A Spatio-Temporal Analysis of Changes in Vegetation Cover on The Absheron Peninsula

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Abstract

Rapid urbanisation and industrial activity on the Absheron Peninsula, oil and gas extraction, the expansion of transport infrastructure, and climate change have led to significant environmental changes in the landscape and vegetation cover. The primary objective of the research in this area is to identify the spatial and temporal patterns of vegetation cover change, to assess the magnitude of these changes and their spatial variation, and to investigate the relationship between these processes and natural and human-induced factors. As part of the study, an assessment was carried out of changes in vegetation cover over various years using Landsat 5 TM, Landsat 8 OLI/TIRS and Landsat 8 LC08_L2SP satellite data, the Normalised Difference Vegetation Index (NDVI) and spatial analysis methods. It has been established that, over the period 2006–2025, significant changes in the spatio-temporal dynamics of vegetation cover were recorded, as determined on the basis of NDVI indices. In 2006, the total area of land without vegetation cover was 167,961 hectares, of which 26,280 hectares had sparse vegetation, 2,200 hectares had moderate vegetation, and 186 hectares had dense vegetation. In 2016, the total area of land devoid of vegetation cover was 196,424 hectares, of which 53,595 hectares had sparse vegetation cover, 3,702 hectares had moderate vegetation cover, and 619 hectares had dense vegetation cover, In 2025, the total area of land without vegetation cover was 203,369 hectares, of which 77,443 hectares had sparse vegetation cover, 7,277 hectares had moderate vegetation cover, and 880 hectares had dense vegetation cover. These changes indicate that the condition and spatial distribution of vegetation in this area vary from year to year.

Keywords: Absheron Peninsula, vegetation cover, transformation, spatio-temporal analysis, geographic information systems (GIS), remote sensing, NDVI, anthropogenic impact, land degradation

1.Introduction

The Absheron Peninsula enjoys a favourable economic and geographical location. Economic and geographical location is an important factor influencing the development and formation of an economic region (figure. 1). This factor has influenced the development of the region to varying degrees at different stages in history. Consequently, this is where the most important rail, road, water, and air transport hubs converge, linking the republic with other countries. This region's border with the Caspian Sea highlights the unique nature of its transport links. Access to Russian territory via the Caspian-Volga Canal provided a link to the northern seas, transforming the city of Baku into a port of international importance. The natural conditions, combined with the favourable geographical location of the Absheron Peninsula, play an important role in its future development as an economic region (Bədəlov, 2016).



Figure 1. *Satellite image of the Absheron Peninsula.*

Owing to its geographical, economic, and social characteristics, the Absheron Peninsula has been subject to significant human impact over many years, which has led to a complex environmental situation. In a region where two-thirds of the republic's industrial capacity and one-third of its population are concentrated, the land is more heavily affected by human activity. The improper operation of local oil fields, oil extraction carried out without complying with basic environmental protection requirements, and other breaches have led to the pollution of various landscape areas on the Absheron Peninsula (Ağayev & Əfkərov, 2007; Aslanov & Səfərli, 2008; Həsənov, 1997).

The modern flora of the Absheron Peninsula has developed since the Quaternary period under the influence of natural and historical conditions. Across the entire peninsula, the structure and composition of plant communities depend on the terrain, soil conditions, climate, and other natural factors. Most plant communities are widespread on saline, grey, grey-brown, meadow-marsh and alluvial-meadow soils, which are characteristic mainly of the semi-arid, arid and arid subtropical zones of the peninsula. The peninsula has its own distinctive phytogeographical boundary, which marks the outermost limit of the ranges of certain endemic species. This once again confirms the uniqueness of this area. Consequently, the relevance and timeliness of conducting a comprehensive inventory survey of the flora stem from the fact that, over the past seventy years, the territory of the Absheron Peninsula has undergone significant anthropogenic changes, and no detailed monitoring of this area has ever been carried out. This is due to the large-scale man-made transformation of ecosystems resulting from the development of oil fields and the intensive construction of residential areas, as well as technical and social infrastructure. Such factors threaten the survival of many local stenotopic species. At the same time, they create new habitats and conditions for invasive and expansive species (Mirzəyeva, 2025; Sadigova, 2023; Zernov & Mirzayeva, 2021).

Years of oil extraction, industrial activity, traffic congestion, and urbanisation on the peninsula have altered the chemical and physical properties of the soil, leading to the degradation of vegetation cover and a decline in crop yields. In particular, petroleum products, industrial and domestic wastewater seeped into the soil, causing environmental stress and becoming one of the main causes of soil erosion and damage to vegetation.

On the Absheron Peninsula, soil pollution and degradation are primarily caused by oil extraction, oil waste, and other forms of extractive activity. The discharge of petroleum products and large volumes of well water into surface waters also leads to a rise in the groundwater level and the re-salinisation of the soil. The improper operation of oil fields in Absheron, where oil extraction took place for decades without compliance with even the most basic environmental protection standards, and the discharge of oil, gas, chemicals, and highly mineralised and radioactively contaminated water onto the ground have led to the contamination and degradation of certain natural and man-made landscape areas (Xəlilova & Zeynalova, 2022; Qurbanov, 2016; Mirzəyev & Şıxəliyev, 2012).

The vegetation of the Absheron Peninsula, particularly along its Caspian Sea coastline, is characterised by its diversity and has been subject to various forms of salinisation. Here, salinisation is classified into chloride-sulphate, sulphate-chloride, and chloride-sulphate-carbonate types. Most of the peninsula's territory consists of sandy soils, and in rare cases, light sandy loam soils. The pH of such saline soil types ranges from 6.0 to 7.5, and there is virtually no humus layer in these soils. Natural vegetation on such soils is sparse and, in early spring, consists of short-lived ephemerals and hemiphytes (Ağayev & Əfkərov, 2007).

The storage of crude oil and well water produced during the initial phase of operation of the Absheron oil fields in above-ground earthen reservoirs, as well as the lack of technologies that met the economic requirements of that period, had a negative impact on the environment, including high levels of oil contamination of land. Soils contaminated with oil are light grey-brown, loose, medium loam, and moderately saline. 33,000 hectares of the peninsula's territory are covered by wasteland. The area of land contaminated by oil is 10.6 thousand hectares. Bituminous (pyritisised) soils are a type of asphaltic soil that has undergone fundamental changes over time (Ağayev & Əfkərov, 2007; Aslanov & Səfərli, 2008; Qurbanov, 2016).

In addition, the peninsula also has deposits of salt, sand, limestone, and clay. Cement, gypsum and lime in Garadagh; brick clay in Sumqait and Zykh; building sand in the vicinity of Shykhlar, Balakhani and Hokmali; paving stones in the vicinity of the settlements of Garadagh, Gyuzdek, Mashtagha, Nardaran and Korgoz; Nardaran, Shuvelen, Mashtagha, Zira and Zykh – near limestone deposits; Karadag, Gyuzdek, Zykh and Korgoz – near villages where facing stone is quarried. The aforementioned building materials are widely used. The total area of the five domestic waste landfill sites on the peninsula is 232.5 hectares. The area covered by unauthorised rubbish dumps totals 448.6 hectares, and there are 128 of them in total. The officially operating landfill sites in Baku do not comply with environmental regulations and standards. Hazardous waste generated during the production of caustic soda and chlorine using the mercury process is one of the factors causing serious environmental problems in the city of Sumgait and on the Absheron Peninsula as a whole (Xəlilova & Zeynalova, 2022; Qurbanov, 2016).

According to the findings of an assessment of the environmental situation in the region, the following four instances of landscape degradation were identified on the Absheron Peninsula:

- Satisfactory – the soil and vegetation cover are undamaged;
- Moderate – the soil cover is slightly damaged;
- Critical – the soil cover has been destroyed, and the relief has changed;
- Catastrophic – all elements of the landscape have been altered, and all internal landscape connections have been disrupted.

The exploitation of natural resources, industrial activities, and human-induced activities are leading to excessive pollution and land degradation. Another environmental problem is the poor condition of the sewerage systems on the peninsula. Overall, around 560 million cubic metres of wastewater are generated in the Baku district over the course of a year. A sharp rise in the groundwater level on the peninsula, the dilapidated state of the town's water supply and sewerage networks, and the inefficiency of the municipal services have led to a sharp deterioration in the environmental situation, posing a serious threat to public health. The main causes of the high level of environmental pressure in urban areas are: the concentration here of 70% of the country's economic potential, without due regard for natural conditions and environmental carrying capacity; the use of outdated technologies by industrial enterprises; the dilapidated state of the water supply network and sewerage system; vehicles that do not meet environmental standards; vast areas occupied by landfill sites; insufficient funding allocated to environmental protection; and a lack of attention to this area on the part of the city administration and environmental protection bodies and organisations (Həsənov, 1997; Xəlilova & Zeynalova, 2022).

Along the Absheron coastline in the north, east and south, landforms of abrasive-accumulative origin and sand dunes are widespread. Due to the large number of windy days (300-350), shifting sands are

constantly blown into the air, leading to an increase in the amount of dust in the air. This, in turn, causes enormous damage to the economy and the population (Google, n.d.).

The Absheron Peninsula is the main region in Azerbaijan and even in the whole world where mud volcanoes are active. Frequent surges in their activity cause damage to the landscape, leading to natural changes in the soil and vegetation cover. Azerbaijan ranks first in the world in terms of the number and variety of mud volcanoes. Of the 800 known mud volcanoes in the world, 400 are located in the southern Caspian oil and gas basin, including more than 300 on the mainland of Azerbaijan and in the Caspian Sea. Therapeutic mud is found on the Absheron Peninsula, in Lake Masazir, in the Gobustan and Lower Kurin depressions, and also in areas where mud volcanoes erupt (Bədəlov, 2016).

The arid climate of the peninsula creates favourable conditions for the development of gully and ravine erosion, as well as arid denudation processes. The annual number of hours of sunshine here reaches 2,450-2,500. Annual rainfall is 250-300 mm, whilst in the south-west (in the Buty area) it is 130-150 mm, which is low for the Absheron Peninsula. A significant difference between precipitation and evaporation (950-1,000 mm) leads to the development of physical erosion and the degradation of vegetation cover.

2. Materials and methods

This research is primarily devoted to assessing the long-term spatial and temporal characteristics of vegetation cover change on the Absheron Peninsula. The main scientific objective of this study is to identify changes in vegetation cover between 2006 and 2016 and in 2025, and to analyse the intensity of anthropogenic impacts using GIS.

Landsat satellite images obtained from the archives of the United States Geological Survey (USGS) were used to analyse the terrain. To ensure seasonal comparability of the study and the accuracy of the results based on satellite imagery from three satellites, a suitable season was selected, and for the months marking the transition from summer to autumn 'Level 2 Surface Reflectance' (L2SP) products characterised by the lowest cloud cover were selected:

For 2006, a satellite image acquired by the TM sensor on Landsat 5 (LT05_L2SP) on 10 August 2006 was used. At this stage, Band 4 channels, corresponding to the near-infrared (NIR) spectrum, and Band 3 channels, corresponding to the red (Red) spectrum, were used to determine the spectral reflectance of vegetation.

For 2016, images obtained using the OLI/TIRS sensor on the Landsat 8 satellite (LC08_L2SP), taken on 21 August 2016, were used. In the case of the Landsat 8 satellite, the near-infrared channel is designated as Band 5, and the red channel as Band 4.

For 2025: to provide an up-to-date assessment of the current situation, satellite imagery from Landsat 8 (LC08_L2SP) taken on 30 August 2025 and 3 September 2025 (bands 5 and 4) was used.

During the processing of the satellite images, all data were transformed into a single coordinate system (UTM, Zone 39N, WGS 84). The standard normalised difference vegetation index (NDVI) has been used for many years to calculate the density of vegetation cover, its health status and variations in its spatial distribution. Taking into account the characteristics of the sensors, the indicator was calculated using the following mathematical formulae. As different satellites were used in the study, the calculations were carried out using two different formulae:

For Landsat 5 (2006):

$$\mathrm{NDVI} = \frac{\mathrm{Band\ 4} - \mathrm{Band\ 3}}{\mathrm{Band\ 4} + \mathrm{Band\ 3}}$$

For Landsat 8 (2016, 2025):

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4}$$

Here, B5 (or B4 for Landsat 5) refers to the near-infrared spectral band, whilst B4 (or B3 for Landsat 5) refers to the red light band. NDVI values, which range from -1 to +1, also enable the accurate classification of bodies of water, bare soil, building sites, and areas with dense vegetation.

At the same time, the images were classified using supervised classification methods in order to assess overall changes to the landscape in this area. Based on the large-scale maps and statistical indicators obtained, a comparative analysis of environmental and geographical trends on the Absheron Peninsula was carried out.

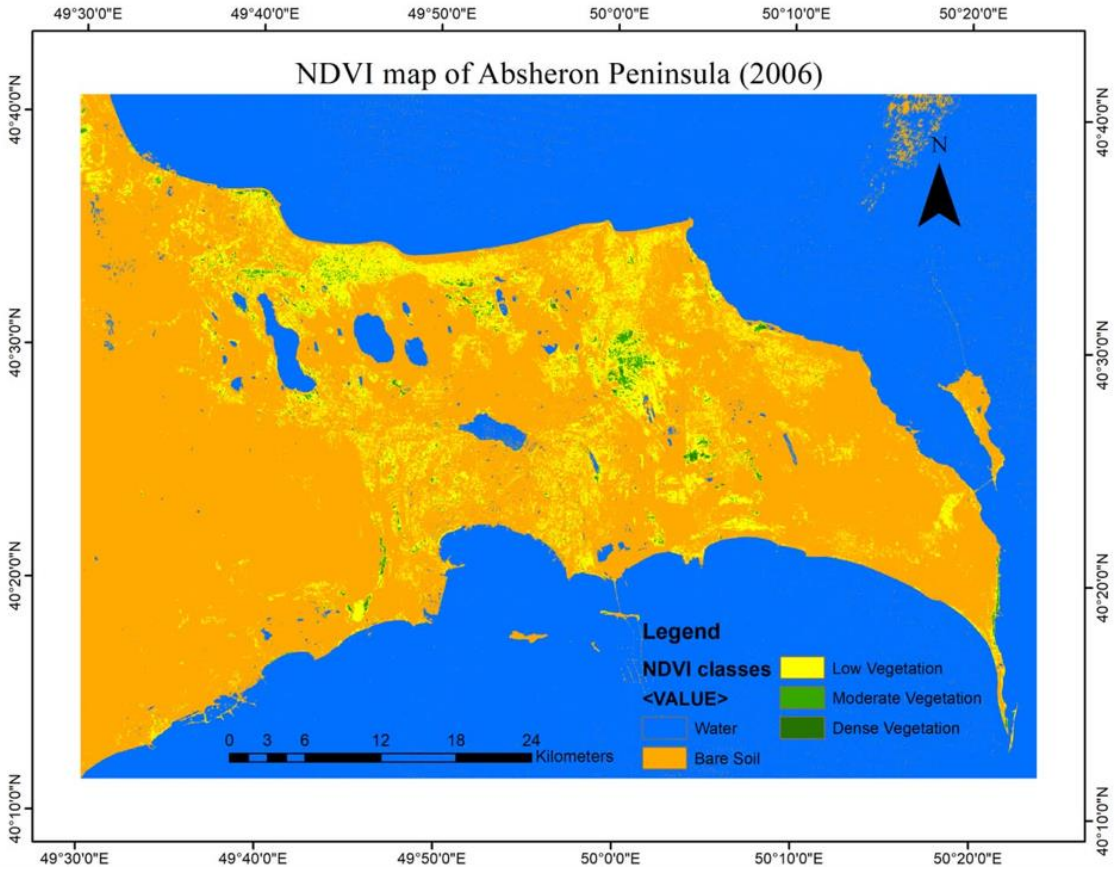


Figure 2. *NDVI map of the Absheron Peninsula, 2006.*

Table 1. *Analysis of the NDVI index for the Absheron Peninsula – 2006.*

NDVI classes (2006)	Area (ha)
Bare Soil	167961
Low Vegetation	26280
Moderate Vegetation	2200
Dense Vegetation	186

As can be seen from Figure 2 and Table 1, in 2006, bare soil and sparse vegetation predominated across vast areas of the Absheron Peninsula. Vegetation occurs in limited areas. It would appear that this landscape reflects conditions associated with the peninsula's arid climate, low rainfall, high evaporation rates, and a lack of moisture in the soil. On the map, the vegetation is fragmented and distributed unevenly. Long-term

human-induced impacts also play a role in this process. Oil production, industrial activity, and the development of transport infrastructure are contributing to changes in the natural composition of the soil and vegetation cover. It should be borne in mind that low NDVI values cannot be regarded solely as a consequence of anthropogenic degradation, as natural vegetation in semi-arid landscapes is also sparse. The main purpose of the 2006 map is to establish a baseline for assessing subsequent changes.

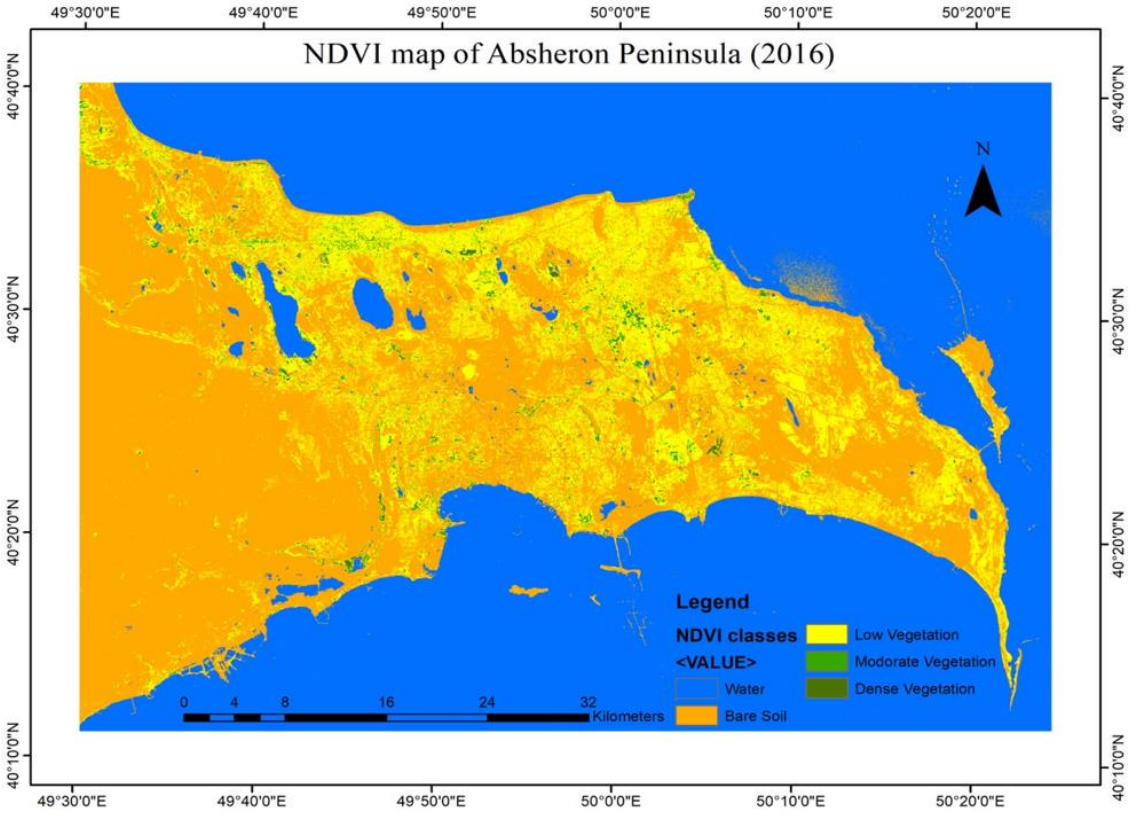


Figure 3. *NDVI map of the Absheron Peninsula, 2016.*

Table 2. NDVI analysis of the Absheron Peninsula-2006.

NDVI classes 2016	Area (ha)
Bare Soil	196424
Low Vegetation	53595
Moderate Vegetation	3702
Dense Vegetation	619

As can be seen from Figure 3 and Table 2, certain changes are observed in the spatial description of vegetation in 2016 compared to 2006. Alongside this, an expansion of medium and high NDVI values is noticeable in various areas. These changes are associated with greening measures carried out under conditions of intensive urbanisation, the creation of park and garden areas, the planting of ornamental trees and shrubs, as well as reclamation measures undertaken to eliminate the consequences of anthropogenic impacts. Although at first glance the changes towards a positive result on the map may be understood as an improvement in the peninsula's ecological condition, it would be more accurate to regard them as aesthetic changes in the spatial structure of the vegetation cover. This is because the restoration of oil-contaminated and salinised soils to their original state is not possible, and compared to 2006, the area of areas without observed vegetation cover has increased by 28,463 ha.

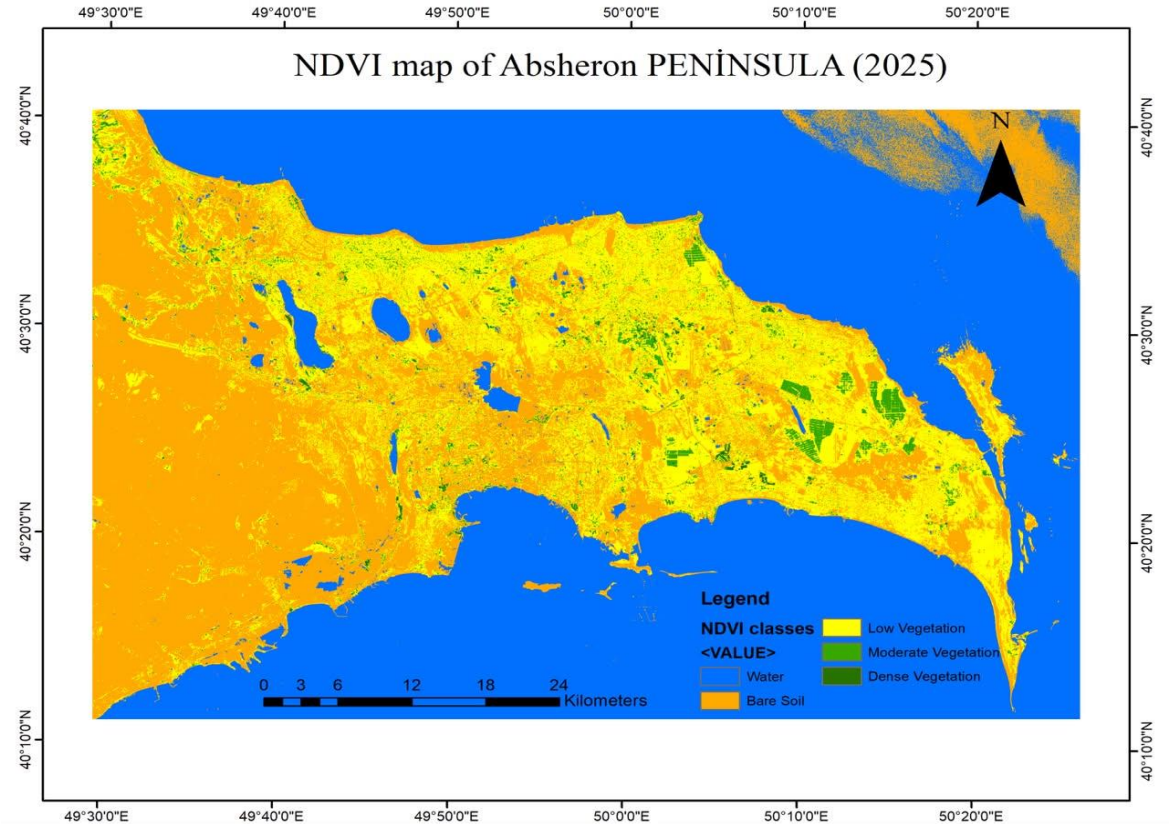


***Figure 4**. NDVI map of the Absheron Peninsula, 2025.*

***Table 3.** NDVI analysis of the Absheron Peninsula-2025.*

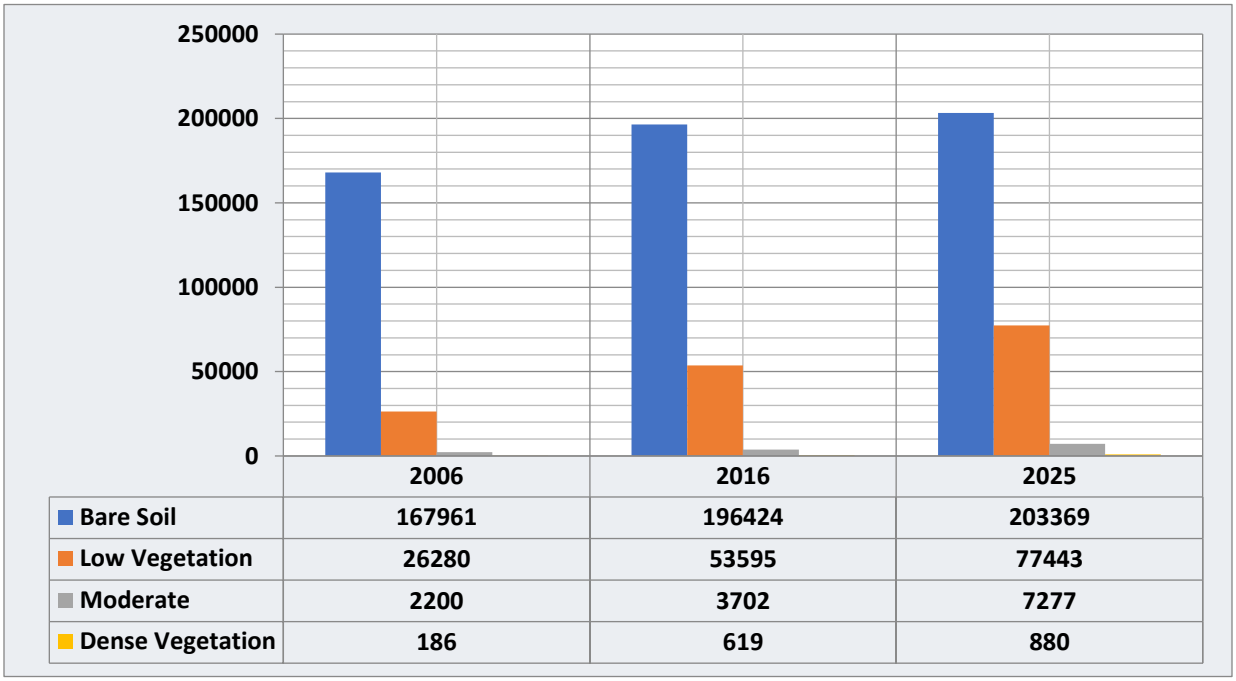
NDVI classes 2025	Area (ha)
Bare Soil	**203369**
Low Vegetation	**77443**
Moderate Vegetation	**7277**
Dense Vegetation	**880**

As can be seen from Figure 4 and Table 3, the more pronounced presence of areas with medium and high NDVI values in 2025 compared with other years (2006, 2016) indicates an increase in vegetation cover. This trend can be explained by the creation of parks on the peninsula as part of urban planning and improvement measures; significant contributing factors include green belts along riverbanks, ornamental plantings, irrigated landscape areas, and cultivated landscapes created for aesthetic purposes. Nowadays, the ongoing expansion of industrial activity and oil and gas extraction, soil pollution, salinisation and the fragmentation of natural habitats represent constant environmental pressures, whilst the area of vegetation cover is increasing rapidly. Therefore, an increase in NDVI values should not be regarded as direct evidence of the natural recovery of ecosystems, an increase in species diversity, or improved soil fertility. Accordingly, the changes shown on the 2025 map highlight the importance of studying the relationship between the increase in green space in Absheron and improvements in environmental quality.

3. Conclusion

In the course of our study, which focused on a spatio-temporal analysis of changes in vegetation cover on the Absheron Peninsula, it was established that, according to NDVI indices, the total area of land devoid

of vegetation in 2006 amounted to 167,961 hectares, with 26,280 hectares of land having sparse vegetation, 2,200 hectares having moderate vegetation cover, and 186 hectares having dense vegetation cover; in 2016, the total area of land devoid of vegetation was 196,424 hectares, with sparse vegetation cover covering 53,595 hectares, moderate vegetation cover covering 3,702 hectares, and dense vegetation cover covering 619 hectares; in 2025, the total area of land without vegetation cover was 203,369 hectares, of which 77,443 hectares had sparse vegetation cover, 7,277 hectares had moderate vegetation cover and 880 hectares had dense vegetation cover.



	2006	2016	2025
Bare Soil	167961	196424	203369
Low Vegetation	26280	53595	77443
Moderate	2200	3702	7277
Dense Vegetation	186	619	880

***Figure 5**. Vegetation dynamics from 2006 to 2025.*

As can be seen from Figure 5, although there has been an increase in the area of parks and green spaces in the study area in recent years, the area of land where vegetation cover has undergone radical changes or disappeared entirely is growing at a faster rate. Consequently, compared with 2006, the area of land devoid of vegetation had increased by 35,408 hectares by 2025.

The results obtained are of great significance for tracking the positive changes taking place in the peninsula's ecosystem, as well as for planning future environmental monitoring.

Author's contribution

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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