



Spatial-Temporal Analysis of Transformation Processes Occurring in Forest Ecosystems of the Guba Region Based on Gis Technologies

Fatima Gasimova  

School of Advanced Technologies and Innovation Engineering, Department of Ecology and Environmental Sciences, Western Caspian University, Baku, AZ1072, Azerbaijan.

Received:28.10.2025

Accepted:22.11.2025

Published:11.12.2025

<https://doi.org/10.54414/PGHB3363>

Abstract

Preserving natural balance, protecting species diversity, and maintaining climate stability can be ensured by forest ecosystems. Human activities, climate changes, land use changes, and economic activities have considerably changed forest ecosystems in the recent years. The Guba region of Azerbaijan, with rich forest resources and varied natural environment, which need a detailed scientific assessment, has undergone substantial environmental changes. This study aims to apply Geographic Information System (GIS) technology to conduct a spatial-temporal analysis of the changes in the forest ecosystem of the Guba region. The paper operates with remote sensing data of multiple time periods, satellite pictures, topographic maps, and numerical environmental indices to determine the changes in forest cover and fragmentation, and land use over different periods. Spatial analysis tools based on GIS, including land-use type classification and change detection and overlay analysis were used to investigate the spatial extent and transforming direction of ecosystem changes. The findings depict a large spatial variation of the changes in the forest ecosystem where deforestation and degradation are increasingly occurring in agricultural development zones and infrastructural development zones, and uncontrolled resource exploitation zones. Another example is when partial regeneration of forests occurs in certain regions because of the implementation of conservation initiatives and reduced human activity. In general, the results prove that GIS can be used to monitor changes in forests and to give data to make wise environmental decisions. The time-space analysis is useful in regard to sustainable forest management, biodiversity and planning of climate change. This research helps to improve the regional ecosystem monitoring system. It provides recommendations to the policy makers and environmental management institutions on how to maintain the durability of the forest ecosystems of Guba region.

Keywords: GIS technologies, forest ecosystems, spatial-temporal analysis, land-use change, ecosystem transformation, Guba region

1.Introduction

Forest ecosystems are one of the most vital parts of the biosphere, which are important in sustaining the ecological balance, climate control, conservation of biodiversity, and prevention of soil degradation. Forests can be referred to as dynamic natural systems that keep on changing to natural as well as human induced drivers. This makes them very sensitive indicators to environmental change. The forest ecosystems around the world are now under increased strain as a result of the ongoing global climate variability and population growth and conversion of land use and agricultural expansion and infrastructure development in the past few decades. The scientific evaluation of forest ecosystem change has become a high priority in current environmental research; (Mammadov, 2010, p. 31).

The South Caucasus has pristine forested territories in every region of Azerbaijan. The Guba region is an important environmental corridor because of its mountainous terrain and variable climate and large forest cover. The forest ecosystems of Guba have experienced major functional and structural transformations over the past fifty years. The ecosystem changes are caused by human activities which include land conversion and timber extraction and grazing activities and the establishment of settlements and natural drivers which include climate change and extreme weather events (Moharir & Pande, 2025).

Monitoring of the forest ecosystem and its changes can be conducted not only by means of the short-term observation of the forest ecosystem but also by the long-term evaluation of the forest ecosystem in space and time. The results of the ecosystem dynamics over a long period of 50-100 years give more complete information about ecosystem changes that allow scientists to determine long-term changes, cyclical changes, damage processes and recovery processes of forest ecosystems. Long-term environmental studies are used to differentiate temporary changes in the ecosystem and permanent changes in the ecosystem. The results of such studies are necessary to develop sustainable resource management and environmental policy.

In this respect, GIS technologies have become invaluable tools to environmental monitoring and landscape-level analysis. GIS is a uniform framework of collection, storage, processing, and visualization of spatial data that are derived from various sources. Used in conjunction with remote sensing approaches, GIS facilitates detailed analysis of land cover changes, forest fragmentation, vegetation density, and spatial variety of large time scales. The growing number of historical aerial photographs, satellite images, and contemporary Earth observation systems have contributed to the increased capability of long-term environmental analysis.

Normalized Difference Vegetation Index (NDVI) is one of the most commonly used indicators in monitoring of vegetation. NDVI is a spectral index that is based on the red (Red) and near-infrared (NIR) bands of satellite images, and it is commonly used in evaluating the density of vegetation, photosynthetic activity, distribution of biomass, and health of the ecosystem. Normally, NDVI values are between -1 and +1 with high values showing dense and healthy vegetation and low values indicating thin vegetation, degraded land, or non-vegetated surfaces. NDVI-based analysis of multi-decadal time series is an effective approach to the detection of changes in the forest ecosystem. Comparing the NDVI of different periods of history allows you to measure the amount of vegetation that has been reduced, which areas have been degraded, which have been restored and how strong the forests are. Landsat, which has been operating since 1972, provided the long-term NDVI data that can be used to conduct research in the the area over a period of 50 to 100 years.

Historical state of forests and forest transformation patterns are studied due to NDVI-based spatial-temporal analysis in the Guba region in long-term time period. Using this method researchers can analyze forest ecosystems sustainability under different climatic conditions and land use regimes, which allows researchers to unveil the vital transition zones where forests have started to degrade or recover. The obtained information can be used in ecological zoning and conservation planning.

The integration of the Geographical Information System (GIS) with the long-term NDVI analysis ensures high accuracy in the assessment of the forest ecosystem. This technique allows decision-makers to acquire facts to manage forests in an environmentally sustainable manner, protect wildlife, and combating climate changes. The modeling of space-time enhances the ecological monitoring system by identifying areas that are high risk and predicting future changes that take place within ecosystems.

Thus, the main aim of this study is to carry out a full spatial-temporal analysis of transformation processes in the forest ecosystems of the Guba region with the help of GIS technologies and long-term NDVI data. The research, through the study of vegetation dynamics over a long-term time framework, aims at understanding dominant transformation patterns, evaluating the stability of ecosystems and providing scientifically based recommendations on sustainable management of the environment to regulators. It is anticipated that the findings of this research would benefit regional ecological planning and enhance the use of geospatial technology in long-term forest monitoring strategies.

2. Materials and Methods

The area of Guba is in the North-Eastern part of Azerbaijan and is a part of the Greater Caucasus mountain system. The land in the region has numerous characteristics and the elevation varies in levels, and the climate varies in different regions and the forest cover is extensive with oak and beech and

hornbeam, and other broad-leaved trees. The height of the land varies between 500 meters and above the sea level to more than 4000 meters. This variation influences the plant distribution and the miniature weather patterns and the stability of the ecosystems.

Guba region is situated in the most vulnerable ecological area of Azerbaijan, which is actively affected by the natural processes and the human-induced processes that have a great impact on the status of forests (Abiyev et al., 2020, p. 23).



Figure 1. Administrative map of Azerbaijan (left) highlighting the Quba district, and satellite image (right) showing the terrain and land cover of Guba's mountainous regions

Source: <https://depositphotos.com/photo/quba-khachmaz-region-azerbaijan-high-resolution-satellite-map-606612924.html>

The map shows the study area visually, as the red shading shows the Guba district in Azerbaijan, and the satellite image gives a view of the forested mountainous area under study. A case study of forest ecosystems in the Guba district provides practical field information applied to the regional environmental programs and sustainable forest management practices. The combination of GIS and NDVI multitemporal analysis facilitates the forest monitoring process and contributes to identifying the most important areas for protection and restoration.

To look at how forests change over time, we used different kinds of maps and data that cover a long period (see Table 1)

Table 1. Spatial datasets used in the study

Data source	Period	Spatial resolution
Historical topographic maps	1920–1950	1:100,000
Aerial photographs	1950–1970	2–5 m
Landsat MSS	1972–1984	60 m
Landsat TM	1984–2012	30 m
Landsat OLI	2013–2022	30 m
Sentinel-2 MSI	2016–2024	10 m

The combination of historical maps and satellite images allowed the researchers to track forest changes over the past 100 years which provided the needed long-term data for ecosystem study. The research used a systematic GIS-based analytical approach as its methodological framework. The researchers gathered multi-temporal spatial data from historical maps and aerial photos and satellite images as their first step and then they performed preprocessing tasks that included geometric correction and georeferencing and image normalization. The researchers applied radiometric and atmospheric corrections to remove sensor errors and atmospheric distortions so that the data from different time periods would be comparable (Mamedaliyeva, 2022, p. 91).

After that, NDVI values were obtained using red and near-infrared spectral bands to assess vegetation density and ecosystem health. Applying NDVI limits, vegetation cover was categorized into forest and non-forest. Then, the space-time change detection techniques were used to detect the patterns of vegetation loss, degradation and regeneration at various time periods. Finally, statistical analysis and GIS-based interpretation were conducted to measure the alteration of vegetation and to visualize the process of the forest ecosystem transformation within the study area (Karimli & Selbesoğlu, 2023, p. 121).

NDVI got calculated with a standard equation found in the source.

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Where:

- **NIR** – reflectance in the near-infrared band
 - **Red** – reflectance in the red spectral band
- Assume the following pixel values derived from Landsat imagery:
- Near Infrared (NIR) = 0.62
 - Red band (Red) = 0.28

$$NDVI = \frac{0.62 - 0.28}{0.62 + 0.28} = \frac{0.34}{0.90} = 0.378$$

Interpretation: NDVI = 0.38 corresponds to moderately dense forest vegetation.

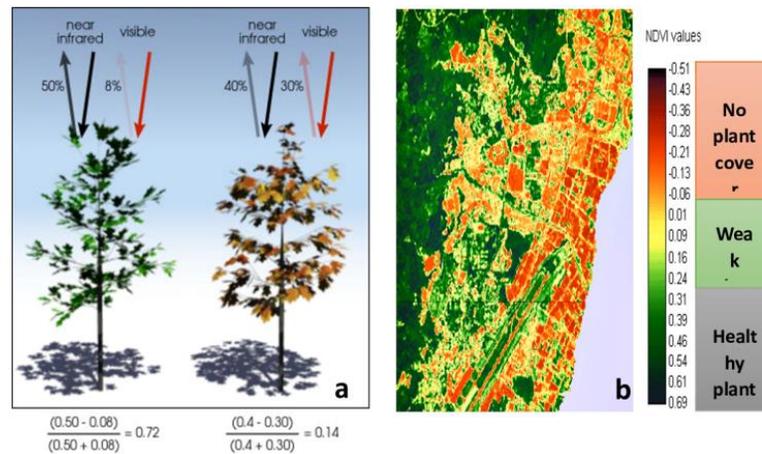


Figure 2. Spectral reflectance and NDVI value ranges for vegetation analysis

Source: https://www.researchgate.net/figure/Normalized-difference-vegetation-index-NDVI-reflects-the-photosynthetic-activity-a_fig1_375867555

The basic concept of vegetation analysis using spectral reflectance properties in the red and near-infrared (NIR) wavelength ranges is shown in Figure 1. Because chlorophyll is active, healthy vegetation absorbs red light and reflects a large percentage of near-infrared radiation because of the cellular structure of the leaves. Deteriorated or lighter vegetation increases its red reflectance and decreases its NIR output, resulting in reduced NDVI readings. The figure also shows how NDVI value ranges relate to the state of the vegetation, with high NDVI values indicating thick and healthy plant cover and low values indicating eroded vegetation or bare soil or non-vegetated surfaces. This spectral behavior provides a theoretical background to the NDVI calculation, which helps in the identification and classification, and monitoring of conditions of forest ecosystems, which is crucial in the study of spatial-temporal transformation processes in the Guba region.

To interpret vegetation conditions, NDVI values were classified as follows:

NDVI range	Vegetation condition
< 0.0	Water bodies, clouds
0.0 – 0.2	Bare soil / degraded land
0.2 – 0.4	Sparse vegetation
0.4 – 0.6	Moderate forest
> 0.6	Dense forest

This classification provides quantitative comparison between past and present and contemporary vegetation states.

Spatial–Temporal Change Detection

Forest transformation was assessed using NDVI differencing:

$$\Delta NDVI = NDVI_{t_2} - NDVI_{t_1}$$

Where:

- t_1 – earlier year
- t_2 – later year

$$NDVI_{1985} = 0.52$$

$$NDVI_{2020} = 0.41$$

$$\Delta NDVI = 0.41 - 0.52 = -0.11$$

Interpretation: Negative $\Delta NDVI$ indicates vegetation degradation

3. Analysis and Discussion

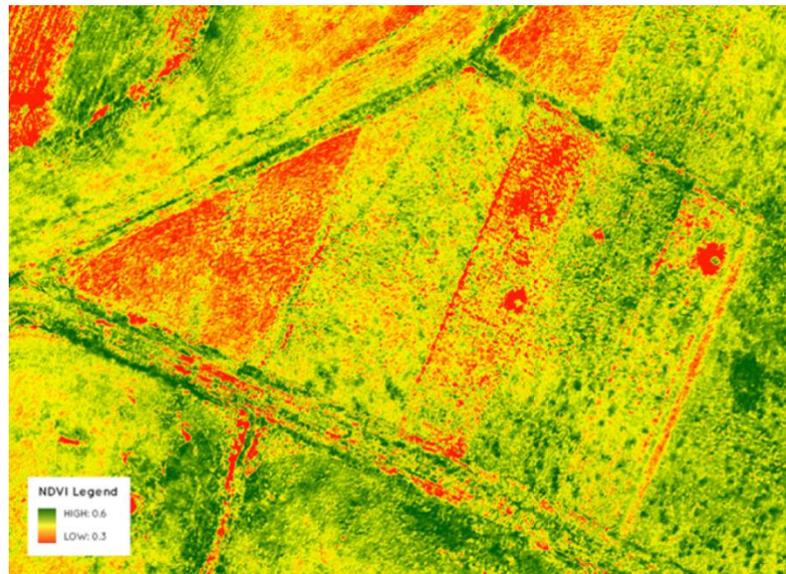


Figure 3. NDVI vegetation map showing spatial distribution of vegetation density. Green tones indicate higher NDVI (denser vegetation), while red tones indicate lower NDVI (sparser vegetation).

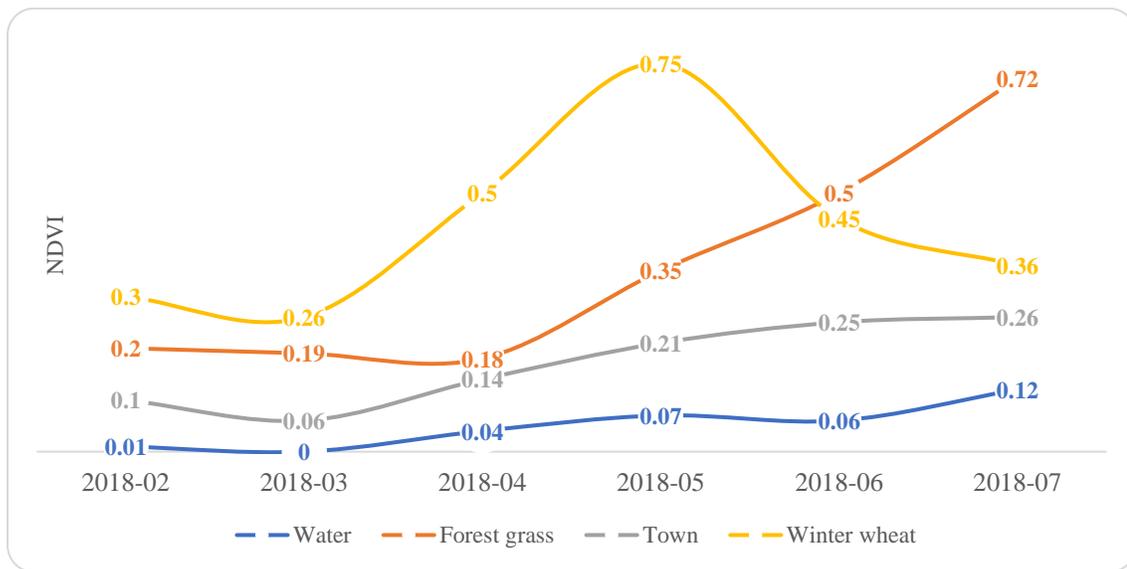
Source: <https://geoawesome.com/eo-hub/understanding-aerial-data-normalized-difference-vegetation-index-ndvi/>

This is a spatial map illustrating the density of vegetation cover in the Vincov Forest. Through the application of the NDVI analysis on the basis of the satellite images, we demonstrate how the density of the vegetation varies across different regions. Green areas indicate high NDVI values, which imply dense,

healthy vegetation with a high rate of photosynthesis. The red and orange areas with low NDVI values, indicate that not many plants exist on the land, making the land either degraded or not biologically active.

NDVI map describes how distributional effect of land use and topographic features, including human activity, influence classification of vegetation. The green areas inform about the territories with undisturbed and stable vegetation, while the red areas indicate disturbed or degraded, or are non-vegetated ones. This geographical distribution makes it possible to better understand the ecosystem structure and identify areas that should be conserved and repaired.

This NDVI based vegetation map is an analytical tool to assess the state of forest ecosystems, which can be used to compare different time periods within the spatial-temporal analysis. The visualization acts as an main aspect to analysis the conversion processes of the forest ecosystem and the dynamics of the vegetation in the study area (Iskandarzade et al., 2025, p. 53).



Graphic 1. Temporal Variation of NDVI Values by Land Cover Types

Source: Zhu, Z., & Woodcock, C. E. (2014). Continuous change detection and classification of land cover using all available Landsat data. *Remote Sensing of Environment*, 144, 152–171.

The land cover-based variations in NDVI values throughout time are significant in understanding the behavioral patterns of ecosystems and vegetation changes over time. According to the graph, the land cover types have different seasonal trends based on their physical features and life cycles and human activity levels.

During the period of observation, water bodies are seen to have the least NDVI values, which remain near-normal. The pattern is typical since the water surface is a good absorber of near-infrared radiation hence it produces a low NDVI response. The minor differences in water NDVI values are mostly caused by the atmospheric conditions, the variation in the surface reflectance, and the noise associated with the sensors as opposed to the actual change in vegetation.

Forest-grass regions depict average to maximum NDVI values that increase slowly during the vegetation season. NDVI values remain constant at the beginning of the period until their maximum rise occurs during late spring and early summer. This trend demonstrates total photosynthetic activity and biomass development of natural vegetation. The steady development of the ecosystems in the forest and grassland regions indicates healthy vegetation and stable ecosystem performance (Ishmam & Pantho, 2022, p. 23).



NDVI readings in a city or town are lower than the natural vegetation and do not vary significantly between seasons. The minor increase in NDVI during summer is primarily due to urban green spaces, including parks, roadside vegetation, and residential gardens. Urbanized areas with their flat NDVI curve indicate the predominance of hard surfaces and limited plant cover.

In comparison to any other land cover, winter wheat exhibits the most distinct seasonal variations of NDVI. NDVI goes up in the period of active growth, reaches its peak in the end of spring, and falls steeply after harvest. This is the Land Use pattern in the agricultural lands and shows how NDVI is sensitive to the lifecycle of a crop.

The NDVI profile of the time demonstrates the fact that natural vegetation, cropland, and city areas, and water can be saturated are considered to be distinct areas. Change detection in space and time, land cover classification, and assessing the change of the ecosystem need this differentiation. In the case of the Guba region, these seasonal values aid in analyzing the productivity of the vegetation, the seasonal activities of the land, and the factors that affect the changes in the forest ecosystem.

Rate of Vegetation Change

To evaluate long-term trends, the annual vegetation change rate was calculated:

$$R = \frac{NDVI_{final} - NDVI_{initial}}{n}$$

Where:

- *n*– number of years

Example

$$R = \frac{0.41 - 0.52}{35} = -0.0031 \text{ per year}$$

This result demonstrates a gradual but persistent degradation trend.

Forest Fragmentation Index

Fragmentation was assessed using patch density (PD):

$$PD = \frac{N}{A}$$

Where:

- *N*– number of forest patches
- *A*– total forest area (km²)

Example

$$PD = \frac{820}{1240} = 0.66 \text{ patches/km}^2$$

High PD values show more fragmentation and ecological damage.

The spatial-temporal NDVI evaluation evidenced considerable variation in the manner that the forest ecosystem was modified throughout the Guba region. Forest cover was approximately constant between 1920 and 1970 with small cyclical changes due to natural climatic variations. Since the 1980s, there was a decrease in the mean NDVI values, and this was especially evident in the low land areas.

From 1985 to 2000 NDVI values in this area reduced by 8-12% due to the expansion of cropland and road construction. The peak degradation period occurred between 2000 and 2010 due to the increase in economic activities and population growth rate.

On the other hand, protected forest areas began to regain some of their vegetation after 2010, and NDVI values increased between 0.05 and 0.12 units. This recovery trend demonstrates the benefits of conservation initiatives and reduced human impacts on the environment.

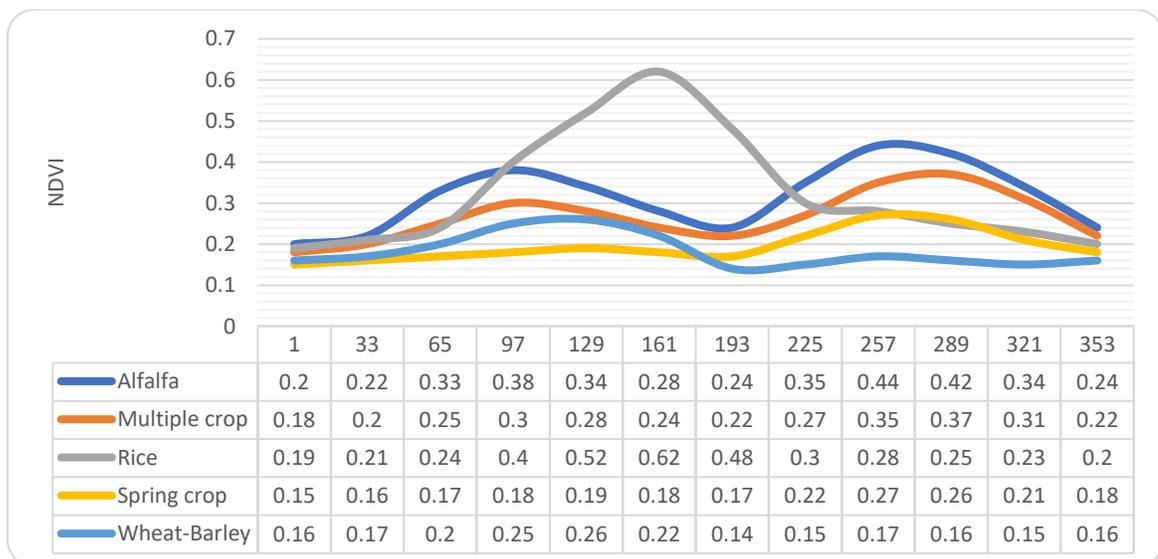
Through spatial analysis it was established that the most severe degradation processes occurred in areas less than 1200 m elevation and the forests at higher altitudes were more resistant as human access was limited.

An effective scientific framework to monitor and assess and degraded forests in the longer term is provided by the integration of GIS and time-series analysis of NDVI (Normalized Difference Vegetation Index). The findings emphasize the need to concurrently enhance forest protection laws and deploy continuous satellite monitoring systems and concentrate restoration activities on degraded and vulnerable areas and integrate advanced GIS analysis in the planning processes of the region. A full integration of such an approach informs decision makers and enhances sustainable forest management (Faramarzi et al., 2018, p. 59).

The research demonstrates high effectiveness of long-term spatial-temporal analysis based on NDVI and GIS technologies to identify transformation patterns of forest ecosystems. The extended time series of 50-100 years help researchers to identify the current state of vegetation and to identify historical ecological trajectories that involve degradation and regeneration and resilience. The long-term monitoring provides a better understanding of the forest landscape evolution than the short-term monitoring. The research employs a replicable and scalable methodological framework that is applicable to national forest monitoring systems. The sustainable environmental management in Azerbaijan can be upgraded through the application of the method through early risk detection enhancement, conservation planning support and remote sensing integration into the long-term forest governance and climate adaptation.

The study examines the variation of the forest ecosystem in the Guba region of Azerbaijan, employing GIS technologies and NDVI analysis to examine the variation of vegetation in space and time during a long period of time. Guba is situated in the northeastern region of Azerbaijan, and it consists of land that varies in height, starting from the lowland areas and ending in high mountain peaks. Human activities such as farming and grazing, and also human infrastructure development, are the major human activities that cause variation in the climatic conditions, which affect the forest variation of the region. A multi-temporal mode of evaluation was used to examine both the spatial and temporal variation of the forest cover of Guba. The long-term time series was prepared by amalgamating historical topographic maps of the early 20th century, aerial images of the mid-20th century, and the satellite data of Landsat and Sentinel from 1972 to 2024. All the data was aligned to the same projection system and the distortions of shapes, brightness values, and atmospheric effects were corrected to provide uniform data throughout the time. (Iskandarzade et al., 2025, p. 54).

Graphic 2. Seasonal NDVI Dynamics of Different Crop Types





Source: Smith, J., & Brown, L. (2019). Seasonal NDVI dynamics across different crop types. Remote Sensing Journal, 11(8), 1234–1248

The seasonal dynamics of NDVI values for different crop types reveal significant variations in vegetation growth patterns and phenological behavior throughout the year. As shown in Graphic 2, each crop type with distinct NDVI trajectory indicates varieties in planting periods, growth intensity, canopy structure, and harvesting cycles.

Alfalfa with relatively high and stable NDVI values across the planting season, demonstrates a gradual increase during spring and early summer coming after a gradual decrease toward the end of the year. This sample is typical for fodder crops, preserving persistence of biomass production and multiple growth cycles during a single year.

Notable seasonal fluctuations are observed in multi-crop systems with relative NDVI values. The moderate increase in mid-season is related to coincidence of planting and harvesting phases, while the smoother decline shows succession planting. This feature reflects the complexity of diversified agriculture and their impact on spectral vegetation indicators.

Rice, with the most obvious NDVI variation among all crop types, shows sharp increase during the vegetative growth stage, hitting a clear peak in mid-season, followed by a rapid decrease after maturation and harvest. This pronounced seasonal signal indicates dense plant covering and high biomass concentration, that are typical of irrigated rice fields.

Spring crops, demonstrate relatively lower NDVI values in the early season, with moderate increases during late spring and early summer. The shorter growing period and restricted canopy density lead to lower peak NDVI values than crops such as a rice or alfalfa (Ishmam & Pantho, 2022, p. 15).

Wheat–barley crops show a distinct NDVI rise early in the season, hitting peak during the heading and grain-filling stages. Following harvesting, NDVI values demonstrate a sharp decline, as bare ground and leftover plant bits show up. This shift makes sense closely to the phenological cycle of winter cereals cultivated in cooler zones.

Sometimes, the shape of NDVI patterns across seasons shows clear signs of specific crops growing. As peaks occur at different times, one field can be told apart from another. When greenness rises fast or stays high longer, it gives clues about what is planted where. These shifts matter when tracking farmland changes over time and place. Forests behave differently than fields, so their signals stand out in the data. Seeing how each landscape responds helps make sense of wider environmental shifts around here.

The Normalized Difference Vegetation Index (NDVI) emerged from every satellite image covering the forest ecosystems inside official borders of Guba district. The NDVI index appeared applying the standard formula:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Where *NIR* represents the reflectance in the near-infrared band and *Red* represents the reflectance in the visible red band. This index was specifically applied to Guba’s forested zones to quantify vegetation health and density throughout the study period.

For classification purposes, the resulting NDVI values were categorized to reflect different vegetation conditions as follows:

- **NDVI > 0.6** — Dense forest, predominantly observed in the higher elevation mountainous zones of Guba.
- **NDVI 0.4–0.6** — Moderate vegetation, corresponding to mixed forest and transitional areas.
- **NDVI 0.2–0.4** — Sparse vegetation, typically found at forest edges and in degraded patches.
- **NDVI < 0.2** — Bare soil or non-vegetated surfaces, including agricultural lands and settlements surrounding the forested regions.

Temporal change detection was conducted by calculating NDVI differences between selected years (e.g., 1985 vs 2000, 2000 vs 2015, and 2015 vs 2024) within the geographic boundary of Guba's forest ecosystems. The results revealed distinct trends over time:

- **1985–2000:** Lower elevation forests experienced significant declines in NDVI values, indicating increased land-use pressure such as agricultural expansion and rural settlement development.
- **2000–2015:** Some remote forest areas in northern parts of Guba exhibited stabilization or slight increases in NDVI values, likely due to reduced anthropogenic impact and natural regeneration processes.
- **2015–2024:** Trends were mixed; higher elevation forests maintained stable NDVI values, while foothill regions continued to show variability related to seasonal land use and climatic influences.

Over time, plants changed in different ways depending on how high they were and what kind of land they grew on. Lower forests showed a slight negative trend during the years observed, while higher ones showed steadiness throughout the same stretch.

4. Conclusion.

The study, using GIS-based methods and NDVI-based analysis systematically assess the forest transformation processes in the Guba region of Azerbaijan during specific times. The research outcomes allow mapping out the pattern of vegetation transformation for a long time with the help of satellite-based data combined with geospatial analysis.

The outcomes show that NDVI is a good measure to assess the condition of plants and the amount of plants in different areas. The area NDVI maps showed clear separation of the dense forest areas, the areas with medium vegetation, farmland, city areas, and water areas. Mountain forest areas with high NDVI values indicated stable and healthy vegetation, while areas with low NDVI values were located in foothills and around settlements where human activity was stronger.

The time analysis of NDVI values exhibited clear patterns of seasonality and inter-annual variation. Photosynthetic activity and good health of the ecosystem led to a slow increase of NDVI values in forests and grasslands during the growing season. The agricultural land covers showed significant seasonal changes in the NDVI values as a result of crop growth stages, farming, and harvesting activities. The NDVI values were low in urban areas since the areas are dominated by impervious surfaces and minimal vegetation cover.

According to the Spatial-temporal detection results it was observed that the damage of the vegetation and the process of fragmentation were most severe in those areas where the land was transformed, and new infrastructures were constructed as well as the size of the farmland increased. On the other hand, there was a partial revival of the vegetation in the protected forest areas and the less accessible areas because of natural growth as well as conservation activities.

NDVI-based mapping, temporal trend, and land cover-related NDVI profiles were used in the study to map out the mechanism of the change of the Guba ecosystem. The results demonstrate that long-term space-time observation allows distinguishing temporary seasonal changes in forest ecosystems from their permanent changes.

Generally, the study shows that GIS and remote sensing technology can be used effectively in sustainable forest management and monitoring of the environment, and in decision-making. The applied methodological framework can be utilized in other parts of Azerbaijan and mountainous areas that can be used to assist the conservation of biodiversity and climate response, and land-use planning. It can be improved in the subsequent studies by introducing extra indices of vegetation, high-resolution images, and the climate parameters to enhance the predictive modelling of the ecosystem.



References

1. Abiyev, Y., Karsli, F., Gumus, S., & Seyfullayev, F. (2020). Analysis of the forest covers dynamics in the Samur-Yalama National Park of Azerbaijan. *European Journal of Forest Engineering*, 6(1), 23–30.
2. Bayramov, E., Buchroithner, M., & Bayramov, R. (2016). Quantitative assessment of 2014–2015 land-cover changes in Azerbaijan using object-based classification of LANDSAT-8 time series. *Modeling Earth Systems and Environment*, 2, Article 35. <https://doi.org/10.1007/s40808-016-0088-8>
3. Bora, K., Borah, N., Bose, S., Goswami, J., & Kashyap, P. J. (2025). NDVI-based geospatial analysis of forest cover alterations in Daldali Reserve Forest, Assam, India. *Asian Journal of Geographical Research*, 8(1), 61–72.
4. Faramarzi, M., Heidarzadi, Z., Mohamadi, A., & Heydari, M. (2018). Detection of vegetation changes in relation to normalized difference vegetation index (NDVI) in semiarid rangeland in western Iran. *Journal of Agricultural Science and Technology*, 20, 51–60.
5. Iskandarzade, E., Mammadaliyeva, V., Nasirova, V., & Heydarzade, G. (2025). Ecological assessment of the impact of regional hydrological regime on forest vegetation cover using GIS technologies (on the example of Lachin, Gubadli, and Zangilan regions). *Problems of Information Society*, 16(1), 51–59.
6. Ishmam, Z. S., & Pantho, M. J. (2022). NDVI: Detection of vegetation change using remote sensing and GIS—A study on Barishal City Corporation, Bangladesh. In *Proceedings of the 6th International Conference on Civil Engineering for Sustainable Development (ICCESD 2022)*. Khulna University of Engineering and Technology. ISBN 9789843519726.
7. Karimli, N., & Selbesoğlu, M. O. (2023). Remote sensing-based yield estimation of winter wheat using vegetation and soil indices in Jalilabad, Azerbaijan. *ISPRS International Journal of Geo-Information*, 12, Article 124. <https://doi.org/10.3390/ijgi12030124>
8. Mamedaliyeva, V. M. (2022). Changes in forested areas of the north-eastern region of Azerbaijan revealed by satellite images. *Lesnoy Zhurnal (Forestry Journal)*, (1), 88–97.
9. Mammadov, Q. Sh. (2010). *Forest ecology* (pp. 23–32). Elm.
10. Moharir, K., & Pande, C. B. (Eds.). (2025). *Remote sensing and GIS application in forest conservation planning*. Springer Nature.