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Monitoring Temporal Changes in Forest Extent Using the Normalized Difference Water Index (NDWI) and Bare Soil Index (BSI) in Northeastern Iraq During (1982–2022)

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Abstract
Forests are among the most important habitats for biodiversity and are characterized by highly dynamic and complex ecosystems. However, they are continuously exposed to degradation as a result of climate change, population growth, and the increasing demand for land resources. These challenges can rapidly affect forest-dependent communities, highlighting the need for appropriate policies and informed decision-making. This study aims to monitor the annual changes in forest cover in northeastern Sulaymaniyah during the period 1982–2022. The study area covers 4,217.64 km² and extends between longitudes 44°50′00″ E and 46°20′00″ E, and latitudes 35°20′00″ N and 36°30′00″ N. Satellite imagery acquired from Landsat 3, Landsat 5, Landsat 7, and Landsat 8 at different dates was used to extract the annual changes over four seasons. Model Builder was employed to analyze the data at ten-year intervals using the NDWI and BSI indices. The results revealed clear changes in the forest cover. In particular, the highly moist land-cover class showed a substantial increase in 2022, reaching 634.6144 km² compared with 311.3683 km² in 1982. This represents an increase of 323.2461 km², equivalent to a percentage change of 103.81%.

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Keywords: Forest Cover Change, Remote Sensing, Geographic Information System (GIS), Normalized Difference Water Index (NDWI)

Introduction

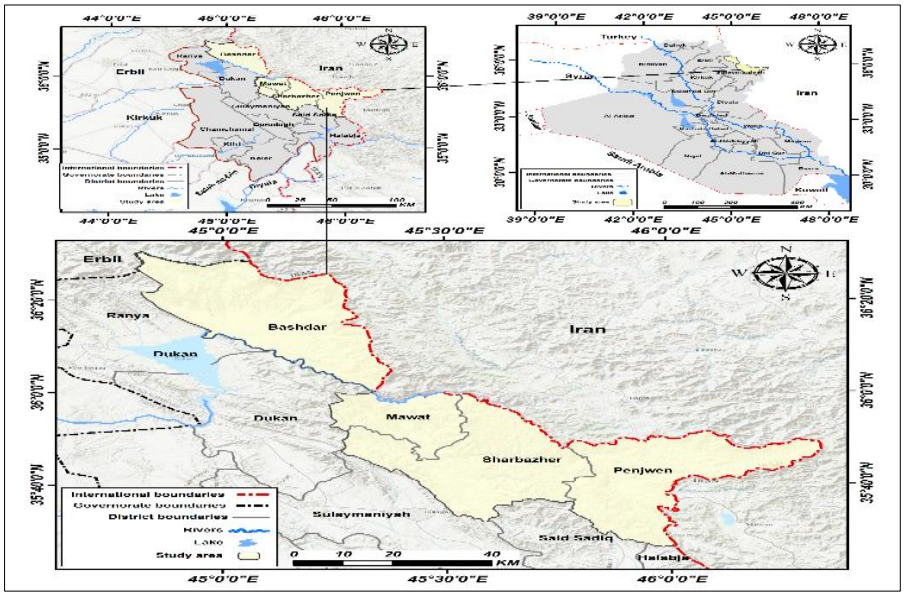
Forests constitute one of the most important components of terrestrial ecosystems, owing to their fundamental role in maintaining ecological balance, supporting biodiversity, regulating hydrological processes, and contributing to carbon sequestration. They also provide essential habitats for a wide variety of plant and animal species and represent an important natural resource for human communities. Despite their ecological and environmental significance, forest ecosystems are increasingly subjected to various natural and anthropogenic pressures that may adversely affect their structure, spatial extent, ecological condition, and long-term sustainability.

Climate change represents one of the major factors influencing the dynamics of forest ecosystems, particularly through alterations in temperature regimes and precipitation patterns, as well as changes in water availability and moisture conditions. Such changes may affect vegetation growth and productivity and contribute to shifts in the spatial distribution of plant species. In addition to climatic pressures, human-induced disturbances, including deforestation, land-use changes, and forest fires, may accelerate the degradation and fragmentation of forest ecosystems and contribute to changes in their spatial extent over time. Consequently, monitoring the spatial and temporal dynamics of forest areas has become an important requirement for understanding the environmental changes affecting forest ecosystems and for supporting sustainable natural-resource management. In this context, remote sensing and Geographic Information Systems (GIS) provide effective tools for detecting and quantifying changes in vegetation and land-surface characteristics over different temporal periods. The application of

spectral indices, particularly the Normalized Difference Water Index (NDWI) and the Bare Soil Index (BSI), enables the assessment of variations in surface moisture and bare-soil conditions and facilitates the identification of areas experiencing changes in forest environments. Accordingly, monitoring the annual changes in the forest range provides valuable information for identifying the spatial patterns and temporal trends of forest dynamics, determining areas subjected to environmental pressures, and supporting appropriate management strategies aimed at conserving forest resources and reducing their degradation.

Location

The study area is located in the northeastern part of Iraq, within Sulaymaniyah Governorate, as shown in Map (1). It extends geographically between 44°50′00″ E and 46°20′00″ E longitudes and 35°20′00″ N and 36°30′00″ N latitudes, covering an area of approximately 4217.64 km². The study area is bounded to the northeast by the Iraqi–Iranian international border, which is associated with the Zagros Mountain Range. To the west, it shares a boundary with Dukan District, while Ranya District is located to the northwest. To the south, the study area is bounded by Halabja and Sayyid Sadiq districts. This geographical setting, together with the region's mountainous terrain and environmental characteristics, contributes to considerable spatial variation in vegetation conditions and forest distribution, making the area suitable for investigating the spatial and temporal dynamics of forest ecosystems using remote-sensing techniques.



Source: Based on Republic of Iraq, Ministry of Planning, Central Statistical Organization, Administrative Map of Iraq (2012).

Fig 1: map(1)lLocation map of the study area in relation to Iraq

Temporal Boundaries

The temporal boundaries of the study are represented by the period covered by the climatic data and forest-area data, extending over 41 years from (1982 to 2022). This period was selected to monitor and assess temporal changes in forest area in northeastern Iraq.

Research Problem The research problem can be formulated through the following questions: 1. Have there been changes in forest area in northeastern Iraq during the study period? 2. To what extent have forest fires and inappropriate human practices contributed to the reduction in forest area in northeastern Iraq?

Study Objectives

The study aims to achieve the following objectives:

1. To detect and monitor temporal changes in forest extent within the study area during the study period.
2. To quantify the magnitude and spatial distribution of changes in forest extent across the study area and the selected observation periods.
3. To identify the areas experiencing the most significant changes in forest extent, thereby providing a spatial basis to support environmental management and decision-making processes.

Research Methodology

The study adopted an analytical and descriptive methodological approach to detect and assess temporal and spatial changes in forest extent. Multi-temporal satellite imagery representing the four seasons was analyzed using remote-sensing and GIS techniques. The imagery was processed and classified to derive the spatial distribution of forest-related land-cover classes and to quantify their changes over the study period.

Application of ModelBuilder

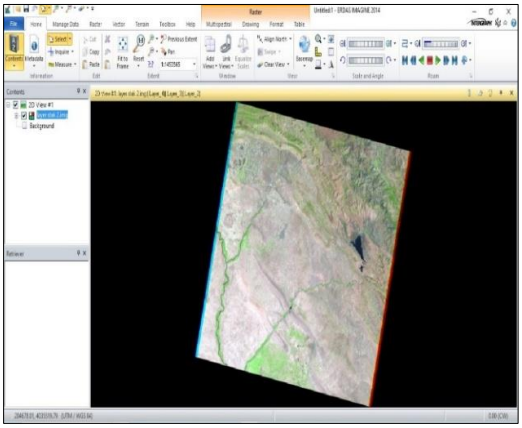
ModelBuilder was employed as a geoprocessing environment to develop and implement a systematic analytical workflow for processing the satellite imagery. ModelBuilder provides a visual programming interface that enables geospatial processing operations to be organized into interconnected sequences of tools and datasets. This approach facilitates the automation, standardization, reproducibility, and documentation of spatial analysis procedures. In the present study, ModelBuilder was used to develop a sequential processing workflow for analyzing the satellite imagery of the study area and detecting annual and seasonal variations in forest extent. The analysis utilized four satellite images representing different observation periods and seasons. The datasets included imagery acquired by the Thematic Mapper

(TM) sensor onboard Landsat satellites and imagery acquired by the Operational Land Imager (OLI) sensor onboard Landsat 8, as presented in Table (1). The satellite imagery was processed using the geoprocessing tools available within the ArcGIS environment. A ModelBuilder workflow was constructed by integrating the required datasets and analytical tools into a sequential processing chain. This workflow was designed to ensure a consistent application of the analytical procedures to the different satellite images and to facilitate the extraction, comparison, and spatial assessment of forest-related changes. The successive stages of the analytical workflow are presented in table (1).

Table 1: Satellite imagery used for the analysis of annual changes in forest extent using the ModelBuilder environment.

Year and Month	Date of Capture	Satellite
1982-5 1982-10	1982-5-4 1982-10-19	Landsat -3 Land sat-3
1992-5 1992-10	1992-5-14 1992-10-9	Landsat -5 Landsat -5
2002-5 2002-10	2002-5-24 2002-10-8	Landsat -7 Landsat -7
2012-5 2012-10	2012-5-14 2012-10-8	Landsat -7 Landsat -7
2022-5 2022-10	2022-5-13 2022-10-16	Landsat -8 Landsat -8
1982-8 1982-1	1982-8-26 1982-1-14	Landsat -3 Landsat -3
1992-8 1992-1	1992-8-19 1992-1-28	Landsat -5 Landsat -5
2002-8 2002-1	2002-8-11 2002-1-6	Landsat -7 Landsat -7
2012-8 2012-2	2012-8-9 2012-2-13	Landsat -7 Landsat -7
2022-8 2022-1	2022-8-23 2022-1-19	Landsat -7 Landsat -7

Source: Prepared by the researcher based on satellite imagery obtained from the U.S. Geological Survey (USGS) EarthExplorer platform.



using ERDAS 2014

Fig 2: Spectral band stacking (Layer Stack) of the satellite imagery

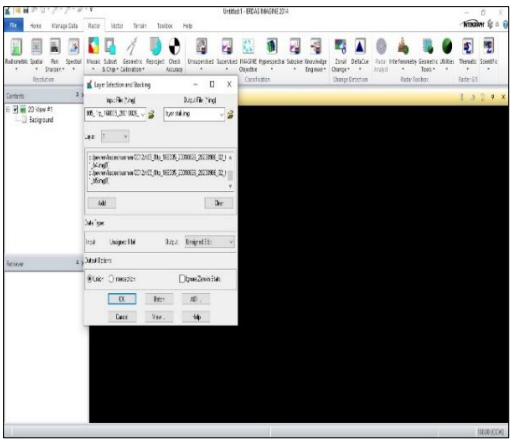
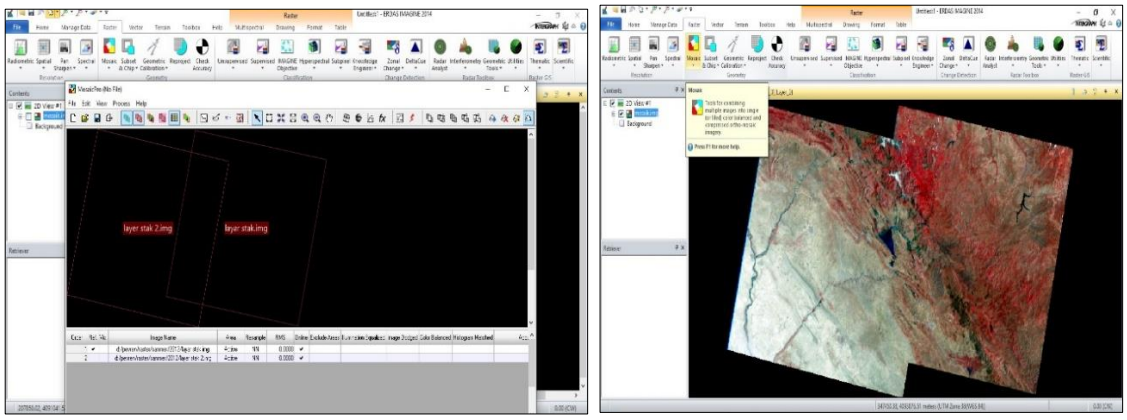


Fig 3: Mosaicking of adjacent satellite scenes to generate a continuous image covering the study area



using ERDAS 2014.

Fig 4: Subsetting (clipping) of the satellite imagery according to the spatial boundaries of the study area

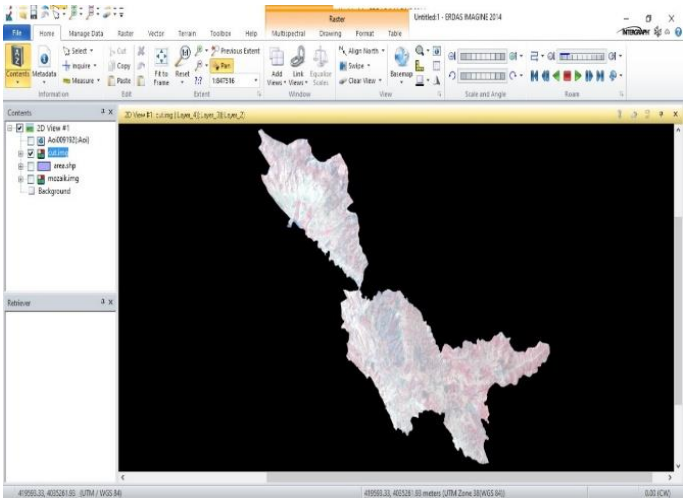


Fig 5: Derivation of spectral indices from the satellite imagery

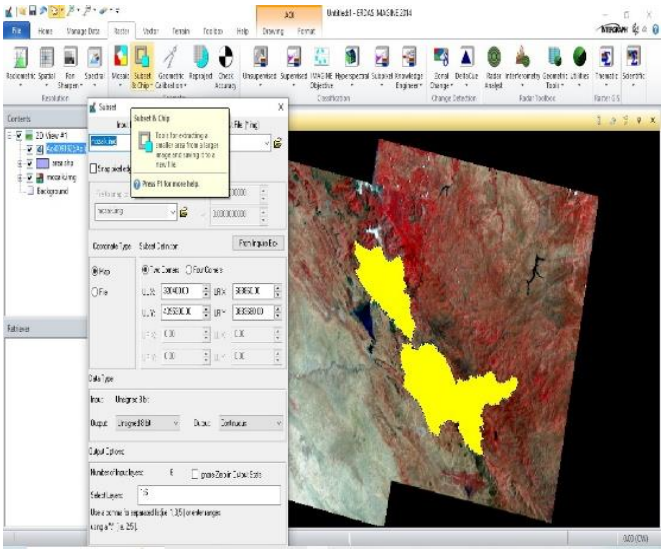
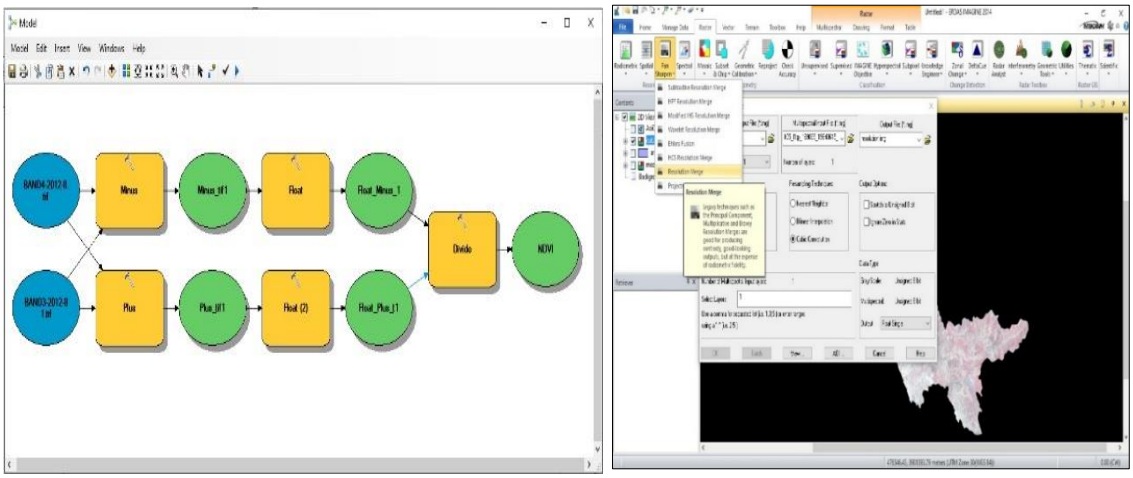
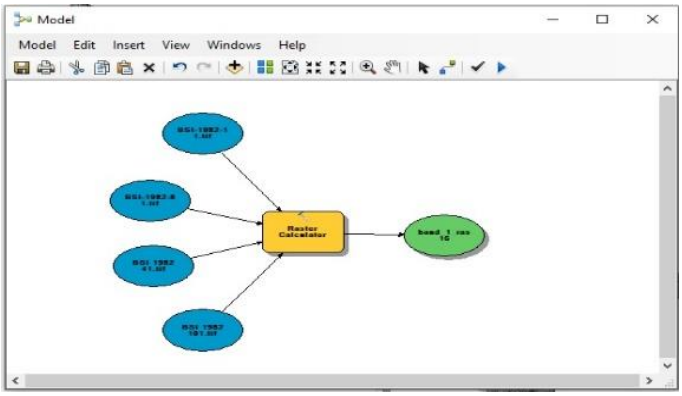


Fig 6: Derivation of spectral indices



using ModelBuilder in ArcGIS 10.8. using ModelBuilder in ERDAS 2014

Fig 7: Integration of seasonal spectral-index outputs to derive annual index values



using ModelBuilder in ArcGIS 10.8.

Fig 8

Spatial distribution of changes based on the Normalized Difference Water Index (NDWI) during the period (1982–1992) The principle underlying NDWI is based on the contrasting spectral responses of water, vegetation, and soil across different regions of the electromagnetic spectrum, particularly within the green and near-infrared (NIR) wavelengths.[(1)] Water generally exhibits relatively low reflectance in the infrared region because of its strong absorption of electromagnetic radiation, whereas vegetation has a distinct spectral response that varies according to its physiological condition, internal leaf structure, and water content. Consequently, differences in the spectral response between these wavelengths can be exploited to identify and monitor spatial and temporal variations in vegetation water status. Accordingly, NDWI provides a useful spectral measure for detecting changes in vegetation moisture conditions and identifying areas experiencing varying degrees of water stress. The index is calculated using the appropriate spectral bands according to the characteristics of the satellite sensor employed, as expressed by the following equation [(2)]:

NDWI= (Nir-SWIR) / (Nir+SWIR)

NDWI = (B4-B5)/(B4+B5) (Landsat for 7 - 5 -3)

NDWI = (B5-B6)/(B5+B6) (Landsat 8)

The NDWI has been applied in a range of environmental and vegetation-related studies, including the assessment of water stress in forest ecosystems, the evaluation of leaf area characteristics in densely vegetated areas, vegetation productivity modeling, and the assessment of vegetation susceptibility to fire [(3)]. The index theoretically ranges from −1 to +1, with its values reflecting differences in the spectral response associated with vegetation moisture conditions. In general, relatively higher positive values indicate greater vegetation moisture and water availability, whereas lower or negative values are generally associated with reduced moisture conditions and may indicate vegetation water stress or drought. The interpretation of NDWI values should, however, be considered in relation to the spectral bands used, the characteristics of the satellite sensor, and the land-cover conditions within the study area.

The Normalized Difference Water Index (NDWI) was applied to the Landsat 3, 5, 7, and 8 satellite imagery to assess the prevailing vegetation conditions during the study period. The spatial extent and percentage of change were subsequently calculated for the respective seasons for each year of the study period. The highest NDWI value recorded during the spring season was 0.66, whereas the lowest value

was 0.48. During the winter season, the highest recorded value was 0.68, while the lowest value was 0.24. In the summer season, the maximum NDWI value reached 0.29, whereas the minimum value was −0.74. These values indicate temporal variations in the moisture conditions of the vegetation cover throughout the study period. The maximum and minimum NDWI values are presented in Table (2).

Table 2: Maximum and Minimum NDWI Values

NDWI		season	Years
Highest value	Lowest value		
0.21	-0.38	summery	1982
0.32	-0.43	Autumn	
0.58	0.37	winter	
0.62	0.41	spring	
0.23	-0.34	summery	1992
0.31	-0.48	Autumn	
0.59	0.24	winter	
0.63	0.48	Spring	
0.22	-0.36	summery	2002
0.39	-0.41	Autumn	
0.68	0.47	Winter	
0.66	0.48	Spring	
0.29	-0.32	summery	2012
0.47	-0.42	Autumn	
0.68	0.41	winter	
0.58	0.38	Spring	
0.23	-0.47	summery	2022
0.26	-0.49	Autumn	
0.48	0.31	winter	
0.46	0.35	Spring	

Source: Prepared by the researcher based on spectral index values derived from Landsat 3, 5, 7, and 8 satellite imagery for the four seasons.

1. Changes Based on the Normalized Difference Water Index

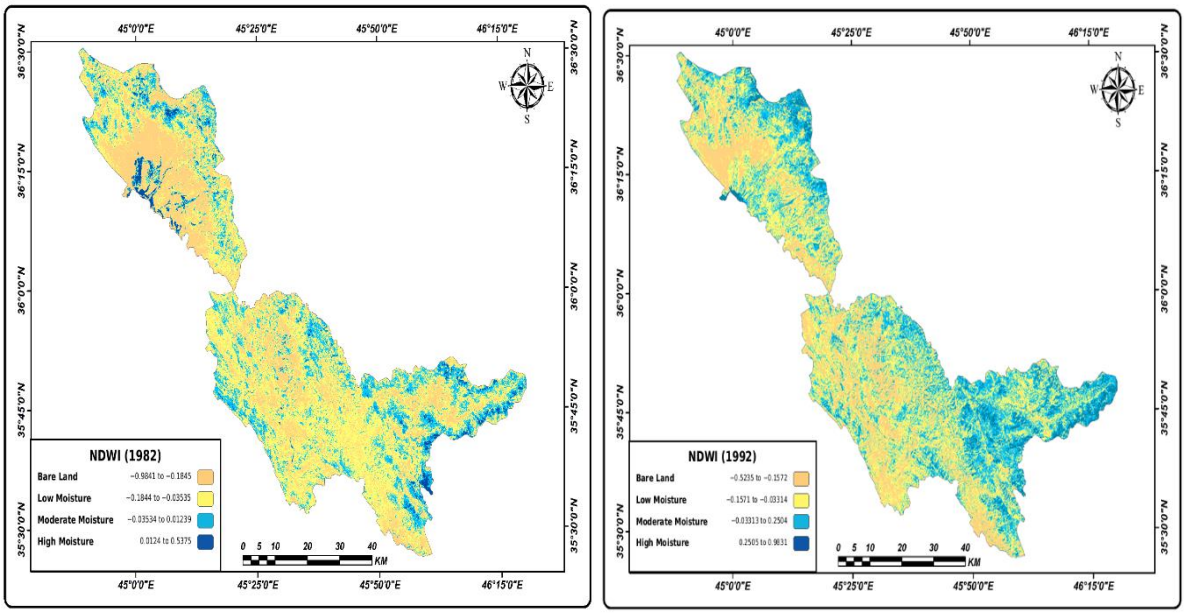
(NDWI) during (1982–1992) Analysis of Map (2) and the data presented in Table (3) reveals clear spatial and temporal variations in the values and spatial distribution of the Normalized Difference Water Index (NDWI) during the period (1982–1992). These variations reflect differences in the moisture conditions of the land and vegetation cover and may be associated with variations in water availability and prevailing climatic conditions, particularly precipitation, in addition to the environmental and spatial characteristicsofthestudyarea.Theobservedchangescanbesummarizedasfollows:

Decrease in the areas of dry and low-moisture land: The area classified as dry land decreased from 1,254.49 km² in 1982 to 1,062.75 km² in 1992, representing a change rate of −15.28%. Similarly, the area classified as low-moisture land decreased from 1,936.01 km² to 1,631.45 km² during the same period, corresponding to a change rate of −15.73%. This decrease indicates a reduction in the spatial extent of areas characterized by relatively low moisture conditions according to the NDWI classification.

Increase in the areas of moderate- and high-moisture classes: In contrast, the area classified as moderately moist increased from 715.7767 km² in 1982 to 1,121.81 km² in 1992, representing a change rate of 56.73%. Likewise, the area of the high-moisture class increased from 311.3683 km² to 401.64 km², corresponding to a change rate of 28.99% during the same period.

These increases indicate a spatial shift toward areas characterized by higher moisture conditions according to the NDWI classification. Such changes may be associated with variations in hydroclimatic conditions, particularly precipitation and water availability, as well as changes in vegetation cover and land use. Overall, the NDWI analysis for the period (1982–1992) indicates a significant spatial redistribution of moisture classes, characterized by a decrease in the areas of dry and low-moisture classes and a corresponding increase in the areas of moderate- and high-moisture classes. These changes are likely to reflect the combined influence of natural and human-induced factors. Therefore, their interpretation should be supported by precipitation records, vegetation-cover changes, and land-use information rather than being attributed to a single factor. With regard to the expansion of tree-planted areas, the source cited in

Reference (4) reports tree-planting activities in the study area involving coniferous species, olive, eucalyptus, and almond trees. However, the cited planting activities refer to 2004, which falls after the 1982–1992 comparison period. Consequently, these activities cannot be considered a direct cause of the changes detected between 1982 and 1992 unless documented evidence is available for similar planting activities during the study period. The 2004 tree-planting activities may instead be discussed in relation to subsequent changes observed after 2004.[4]



Source: Based on spectral indices derived from Landsat-5 imagery.

Fig 8: Map (2) Spatial Distribution of Moisture Classes Derived from the NDWI for 1982 and 1992

Table 3: Percentage of Change Based on the NDWI during the Period (1982–1992)

Class	1982		1992		Amount of Change	Change %	Type of Change
	Area Km	Percentage%	Area Km	Percentage			
Baer land	1254.49	29.74	1062.75	25.20	-191.74	-15.28	Decrease
LOW Humidity	1936.01	45.90	1631.45	38.68	-304.56	-15.73	Decrease
Medium Humidity	715.78	16.97	1121.81	26.60	406.03	56.73	Increase
High Humidity	311.37	7.38	401.64	9.52	90.27	28.99	Increase
Total	4217.64	100.00	4217.64	100.00%			

Source: Areas and change percentages were calculated using ArcMap 10.3. The area and percentage change were calculated using the following

(A2-A1/A1) *100 A_1 = area in the initial year (km²). A_2 = area in the final year (km²)

2. Changes Based on the Normalized Difference Water Index (NDWI) during (2002–2012)

Analysis of Map (3), Table (4), reveals notable changes in the spatial distribution of the moisture classes during the period 2002–2012. These changes can be summarized as follows:

Decrease in the area of highly moist land: The area classified as highly moist land decreased to 314.66 km² in 2012, compared with 369.82 km² in the initial year. This represents a decrease of 55.17 km², corresponding to a change rate of 14.92%. This reduction may be associated with a decrease in precipitation and increased water stress affecting vegetation within the study area.

Decrease in the area of dry land: The area classified as dry land decreased to 864.09 km² in 2012, compared with 993.85 km² in the initial year. The resulting decrease amounted to 129.76 km², representing a change rate of 13.06%.

Increase in the areas of low- and moderate-moisture land: In contrast, the areas classified as low-moisture and moderate-moisture land increased during the study period. The low-moisture class increased to 1,724.42 km², compared with 8.25 km² in the initial year, whereas the moderate-moisture class increased to 1,314.47 km², compared with 176.66 km². These changes indicate a considerable spatial redistribution among the NDWI-derived moisture classes during the study period. Overall, the results demonstrate considerable temporal and spatial variation in the moisture conditions represented by the NDWI. The observed changes may be related to variations in precipitation, vegetation water status, and other environmental and land-surface factors. Therefore, the interpretation of these changes should be considered in conjunction with precipitation data and changes in vegetation cover and land use.

3. Overall Changes Based on the NDWI for the Period (1982–2022)

Analysis of Map (4), Table (5), and Figure (1) reveals considerable changes during the 41-year study period. The high-moisture land class recorded a substantial increase in 2022, reaching 634.6144 km², compared with 311.3683 km² in 1982. This represents an increase of 323.2461 km², correspondingtoa103.81%change. Similarly, the medium-density vegetation cover class increased in 2022, reaching 1,429.372 km², compared with 715.7767 km² in 1982. The resulting increase amounted to 713.595 km², representing a 99.70% change. In contrast, the bare and low-moisture land classes experienced a decline by 2022. The area of the bare-land class decreased from 1,254.489 km² in 1982 to 738.0826 km² in 2022, representing a reduction of 516.4064 km² and a 41.16% decrease. Likewise, the low-moisture land class declined from 1,936.005 km² in 1982 to 1,415.574 km² in 2022, with a reduction of 520.431km²,equivalenttoa26.88%decrease.

Bare Soil Index (BSI) The Bare Soil Index (BSI) is a spectral index that integrates information from different spectral bands to detect and assess variations in bare soil and soil-related surface characteristics. It utilizes spectral information from the near-infrared (NIR), red, blue, and shortwave infrared (SWIR) bands to enhance the detection of exposed

soil surfaces and distinguish them from vegetation cover. The spectral responses of these bands provide information related to soil and surface mineral characteristics, while the combination of the NIR, red, blue, and SWIR bands contributes to differentiating bare soil from vegetated surfaces. The dynamic range of the BSI generally extends from −1 to +1, although the actual range of values may vary depending on the characteristics of the study area and the input imagery. The BSI is calculated according to Equation (6).

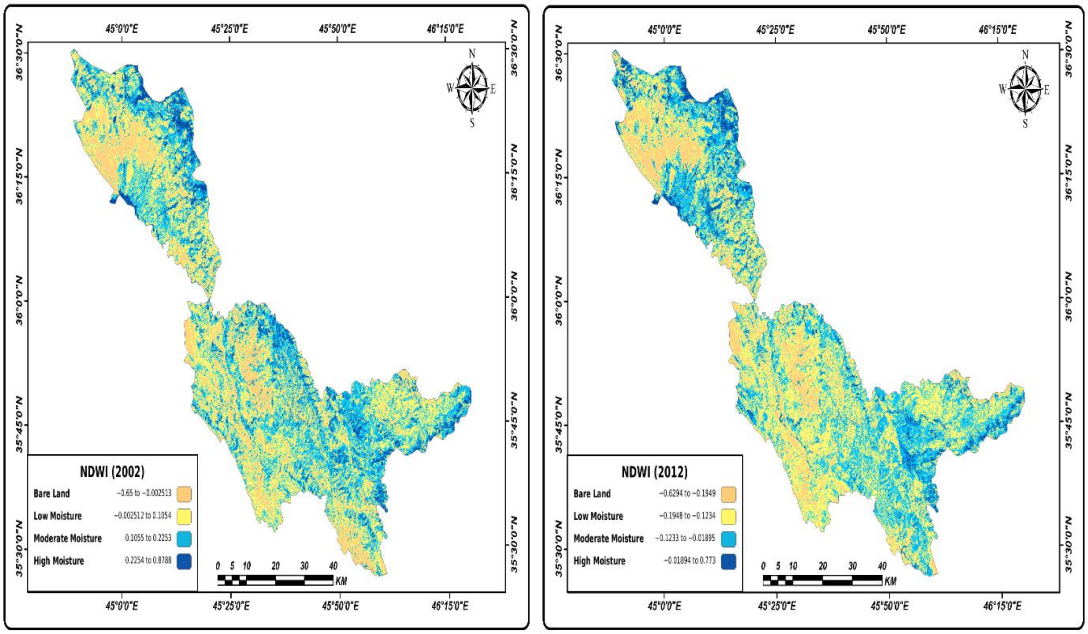
$$1 + BSI = \frac{(SWIR1+RED)-(NIR+BLUE)}{(SWIR1+RED)+(NIR+BLUE)}$$

Short Infrared = (Swir1)= Near Infrared (NIR (

7 -5-3 ETM Landsat- $1 + BSI = \frac{(B5+B3)-(B4+B1)}{(B5+B3)+(B4+B1)}$

OLI Landsat-8 $1 + BSI = \frac{(B6+B4)-(B5+B2)}{(B6+B4)+(B5+B2)}$

The Bare Soil Index (BSI) was applied to Landsat satellite imagery (Landsat 8, 7, 5, and 3) to assess the current status of the prevailing vegetation cover. The area and percentage of change were calculated for the four seasons—spring, summer, autumn, and winter—for all years of the study period. The results showed that the spring season recorded the highest BSI value throughout the study period, reaching 0.62, while the lowest value was −0.36. In the winter season, the highest BSI value was 0.57, whereas the lowest value reached −0.56. During the summer season, the highest BSI value was 0.29, while the lowest value was −0.74. In contrast, the autumn season recorded the highest BSI value, reaching 0.69, while its lowest value was −0.33. The corresponding results are presented in Table (6).



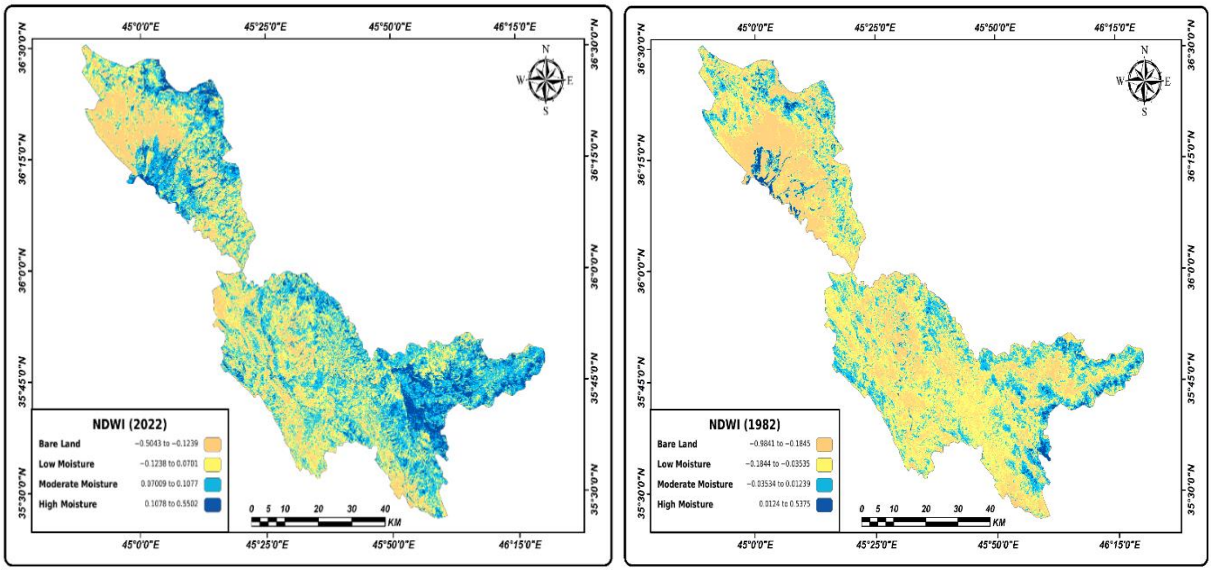
Source: Areas and change percentages were calculated using ArcMap 10.3.

Fig 9: Map (3) Spatial Distribution of NDWI Classes for 2002 and 2012

Table 4: Percentage of Change Based on the NDWI during the Period (2002–2012)

Class	2002		2012		Amount of Change	Change %	Type of Change
	Area Km	Percentage%	Area Km	Percentage			
Bare land	993.85	23.56	864.09	20.49	-129.76	-13.06	Decrease
LOW Humidity	1547.76	36.70	1724.42	40.89	176.66	11.41	Increase
Medium Humidity	1306.22	30.97	1314.47	31.17	8.25	0.63	Increase
High Humidity	369.82	8.77	314.66	7.46	-55.17	-14.92	Decrease
Total	4217.64	100.00	4217.64	100.00%			

Source: Areas and change percentages were calculated using ArcMap 10.3.



Source: Areas and change percentages were calculated using ArcMap 10.3.

Fig 10: Spatial Disteibution of NDWI Classes in 1982 and 2022.

Table 5: Percentage of Change Based on the NDWI during the Period (1982-2022)

CLASS	1982		2022		Amount of Change	Change %	Type of Change
	Area Km	Percentage	Area Km	Percentage			
Bare land	1254.49	29.74	738.08	17.50	-516.41	-41.16	Decrease
LOW Humidity	1936.01	45.90	1415.57	33.56	-520.43	-26.88	Decrease
Medium Humidity	715.78	16.97	1429.37	33.89	713.60	99.70	Increase
High Humidity	311.37	7.38	634.61	15.05	323.25	103.81	Increase
Total	4217.64	100.00	4217.64	100.00%			

Source: Areas and change percentages were calculated using ArcMap 10.3. Figure (1) The overall changes according to the index NDWI for the period (1982-2022)

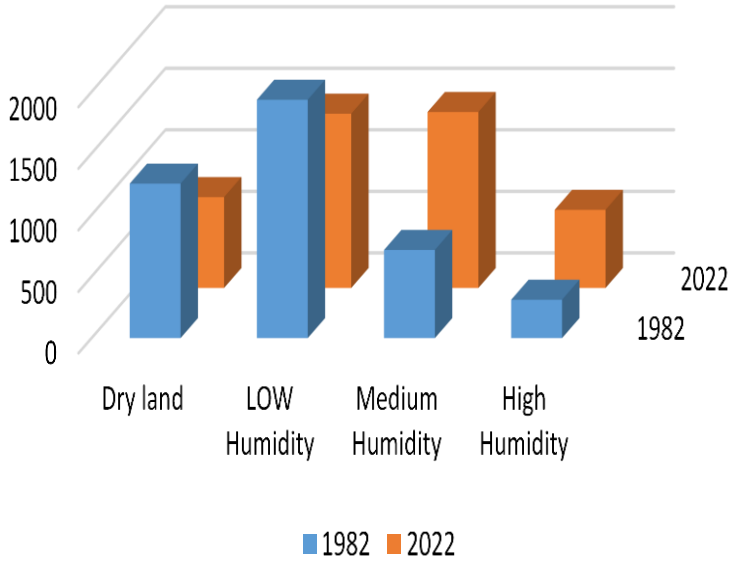


Fig 11: Based on Table (5) using Excel software

Table 6: of highest value and low values with index BSI

BSI		Season	Years
Highest value	Lowest value		
0.74	0.38	Summery	1982
0.69	-0.23	Autumn	
0.52	-0.48	Winter	
0.62	-0.35	Spring	
0.79	0.28	Summery	1992
0.64	-0.33	Autumn	
0.48	-0.42	Winter	
0.58	-0.32	Spring	
0.77	0.31	Summery	2002
0.62	-0.28	Autumn	
0.54	-0.56	Winter	
0.69	-0.25	Spring	
0.79	0.28	Summery	2012
0.66	-0.27	Autumn	
0.57	-0.42	Winter	
0.56	-0.36	Spring	
0.82	0.48	Summery	2022
0.66	-0.29	Autumn	
0.32	-0.53	Winter	
0.42	-0.31	Spring	

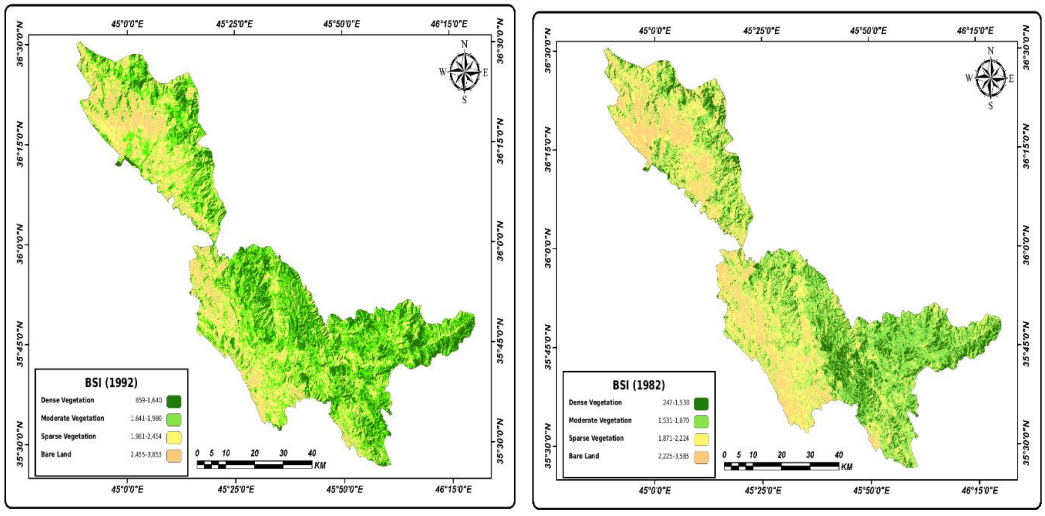
Source: Prepared by the researcher based on spectral index values derived from Landsat 3, 5, 7, and 8 satellite imagery for the four seasons.

Detection of Changes Based on the BSI for the Period (1982–1992)

An analysis of Map (5), Table (7), reveals a decline in the spatial extent of the dense vegetation cover class. In 1992, this class occupied an area of 710.71 km², compared with 812.58 km² in 1982, representing a decrease of 101.88 km² and a change rate of 12.54% of the total study area. Similarly, the moderate-density vegetation cover class declined in 1992, covering 1,216.88 km², compared with 1,315.94 km² in 1982. This represents a reduction of 99.06 km², corresponding to a change rate of 7.53% of the total study area. 3. The low-density vegetation cover class occupied 1,416.50 km² in 1992, compared with 1,445.10 km² in 1982. Thus, the class experienced a decrease of 28.60 km², corresponding to a change rate of 1.98% of the total study area. 4. In contrast, the bare land class recorded an increase in spatial extent in 1992, reaching 873.56 km², compared with 644.02 km² in 1982. This represents an increase of 229.53 km², with the highest change rate among the investigated classes, amounting to 35.64% of the total study area. This increase occurred largely at the expense of the other vegetation-cover classes. The observed decline in vegetation cover can be attributed, in part, to extensive tree cutting and forest fires, which were associated with the presence of numerous military munitions and landmines in the study area. These conditions also posed considerable difficulties for personnel attempting to control and extinguish the fires, particularly because of the high elevation and rugged terrain, which limited accessibility and hindered firefighting operations.

Changes According to the BSI for the Period (2002–2012)

Analysis of Map (6), Table (8), indicates an increase in the areas of both the high-density vegetation cover class and the bare-soil class in 2012, largely at the expense of the low-density vegetation cover class. The area of the high-density vegetation cover class increased in 2012 to 730.53 km², compared with 601.62 km² in 2002, representing an areal increase of 128.91 km². This corresponds to a 21.43% change in relation to thetotalareaofthestudyregion.



Source: Areas and change percentages were calculated using ArcMap 10.3.

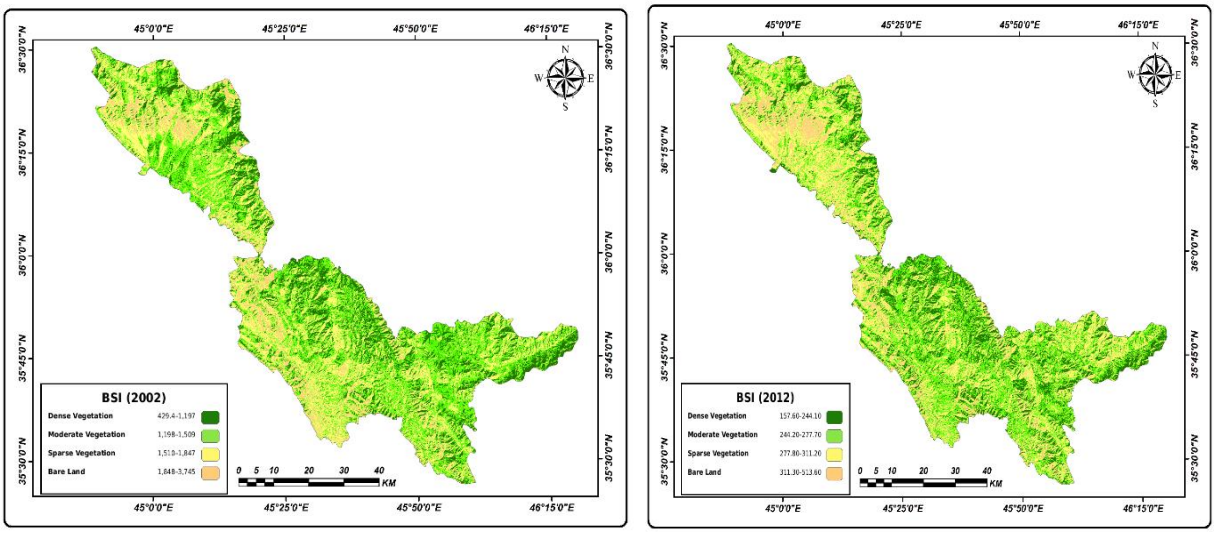
Fig 12: Map (5) (1992–1982)

Table 7: Change according the BSI index for the period (1992-1982)

CLASS	1982		1992		Change Km ²	Percentage of change	Type of change
	Area Km2	Percentage	Area Km2	Percentage			
Dense vegetation	812.58	19.27	710.71	16.85	-101.88	-12.54	Loss
Moderate vegetation	1315.94	31.20	1216.88	28.85	-99.06	-7.53	Loss
Sparse Vegetation	1445.10	34.26	1416.50	33.59	-28.60	-1.98	Loss
Barren land	644.02	15.27	873.56	20.71	229.53	35.64	More
The total	4217.64	100.00	4217.64	100%			

Source: Areas and change percentages were calculated using ArcMap 10.3.

Similarly, the bare-soil class increased in area in 2012, reaching 763.71 km², compared with 709.44 km² in 2002. The increase amounted to 54.26 km², representing a 7.65% change of the total area of the study region. In contrast, the low-density vegetation cover class experienced a decline in 2012, with its area decreasing to 1,301.07 km², compared with 1,502.84 km² in 2002. This represents an areal decrease of 201.77 km², corresponding to a 13.43% change relative to the total area of the study region. This decline may be associated, in part, with the abandonment of agricultural land by some farmers and its conversion into tourist housing, which may be related to limited water availability, insufficient support for Kurdish farmers, and increased reliance on imported agricultural products at the expense of local production.



Source: Areas and change percentages were calculated using ArcMap 10.3.

Fig 13: Map (6) spatial Distrbution of Vegetation -Coverand Bar-Land Classes Derived from (2002–2012)

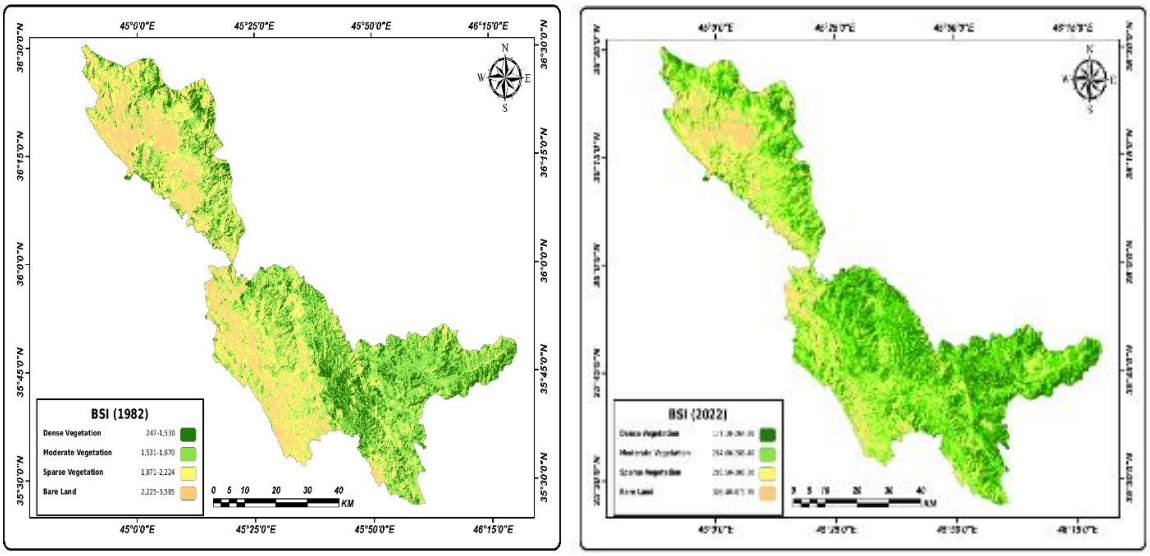
Table 8: Change according the BSI index for the period (2002-2012)

Types	2002		2012		Change Km ²	Percentage of change	Type of change
	Area Km2	Percentage	Area Km2	Percentage			
Dense vegetation cover	601.62	14.26	730.53	17.32%	128.91	21.43	MORE
Moderate vegetation	1403.74	33.28	1422.34	33.72%	18.60	1.33	MORE
Sparse Vegetation	1502.84	35.63	1301.07	30.85%	-201.77	-13.43	LOSS
Barren land	709.44	16.82	763.71	18.11%	54.26	7.65	MORE
The total	4217.64	100.00	4217.64	100%			

Source: Areas and change percentages were calculated using ArcMap 10.3.

Long-Term Changes According to the BSI for the Period (1982-2022)

Analysis of Map (7), Table (9), and Figure (2) reveals a long-term decrease in the area of the high-density and medium-density vegetation cover classesoverthestudyperiod. The area of the high-density vegetation cover class decreased in 2022 to 553.45 km², compared with 812.58 km² in 1982, representing an areal decrease of 259.13 km² and a change rate of 31.90% of the total area of the studyregion. Similarly, the area of the medium-density vegetation cover class decreased in 2022 to 1,117.74 km², compared with 1,315.94 km² in 1982, representing an areal decrease of 198.20 km² and a change rate of 15.10% of the total area of the study region. In contrast, the bare-soil and low-density vegetation cover classes recorded an increase in area over the same period. The area of the bare-soil class increased from 644.02 km² in 1982 to 869.13 km² in 2022, representing an areal increase of 225.11 km² and a change rate of 35.95% of the total area of the study region.Likewise, the area of the low-density vegetation cover class increased from 1,445.10 km² in 1982 to 1,677.32 km² in 2022, representing an areal increase of 232.22 km² and a change rate of 16.07% of the total area of the study region.



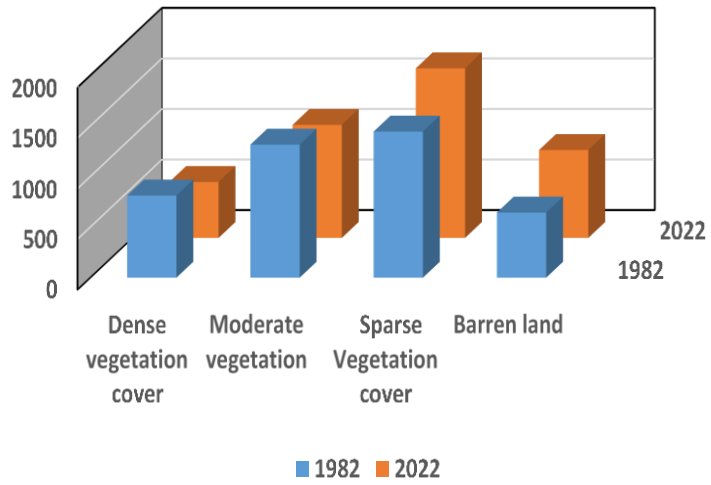
Source: Areas and change percentages were calculated using ArcMap 10.8.

Fig 13: Map (7) Spatial Disteibution of BSI Classes in 1982 and 2022.

Table 9: Percentage of Change Based on the BSI during the Period(1982-2022)

TYPES	1982		2022		Change Km ²	Percentage of change	Type of change
	Area Km2	Percentage	Area Km2	Percentage			
Dense vegetation	812.58	19.27	553.45	13.12%	-259.13	-31.89	LOSS
Moderate vegetation	1315.94	31.20	1117.74	26.50%	-198.20	-15.06	LOSS
Sparse Vegetation	1445.10	34.26	1677.32	39.77%	232.22	16.07	MORE
Barren land	644.02	15.27	869.13	20.61%	225.11	35.95	MORE
The total	4217.64	100.00	4217.64	100.00%			

Source: Areas and change percentages were calculated using ArcMap 10.3



Based on Table (9) using Excel software

Fig 14: Figure (2) The overall changes according to the index BSI for the period (1982-2022)

Conclusions

1. According to the Normalized Difference Water Index (NDWI), the area of the high-moisture land class increased during the period 1982–2022, with an increase of approximately 103.81%. Likewise, the area of the medium-moisture land class increased by approximately 99.70%, whereas the areas of the bare-soil and low-moisture land classes decreased by approximately 41.16% and 26.88%, respectively. 2. The results of the Bare Soil Index (BSI) revealed clear changes in the spatial distribution of vegetation-cover classes and bare-soil areas during the period 1982–2022. The area of the high-density vegetation cover class decreased by 259.13 km², representing a change rate of 31.89%. Similarly, the area of the medium-density vegetation cover class decreased by 198.20 km², representing a change rate of 15.06%. 3. The low-density vegetation cover class recorded an areal increase of 232.22 km², representing a change rate of 16.07%. Similarly, the area of the bare-soil class increased by 225.11 km², with a change rate of 35.95%.
2. These results indicate considerable changes in the spatial distribution of vegetation cover and bare-soil areas within the study region. The observed changes in agricultural land and bare-soil areas may vary according to the index used, the observation year, and rainfall

conditions. 5. The study demonstrated the effectiveness of modern geospatial technologies, particularly sequential processing models implemented through ModelBuilder, in detecting and monitoring changes in vegetation cover. These techniques contribute to accelerating analytical procedures and facilitate the repetition of analyses over different time periods. The comparative analysis of the BSI and NDWI indices demonstrated that the observed changes are not restricted to forest cover alone, but also encompass variations in vegetation density, moisture levels, drought conditions, and water stress.

Recommendations

1. The adoption of modern remote-sensing and GIS technologies is recommended for monitoring changes in forest areas and vegetation cover.
2. Environmental awareness among the inhabitants of the study area should be enhanced through awareness programs, educational posters, and periodic informational publications, with the aim of reducing tree-cutting activities undertaken for various purposes.
3. The BSI and NDWI indices should be utilized as supporting tools for monitoring and assessing environmental changes and their spatial distribution.
4. Greater emphasis should be placed on planting tree and plant species that are more tolerant of drought conditions, in order to adapt vegetation cover to current climatic changes and enhance its resilience to water stress.
5. Strict enforcement of environmental legislation is recommended, including the imposition of appropriate financial penalties and legal sanctions, to protect forest areas from repeated tree cutting and other activities contributing to forest degradation.

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