Baku State University Journal of Earth Sciences & Environment **2025**, v 2 (2), p. 43-52

journal homepage: http://bsuj.bsu.edu.az/en

ECOGEOGRAPHICAL ANALYSIS OF VEGETATION IN THE AREAS OF MUD VOLCANOES INCLUDED IN THE MUD VOLCANOES GROUP STATE NATURE RESERVE

Akif S. Aghbabali, Tahir A. Yunuslu

Baku State University, Baku, Azerbaijan

https://doi.org/10.30546/209805.2025.2.2.1127

Abstract

This study first explores the distinctive characteristics of vegetation in mud volcano areas and investigates the key factors influencing its distribution, including soil properties, climatic conditions, geochemical influences, volcanic activity, and anthropogenic impacts.

It was investigated in the article the vegetation of the areas where mud volcanoes are located, which are part of the Mud volcanoes group State Nature Reserve. The plant species distributed in the area, comparison of ecogeographic parameters by landscape complexes, and the state of vegetation based on NDVI indicators were studied by using the obtained Sentinel-2 satellite images, NDVI (Normalized Difference Vegetation Index) indicators and literature materials.

The area was categorized according to the variety of species present, with an emphasis on understanding the distribution and abundance patterns of each species throughout the reserve. This included a thorough analysis of how species are spread across different sections of the territory. In addition, the study focused on comparing the ecogeographic factors within various landscape units to explore the ecological interactions and environmental influences that contribute to the overall distribution of plant species. Also, maps, tables and graphs were prepared based on the results obtained.

Keywords: mud volcanoes, vegetation, NDVI, landscape complexes, ecological characteristics

**Corresponding author. Tel.:+994-51-760-73-48*

E-mail address: aghbabali@bsu.edu.az; ORCID ID: 0000-0001-5793-9252 (Akif S. Aghbabali)

E-mail address: tahiryunuslu.a@bsu.edu.az; ORCID iD: 0009-0007-4109-9763 (Tahir A. Yunuslu)*

Introduction:

Mud volcanoes are natural landforms that originate when clay-rich substances are expelled to the surface. This occurs when enough water and gas combine with the material, creating a semi-fluid state that pushes it upwards through deep, narrow cracks or fissures in the Earth's crust. The expelled mud accumulates on the surface [5].

The water in mud volcanoes is highly rich in minerals. Unlike geothermal mud, which is hot due to magmatic influence, mud volcanoes remain relatively cool because they are not caused by magmatic heat. Instead, the primary force behind their activity is the release of gases formed during the decomposition of organic matter deep within the Earth's crust. [6]

Research into vegetation surrounding geological features like geothermal areas, geysers, hot springs, solfataras, and mud volcanoes offers valuable insight into the spatial organization and functional roles of plant communities under extreme environmental pressures. Such environments also allow scientists to observe how plant dynamics evolve over time in response to these stresses. However, vegetation on magmatic volcanic formations remains relatively underexplored [4]

Vegetation is considered one of the main components of natural landscape complexes. The extent and structure of vegetation in the areas where mud volcanoes are located are closely related to a number of ecogeographical factors (soil properties, salinization degree, water supply and anthropogenic impacts).

The vegetation of the mud volcano area was studied in the mentioned districts, because the mud volcanoes included in the State Nature Reserve are located in the Absheron, Shamakhi-Gobustan and Ashaghi-Kur oil and gas districts.[2]

Research method

Sentinel-2 satellite data and NDVI (Normalized Difference Vegetation Index) were utilized for the ecogeographic analysis of vegetation in the study area. NDVI is a widely used remote sensing indicator that allows the assessment of vegetation density and overall health. The satellite data were sourced from the Copernicus Open Access Hub platform and processed with ArcGIS software for detailed spatial analysis. NDVI values were calculated based on Sentinel-2 satellite imagery, and the vegetation cover was assessed throughout the research period.

Additionally, soil maps, vegetation data, and indicators of anthropogenic impact were thoroughly analyzed to understand the effects of human activity on vegetation. The study also incorporated various literature sources, including maps and atlases related to the region where the Mud Volcanoes Group State Nature Reserve is located, providing a comprehensive understanding of the area’s ecological and environmental context.

Purpose

This study is designed to examine the spatial distribution of vegetation and its density within the Mud Volcanoes State Nature Reserve, as well as to analyze the extent of vegetation cover across different sections of the reserve. Furthermore, the research explores the relationship between vegetation patterns and various ecogeographic factors such as soil characteristics, climatic conditions, volcanic activity, and human-induced impacts. The study aims to provide a comprehensive scientific analysis of these factors and their interplay, offering valuable insights into the dynamics of vegetation within the reserve and contributing to a better understanding of the ecological processes at work in the region.

Discussion of results

The development of vegetation on the surface of mud volcanoes is a long-term ecological process that includes both primary succession (the emergence of pioneer species) and secondary succession (vegetation changes resulting from recurring eruptions), encompassing both short- and long-term stages. Although approximately 80% of mud volcano eruptions occur on the ocean floor, terrestrial volcanic events are also relatively frequent and significantly impact surrounding vegetation. The primary effects of volcanic activity on vegetation are linked to lava flows, pyroclastic flows, debris avalanches, mudflows, and deposits of tephra and ash.

Phytocenotic observations of mud volcano vegetation reveal that plant distribution is closely related to the volume, direction, and spread of clayey mud emitted from the volcano's central vent. In areas with high accumulation of eruptive mud, vegetation is either absent or significantly reduced in species diversity. As a result, the spatial distribution of vegetation on mud volcano surfaces exhibits a mosaic-like pattern. The presence and flow of clayey-mud lava hinder the establishment of stable plant communities. Such zones remain barren or become sporadically colonized by halophytic species genetically adapted to saline clayey soils.

The formation of vegetation cover in mud volcano regions is influenced by a complex interplay of factors including soil characteristics, climate, geochemical processes, volcanic activity, and anthropogenic impacts. The soil cover in these areas is typically underdeveloped, consisting of unaltered primary mud layers that are highly mineralized and saline, with an alkaline pH (8–9), low organic matter content, and weak structural composition. These conditions contrast sharply with the surrounding natural semi-desert soils and create a stressful environment where only morpho-physiologically adapted plant species can survive.

Mud volcanoes are predominantly found in semi-desert and arid climatic zones, characterized by low annual precipitation (200–400 mm) and high temperature fluctuations. During summer, intense solar radiation leads to significant soil heating, enhancing evaporation and increasing salinity levels.

Geochemical emissions from mud volcanoes further influence vegetation. Substances released during eruptions—such as gases (H_2S, CO_2, CH_4)—can be toxic to vegetation, while minerals like Na, Mg, Ca, and Fe may serve as nutrients for certain species. Additionally, the accumulation of trace elements (e.g., B, Mo, Sr) is common in volcanic regions. Mud volcano waters and breccias are enriched with trace and toxic elements (Mo, As, Yb, B, Hg, Sr, Li, Pb), often at concentrations exceeding average crustal values (Clarke). Saline solutions discharged to the surface result in a highly saline lithogenic base, supporting the intensified development of halophytic vegetation compared to adjacent zones. [3]

The spread and density of vegetation are also affected by the frequency and intensity of mud volcano activity. During active phases, vegetation is destroyed, the land surface is covered with mud, and the soil profile is disrupted. Following eruptions, vegetation undergoes gradual regeneration, starting with the appearance of ephemeral and halophytic species. In dormant periods, shrubs and semi-shrubs reestablish on the site.

Based on the analysis of topographic maps, literature sources, and field observations within the reserve territory, the vegetation cover is typically sparse and exhibits a mosaic distribution. The dominant plant groups include halophytes, xerophytes, ephemerals, shrubs, and semi-shrubs. Representative species are as follows:

Halophytes: Salsola dendroides, Halostachys caspica, Atriplex tatarica

Xerophytes: Artemisia fragrans, Astragalus aureus

Ephemerals: Alyssum desertorum, ephemeral grasses (Poaceae)

Shrubs and Semi-shrubs: Tamarix ramosissima, Calligonum spp.

Fig. 1*. Distribution of Ephemeral Plant Communities on the Breccia Surface of Mud Volcanoes*

The Mud volcanoes State Nature Reserve is located in the southeast of the Absheron Peninsula, along the coast of the Caspian Sea. The territory of the reserve is characterized by volcanic relief forms, saline soils and arid climatic conditions. The Absheron Peninsula, which at first glance gives the impression of unfavorable and extreme conditions for vegetation, actually has a very rich floristic biodiversity. 10-12 plant species occur per 1 m^2 in some parts of this territory. [11]

The prevailing climatic conditions on the Absheron Peninsula-including saline and unproductive soils, limited annual precipitation, and frequent strong winds-create an unfavorable environment for the development of forest ecosystems. Halophyte plants are widespread in saline areas, and semi-desert and drought-resistant species are widespread in dry steppe zones. In areas where volcanic craters and mudflows are active, vegetation is either very poorly developed or completely devoid of vegetation.

The Caspian coastal areas of the peninsula are represented by saline vegetation. These areas are mainly populated by halophytic species such as *Suaeda confusa Iljin*, *Salicornia europaea* L. (commonly known as European saltwort), *Atriplex fomini Iljin*(Fomin vinegar), and *Nitraria schoberi* L. (Schober saltwort). The coastal areas are also rich in cereal plants. As you move away from the coast, after a relatively hard, clayey and moist sandy zone, the zone of Siberian argusia (*Argusia sibirica* L.) mixed with Tatar milkweed (*Lactuca tatarica* C.A.M.), common meadowsweet (*Aster tripolium* L.), and tongalotu (*Anisantha rubens* (L.) Grossh.) begins.

Fig. 2*. Distribution of Limonium sp. around the Shekikhan Mud Volcano*

One can find the sedge (*Picris sirigosa* M. Bieb.), the Baku sedge (*Astragalus bakuensis* Bunge.), the fiery sedge (*Astragalus igniarius* Pall.), the finger-shaped meadow (*Cynodon doctylon* (L.) Pers.), etc. in the coastal areas of the northern part of the peninsula. In some locations, this vegetative zone expands to include *Juncus litoralis* C.A.M. (coastal sedge), *Phragmites australis* Trin. (southern reed), and *Tamarix ramosissima* Ledeb. (polygonal tamarisk). In the northwestern (Pirakashkul) and northeastern (Nardaran) regions at relatively low elevations, *Achillea species* (boymardan formations) are dominant, whereas higher altitudes are marked by the presence of *Ecballium elaterium* (dog cucumber). At elevations around 200 meters, *Capparis spinosa* Willd. (thorny caper) becomes prevalent.

Licorice formation is widespread in the southeastern part of the peninsula, especially from Hovsan to Pirallahi Island and in Nardaran, Laish coastal and relatively remote areas. Thorny caper (*Capparis herbacea* Willd.) is found in the western and northwestern parts of the area.

A rare and endangered endemic species, *Calligonum bakuense* Litv. (Baku juzgun), is found in the southwestern regions. The Sumgayit area and its northern surroundings host extensive wormwood (*Artemisia* sp.) formations, which in certain sites are replaced by *Ephedra* spp. (bitter gourd). One of the most widespread plants of the area is the davatikana (*Alhagi pseudoalhagi* (Bieb.) Fisch.) The davatikana, which has a high vitality, grows even on rocks. The Gobu Valley and the Qizilgaya areas are covered in a colorful dress with bird's milk in the spring. [1][11]

The most widespread plant formation of the area is the wormwood forests that occupy vast areas. According to most botanists, 16 species of wormwood are widespread in Azerbaijan, one of which is considered an endemic species for the Azerbaijani flora. 7 species and ecological form of wormwood, which are considered a very valuable feed base for winter pastures, are described in Absheron.

In conclusion, it should be noted that the biodiversity of the Absheron Peninsula is very rich. 730 plant species belonging to 63 families and 370 genera grow naturally on the territory of the Azerbaijan Peninsula. About 160 of these plant species are plants of medicinal and aesthetic importance. In the vegetation of the place, there are perennial sorghums - black sorghum (*Halocnemum strobilaceum* (Pall.)), saffron (*Kalidium caspicum* (L.) (Ung.-Sternb.), saffron (*Halostachys caspica* C.A. Mey.), saffron (*Tamarix ramosissima* Ledeb. (1829), *Halostachys caspica* (Moq.) Botsch.), it belongs to the sedge (*Suaeda dendroides* (C.A. Mey.) Mog.), ephemeral (*Salsola nodulosa* (Mog.) Iljin), wormwood (*Artemisia szowitziana* (Besser) Grossh., *Salsola dendroides* Pall.).

One-year herbaceous plants include cornflower (*Salicornia europaea* L.), branched winterwort (*Petrosimonia* Bunge.), ephemeral-wortwort winterwort. (*Artemisia fragrans* Willd., *Petrosimonia brachiata* (Pall.) Bunge). Wormwood-ephemeral (*Artemisia fragrans* Willd.) develops in the gray-grass soils of the area.

The species composition of this association includes ephemerals - Japanese brome (*Bromus japonicus*), hard ryegrass (*Lolium rigidum* Gaudin), as well as ephemeroids - bulbous grass (*Poa bulbosa* L.), etc. In the winter season, fragrant wormwood, blackgrass, genghis and other perennial herbs are observed in the Aghzibir and Bandovan mud volcanoes.

Fig. 3*. Floral Composition within the Breccia of Bandovan Mud Volcano*

As a result of research conducted at the foot of the Bandovan mud volcano, several beneficial medicinal plants have been found: plantain (*Plantago lanceolata* L.), laborer (*Malvalthaea transcaucasica* (Sosn.) Iljin), sedge (*Polygonum lapathifolium* L.), etc.

The Pirakashkul mud volcano is situated at an elevation of 315 meters above sea level, falling within the vertical zonation framework. The vegetation composition surrounding this volcano comprises up to 18 plant species, belonging to 6 families and 15 genera. Six distinct vegetation units have been identified in the area, including three fully developed associations and three in stages of aggregation and semi-aggregation, indicating ongoing community formation. These units are as follows: Salt-tolerant semi-desert aggregation dominated by Suaeda microphylla; Salt-tolerant semi-desert semi-aggregation of Salsola nodulosa, Salsola dendroides, and ephemeral species; Salt-tolerant semi-desert semi-aggregation of Suaeda dendroides, Suaeda microphylla, and ephemerals; Salt-tolerant semi-desert association of Suaeda dendroides, Suaeda microphylla, and ephemerals; Salt-tolerant semi-desert association of Salsola nodulosa, Salsola dendroides, and ephemerals; Annual salt-tolerant desert association of Petrosimonia brachiata, Climacoptera crassa, and ephemerals. [7]

The Toragay mud volcano is located in a semi-desert zone at an altitude of 155 meters above sea level. The vegetation cover of this volcano includes up to 44 plant species, representing 20 families and 43 genera. Four plant community units have been identified here, two of which are fully established associations: Salt-tolerant semi-desert aggregation of Salsola dendroides; Salt-tolerant semi-desert semi-aggregation of Salsola dendroides and ephemerals; Salt-tolerant semi-desert association of Salsola nodulosa, Salsola dendroides, and ephemerals; Salt-tolerant semi-desert association of Salsola nodulosa, Artemisia fragrans, and ephemerals.

In the few areas included in the State Nature Reserve, due to favorable conditions, meadow plants are more widespread. This type of plants has its own groupings.

The meadows and saline meadows have a rich species composition. The components of the meadow groups are Japanese brome (*Bromus japonicus* Thunb.), red brome (*Bromus rubens* L.), vulpia (*Vulpia myuros* (L.) CC Gmel.), hard einkorn wheat (*Lolium rigidum* Gaudin), Persian clover (*Trifolium resupinatum* L.), field peas (*Vicia sativa* L.), small black clover (*Medicago minima* (L.)L.) and others.

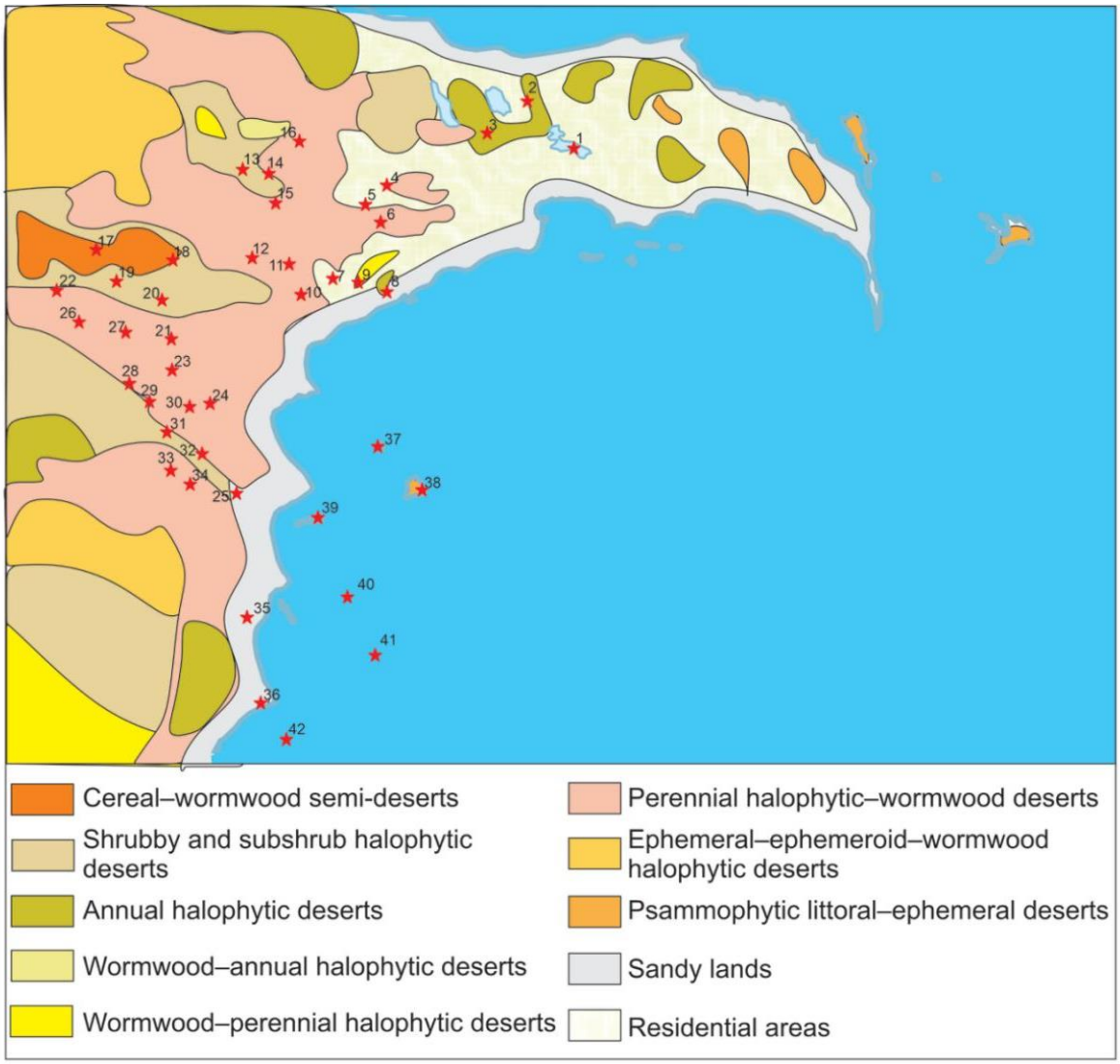

Fig. 4*. Vegetation types of the Mud Volcanoes Group State Nature Reserve. Mud Volcanoes: 1.Girmaki; 2. Gullutepa; 3. Keyraki; 4. Guzdek-Bozdag; 5. Shorbulag; 6. Gulbakht-Sarynca; 7. Pilpili Garadagh; 8. Garadagh Aktarma; 9. Torpagli Aktarma; 10. Otman-Bozdag; 11. Shahgaya; 12. Chapilmish; 13. Saridas Boyanata; 14. Kirdag; 15. Buransiz-Chulga; 16. Pirekushkul; 17. Suleymanakhtarma; 18. Cheilakhtarma; 19. Cheyildag; 20. Qalenderakhtarma;21. Kilinc; 22. Agnohur; 23. Toragay; 24. Kichik Kenizadag; 25. Gotur; 26. Shekikhan group; 27. Agdam group; 28. Durandag; 29. Goturdag; 30. Agtirma; 31. Emjek-emjek; 32. Oyukh; 33. Garakhura; 34. Ayrantokan; 35. Agzibir; 36. Bandovan; 37. Zanbil Island; 38. Khara-Zira Island; 39. Gil Island; 40. Garasu Island; 41. Sangi-Mugan Island; 42. Jigil Island*

Analysis of the vegetation structure of the Mud Volcanoes Group State Nature Reserve, based on scientific literature, cartographic materials, and field observations, reveals that perennial halophytic–wormwood desert plant communities are dominantly distributed throughout the area.

In the mud volcanoes located near the Caspian Sea coast and their surrounding areas, psammophytic littoral–ephemeral desert vegetation is observed. These plant communities are primarily found on Khara-Zira Island, Gil Island, and Zanbil Island.

Fig. 5*. Vegetation Surrounding the Mud Volcanoes of Khara-Zira Island - Psylliostachys spicata (Willd.)*

The landscapes surrounding the Galenderarkhtarma, Cheyildag, Agnohur, Cheilakhtarma, Sarıdas, Boynata, Kirdag, Oyukh, Gotur, and Goturdag mud volcanoes are predominantly characterized by shrubby, undershrub, and subshrub halophytic desert plant communities.

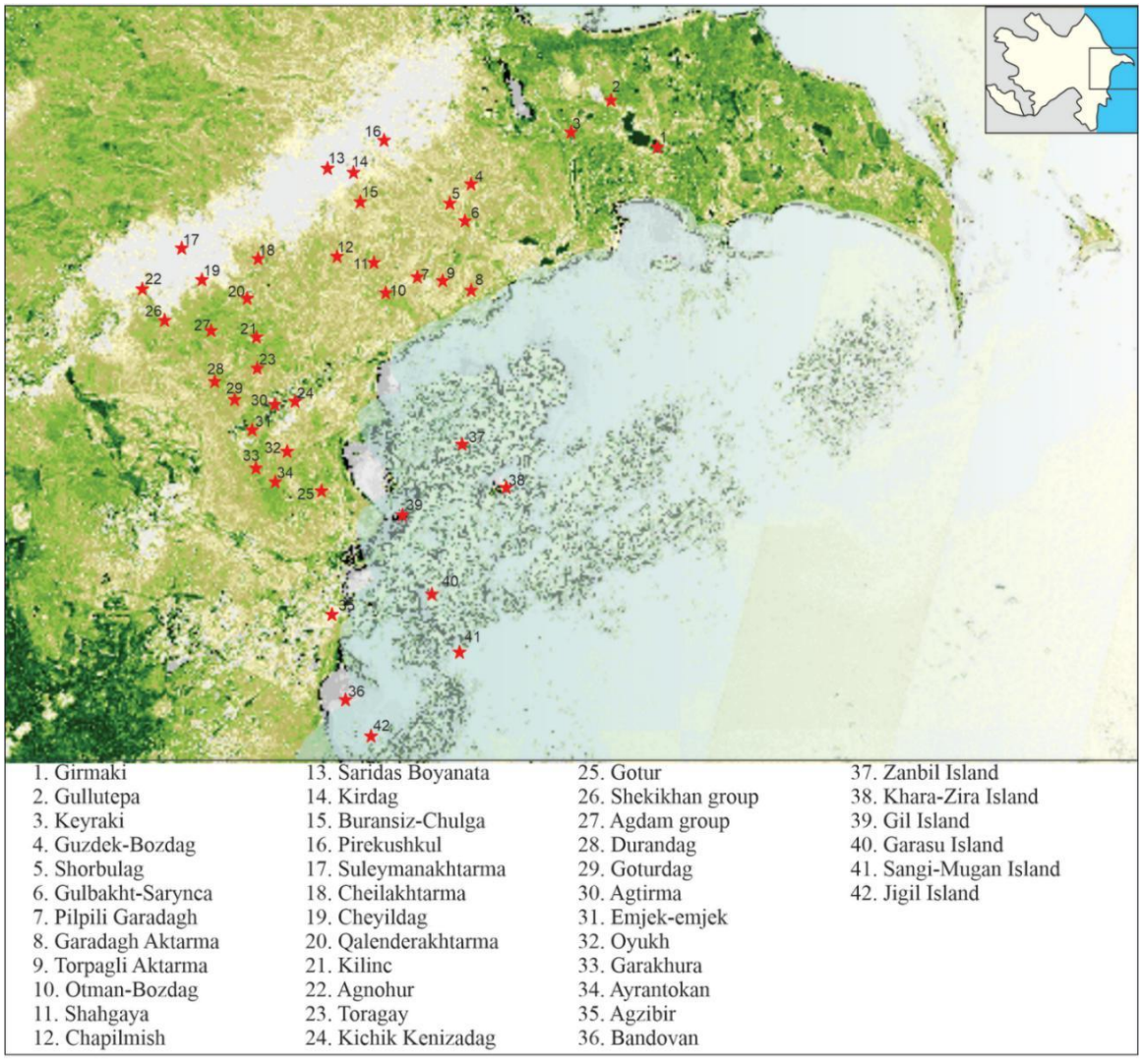

Fig. 6*. Sentinel-2_L2A_NDVI*

Vegetation status based on NDVI indicators

The following vegetation zones were identified as a result of NDVI analysis:

- NDVI: 0.0–0.2 – Areas with no vegetation or weak vegetation (gray color)
- NDVI: 0.2–0.4 – Areas with medium vegetation (brown color)
- NDVI: 0.4–0.6 – Areas with high vegetation (green color)

The vegetation index was closely related to relief, soil type and anthropogenic impacts. NDVI values are minimal in volcanic cones and areas near the crater.[7]

Table 1. Comparison of ecogeographic parameters on landscape complexes

Landscape complex	**Soil Type**	**NDVI (average)**	**Antropogenic impact**	**Plant species**
Salinized semi-desert	Saline	0.1	Medium	*Atriplex fomini Iljin, Salicornia europaea* L*., Suaeda confusa Iljin*
Vegetless mud zone	Mud	0.0	Low	-
Steppe meadows	Steppe	0.3	High	*Artemisia*
Dry shrublands	Saline	0.2	Medium	*Lactuca tatarica* C.A.M*., Salsola nodulosa, Artemisia*

Conclusion:

The ecogeographical analysis of vegetation in the Mud Volcanoes State Nature Reserve revealed that plant cover is highly dependent on local soil salinity, moisture availability, and anthropogenic pressure. Vegetation is sparse or absent in active mud zones, while halophytic and drought-resistant species dominate saline and steppe landscapes. NDVI data proved valuable in detecting vegetation density and ecological stress levels. The study highlights the importance of integrating satellite data and GIS tools for monitoring, preserving, and managing the unique vegetation structure of mud volcano ecosystems.

References:

[1] Aliyev A., Guliyev I., Dadashov F., Rahmanov R. Atlas of the world mud volcanoes. Baku, 2015, 322 p.

[2] Aliyev A.A., Guliyev I.S., Feyzullayev A.A. What do we know about mud volcanoes? Baku, 2012. 206 p.

[3] Akhmedov, A.G. Mud volcanoes and the environment /Baku-Azerbaijan SSR, - 1985. - 50 p.

[4] Chiarucci, A., Calderisi, M., Casini, F. & Bonini, I. 2008. Vegetation at the limits for vegetation: vascular plants, bryophytes and lichens in a geothermal field. Folia Geobotanica 43: 19–33.

[5] Dimitrov, L.I. 2002. Mud volcanoes – the most important pathway for degassing deeply buried sediments. Earth-Science eviews 59: 49–76.

[6] Kopf, A.J. 2002. Significance of mud volcanism. Reviews of Geophysics 40: 1–52.

[7] Isayeva Sh.G. - Flora, vegetation and palynology of some species of mud volcanoes of the Shamakhi-

Gobustan region. Baku, 2024
[8] Geography of the Republic of Azerbaijan. volume I. Physical geography. Baku, 2014. 530 p.
[9] Gurbanov E.M. Vegetation of Azerbaijan. Monograph. Baku, 2024, – 536 p.
[10] Rahmanov. R.R. Mud volcanoes in Azerbaijan. Baku, 1960. 42 p.
[11] Yusifov E., Isayeva N., Askerov F. Biological diversity: Natural monuments of the Absheron Peninsula. Baku, 2007, 448 p.
[12] https://apps.sentinel-hub.com/eo-browser/