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MONITORING THE CURRENT STATE OF SOIL-VEGETATION COVER USING TRADITIONAL AND REMOTE SENSING METHODS

Sahib Shukurov Khudaverdi [1,4], Leyli Karimova Rashid [2], Sabina Yusifova Nizami [3], Vusala Isagova Gudrat [4], Sevinj Novruzova Saleh [4], Gunel Jafarova Ali [4], Gunay Mammadova Israphil [4,5], Gunel Asgarova Farhad [4] and Shahnaz Amanova Salim [2]

[1]The State Cadastre and Registry of Real Estate Public Legal Entity, State Service on Property Issues under the Ministry of Economy of the Republic of Azerbaijan, Baku, Azerbaijan;
[2]Baku State University, Faculty of Ecology and Soil Science, Ministry of Science and Education, Baku, Azerbaijan;
[3]Sumgayit State University, Faculty of History and Geography, Department of History, Geography and Methodology, Sumgayit, Azerbaijan;
[4]Institute of Geography, Public Legal Entity, Ministry of Science and Education, Baku, Azerbaijan;
[5]Sumgayit State University, Faculty of Natural Sciences, Department of Biology, Sumgayit, Azerbaijan

**Corresponding author*: sukurov.sahib@inbox.ru

ABSTRACT

This study focuses on monitoring the current state of the soil. For the first time in this area, correlations were found between fulvic acid carbon, humic acid carbon, average annual temperature, excess analysis, soil moisture, and soil organic carbon, compared with altitude and latitude. Based on monitoring conducted over 25 years (2000–2025), anthropogenic activities have negatively impacted soil and vegetation cover in the Republic of Azerbaijan. The article analyzes the main vegetation indices and the organic composition of soils in landscapes of the lowland and low-mountain regions (Ujar, Kurdemir, Agdash, Zardab, Hajigabul). The problem of protecting soils from erosion has acquired the most important socio-ecological significance; this study uses remote sensing.

***Keywords*:** SOM, SOC, Vegetation cover map, Environmental factors, NDVI, SAVI.

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1. INTRODUCTION

Agriculture faces an important challenge: providing the population with a wide range of fresh, environmentally friendly products. The first necessary step in solving modern environmental problems must be the creation of a system for obtaining (collecting) reliable information on the state of the plant environment. Machine learning models commonly used for mapping in various fields of environmental research include decision mechanism models, linear equation models, adaptive network-based fuzzy inference system, soil regime algorithms, support vector regression, artificial ecosystem networks, hybrid models, partial least squares regression, principal component regression, additive regression mechanisms, and radial basis function (Biswas, 2021; Akbarova & Mammadova, 2024; Amanova et al., 2024). Satellite images enable rapid, timely recording of the presence and intensity of erosion processes, forecasting their impact on topography, soils, agricultural lands, and landscape systems, and proposing measures to mitigate their negative impact on the natural environment. Remote sensing is a valuable and cost-effective means of obtaining data for mapping and modeling soil properties, soil resources and their temporal and spatial changes (Bunyatova et al., 2025; Guliyeva et al., 2025; Gahramanova et al., 2026). Using visible, near-infrared, and shortwave-infrared sensors, it is possible to calibrate site-specific datasets that show the correlation between spatiotemporal and quantitative soil information changes over large regions and to estimate soil erodibility using support vector regression on Landsat-8 imagery (Akhundova et al., 2025). The studied fields are a very important ecosystem type, supporting transhumance and biodiversity conservation while maintaining grazing standards. Monitoring the condition and timely regulation of livestock numbers based on their carrying capacity help prevent vegetation degradation (Gahramanova et al., 2026). The presence of vegetation, crop residue, or clouds can reduce the accuracy of soil property predictions, so extracting spectral information solely from bare-soil pixels can yield reliable results. A single satellite image captures only 0.5% of the actual bare-soil pixels, which is insufficient for soil mapping. To address this issue, new bare-soil detection methods are being used, particularly with Landsat imagery. With a spatial resolution of 30 m, it remains one of the most widely used satellite images for vegetation modeling (Hasanova et al., 2021; Ismayılova et al., 2025a). Accurate monitoring and assessment of

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spatial and temporal changes in soil moisture are essential. Soil moisture assessment becomes more challenging in regions with dense vegetation or snow cover, as well as in areas with complex topography. Remote sensing is increasingly used to provide input data for vegetation models. Intrazonal complexes, formed by the presence of rivers and alluvial fans, also developed among semi-desert landscapes. In low-lying areas with shallow saline groundwater, solonchaks, saltwort vegetation facies, and salt lakes are common (Ismayilov et al., 2025; Ismayılova et al., 2025a; 2025b; Khalilov & Eminov, 2024). Along the rivers, riparian and lowland forests and shrubs have become widespread, forming zonal landscapes. In recent decades, they have been severely impacted by anthropogenic factors, leading to a significant reduction in their habitat (Mammadova et al., 2024). It should be noted that in some areas, steppe landscapes are secondary: they emerged in place of forest and forest-shrub complexes after human clearance of woody vegetation. Steppe landscapes have been almost completely reclaimed by humans. In their place lie grain fields, vineyards, orchards, and melon fields. The steeper slopes are used as pastures (Mammadova et al., 2025a; Macnunlu et al., 2025). Vegetation was studied in the spring season (March, April, May). Vegetation is intrazonal in nature and occurs in the form of small patches among semi-desert vegetation in coastal tugai forests, near large rivers, canals, ports, and dams (Mammadova et al., 2025b; Mirzezadeh et al., 2025).

Morphometric measurements were taken from the plants and entered into a database of Azerbaijani plants. These parameters include plant height, average leaf length and width, inflorescence length, number of flowers per inflorescence, and number of seeds per fruit. *Tamarix ramosissima* Ledeb. (100 cm), *Suaeda microphylla* Pall. (30 cm), *Anabasis aphylla* L. (20 cm), *Salsola dendroides* Pall. (41 cm), *Hordeum leporinum* Link. (17 cm), *Anisantha rubens* L. (10 cm), *Bromus japonicus* Thunb. (17 cm), *Petrosimonia brachiata* Pall. (14 cm), *Suaeda acuminata* C.A. Mey. (12 cm), *Torilis nodosa L.* (11 cm), *Lagoseris glaucescens* Koch. (8 cm), *Malvalthaea transcaucasica* (9 cm), *Halostachys belangeriana* Moq. (120 cm), *Tamarix meyeri* Boiss. (250 cm), *Frankenia hirsuta* L. *(12 cm), Bromus danthoniae* Trin. (14 cm), *Aegilops triuncialis* (20 cm), *Setaria verticillata* (16 cm), *Lolium rigidum* Gaudin. (17 cm), *Anisantha tectorum* L. (12 cm), *Plantago major* L. (10 cm), *Climacoptera crassa* M. Bieb. (14 cm), *Torilis arvensis* Huds. (15 cm), *Astrodaucus orientalis* L. (76 cm), *Artemisia lercheana* Weber ex Stechm. (25 cm), *Phalaris minor* Retz. (30 cm), *Lolium rigidum* Gaudin. (19 cm), *Hordeum leporinum* Link. (30 cm), *Cynodon dactylon* L. (15 cm), *Petrosimonia brachiata* Pall. (20 cm), *Salicornia europaea* L. (12 cm), *Atriplex sagittata* Borkh. (15 cm), *Limonium scoparium* Pall. (15 cm), *Halimocnemis pilosa* Pall. (11 cm), *Spergularia diandra* Guss. (17 cm), *Plantago ovata* (9 cm), *Geranium molle* L. (22 cm), *Erodium ciconium* L. (19 cm), *Strigosella africana* L. (18 cm), *Poa bulbosa* L. (17 cm), *Anisantha rubens* L. (18 cm), *Phleum paniculatum* Huds. (22 cm), *Petrosimonia brachiata* Pall. (16 cm), *Sisymbrium loeselii* L. (28 cm), *Stellaria media* L. (14 cm), *Lepidium vesicarium* L. (16 cm), *Malva neglecta* Wallr. (20 cm), *Scandix pecten-veneris* L. (20 cm), *Parentucellia latifolia* L. (13 cm). Due to the gentle slopes and plateau-like nature of the forest-steppe foothills, large areas are plowed and occupied by grain and vegetable crops and orchards. The processes of swamping, overgrowing of lands with shrubs and small trees, and desertification have reached dangerous proportions. The problem of protecting soils from erosion has acquired crucial socio-ecological significance. A change in the environmental conditions alters the potential of colloids: alkalization increases the negative potential, whereas acidification increases the positive potential (Mondal, 2021; Nguyen et al., 2021; Makki et al., 2025). Consequently, anion absorption is greater in an acidic environment, while it is weakened in an alkaline one. In agricultural practice, negative anion uptake must be taken into account (Nazim & Oqtay, 2024). As mineral fertilizers, they are applied to the soil, especially those with a light particle-size distribution, as close to planting as possible to prevent them from being washed out of the soil and to ensure they can be utilized by plants. They are also used as summer and foliar applications (Nigussie, 2024; Mazhar et al., 2025; Madnee et al., 2025). Most of the land is artificially irrigated. The slopes are used for summer pastures and, to some extent, hayfields. At present, the rate of growth of the humus horizon for different regions of Azerbaijan and time intervals has been satisfactorily studied (Jafarova et al., 2026). Traditional methods of studying and monitoring soil and vegetation cover are still considered the most specific, but comparison of results with remote sensing data provides a complete framework for compiling clear electronic maps.

2. MATERIALS AND METHODS

Recent soil survey data such as LUCAS topsoil data and remote sensing data have made large-scale soil vegetation modeling more feasible, which is an extensive and repetitive topsoil survey conducted every three years throughout Azerbaijan. Data on vegetation dynamics were obtained through field observations of fallow lands located in the Aran-Shirvan region. The fallow areas were selected based on a large-scale (1:25,000) geobotanical survey and Landsat 8.0 imagery. The Excel program was used to process the material, and the ArcGIS program was used to create the maps. First, a study of the dominant soil types in Aran-Shirvan was conducted, followed by soil sampling across different latitudes (38°N-42°N) and altitudes. For each sampling site, three standard plots measuring 25 x 25 m were established, from which surface litter and fallen leaves were removed. Soil samples were

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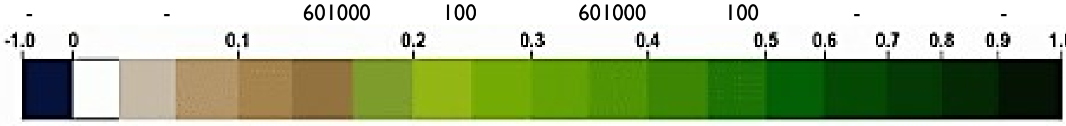
collected from the 0-15 cm soil layer at each plot using the envelope method and thoroughly mixed. A total of 57 soil samples were collected and then transported to the laboratory. After allowing the soil to air-dry naturally, stones, plant debris, and animal remains were removed. For analysis, partial soil samples were collected by dividing them into four portions and sifting them through a sieve. Soil pH was determined using a pH meter (Myron L. Company, Carlsbad, CA, USA) from a soil suspension mixed with distilled water (1:2.5, v/v). SOC was determined using the potassium dichromate oxidation method (Rowell, 1999; Nasirova et al., 2022; Oishy et al., 2025). Total soil nitrogen was determined using the Kjeldahl method, and the soil C/N ratio was calculated as the ratio of organic carbon to total nitrogen. Soil moisture was determined gravimetrically. SMC was measured after drying the soil samples in an oven at 105°C for 24 h. Soil texture was classified according to an international standard, dividing soils into clayey (<2 µm), powdery (2–20 µm), and sandy (20–2000 µm) (Rianti & Sari, 2024; Nasirova et al., 2025; Nasirova et al., 2026). MAT data were obtained from the Azerbaijan National Hydrometeorological Service. In the active coastal salt marsh zone, disturbance levels range from moderate to high. Signs of overgrazing were recorded on active soils; on other landforms, grazing intensity was moderate to high (Table 1; Fig. 1) and positively correlated with species richness ($r=0.88$, $P<0.01$) and total vegetation cover ($r=0.81$, $P<0.01$).

Table 1: A. NDVI (2000-2025 years); B. SAVI (2000-2025 years)

No	NDVI		Area, 2000		Area, 2025		Dynamics	
	min	max	Ha	%	ha	%	ha	%
1	low	0.045	4262	0.7	5113	0.8	-851	-20
2	0.05	0.1	229303	38.1	26815	4.5	202488	88
3	0.1	0.2	129553	21.6	203210	33.8	-73657	-57
4	0.2	0,3	87907	14.6	191880	31.9	-103973	-118
5	0.3	0.4	65945	11	121820	20.3	-55875	-85
6	0.4	high	84030	14	52162	8.7	31868	38
7	-	-	601000	100	601000	100	-	-



№	SAVI	2000		2025		Dynamics	
		ha	%	Ha	%	ha	%
1	low-0	25843	4.3	3005	0.5	-22838	-88
2	0-0.1	169482	28.2	10217	1.7	-159265	-94
3	0.1-0.2	91953	15.3	67913	11.3	-24040	-26
4	0.2-0.3	79332	13.2	153856	25.6	74524	94
5	0.3-0.4	59499	9.9	135826	22.6	76327	128
6	0.4-0.5	51085	8.5	103973	17.3	52888	104
7	0.5-0.6	40868	6.8	73923	12.3	33055	81
8	0.6-high	82938	13.8	52287	8.7	-30651	-37
9	total	601000	100	-	100	-	0

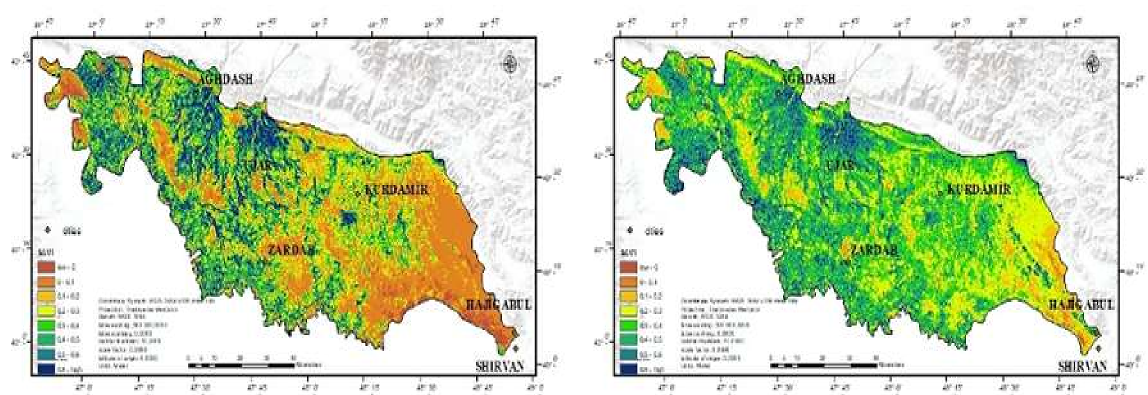


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Fig. 1: A. SAVI (2000 year); B. SAVI (2025 year).

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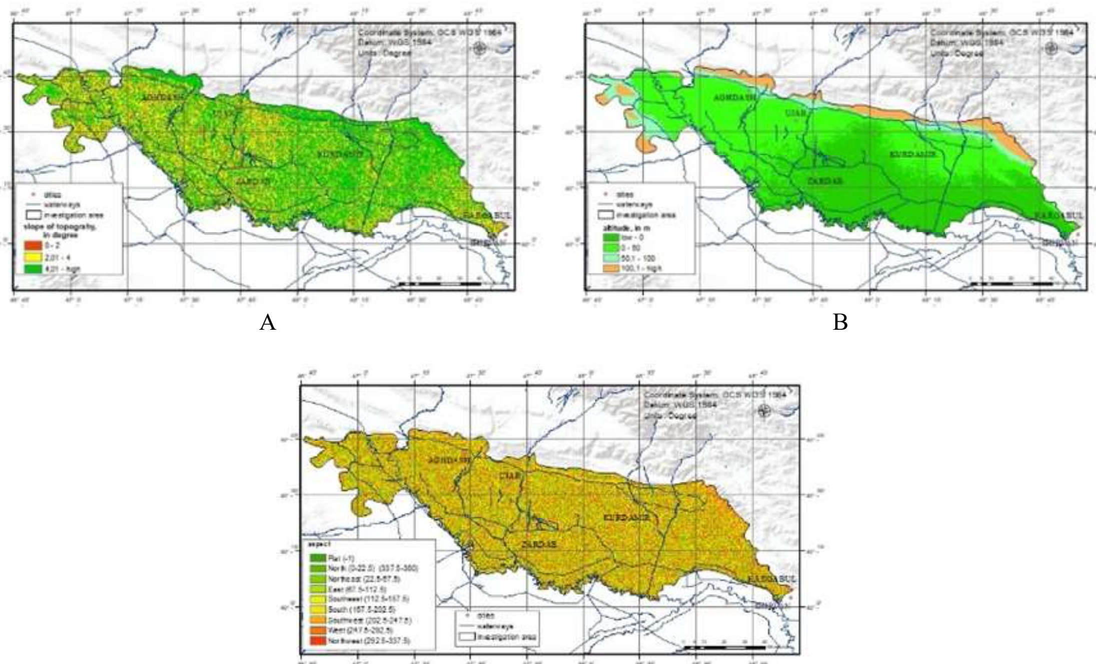
3. RESULTS AND DISCUSSION

The explanatory information value of the first sorting axis was 33.18%, and that of the second sorting axis was 34.57%, with the total explanatory information value being 64.15%. The total explanatory power of SOM composition by various environmental factors was 30.1%, with the C/N ratio ($P<0.01$) having the highest explanatory power at 20.2%, followed by MAT, SMC, pH, and powder ($P<0.05$). C/N, as an indicator of humus properties, can to some extent reflect the characteristics by which the carbon content of humus varies in low-latitude plateaus (Fig. 4A and B).

The Aran-Shirvan region is a vast agricultural and industrial zone located in the central plain of Azerbaijan, in the Kur-Araz Lowland. It was known as the "Aran Economic Region" until July 7, 2021, and is currently divided into Central Aran, Shirvan-Salyan, Mil-Mughan, and part of Karabakh. It is characterized by a dry subtropical climate, fertile soils, cotton and grain cultivation, and a strategic location along the Kur river. The use of machine learning methods to establish relationships between structural and spectral-reflective features of vegetation generally yields higher accuracy compared to approximation by various functions, multiple linear regression, principal component analysis, and others. However, machine learning methods require significantly more reference data. In this study, we attempted to use the Random Forest algorithm to construct a regression model for structural and spectral-reflectance characteristics using Landsat 8.0 data, which resulted in slightly improved accuracy compared to linear regression for phytomass (Shukurov et al., 2025; Sadigov et al., 2025; Sadigov et al., 2026).



A B

C

Fig. 2: A. Slope inclination; B. Absolute relief height; C. Slope exposure map; Note: NDVI value: 0.6 - 1.0 very dense and healthy vegetation; 0.4 - 0.6 medium dense vegetation; 0.2 - 0.4 weak and sparse vegetation; 0 - 0.2 very little vegetation cover; < 0 water, asphalt, rock, building, etc.

According to research results, average productivity was 5.12 t/ha wet mass and 1.08 t/ha dry mass. Taking into account waste, the average dry phytomass was 1.2 t/ha. Similar estimates for the region range from 1–2 t/ha dry mass and 2–7 t/ha wet mass of aboveground plant biomass. However, before the intensification of degradation processes in the region, the mass significantly exceeded green phytomass. To spatially characterize the soil cover, large-scale soil and vegetation maps were compiled to document the current state of the vegetation cover. This created a basis for long-term monitoring of the soil and vegetation cover in the central part of the Republic of Azerbaijan. A network of reference soil sites was created using reference polygons, for which the necessary thematic information characterizing the current ecological state of the soils was obtained. Due to the relative simplicity of calculating NDVI, it is widely used for thematic mapping, including landscape mapping (Tung et al., 2020; Verdiyeva et al., 2025). In fact, this spectral index is linked to such a landscape-geophysical indicator as

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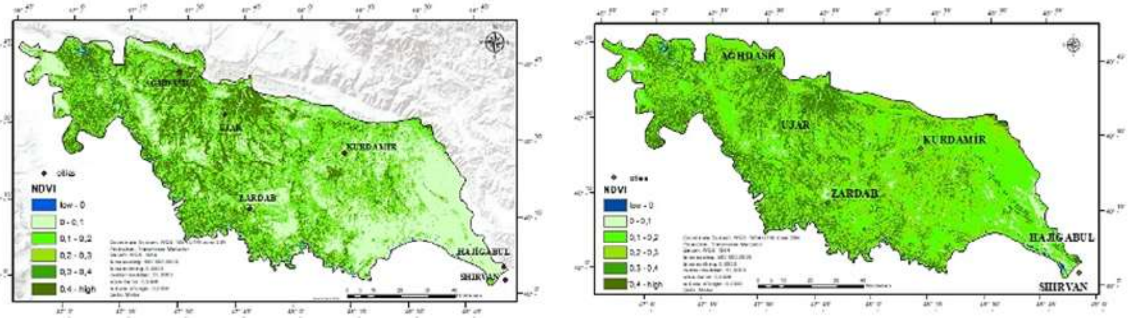
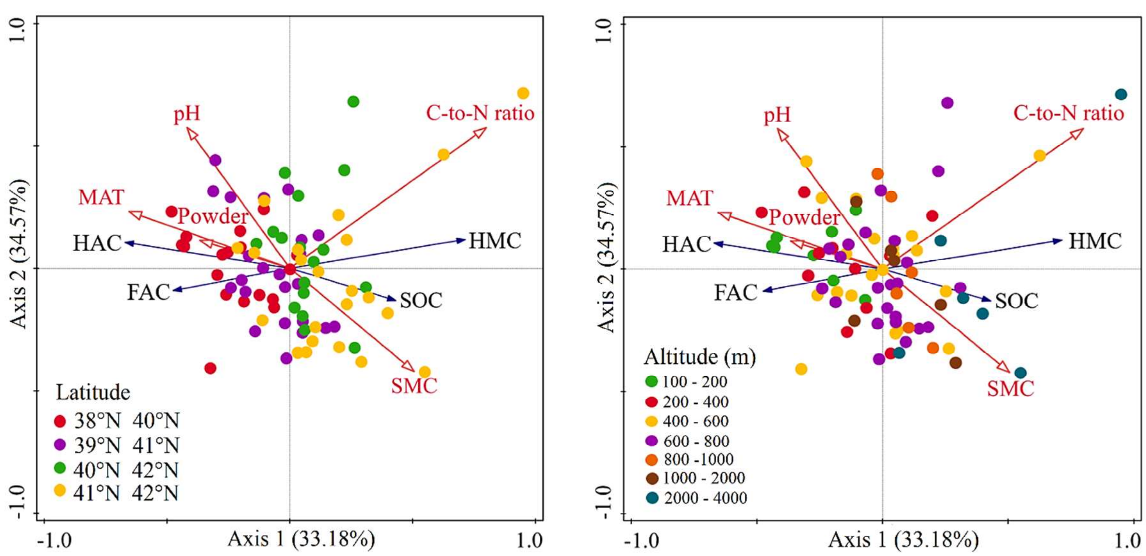
phytomass reserves. Parameters were developed that most accurately reflect the dynamics of vegetation and soil cover transformation under the influence of global climate change (Zhao et al., 2023).



A B

Fig. 3: A. NDVI in 2000 year; B. NDVI in 2025 year.

The population of Azerbaijan's Aran-Shirvan region has been engaged in agriculture and livestock farming since ancient times. Due to the continuous use of traditional farming methods and the relatively flat terrain, erosion and deforestation have progressed rapidly. Given the significant economic importance of these areas, the topic of this study is relevant. Maps (Fig. 2 and 3) display the investigation area of a geographic study, likely focused on parts of Azerbaijan. It specifically highlights topographical and administrative features in a region that includes several districts. The investigation focuses on several named administrative zones, including Aghdash, Ujar, Zardab, and Kurdamir. A color-coded legend indicates the altitude in meters, ranging from below 0 (dark green) to over 100 meters (orange/red). The maps use the GCS WGS coordinate system, with units in degrees (Fig. 2b). Redundancy analysis shows that altitude is a major factor determining soil organic matter composition, explaining significant variation in soil chemical properties, with soil organic carbon and nitrogen contents often peaking at mid-elevations. Altitude acts as a climate indicator, influencing microbial communities and mineral weathering. In the case of complete phenological isolation of populations (with an altitude gradient of 450–500 m), the degree of their genetic differentiation also depends on the occurrence of mountain barriers and the disjunctive nature of the range (Fig. 4a-b). As water deficit increases in lichen thalli, the oxidative pentose phosphate cycle of respiration increases and the glycolytic cycle weakens.



A B

Fig. 4: RDA of SOM composition and environmental factors at different altitudes of study area; Note: FAC - fulvic acid carbon; HAC - humic acid carbon; HMC - humic carbon; MAT - mean annual temperature; RDA - redundancy analysis; SMC - soil moisture; SOC - soil organic carbon.

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Lichens, which have different pathways for converting respiratory material, utilize one or another respiratory pathway or all pathways simultaneously, depending on external conditions, particularly water availability, thereby increasing their adaptability to the changing conditions of their environment. In dehydrated lichens, the coupling of respiration (oxidation) with phosphorylation is maintained, thereby ensuring the preservation of their submicroscopic structure even in a state of cryptobiosis. It has been established that pigments, particularly chlorophyll content, as well as the intensity and productivity of photosynthesis, can serve as indicators of lichen health and parameters of their response to changing environmental conditions. Total phytomass reserves vary significantly across landscapes. The ecological groups of plants are represented by the following spectrum: mesophytes – 48.9%, xeromesophytes – 27.3%, mesoxerophytes – 19.9%, xerophytes – 0.01%, hygromesophytes – 0.03%. Thus, the spectrum of ecological groups is dominated by mesophytes. Within-landscape differences in phytomass reserves are related to the mosaic nature of local conditions. The latter is reflected in the fact that within landscapes belonging to the same genus or species, different vegetation groups may be found, confined to different locations. When using vegetation indices to create a landscape map, it is necessary to analyze the spatial distribution of their values. In the case of, for example, NDVI (it is necessary to take into account the fact that areas with similar vegetation index values may belong to different landscape types), this value actually reflects vegetation characteristics such as its character and density, related to phytomass reserves. Due to the data's minimal temporal resolution, NDVI calculated from them can provide operational information on the ecological and climatic situation and enable tracking of the dynamics of various parameters at a frequency of up to 1 week. The density of vegetation given point in the image is equal to the difference in the intensities of reflected light in the red and infrared ranges, divided by the sum of their intensities. The relationships among these indicators allow us to clearly separate plant life from other natural objects. A limitation of this and other machine learning methods is the need for significantly larger sample sizes. Thus, the limited availability of ground-based data on vegetation biomass is a limiting factor for the further development of satellite-based mapping methods for structural characteristics using both machine learning and traditional statistical methods (Madnee et al., 2025; Ismayılova et al., 2025a; 2025b).

Despite Azerbaijan having a large percentage of protected areas and the Constitution of the Republic guaranteeing everyone's right to a favorable environment and reliable information about its condition, the environmental situation remains tense. The intention to publish a new Red Book of Azerbaijan's flora also testifies to the alarming state of the environment (Sadigov et al., 2025; Nasirova et al., 2026).

4. CONCLUSION

In this study, the response of soil organic matter composition to latitude and altitude, as well as the main regulating factors, was investigated. SOM composition increased with increasing altitude and latitude. The composition of soil organic matter was arranged in the following order: HAC < FAC < HUC. Over the entire latitude range (38–42° N), the effect of altitude on the carbon content in soil humus was significant only from 39° N to 42° N. Latitudinal and altitudinal patterns of SOM composition in lowlands and foothills are controlled by MAT and SMC, and soil chemical properties (pH, C/N, and water content) also have a certain effect on the accumulation of SOC and carbon in humus. In low-latitude regions (38–40° N), HAC and FAC are mainly controlled by MAT and water content. The formation and transformation of SOC and humus carbon in high-latitude and high-altitude regions are primarily dependent on moisture content and the C/N ratio. In general, high-latitude and high-altitude conditions are favorable for carbon accumulation in soil humus in the surface layer (0–10 cm). In the current response to global climate change, it is imperative to prioritize and protect this high carbon sequestration capacity. Based on monitoring conducted over 25 years (2000–2025), anthropogenic activities have negatively impacted soil and vegetation cover in the Republic of Azerbaijan. A modern approach uses machine learning. Algorithms combine remote sensing data, climate maps, and soil laboratory analysis results to create high-resolution global SOC maps. Global initiatives, such as the GSO cmap project, aim to create a unified digital database to enable countries to effectively manage their carbon credits and combat degradation.

Declarations

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Ethics Statement: This article does not contain any studies with humans/animals, thus requires no ethical approval.

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