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SPATIOTEMPORAL DYNAMICS AND DECADAL LOSS OF VEGETATION COVER ON THE ABSHERON PENINSULA

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Abstract

This study evaluates the ten-year spatio-temporal dynamics of the soil-vegetation cover on the Absheron Peninsula using Landsat 8 OLI/TIRS satellite data from 2015 and 2025. Normalized Difference Vegetation Index (NDVI) mapping within ArcGIS Pro revealed significant ecological degradation. Medium- and high-density vegetation (NDVI classes 3–5) contracted from 2022.25 km^2 to 1624.20 km^2, while bare territories and sparse zones (classes 1–2) expanded from 833.52 km^2 to 1231.47 km^2. This loss equals 13.95% of the total area of the peninsula (19.7% of the vegetation cover of 2015) and is driven by anthropogenically induced land degradation and urban heat island effects. These empirical findings provide crucial baseline data for urban planners and environmental agencies, highlighting the urgent need to restore landscapes which have been disrupted as a result of human activity, and the immediate implementation of strategies for sustainable land management, with a view to preventing further deterioration of the regional ecosystem.

Key words: NDVI, soil degradation, vegetation dynamics, remote sensing

Introduction. Monitoring the soil and vegetation cover of the Absheron Peninsula is extremely relevant due to the combined impact of anthropogenic factors (oil production) and arid climate conditions (semi-desert climate, strong winds, salinization). The Absheron Peninsula is located on the western coast of the Caspian Sea, within Azerbaijan, in the Greater Caucasus physical-geographical

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region [1]. This territory, covering about 3000 km^2, includes the country's largest cities (Baku, Sumgait, Khirdalan) and 32 suburban settlements. The peninsula's population exceeds 3.6 million people.

The environmental situation in Absheron represents a unique and complex scientific problem [2]. Centuries of oil extraction, natural aridity, and intensive urban expansion have greatly complicated the ecological state. The peninsula's geological structure consists of Cenozoic deposits, in particular sandy-clayey sediments, gravels, and limestones of Late Pliocene and anthropogenic age. Older marine formations (clays, sands, etc.) emerge at the surface in the cores of anticlinal folds and are represented mainly by the Middle and Lower Pliocene, while in the far west – by Paleogene-Miocene deposits [3]. The Fatmai-Zykh anticlinal zone runs roughly through the central part of the peninsula and forms one of its main structural elements.

One of the main morphological features of the landscape is the presence of mud volcanoes. The northeastern and eastern parts of the peninsula are plains (from −26 to 60–70 m). The central part comprises rolling elevations, between which lie depressions with saline lakes; absolute heights here reach 150–170 m. In the western and southwestern parts, low mountains with anticlinal ridges and synclinal plateaus predominate. This area is characterized by an inverted relief: anticlinal valleys, high synclinal plateaus armoured with Absheron limestones, and large mud volcanoes (Bozdag, Gyuzdek, etc.), where elevations exceed 300 m [4].

The region has a moderately warm and dry subtropical climate. It is the driest region of Azerbaijan (precipitation 200–400 mm), while evapotranspiration reaches 1000 mm. The peninsula is the windiest zone of the country; average wind speed is 5.8–7 m/s, and the number of days with storm winds (> 15 m/s) ranges from 64 to 145 per year [5]. The strong northern wind "Khazri" causes mechanical damage to leaves and soil desiccation.

The natural hydrographic network is extremely poor. The only relatively large river is the Sumgaitchay. The abundance of gullies, tectonic and deflationary depressions hinders surface water runoff. Depressions are often occupied by salines and saline lakes (Masazyr, Mirzaladi). The Jeyranbatan reservoir plays an important role in water supply – an example of artificial amelioration under water scarcity. Underground water resources are estimated at 10 billion m^3, but their quality often suffers due to mineralization and technogenic pollution of the aquifers from oil production.

Soils of the peninsula are predominantly grey-brown, brown, and grey, genetically prone to salt accumulation [6]. As evaporation exceeds precipitation, salts are brought to the surface. Humus content is extremely low (1.5–2%). This requires intensive fertilization and special agronomic care for agriculture. The widespread presence of saline soils in the central and southern parts of the peninsula is due to the closed relief and arid climate. On steep slopes and elevations, the poorly developed and eroded soil layer necessitates protection of the vegeta-

tion cover. The coastal areas being covered by sand dunes require stabilization of these soils and measures to combat wind erosion. The soil cover of the area has been thoroughly studied by prominent Azerbaijani scientists, providing a strong scientific basis for future reclamation works.

Vegetation is adapted to aridity: semi-desert and desert types predominate (ephemerals, wormwood, saltwort). Ephemerals such as bulbous sedge and other cereals occupy an important place in the biodiversity of the region, but their vegetation period is short. In the northwestern part of the peninsula, wormwood-saline plants prevail. Shrubby saline plants are widespread in the playa-like depressions. The vegetation of the Absheron Peninsula is sensitive to anthropogenic influences, and it is important to protect the unique ecosystem here.

Urbanization and the lack of drip irrigation systems in parks, together with leaks from water supply networks, lead to the rise of mineralized groundwater, turning fertile plots into saline swamps. The shortage of fresh water keeps the green areas of Baku and the surrounding settlements under constant pressure. Natural humidity is not enough for most ornamental plant species used in the greening of the city (except for xerophytic plants). The use of low-mineralized water for irrigation has a negative impact on plant development. Dense development raises the temperature of the city by 3–5 °C above normal and further dehydrates the soil in park areas. Covering large areas with asphalt, concrete and stone surfaces not only increases the temperature at the surface of the earth, but also completely removes the soil from biosphere processes.

The landscapes of the Absheron Peninsula are mainly dry-desert, steppe and semi-desert types adapted to the semi-arid climate [7, 8]. As a result of intensive oil production and anthropogenic impact, natural landscapes have undergone serious transformation and turned into technogenic and polluted areas. Based on the conducted analyses [9], it was determined that 1% of the total area has been subjected to weak, 24% to moderate, 54% to strong, and 21% to very strong desertification. The types of desertification observed on the peninsula are: salinisation – 26.3%, anthropogenic – 15.29%, water erosion – 10.3%, wind erosion – 1.4% and rising groundwater levels – 0.7%. The aim of the present study is to quantify the decadal change of the soil-vegetation cover of the peninsula from Landsat 8 NDVI and, in contrast to the earlier assessments cited above, to provide a spatially continuous and repeatable estimate that can serve as baseline data for reclamation planning.

Materials and methods. This study used Landsat 8 data (OLI and TIRS sensors) for 2015 and 2025 (Level-2 products with atmospheric correction). Both scenes were acquired in May, so that the two dates correspond to the same phenological phase (scene identifiers: LC08_L2SP_166032_20150531_20200909_02_T1;LC08_L2SP_166032_20250510_20250531_02_T1). The NDVI index was calculated in GIS [10] based on the combination of near-infrared (NIR) and red (Red) bands using formula (1):

$$\text{NDVI} = (\text{NIR} - \text{Red})/(\text{NIR} + \text{Red}), \tag{1}$$

where NIR is near-infrared light reflectance and Red is red light reflectance. Healthy vegetation strongly absorbs red light (for photosynthesis) and reflects near-infrared light (due to cellular structure), producing values ranging from -1 to $+1$. Despite the appearance of newer indices (EVI, SAVI, NDRE), NDVI remains the basis of vegetation monitoring owing to its simplicity, its wide applicability and its long continuous record [11]. The calculated values were divided into five classes (Table 1); the class limits were derived separately for each date from its own NDVI distribution, which is why they differ between 2015 and 2025, and for the comparison of areas the classes were aggregated into classes 1–2 (non-vegetated and sparse) and classes 3–5 (moderate and dense vegetation).

Results and discussion. The NDVI results are interpreted against the long history of technogenic pressure on the peninsula. The Absheron Peninsula is one of the oldest oil-producing regions in the world. Decades of intensive field development have resulted in large-scale oil contamination of soils over an area exceeding 21.3 thousand hectares, causing a sharp deterioration of the environmental situation. A significant portion of these lands (about 10.1 thousand hectares) consists of sites and water bodies directly contaminated by oil and formation waters.

When oil wastes enter the soil profile, the light hydrocarbon fractions evaporate or undergo mineralization, while heavy fractions (metabolic products) accumulate in the upper horizon and remain there for long periods. High concentrations of heavy metals contained in oil, such as V, Ni, Co, Pb, Cu, exert toxic effects on living organisms [12].

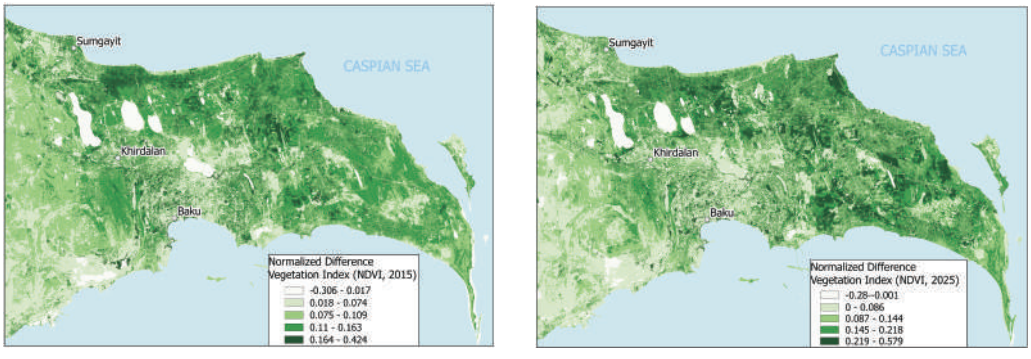
The formed technogenic layer (consisting of kerogen, bitumen, polyphenols, etc.) covers the soil surface for decades, creating a persistent hydrophobic barrier. As a result, water infiltration into the soil is disrupted, porosity (aeration) of the soil substrate is reduced, gas exchange and redox processes cease, natural fertility is lost, the microflora degrades, and the plant cover dies off completely. The depth of contamination penetration at different sites ranges from 10 to 50 cm [13]. Soils in the region are characterized by a thin humus horizon (on average 1–2%). Heavily polluted sites are almost devoid of vegetation, whereas clean or slightly degraded lands are dominated by wormwood and alfalfa communities, ephemerals, and halophytes.

In the western part of the peninsula, soils are subject to secondary salinization caused by both natural factors and the influence of irrigation and oilfield waters. The eastern part, by contrast, is less prone to saline formation. During the transgression of the Caspian Sea (1977–1995) and due to leaks of formation waters from wells, the groundwater level rose, leading to waterlogging and secondary salinization of about 5 thousand hectares of land. An additional destructive contribution

comes from technogenic activity of stone quarries, which completely destroyed the soil cover over an area of 1090 hectares.

Even after reclamation works, there remains a risk of vertical migration of harmful hydrocarbons to deeper horizons, which may lead to contamination of groundwater aquifers. The most intensive pollution has been recorded in the Garadagh, Sabunchu, Binagadi, Surakhani, and Khazar districts, as well as in the oil and gas field zones of Pirallahi, Gala, and Mashtaga [14]. The combined impact of oil pollution, salinization, waterlogging, and technogenic pressure has led to loss of soil productivity, landscape transformation, and reduction of biodiversity, necessitating urgent measures for comprehensive land reclamation.

Within this study, monitoring of the soil-vegetation cover of the Absheron Peninsula was carried out based on digital processing of remote sensing data for 2015 and 2025. To assess ecosystem dynamics, the vegetation index NDVI was calculated (Fig. 1, Table 1).



a) b)

Fig. 1. NDVI values on the Absheron Peninsula: a) 2015; b) 2025. Colour scale: from light green (low NDVI) to dark green (high NDVI)

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Normalized Difference Vegetation Index (NDVI) classes and their areas on the Absheron Peninsula, 2015 and 2025

NDVI class	NDVI range (May)		Area S, km^2		Area S, %	
	2015	2025	2015	2025	2015	2025
1 (bare)	−0.306 to 0.017	−0.281498 to −0.001443	85.67	68.17	3.00	2.39
2 (sparse)	0.018 to 0.074	−0.001443 to 0.086285	747.84	1163.34	26.19	40.74
3 (moderate)	0.075 to 0.109	0.086285 to 0.143645	1212.34	891.77	42.45	31.23
4 (dense)	0.110 to 0.163	0.143645 to 0.217877	696.06	553.08	24.37	19.37
5 (very dense)	0.164 to 0.424	0.217877 to 0.578911	113.85	179.4	3.99	6.28
Total (Σ S)			2855.76		100	

As a result of the calculations, it was determined that over the ten-year period the total area of territories with medium- and high-density vegetation (classes 3–5 in Table 1; NDVI 0.075 to 0.424 in 2015 and 0.086 to 0.579 in 2025) decreased from 2022.25 km^2 to 1624.20 km^2. At the same time, there has been an expansion of areas without vegetation and of plots with sparse vegetation (classes 1–2; NDVI −0.306 to 0.074 in 2015 and −0.281 to 0.086 in 2025): their combined area increased from 833.52 km^2 to 1231.47 km^2.

Conclusion. Analysis of NDVI indicators for the period 2015–2025 confirms a negative trend: against the backdrop of an increase in the area of land stripped of vegetation, areas with stable vegetation cover have decreased by 13.95% of the total area of the peninsula, i.e. by 19.7% of their extent in 2015. The results underscore the critical need for large-scale reclamation of technogenically disturbed lands and optimization of environmental management in the region.

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