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Monitoring The Vitality Of Vegetation Covers Based On Drought Indicators For Gara Mount For The Period (2014-2024) A.D. In Northern Iraq

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ABSTRACT
The vegetation cover and vitality of the Mount Gara region located in northern Iraq were monitored through drought indices (TCI, VHI, VCI), using Landsat-8 OLI/TIRS satellite data in the month of August for each of the years 2014, 2018, 2024. The results of the drought index (VCI) for the year 2014 showed a difficult year for the Mount Gara region, where the extreme drought category was the most prevalent, covering an area of (81.04%). In 2018, the region witnessed a remarkable improvement in environmental conditions and vegetation cover, as the percentage of areas classified as extreme drought decreased to (9.67) %, while the percentage of the extreme drought category increased from (9.67) % in 2018 to (14.23) % in 2024, As for the TCI, in 2014, the category of extreme drought covered about 94.05% of the area (54.90 km²), but by 2018, this percentage decreased to only 8.14% (4.75 km²), and between 2018 and 2024, a near-complete alleviation of drought severity is expected, highlighting a significant shift in temperature dynamics on the Earth's surface. The extreme drought conditions, which recorded 8.14% with an area of 4.75 km² in 2018, declined to a small percentage of 0.45% with an area of 0.26 km² by 2024, with a decrease of (-4.49 km²). As for VHI In 2014, the extreme drought category was the most widespread, covering about 79.66% of the total area. However, this category witnessed a significant decrease by 2018, dropping to (1.86) % of the area, equivalent to (1.08) km², while in 2024, the extreme drought category witnessed a further decrease, reaching to only (0.27) % of the studied area, equivalent to (0.45) km², compared to (1.86) % in 2018, representing a decrease of (-0.81) km².
Keywords: *Drought indicators, vegetation, remote sensing, changes in vegetations.*

INTRODUCTION

Pure and mixed forests represent essential natural resources distributed across diverse regions and ecosystems worldwide, spanning both the Northern and Southern Hemispheres. These forests supply vital raw materials—such as timber, medicinal plants, and various non-timber products—and provide important ecosystem services, including ecotourism, thereby constituting a significant component of the global economy (Li and Linhares-Juvenal, 2019). The composition and diversity of tree species in these ecosystems are shaped by multiple environmental factors, including climate, soil composition, topography, water availability, and human activities. Among these, climate plays a central role in determining forest structure and species distribution (Foley *et al*., 2005). Climate change driven by global warming is altering temperature and precipitation patterns, which in turn cause shifts in species habitats and pose substantial threats to forest biodiversity. Iraq exemplifies these environmental challenges, facing acute water scarcity caused by overlapping stressors such as rising temperatures, decreasing precipitation, changes in rainfall distribution, and elevated evaporation rates (Nosir, 2023). These interrelated pressures have severely impacted the country's water resources, leading to degradation of its ecological systems and loss of biodiversity. Given these escalating threats, particularly in ecologically vulnerable regions like Iraq, there is a growing recognition of the need to adopt strategic management approaches that balance resource utilization with the health and sustainability of ecosystems. Emphasizing forest conservation, ecological restoration, and scientifically grounded sustainable forest management is considered essential to mitigating degradation and enhancing the long-term resilience of forest systems (Ali *et al.*, 2024). Remote sensing techniques are emerging as a powerful tool for monitoring, and analyzing large-scale environmental changes in forests over time, providing valuable insights into vegetation vitality, forest density and other indicators of ecosystem vitality. (Kogan, 2002) One of the prominent applications of remote sensing techniques is the detection of drought stress in forests. These techniques enable monitoring of vegetation cover in the study area. Key indices include: the Vegetation Condition Index (VCI), which represents drought conditions based on the normalized difference vegetation index (NDVI); the Temperature Condition Index (TCI), which represents plant thermal conditions; and the Vegetation Health Index (VHI), which combines VCI and TCI to represent the overall effect of drought and thermal stress on plant health, which can be used as an early warning indicator of deteriorating forest vitality as, a result of reduced water availability. By analyzing Land Surface Temperature (LST) using remote sensing, researchers can identify areas under drought stress and assess potential impacts on biodiversity (Yue et al., 2007). This information is vital for resource conservation and land management, as it enables informed interventions to minimize biodiversity losses and support forest resilience. Remote sensing applications, including satellite imagery and GIS analysis, are increasingly used to extract vegetation information and assess forest condition (Rashid and Al-Allaf, 2025). Therefore, our study aimed to monitor the vegetation cover and vegetation vitality of the Mount Gara region in northern Iraq through remote sensing data for the years 2014, 2018, and 2024.

MATERIALS AND METHODS

The study area is located in Mount Gara in the northwestern part of Dohuk Governorate, within the Zagros Mountain that extends between Iraq, Turkey and Iran and is one of the most prominent topographical features, as it is characterized by unique geographical characteristics that make it an area of environmental and economic importance, confined between two latitudes 43°17' 31.9″– 43°20' 13.3″E and longitudes 36°59' 53.4″– 37°01' 02.4″N, at an altitude ranging from 1402 to 1745 meters above sea level (Sissakian *et al.*, 2020). Among the most important types of trees that are naturally distributed in the study *area are Quercus aegilops*, *Quercus infectoria*, as well as other types of trees and shrubs present in the study area, including *Acer monspessulanu*, *Prunus microcarpa*, *Pyrus syriaca*, *Juniperus oxycedrus*, *Crataegus azarolus*, *Prunus webbii*, *Pistacia eurycarpa* and *Lonicera arborea*. Climatic factors (such as temperature, rainfall, and light) interact with the genetic characteristics of plant species and environmental site features (such as topography and soil type) to determine tree growth and productivity. Compatibility between these elements is a prerequisite for achieving environmental efficiency and sustainability. The study area is in an arid to semi-arid region, highlighting the importance of thermal and moisture conditions in species survival. Temperatures directly affect the geographical distribution of species and determine their tolerance to extreme conditions, and evapotranspiration processes regulate the availability of soil moisture, which is a crucial factor in determining plant productivity and the stability of mountain ecosystems (Dainese *et al.*, 2024). Satellite imagery was used to analyze and extract spectral values, evidence, and indicators according to specific equations, relying on geospatial technology software: ENVI 5.3 and ArcGIS 10.8.1

Table (1): Characteristics of the Satellite imagery used in the study

No.	Years	Spacecraft-ID	Sensor	Path/Raw	Date
1	2014	LANDSAT-8	OLI-TIRS	170/34	12-8-2014
2	2018	LANDSAT-8	OLI-TIRS	170/34	7-8-2018
3	2024	LANDSAT-8	OLI-TIRS	170/34	24-8-2024

Table (2): Channels used from the LANDSAT_8 OLI satellite data

No.	Band	Wavelength (μm)	Spatial Resolution (m)
1	Band-3 Green	0.533-0.590	30*30
2	Band-4 Red	0.636-0.673	30*30
3	Band-5 Near Infrared	0.851-0.879	30*30
4	Band-6 ShortwaveInfrared (SWIR)2	1.566-1.651	30*30
5	Band-10ThermalInfrared (TIRS)	10.60-11.19	100*100

Vegetation Condition Index (VCI)

This indicator is used to monitor areas where plants may be exposed to moisture stress as a way to detect drought. It is based on the actual NDVI value for the study period, and the highest and lowest NDVI values during the study period, according to the following equation:

$VCI=(NDVI_i-NDVI_{min}) /(NDVI_{max}-NDVI_{min})*100$ ...... (Kogan *et al.* 2004)

VCI = Vegetation Condition Index

$NDVI_i$ = Actual NDVI value

$NDVI_{max}$ = Maximum NDVI value

$NDVI_{min}$ = Minimum NDVI value

Temperature Condition Index (TCI)

The Temperature Condition Index (TCI) provides the opportunity to identify subtle changes in plant vitality due to heat and drought and is calculated by the following equation:

$TCI= (LST_{max} -LSTi) / (LST_{max}-LST_{min}) *100$ .... (Kogan *et al.* 2004).

LST_i = Land Surface temperature for the study time

LST_{max} = Maximum surface temperature for several years

LST_{min} = Minimum surface temperature for several years

While the Land Surface Temperature: Land Surface Temperature (LST) is an important indicator for understanding climate and environmental changes, as it plays a major role in ecological balance and climate impacts on a global scale. Changes in land surface temperature are attributed to multiple factors, and the degree of radiation in the thermal band (10) is extracted according to the following equation:

$L(\lambda) = ML \times Band\ 10 + AL - Oi$ .... (Rajeshwari and Mani 2014)

TOA = 0.0003342 * "B10" + 0.10 - 0.29

Where in:

$L\lambda$ = Top-of-Atmosphere (TOA) Spectral Radiance

ML = Multiplicative Factor for Radiance. Table (3)

$Q_{CAL = Band\ 10}$ Digital number (DN) $_{Values}$

AL = Additive rescaling coefficient for each spectral band (0.1). Table (3)

Oi = Band 10's correction constant is 0.29 Table (3)

Table (3): Rescaling Factors for Landsat-8 Thermal Band 10

Rescaling coefficients	Degree	Source Data
ML Multiplicative Factor for Radiance	0.000334	Descriptive data
AL Additive rescaling coefficient for each spectral band)	0.1	Descriptive data
K1 (first thermal constant)	774.8853	Descriptive data
K2 (second thermal constant)	1321.078	Descriptive data
Oi Correction constant value	0.29	Descriptive data

The extraction of the brightness degree, which shows the temperature of the earth's surface within the band (10), is done through the following equation:

$BT = K2 / \ln (k1/L(\lambda)+1) - 273.15$ .... (Becker and Li 1990)

BT= Spectral brightness temperature at the top of the atmosphere (°C)
Lλ = Top-of-Atmosphere (TOA) Spectral Radiance
K1= first constant Band (774.8853)
K2 = Second constant Band (1321.078)

The Normalized Difference Vegetation Index (NDVI) was then calculated according to the following equation:

$NDVI = (NIR - RED)/(NIR + RED)$ .... (Rouse *et al.* 1974)

Normalized Difference Vegetation Index (NDVI) was used to extract Land Surface Emissivity (LSE), an adjustable parameter in the land surface temperature correction in the next step. LSE values were calculated based on the proportion of vegetation cover (Sobrino et al. 2004, Jiménez-Muñoz et al. 2014).

$LSE = 0.004 * PV + 0.986$ .... (Norman and Becker1995)

While PV is the percentage of vegetation cover, it is calculated based on the Normalized Difference Vegetation Index (NDVI) value for each pixel.

$$PV = ((NDVIi - NDVI_{min}) / (NDVI_{max} - NDVI_{min}))^2$$

Where in:
PV= Proportion of vegetated area
NDVI= Normalized Difference Vegetation Index
$NDVI_{max}$ = Maximum NDVI value
$NDVI_{min}$ = Minimum NDVI value

The surface emissivity is also derived from the equation:

$E = 0.004 * PV + 0.986$ .... (Sobrino *et al.* 2004)

E =Emissivity of the land surface
PV= Proportion of vegetated area
0.986= Represents a correction factor in the thermal calibration equation.

Finally, the land surface temperature (LST) is calculated using the equation:

$LST = BT / (1+ (\lambda * BT / C2) * \ln (LSE)$ .... (Sobrino *et al.* 2004)

LST= land Surface Temperature
BT= Spectral brightness temperature at the top of the atmosphere (°C)
λ= Wavelength range of thermal emission detected by Landsat-8 Band 10
LSE= Land Surface Emissivity

*C2 = is h * c/s = 1.4388 * 10-2 Mk) = 14388 km*
h= Planck's Constant
S= Boltzmann constant
C= Velocity of Light

The Vegetation Health Index (VHI)
Directly observes and monitors vegetation drought, which represents the final stage of drought. The VHI is derived from the Vegetation Condition Index (VCI) and the Thermal Condition Index (TCI) using the following equation:
VHI=0.5 X VCI+ 0.5 X TCI ………… (Kogan *et al.*, 2004)
Where in:
VHI= Vegetation Health Index
VCI= Vegetation condition Index
TCI= temperature condition index
0.5= Constant value

RESULTS AND DISCUSSION

Vegetation Condition Index (VCI)
Satellite-based drought indices, including the Vegetation Condition Index (VCI) (Kogan, 1995), are widely used to detect the onset, severity, and duration of drought. The VCI is easily calculated, does not require data from observation stations, and being a satellite-based product, provides regularly updated data globally with high relative spatial resolution (Quiring *et al.*, 2003). Landsat-8 OLI/TIRS satellite imagery for the years 2014, 2018, 2024 was used in the eighth month and was obtained from the USGS and then processed using geospatial software, ENVI 5.3, and analyzed in ArcGIS 10.8.1 for the location of Mount Gara study area shows cyclical variability in drought patterns in the Mount Gara region, linked to climate variability and human pressures. The temporary improvement in 2018 suggests ecosystem recovery with better resource management, while increased drought in 2024 (table 4) highlights long-term climate change risk.

Table (4): Drought comparison based on the Vegetation Condition Index (VCI) for 2014, 2018, 2024 in the Mount Gara region, Dohuk Governorate.

VCI	Year 2014		Year 2018		Year 2024			
VCI Severity Level	Area. km^2	%	Area. km^2	%	Area. km^2	%	Rate of Change km^2.of Area (2014-2018)	Rate of Change km^2.of Area (2018-2024)
Drought Extreme	47.31	81.04	5.65	9.67	8.31	14.23	-41.66	2.66
Severe Drought	1.09	1.86	0.6	1.03	1.58	2.7	-0.49	0.98
Moderate Drought	1.03	1.76	0.78	1.34	2.18	3.74	-0.25	1.40
Mild	0.93	1.60	0.99	1.69	3.07	5.25	0.06	2.08
No Drought	8.02	13.74	50.36	86.27	43.24	74.07	42.34	-7.12
Total	58.38	100	58.38	100	58.38	100		

The data in Table (4) used to monitor the severity of drought during the period 2014-2024, The analysis showed 2014 was a difficult year for the Mount Gara region. The extreme drought category covered 81.04% of the area, reflecting negative climatic and environmental impacts. This indicates that these areas were exposed to significant moisture stress, which led to a clear deterioration in vegetation cover. This degradation is attributed to climatic fluctuations that have profoundly affected vegetation cover, a key component of stand structure and forest composition (Mohammed *et al.*, 2025). By 2018, the region witnessed an improvement in environmental conditions, as the percentage of areas classified under the category of extreme drought decreased to 9.67%, recording a decrease of (-41.66) km^2.This improvement is attributed to more favorable environmental and climatic conditions that contributed to the reduction of moisture stress and recovery of vegetation (Pouyan *et al.*, 2023). Other categories also changed: with the percentage of severe drought decreasing from 1.86% in 2014 to a lower percentage of (1.03) % in 2018. As for the moderate drought category, it recorded (1.76) % in 2014 and decreased to (1.34) % in 2018, representing a decrease of (-0.25) km^2. By contrast, the mild category witnessed a slight increase, rising from (1.60) % in 2014 to (1.69) % in 2018, with a small change of (0.06) km^2. As for the areas where there is no drought, they witnessed a significant improvement, as their percentage increased from 13.74% in 2014 to 86.27% in 2018, with a significant positive change of (42.34) km^2. When comparing the situation between 2018 and 2024, the VCI analysis shows an overall improvement in vegetation condition and a decrease in the frequency of droughts. This decrease reflects a decline in vegetation condition as a result of negative impacts associated with higher temperatures or lower rainfall. In contrast, the percentage of the extreme drought category increased from 9.67% in 2018 to 14.23% in 2024, with an increase of 2.66 km^2, indicating the return of some areas to the state of extreme drought. The moderate drought category also witnessed an increase from (1.34) % in 2018 to (3.74) % in 2024, with an increase of (1.40) km^2.This increase reflects the expansion of moderately dry areas, indicating the presence of gradual climatic changes mainly represented by higher average temperatures, increased evaporation, and changing temporal and spatial patterns of rainfall distribution that affected the stability of vegetation. As for the mild category, its percentage increased from (1.69) % in 2018 to (5.25) % in 2024, with a change of (2.08) km^2. Although this category represents less severe cases of drought, its increase indicates that some areas are shifting from good vegetation to levels that require monitoring and response. As for the severe drought category, it recorded the lowest rates of change, increasing from (1.03) % in 2018 to (2.7) % in 2024, with an increase of (0.98) km^2. Although this ratio is low compared to the rest of the categories, its increase reflects a gradual increase in moisture stress in some parts.

Temperature Condition Index (TCI)

Land Surface Temperature (LST) is a vital indicator of the energy balance at the Earth's surface, where changes in surface characteristics such as the presence of water, snow, or vegetation cover directly influence this balance. The energy balance constitutes a fundamental pillar of the climate system, regulating hydrometeorological processes within the Earth's Critical Zone. Variations in surface temperature significantly impact the health of vegetation cover; elevated temperatures induce thermal stress that reduces photosynthetic efficiency and increases water loss in plants, thereby threatening their growth and survival (Brooks *et al.*, 2015). Given the pivotal role of surface temperature in detecting thermal stress in vegetation, the Temperature Condition Index (TCI) is used to assess this stress by comparing current satellite-derived LST values with long-term average temperatures, where low TCI values indicate harsher thermal conditions leading to increased plant stress (Li *et al.*, 2013). We therefore processed Landsat 8 OLI/TIRS satellite imagery (August acquisitions: 2014, 2018, 2024; USGS source) for Mount Gara using ENVI 5.3, followed by spatial analysis in ArcGIS 10.8.1.

Table (5): Drought comparison based on the Thermal Condition Index (TCI) for the years 2014, 2018, 2024 for the mountain Gara region/Dohuk Governorate

TCI	Year 2014		Year 2018		Year 2024			
TCI Severity Level	Area. km^2	%	Area. km^2	%	Area. km^2	%	Rate of Change of Area. km^2 (2014-2018)	Rate of Change of Area. km^2 (2018-2024)
Extreme Drought	54.90	94.05	4.75	8.14	0.26	0.45	-50.15	-4.49
Drought Severe	0.62	1.06	1.36	2.32	0.05	0.09	0.74	-1.31
Moderate Drought	0.57	0.97	2.23	3.82	0.07	0.12	1.66	-2.16
Mild	0.48	0.82	3.26	5.59	0.08	0.14	2.78	-3.18
No Drought	1.81	3.10	46.78	80.13	57.91	99.2	44.97	11.13
Total	58.38	100	58.38	100	58.38	100		

The data in Table (5) showed a significant shift in droughts between 2014 and 2018. In 2014, the category of extreme drought covered about 94.05% of the area Table 4.4 shows a significant shift in droughts between 2014 and 2018. In 2014, the extreme drought category covered about 94.05% of the area (54.90) km^2, but by 2018, this percentage decreased to only 8.14% (4.75) km^2, with a decrease of (-50.15) km^2, indicating a remarkable recovery. At the same time, the areas that do not suffer from drought in 2014 increased from (3.10) % with an area estimated at (1.81) km^2 and in 2018 to (80.13) % with an area estimated at (46.78) km^2 and with a change of (44.97) km^2.Analyzing the trends of the Temperature Condition Index (TCI) between 2018 and 2024 reveals an almost complete mitigation of drought severity across the study area, highlighting a significant shift in temperature dynamics on the Earth's surface. The extreme drought conditions, which recorded (8.14) % with an area of (4.75) km^2 in 2018, decreased to a small percentage of (0.45) % with an area of (0.26) km^2 by 2024, with a decrease of (-4.49) km^2, which reflects a decrease in land surface temperature (LST) associated with a reduction in radiative thermal stress. Similarly, the severe drought, moderate, and mild drought categories witnessed significant reductions, as the total areas were reduced to (2.32, 3.82 and 5.59) % in 2018 with an area of (1.36, 2.23, and 3.26) km^2, respectively, to (0.09, 0.12, and 0.14) % in 2024 with an area of (0.05, 0.07, and 0.08) km^2.This indicates the wide mitigation of thermal deviations with an amount of change of (-1.31, -2.16, and -3.18) respectively. At the same time, no drought areas in 2018 expanded from 80.13% (46.78 km^2) to 99.20% (57.91 km^2) in 2024, with a change of 44.97 km^2.

Vegetation Health Index (VHI)

The Vegetation Condition Index (VCI) quantifies the relative difference between current NDVI values and their historical range, enabling precise assessment of drought impact on vegetation. The Thermal Condition Index (TCI) utilizes satellite-derived land surface temperature (LST) measurements to evaluate thermal stress effects by comparing current LST against historical extremes. VCI and TCI combine via weighted averaging to form the Vegetation Health Index (VHI). Equal weights (0.5 each) are typically applied when optimal weights are unknown (Kogan, 1995). As a composite time-series indicator integrating moisture and thermal constraints, VHI serves as a robust ecosystem health metric. Studies confirm that improved vegetation indices correlate strongly with favorable seasonal rainfall distribution (Kogan, 1990; 1997), highlighting climate-vegetation linkages in these regions (Table 6).

Table (6): Drought comparison based on VHI for the years 2014, 2018, 2024 for Mount Gara region / Dohuk Governorate

VHI	Year 2014		Year 2018		Year 2024			
VHI Severity Level	Area. km^2	%	Area. km^2	%	Area. km^2	%	Rate of Change of Area. km^2 (2014-2018)	Rate of Change of Area. km^2 (2018-2024)
Extreme Drought	46.51	79.66	1.08	1.86	0.27	0.45	-45.43	-0.81
Severe Drought	2.50	4.29	0.95	1.63	0.14	0.24	-1.55	-0.81
Moderate Drought	1.99	3.42	1.43	2.45	0.33	0.57	-0.56	-1.10
Mild	1.56	2.673	1.87	3.20	0.83	1.42	0.31	-1.04
No Drought	5.81	9.96	53.04	90.85	56.81	97.31	47.23	3.77
Total	58.38	100	58.38	100	58.38	100		

Table (6) shows the changes in drought severity, according to the Vegetation Health Index (VHI). In 2014, the extreme drought category was the most widespread, covering about (79.66) % of the total area, equivalent to (46.51 km^2). However, this category witnessed a significant decline by 2018, falling to (1.86) % of the area, representing a decrease of (-45.43) km^2. This decrease reflects a marked improvement in environmental conditions, resulting in improved vegetation health in the region (Hameed, 2011). On the other hand, no drought areas witnessed a significant increase, rising from (9.96) % in 2014, equivalent to (5.81 km^2), to (90.85) % in 2018, with an area of (53.04 km^2), indicating a clear environmental improvement with an increase of (47.23 km^2).The environmental improvement continued in 2024, as the percentage of areas not affected by drought increased to (97.31) %, with an area of (56.81 km^2), recording an increase of (3.77 km^2) compared to 2018. On the other hand, the extreme drought category witnessed a further decrease, amounting to only (0.27 km^2) of the studied area, equivalent to (0.45)%, compared to (1.86) % in 2018, representing a decrease of (-0.81) km^2.Other less severe categories, such as severe drought, decreased to (0.24%) with an area of (0.14) km^2, compared to (1.63) % with an area of (0.95) km^2 in 2018, reflecting an improvement of (-0.81) km^2. Similarly, the moderate drought category witnessed a decrease to (0.57) % with an area of (0.33) km^2. While the category of mild drought decreased to (1.42) % with an area of (0.83) km^2, which indicates the continued improvement in the ecosystem of the region and the amount of change (-1.04) km^2 (Zarei *et al.*, 2013).

CONCLUSIONS

This study demonstrated the effectiveness of using remote sensing data and drought indices (VCI, TCI, and VHI) in monitoring vegetation vitality and assessing drought severity in the Mount Gara region of northern Iraq over a decade-long period (2014–2024). The findings revealed clear temporal fluctuations in drought intensity and vegetation health, with 2014 standing out as the most severe drought year across all indicators. Notably, the VCI and VHI indices reflected a significant recovery in vegetation conditions by 2018, with further improvement projected for 2024. Similarly, the TCI data indicated a dramatic decline in extreme surface temperature stress, suggesting a marked reduction in thermal drought pressure over time. These changes underscore the dynamic nature of the region's environmental conditions and the value of time-series satellite data in detecting and analyzing ecological shifts. The results also highlight the importance of continuous environmental monitoring to support sustainable land and vegetation management, particularly in drought-prone areas like Mount Gara.

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