

Assessment of the Spatial and Temporal Variability of Vegetation Cover in Zawita Forest Using Spectral Indices and Geographic Information Systems

Karam J. AL Beno ^{1*}, Muzahim S. Younis ¹, Mohammed Y. Salim ¹

¹Department of Forestry, College of Agriculture and Forestry, Mosul University, Mosul , Iraq.

*Corresponding author's email: Karam.23agp55@student.uomosul.edu.iq

Email addresses of coauthors: muzahim_saeed@uomosul.edu.iq ,
mohammed_yonuis@uomosul.edu.iq

Abstract

This study aimed to analyse the spatial and temporal variability of vegetation cover in Zawita Forest in northern Iraq using remote sensing techniques and GIS, relying on a set of spectral indices extracted from Sentinel- satellite images which included Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Normalized Difference Water Index (NDWI), Soil Adjusted Vegetation Index (SAVI), and leaf area index (LAI), the results showed a clear seasonal variation in the density and vitality of vegetation cover, where the spring season recorded the highest levels of vegetation activity as a result of the improvement of the leaf area index (LAI), in addition to the estimation of the leaf area index (LAI). Spring recorded the highest levels of plant activity as a result of improved climatic conditions and higher photosynthetic efficiency, while summer witnessed a significant decrease in indicator values as a result of water stress and high temperatures, while winter and autumn reflected transitional states associated with plant dormancy and moisture changes. The results also showed that areas of high vegetation density are concentrated in mountainous locations that are less exposed to human disturbances, while low and medium densities are spread in areas that are less elevated and more affected by human activities. The indicators used confirmed their efficiency in detecting physiological and hydrological changes of vegetation, with GNDVI being superior in monitoring chlorophyll-related changes, NDWI in estimating water stress, and SAVI in minimising soil impact in areas with low vegetation cover. LAI results showed a clear positive relationship between vegetation density and bioproductivity. The study emphasises the importance of integrating spectral indicators with field work to improve the accuracy of forest systems assessment and provide a scientific database to support forest management and sustainability in mountainous and semi-arid environments.

Keywords: NDVI, GNDVI, NDWI, SAVI, leaf area index (LAI), vegetation, water stress.

Introduction

Forests are one of the most important natural resources because they provide environmental and economic services that contribute to maintaining biodiversity, regulating the water cycle, protecting soils, and storing carbon. However, these ecosystems are currently under increasing pressure from climate change, especially drought and rising temperatures, as well as

fires, over-cutting and urbanisation, resulting in declining forest areas, vitality and productivity in many regions of the world [15]. Recent assessments by the FAO indicated a significant decline in the area of vegetation cover, as the area of forests decreased by 3% between 1990-2015 [4]. Drought is one of the most influential factors affecting tree growth

and forest structure, as it leads to a decrease in plant water content, physiological activity and photosynthetic efficiency, which negatively affects the growth, productivity and survival of trees. Therefore, it has become necessary to develop accurate and rapid means to monitor the condition of forests and follow up their response to environmental and climatic changes. In this field, remote sensing techniques have emerged as one of the most efficient tools for studying vegetation, as they provide extensive spatial and temporal data that allow continuous monitoring of forest changes at lower costs compared to traditional field methods [13]. These techniques rely on analysing the spectral reflectance of plants and extracting a set of spectral indicators that reflect their biological and physiological state. This study relied on a number of spectral indices extracted from Sentinel-2 satellite data. The normalised difference vegetation index (NDVI) was used to assess vegetation density and vitality [16], the (GNDVI) to estimate the chlorophyll content and the efficiency of plant physiological activity [7], Normalised Difference Water Index (NDWI) to detect water content and water

stress [6], as well as Soil Adjusted Vegetation Index (SAVI) which yielded accurate results in the study area [9]. Leaf Area Index (LAI) was also used to estimate the amount of leaf area and the degree of bioproductivity of the stands [1]. The study aims to assess the seasonal changes of vegetation cover in Zawita Forest, , which is characterised by great diversity, as it comprises various species of trees and shrubs, in addition to the topography of the area, which influences the distribution of the species found there. To identify periods of water stress and the extent of their impact on tree vitality, given that recent climatic changes have had a negative impact on tree vitality, causing water stress that has adversely affected tree vitality, and to reveal the spatial variation in plant densities reveal the spatial variation of plant densities, and estimate plant productivity through the leaf area index (LAI). The study also seeks to provide scientific information that helps in forest management and conservation, and predicts the areas and periods that are most vulnerable to drought and fires, thus supporting the sustainability of forest resources in the region.

Material and Methods

This study was conducted in Zawita district of Dohuk governorate in northern Iraq, located between (42°50'0"E - 43°18'0"E) and (36°48'0"N - 37°1'30"N), at an altitude of about (885 m) above sea level, with an area estimated at (420.66 km²), and about (16 km) away from the centre of Dohuk city. The region is characterised by a mountainous nature and a temperate Mediterranean-like climate, with moderate temperatures, high humidity in winter, and annual rainfall ranging from 600-800 mm, in contrast to hot and dry summers [14]. The area is part of the mountainous region in Iraq, and there are

clear topographical differences in height, slope and slope directions, which is directly reflected in the distribution of vegetation, which consists of forests, trees and shrubs of varying density, most notably oak species (*Quercus infectoria* and *Quercus aegilops*), *Pistacia khinjuk*, *Prunus amygdalus* and *Pinus brutia* Ten. The study relied on remote sensing and GIS to analyse vegetation cover, through the use of spectral indices such as NDVI, GNDVI, NDWI and SAVI, which are essential tools to estimate the density and vitality of vegetation cover, its water content and associated environmental

impacts, as NDVI is based on the difference between reflectance in the red and near-infrared band, while SAVI is based on the difference between reflectance in the red and near-infrared band. GNDVI replaces the red band with green to increase sensitivity to chlorophyll content, NDWI relies on the difference between NIR and SWIR to estimate water content and water stress, while SAVI introduces a soil correction factor (L) to minimise the effect of the ground background, especially in areas with low vegetation cover [17,6,7,9]. These indicators were extracted using satellite images (Sentinel2) with ArcMap environment through ArcToolbox and Raster Calculator tools after identifying the study area and entering the appropriate spectral bands, to produce accurate spatial maps showing the temporal and spatial variation of vegetation cover. In addition, the LAI index was calculated based on the NDVI index using the following equation:

$$LAI = 0.57 * e^{(2.33 * NDVI)} \quad [20]$$

The study methodology also included a field work to validate the results, where a regular grid method (10×10) was adopted to ensure a balanced distribution of sampling points and linking field data to space analysis (Ground Truthing), in addition to selecting (51) samples distributed in three categories of vegetation density (high, medium, and low) , with the aim of producing accurate spatial maps showing the temporal and spatial variation

of vegetation cover based on the NDVI classification for the 2023 dry season, The figure (1-1) shows the ground survey points for the study area. A GPS device was used to accurately determine the coordinates and fix the sample locations in the field within (10 m x 10 m) squares to reduce variability and increase the accuracy of comparison. Field measurements included multiple tree characteristics such as total Tree Height (TH) using a metric ruler and Haga Altimeter, Crown Point Height (CPH) as an indicator of biomass balance and stem stability, Crown Diameter (CD) using standard tape, and stem diameter at breast height (DBH) at (1.30 m) or (5 cm) for young trees. In addition, we calculated Crown Length as the difference between total height and crown centre height, Crown Coverage Area (CPA) as the horizontal projection of the crown, Crown Surface Area (CSA) and Crown Volume (CV) by assuming ideal geometric models as indicated by [5]. Together, these variables are the basis for analysing stand structure and productivity and interpreting the interactions between environmental factors and forest characteristics in the study area.

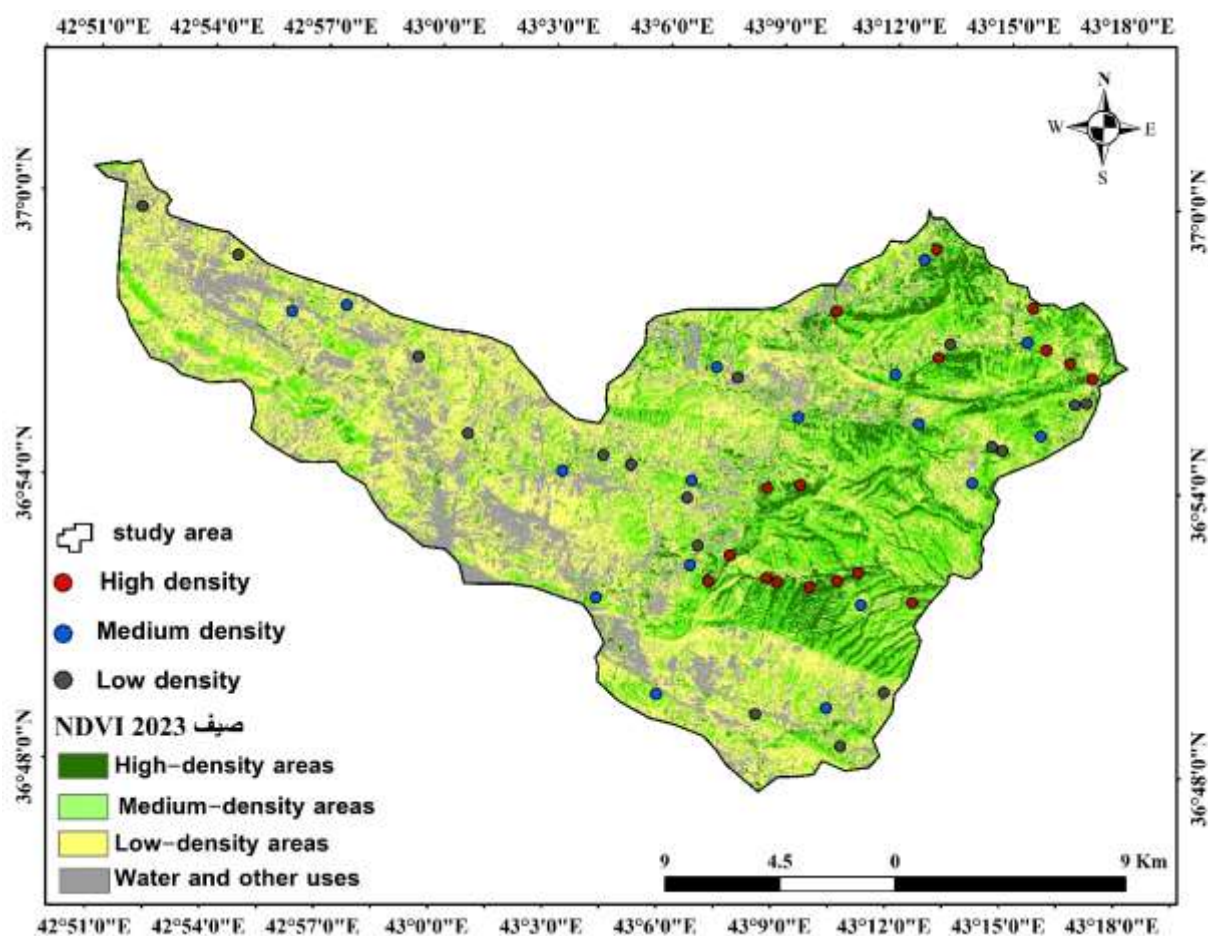


Figure (1-1) shows the 51 ground survey points

Results and Discussion

Spectral characteristics

The Normalized Difference Vegetation Index (NDVI) results showed a clear seasonal variation in density. Densities decreased during the winter as many species went into dormancy and deciduous species shed their leaves, while densities increased during the spring due to the start of the growing season and the activity of natural regeneration processes and increased growth of terrestrial plants. During the summer, the index values decreased as a result of high temperatures,

lack of rainfall and increased water stress, while the autumn season witnessed a relative improvement due to improved climatic conditions and higher relative humidity. The results also showed that high density areas are concentrated in high mountainous and hard-to-reach sites, while medium and low densities are spread in lower elevation sites that are more exposed to human influences and overcutting operations, as shown in (Table1).

Table (1) shows the area occupied by the vegetation cover

Season	Year	Indicator	Area	Area/km2
Winter	2023	NDVI	Barren lands	56.13
			LowDensity	168.65
			Medium Density	170.05
			High Density	25.84
Spring	2023	NDVI	Barren lands	56.92
			Low density	123.29
			Medium density	146.60
			High Density	93.86
Summer	2023	NDVI	Barren lands	75.24
			Low density	171.94
			Medium Density	122.59
			High Density	50.91
Autumn	2023	NDVI	Barren lands	91.36
			Low density	165.76
			Medium density	112.05
			High Density	51.50

Table (1) shows a clear seasonal variation in the distribution of plant densities; the high-density areas recorded the smallest area during the winter due to the entry of plants into dormancy and the shedding of leaves of deciduous species, then increased significantly during the spring due to improved environmental conditions, natural regeneration activity and leaf growth, before decreasing again during the summer due to drought and high temperatures, with a slight improvement in the autumn due to increased humidity and rainfall. Medium- and low-density areas also occupied larger areas than high-density areas due to their prevalence in lower elevation sites that are more exposed to human activities, especially over-cutting. Their areas increased during the growing season as a result of leaf growth in deciduous species and improved climatic conditions, which is consistent with what [11] pointed out about the

importance of seasonal vegetation indicators in distinguishing tree species and studying the movement of vegetation.

Green Normalized Difference Vegetation Index (GNDVI) showed high efficiency in detecting changes associated with chlorophyll content and the physiological state of plants. The results showed that medium-density areas occupied the largest area during most seasons, while the areas of high-density areas varied according to seasonal changes. The index showed high sensitivity to plant physiological changes, especially during summer and autumn, where increased photosynthetic activity and higher chlorophyll content were reflected in increased index values. The relative overlap between low-density and barren areas was also found as a result of the high sensitivity of this indicator to small changes in chlorophyll concentration, as shown in (Table 2).

Table (2) shows the areas occupied by vegetation when using the GNDVI index

Season	Year	Indicator	Area	Area/km2
Winter	2023	GNDVI	Barren lands	18.22
			Low density	71.73
			Medium density	195.85
			High Density	134.86
Spring	2023	GNDVI	Barren lands	24.46
			Low density	108.53
			Medium Density	169.81
			High Density	117.85
Summer	2023	GNDVI	Barren lands	1.57
			Low density	74.51
			Medium Density	227.07
			High Density	117.50
Autumn	2023	GNDVI	Barren lands	1.52
			Low density	80.67
			Medium density	223.99
			High Density	114.47

Table (2) shows that there is a clear seasonal variation in the areas of vegetation cover according to the GNDVI index, where medium-density areas recorded the largest areas during all seasons, followed by high-density areas, while low-density areas recorded the smallest areas. This variation is attributed to the influence of climatic factors and the phenological cycle of plants; areas decrease during winter due to dormancy and leaf fall in deciduous species, then increase during spring and summer due to increased plant activity and high chlorophyll content, before decreasing again in autumn as physiological activity decreases and leaves begin to fall. These results confirm the sensitivity of GNDVI to seasonal changes in the physiological state of vegetation and chlorophyll content [7].

Normalized Difference Water Index (NDWI) provided a clear picture of the seasonal variation in the water content of vegetation. Non-drought-affected areas recorded their largest areas during spring due to favourable environmental conditions and high physiological activity of plants, while they decreased during winter due to plants entering dormancy and reduced movement of plant sap. The results also showed the expansion of areas affected by moderate drought during the summer as a result of high temperatures, low humidity and lack of rainfall. The index emphasised the importance of water content within the plant as a key factor in determining the vital state of the vegetation and its response to seasonal climatic changes, as shown in (Table 3).

Table (3) shows the areas of each area for NDWI

Season	Year	Indicator	Area	Area/km2
Winter	2023	NDWI	High Drought Areas	103.48
			Areas with moderate drought	210.54
			Low Drought Areas	85.86
			Areas with No Drought	20.79
Spring	2023	NDWI	High Drought Areas	73.71
			Medium Drought Areas	152.48
			Low Drought Areas	133.35
			Areas with No Drought	61.14
Summer	2023	NDWI	High Drought Areas	56.07
			Medium Drought Areas	176.62
			Low Drought Areas	141.26
			Areas with No Drought	46.72
Autumn	2023	NDWI	High Drought Areas	75.35
			Medium Drought Areas	181.40
			Low Drought Areas	119.32
			Areas with No Drought	44.60

Table (3) shows the variation in seasonal drought degrees according to the NDWI index, as non-drought-affected areas recorded the largest area during the spring due to favourable climatic conditions, high physiological activity and increased water content within the plants. In contrast, areas of high drought recorded the largest area during winter, despite the availability of moisture in the environment, due to low temperatures and the entry of plants into dormancy and physiological dryness, which reduced the index values. During the summer, the areas of moderate and low drought expanded as a result of high temperatures, increased transpiration rates

and low water content of plants, especially in medium and low density stands with open crown canopies, which is consistent with [6,8]. These results confirm the sensitivity of NDWI to seasonal changes in plant water content and its response to prevailing climatic conditions.

The Soil Adjusted Vegetation Index (SAVI) showed a good ability to minimise the effect of bare soil reflectivity when assessing vegetation cover, especially in areas with low vegetation densities. The results indicated that vegetation densities increased during spring due to vegetative activity and natural regeneration, while

they decreased during summer due to drought and the death of a large part of the ground vegetation. The results also showed that low-density areas were the most affected by seasonal changes as a result of

the opening of the crown canopy and increased exposure of plants to environmental stress compared to high-density areas, as shown in (Table 4).

Table (4) shows the areas of each zone for the SAVI index

Season	Year	Indicator	Area	Area(km2)
Winter	2023	SAVI	Barren lands	56.18
			Low density	168.67
			Medium Density	169.96
			High Density	25.83
Spring	2023	SAVI	Barren lands	59.94
			Low density	126.66
			Medium density	145.58
			High Density	88.47
Summer	2023	SAVI	Barren lands	104.65
			Low density	166.02
			Medium density	108.07
			High Density	41.91
Autumn	2023	SAVI	Barren lands	91.72
			Low density	165.63
			Medium density	111.87
			High Density	51.43

Table (4) shows that there is a clear seasonal variation in the areas of vegetation densities according to the SAVI index, as low-density areas recorded the largest area during the winter due to the shedding of leaves of deciduous species, while their area decreased in the spring due to increased vegetative activity, growth of ground vegetation and natural regeneration processes. During the summer, the areas of low densities increased again as a result of the effect of drought, high temperatures and the death of part of the ground vegetation, which is consistent with [10,12,2,], while the areas of medium and high densities decreased. These results confirm that SAVI clearly reflects the

impact of seasonal changes and drought on vegetation composition, especially in areas with low and medium densities.

The leaf area index (LAI) was also estimated based on NDVI values using a mathematical model linking the two indices. The results showed a clear difference in LAI values between different vegetation densities, with high-density stands recording the highest values compared to medium- and low-density stands. This reflects the increased leaf area, overlapping leaf layers, and higher efficiency of photosynthesis in dense stands. The results also indicated a positive relationship between stand density and

LAI values, which confirms the importance of this indicator in assessing the biological productivity and

physiological state of forests, which we see in Table (5).

Table (5) shows the values of the leaf area index extracted based on the NDVI index during the summer of 2023

High density			Medium Density			Low-density		
NO.	NDVI	LAI	NO.	NDVI	LAI	NO.	NDVI	LAI
1	0.323	1.208	1	0.224	0.961	1	0.153	0.815
2	0.383	1.391	2	0.271	1.071	2	0.169	0.845
3	0.321	1.204	3	0.239	0.994	3	0.139	0.788
4	0.346	1.277	4	0.281	1.096	4	0.172	0.850
5	0.400	1.446	5	0.255	1.031	5	0.167	0.841
6	0.436	1.576	6	0.235	0.986	6	0.175	0.856
7	0.417	1.506	7	0.208	0.925	7	0.180	0.866
8	0.355	1.303	8	0.176	0.859	8	0.158	0.825
9	0.363	1.327	9	0.246	1.010	9	0.177	0.861
10	0.316	1.190	10	0.238	0.993	10	0.153	0.814
11	0.368	1.343	11	0.240	0.996	11	0.171	0.849
12	0.381	1.386	12	0.277	1.087	12	0.185	0.876
13	0.343	1.268	13	0.270	1.070	13	0.144	0.798
14	0.387	1.404	14	0.220	0.951	14	0.169	0.845
15	0.312	1.180	15	0.227	0.967	15	0.166	0.839
16	0.368	1.343	16	0.242	1.002	16	0.157	0.821
17	0.353	1.297	17	0.246	1.010	17	0.175	0.858

From Table (5) we find that there is a variation in LAI values between different densities, as in high densities we observe an increase in LAI values while these values decrease in medium and low densities due to the number of trees in the sample, as high LAI values indicate that there is overlap between leaf layers and also indicates that the biological processes that occur within the plant are at their best,

i.e. peak vegetative activity, efficient photosynthesis and increased growth rates. This is confirmed by [19,3] that high values of LAI indicate higher densities, while low and medium densities give lower values. Also, high values of this index show the overlapping of tree layers and these trees have a relatively complex crown canopy, which is related to photosynthesis and high productivity.

Conclusion

The study found that the use of spectral indices (NDVI, GNDVI, NDWI, SAVI) in combination with the leaf area index (LAI) allowed an accurate understanding of the spatial and temporal variation of

vegetation cover in Zawita Forest, as the results showed a clear seasonal variation in vegetation density and vitality associated with climatic changes, especially drought and high temperatures, with spring

recording the highest vegetation activity against a clear decrease in summer, with spatial variation reflecting the impact of terrain and human pressure. The spectral indicators also proved to be highly efficient in monitoring the physiological state of plants, water content and chlorophyll, with each indicator excelling in a specific aspect of environmental analysis, while the LAI confirmed a positive relationship between vegetation density and biological productivity.

Accordingly, the study recommends the need to rely on remote sensing techniques and GIS as essential tools in forest monitoring and sustainable management, while promoting the integration of field and space data, and conducting seasonal periodic monitoring of vegetation cover for early detection of water stress and drought, to support effective management decisions to preserve forest ecosystems in mountainous and semi-arid areas.

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