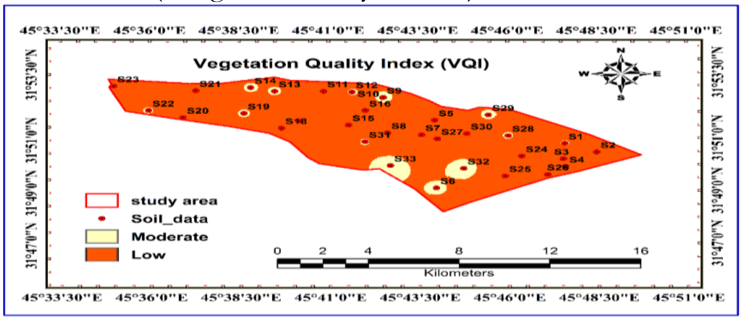
This variability appears to be linked to the dominant soil characteristics in the region, where coarse texture, loose structure, and low moisture-retention capacity prevail. These factors reduce the soil's ability to support balanced vegetation growth, leading to higher erosion risk and sparse plant cover (FAO, 2022), as shown in **Figure (81)**.

The spatial distribution of the VQI values revealed that most areas fall within the **poor** class, which covered **92.39 km²** (93.21%). In contrast, the **moderate** class occupied only a limited area of **6.74 km²** (6.80%). This confirms that vegetation cover across most parts of Dhi Qar Governorate is weak and fails to perform its essential ecological role in protecting the soil surface from erosion agents.

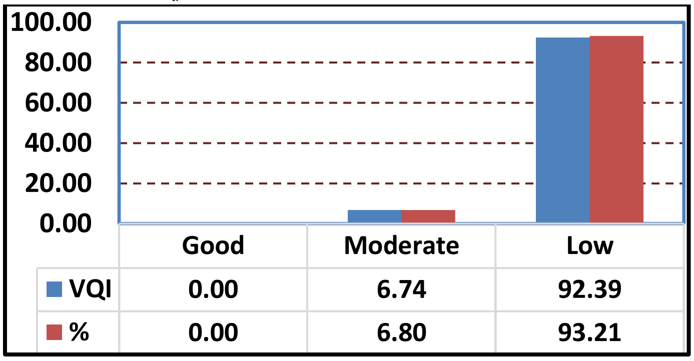
This weakness is attributed to a combination of natural and human-induced factors. Naturally, the arid and semi-arid climate imposes harsh conditions on vegetation growth, where low moisture levels and high temperatures hinder germination and reduce plant density. From a human perspective, overgrazing and unsustainable land-use practices further intensify degradation (Borrelli et al., 2020; IPCC, 2021).

These findings highlight the critical importance of vegetation cover as a fundamental component in combating desertification and land degradation in dry environments. Vegetation not only protects the soil surface from raindrop impact and wind forces but also improves the internal soil system by regulating water–air balance, increasing organic matter, stimulating microbial activity, and enhancing pore distribution and permeability.

Therefore, the decline of VQI values to poor levels across most of the study area reflects an environmental risk that necessitates intervention. Areas recording high erosion rates are often the same areas experiencing drought and low vegetation cover, underscoring the reciprocal relationship between erosion and drought as interlinked factors determining vegetation status (Morgan, 2005; Bryan, 2000).



الشكل (80) دليل نوعية الغطاء النباتي



الشكل(81)التوزيع المكاني لاصناف دليل نوعية الغطاء النباتي

CONCLUSIONS

1. The results of the spectral indices (NDVI, VCI, TCI, VHI) revealed clear spatial and temporal variations in vegetation health within the study area, with relatively high values recorded near the banks of the Tigris River and recently cultivated agricultural zones, in contrast to the sharp decline observed in the southern and western parts affected by drought, salinity, and aeolian activity.
2. Analyses of the NDVI showed that the vegetation cover in the region exhibits pronounced seasonal fluctuations; values increase during February and March due to improved winter rainfall and decline markedly during the summer months, reflecting the dry and seasonal nature of vegetation growth in Dhi Qar.
3. The results of the Vegetation Condition Index (VCI) indicated that approximately **72%** of the study area falls within the moderate-to-severe vegetation stress classes due to the reduction in vegetation cover and

declining soil moisture levels—consistent with the characteristics of the prevailing arid and semi-arid climate.
4. The Temperature Condition Index (TCI) exhibited marked thermal variability, with more than **18%** of the total area experiencing high thermal stress, indicating the negative effect of elevated land surface temperatures on plant productivity, especially during prolonged drought periods.
5. The Vegetation Health Index (VHI) results demonstrated the dominance of the "high vegetation stress" category across more than **40%** of the area, while the "healthy vegetation cover" category accounted for only about **3%**, confirming that the region suffers from severe environmental degradation in vegetation health due to the combined effects of thermal and moisture stress.
6. Spatial analyses using Geographic Information Systems (GIS) showed that areas close to waterways and floodplains exhibit higher levels of vegetation health indicators than more distant areas, highlighting the crucial role of hydrological gradients in sustaining vegetation cover.
7. Integrating vegetation drought indices with the Environmental Sensitivity to Desertification Index (ESAI) indicated that the region falls within the "moderate" to "high" desertification sensitivity classes, reflecting the vulnerability of local ecosystems to climate variability and the lack of sustainable environmental management.

RECOMMENDATIONS

1. Expand the use of remote-sensing indices (NDVI, VCI, TCI, VHI) for continuous monitoring of vegetation health within national programs for drought and desertification management, enabling the identification of critical zones and the development of immediate rehabilitation plans.
2. Adopt an agricultural drought early-warning system based on updated spectral data (MODIS, VIIRS, Sentinel-2), allowing agricultural authorities to detect vegetation stress phases early and minimize production losses.
3. Improve water and irrigation management in agricultural areas by introducing smart irrigation technologies and rainwater harvesting techniques to enhance soil moisture efficiency, thereby increasing VCI and VHI values and improving the growth of perennial vegetation.
4. Expand natural vegetation cover by planting native drought- and salinity-tolerant species such as *Tamarix spp.*, *Atriplex halimus*, and *Salix spp.*, which play a key role in soil stabilization and resistance to wind erosion.
5. Enhance soil organic matter and effectively manage salinity through the use of organic fertilizers and agricultural gypsum, thereby improving water uptake efficiency and supporting better plant growth indicators.
6. Integrate spectral analysis results with climate and soil data into comprehensive GIS-RS-Climate information systems to provide an integrated spatial database for environmental planning and land-reclamation projects.
7. Propose the establishment of a **National Vegetation Health Observatory in Iraq**, dedicated to monitoring agricultural drought and plant productivity through satellite imagery, in collaboration with academic institutions and agricultural meteorology centers.

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