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Comparative analysis of the ecological assessment of soils in localized areas of the southeastern greater Caucasus and Northeastern Lesser Caucasus

Elshad Arshad Oglu Mammadov, Irshad Mehrali Oglu Abbasov*, Cesaret Aliheydar Oglu Shabanov, Lamiya Shakhali Gizi Khalilova, Immi Mahir Gizi Aliyeva

Department of Environmental Protection, Azerbaijan Technological University, Gandja, Azerbaijan

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Abstract

This article presents a comparative study of the ecological condition of soils in the northeastern parts of the Greater and Lesser Caucasus. The methodology used includes the analysis of changes in soil and vegetation cover through biophysical parameters, Geographic Information Systems (GIS), and the Normalized Difference Vegetation Index (NDVI). The study also evaluates the physical and chemical properties of the soils. Significant transformations in soil and vegetation cover, as well as substantial changes in biophysical parameters and physical and chemical properties, were observed in both regions. These findings provide essential information for the conservation and sustainable management of ecosystems. It is recommended to implement regular monitoring programs to track soil changes, carry out ecological restoration projects for damaged areas, and take appropriate measures to preserve soil properties.

* **Corresponding Author:** Irshad Mehrali ✉ mpanah@mail.ru

Introduction

The Greater and Lesser Caucasus mountain ranges are among the most significant ecological and geographical regions of the Republic of Azerbaijan. These regions are renowned for their rich natural resources, diverse soil types, and biological diversity. The northeastern parts of the Greater and Lesser Caucasus are critical areas for natural resource conservation and ecosystem protection. The ecological conditions of both regions are subject to various impacts due to climate change and human activities.

The aim of this study is to conduct an ecological assessment of the soils in the northeastern parts of the Greater and Lesser Caucasus and to comparatively analyze the health of their ecosystems. The condition of soil ecosystems is closely linked to their productivity, biological diversity, and ecological functions. The physical and chemical properties of soils play a crucial role in evaluating their ecosystem services (Tomlinson, 2013). By carrying out a comparative analysis of various indicators of the soils in the Greater and Lesser Caucasus, this study will provide an in-depth assessment of the ecological status of these regions.

The northeastern part of the Greater Caucasus is characterized by rich mineral resources and diverse soil types. The ecological assessment of soils in this region is essential for enhancing their productivity and ecological sustainability (Khalilov, 2020). The Lesser Caucasus, on the other hand, is known for its extensive forest cover and biological diversity. In this study, the physical, chemical, biological, and biophysical properties of soils in both regions have been compared, and their ecological health has been evaluated.

This research will contribute to a better understanding of the ecological status of soils in the northeastern parts of the Greater and Lesser Caucasus and will provide recommendations for their sustainable use.

Materials and methods

This study is focused on the comparative analysis of the ecological and biophysical parameters of soils in the northeastern parts of the Greater and Lesser Caucasus. The primary object of the research is the physical, chemical, biological, and biophysical properties of soils in these regions.

The study area includes various soil types found in the northeastern parts of the Greater and Lesser Caucasus. The ecological assessment of these soils is based on their fertility, chemical, physical, and biophysical properties, as well as vegetation cover and environmental factors (Smith *et al.*, 2015). The research covers the mountain meadow and mountain-meadow-steppe soils in the summer pastures of the northeastern Greater Caucasus, and the turf mountain-meadow and mountain-meadow-steppe soils in the alpine and subalpine meadow and steppe zones of the northeastern Lesser Caucasus (Aliyev and Huseynov, 2018).

Various methods and approaches were employed to conduct the research. Soil samples were collected from different depths at predetermined coordinates in both regions (Greater and Lesser Caucasus). Standard chemical analysis methods were applied to determine soil pH levels, organic matter content, and the concentrations of major macro and microelements (such as nitrogen, phosphorus, potassium, etc.) (Tomlinson, 2013). The biophysical properties of the soil were studied, and the geographical distribution of natural ecosystems (vegetation cover) and ecological indicators were mapped using GIS technology, satellite imagery, and local data. Geographic Information Systems (GIS) were utilized to analyze soil and landscape changes.

The methodology consists of soil sample collection, laboratory analysis, ecological, and comparative analysis stages. Soil samples were randomly collected from different locations at various depths, such as surface, middle depth, and deeper layers (Mustafayev and Zeynalov, 2020). Laboratory analyses were conducted to determine the chemical and physical properties of the soils. Chemical analyses included pH level, nutrient composition (nitrogen, phosphorus, potassium), and organic matter content. The methods used for evaluating biophysical parameters are crucial for monitoring and managing ecosystems (Mammadov and Abbasov, 2021).

The ecological analysis identifies the relationships between the plant species and density present in the soils and the soil properties. Climatic conditions, such as precipitation, temperature, and humidity, influence the ecological assessment of soils (Smith *et al.*, 2015). The comparative analysis examines the fertility and other ecological characteristics of the soils in the northeastern parts of the Greater and Lesser Caucasus. The data obtained were analyzed using statistical methods, and the differences between the soils were assessed (Mustafayev and Zeynalov, 2020). The NDVI (Normalized Difference Vegetation Index) helps determine the density and health of the vegetation cover. High NDVI values indicate good vegetation cover, while low values indicate poor vegetation cover.

The results were interpreted based on the ecological assessment of the soils, and the differences in fertility parameters among various soil types were discussed. Additionally, recommendations regarding soil management and conservation were provided (Aliyev and Huseynov, 2018; Quliyev and Cavadov, 2015).

Results and Discussion

The ecological assessment of the physical properties of soils in the northeastern parts of the Greater and Lesser Caucasus has revealed that the soils in the Greater Caucasus are primarily rich in clay and silt fractions, which contribute to their high water retention capacity.

However, these soils are also more prone to erosion. In contrast, the soils of the Lesser Caucasus are characterized by a higher sand fraction, which enhances their drainage properties and reduces the risk of erosion (Bünemann *et al.*, 2018).

The ecological assessment of the chemical properties in the study area indicated that the soils in the Greater Caucasus (mountain-meadow and mountain-meadow-steppe soils) have a pH level that is neutral to slightly alkaline in water suspension, while in salt suspension, the pH is closer to slightly acidic. This can make the soil less suitable for the cultivation of certain plants. In the Lesser Caucasus, the soils (turf mountain-meadow soils) have an acidic to slightly acidic pH level, while the mountain-meadow-steppe soils have a pH closer to neutral, creating favorable conditions for a wide variety of plants. This is due to the high concentrations of Ca^{2+} and Mg^{2+} cations. The soils of the Greater Caucasus are rich in organic matter, but the levels of macro and microelements, particularly nitrogen and phosphorus, are low. In the Lesser Caucasus, the levels of these elements are higher (Tomlinson, 2013).

The ecological assessment of the biological properties of the soils in the northeastern parts of the Greater and Lesser Caucasus has shown that the diversity of soil fauna and flora is high in both regions, but it is relatively greater in the Lesser Caucasus. This is attributed to the region's richer forest cover and more favorable climatic conditions. The activity of soil microorganisms is also higher in the Lesser Caucasus, positively influencing the soil's ecosystem functions (Hartmann *et al.*, 2015).

The biophysical parameters of the study area encompass the physical and biological characteristics of the soil that affect the living conditions of organisms. In the Greater Caucasus, the soil biomass and microorganism density are higher. The water retention capacity and microbiological activity of the soil in this region indicate its health and productivity. Meanwhile, in the Lesser Caucasus, the soil structure is more stable, and the biophysical conditions are more consistent, contributing to the long-term sustainability of the ecosystem in the region (Gupta *et al.*, 2016).

The findings indicate that the soils in the northeastern parts of the Greater and Lesser

Caucasus possess distinct ecological characteristics, necessitating different approaches to their evaluation and management.

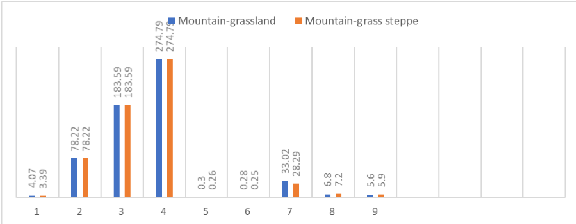
The susceptibility of the Greater Caucasus soils to erosion underscores the need to strengthen soil conservation measures in this region. Such measures should include increasing vegetation cover to combat erosion and enhancing soil structure stability. In the Lesser Caucasus, efforts should focus on improving drainage properties and increasing water retention capacity (Bünemann *et al.*, 2018). To reduce soil acidity in the Greater Caucasus, liming measures should be implemented.

Fertilization strategies should also be employed to increase the organic matter content and ensure the availability of macroelements like nitrogen and phosphorus. In the Lesser Caucasus, the use of organic fertilizers and measures to preserve soil fertility are essential for maintaining productivity (Tomlinson, 2013).

To conserve and enhance soil biodiversity, it is crucial to implement measures that protect and restore natural vegetation in both regions. In the Greater Caucasus, the addition of organic matter and the use of microbiological fertilizers should be encouraged to boost microbial activity. In the Lesser Caucasus, the protection of forest cover and the implementation of sustainable forest management strategies are vital for maintaining high levels of biodiversity (Tomlinson, 2013).

The analysis of biophysical parameters shows that the soils in the Greater Caucasus have higher microbiological activity and biomass, which enhances soil ecosystem functions and productivity. The soils in the Lesser Caucasus, on the other hand, exhibit greater stability, supporting long-term ecosystem sustainability. To preserve and enhance these biophysical parameters in both regions, the use of organic matter and the application of sustainable soil management strategies are recommended (Tomlinson, 2013).

Based on the analysis of the data in Fig. 1, a detailed comparison of the physical, chemical, biological, and biophysical characteristics of mountain meadow and mountain meadow-steppe soils is provided, offering comprehensive information about the overall quality of the soils.



1–Amount of Humus, 2–Humus Content, 0-20 cm (t/ha), 3–Humus Content, 0-50 cm (t/ha), 4–Humus Content, 0-100 cm (t/ha), 5–Total Nitrogen (%), 6–Total Phosphorus (%) 7–Cation Exchange Capacity (CEC, meq/100g soil), 8–pH (in water suspension), 9–pH (in salt suspension)

Fig. 1. Characteristics of the fertility parameters of summer pasture soils in the northeastern part of the greater Caucasus

Mountain meadow soils have higher levels of humus (4.07% in mountain meadow soils, compared to 3.39% in mountain meadow-steppe soils). The humus reserves are 78.22 t/ha at a depth of 0-20 cm, 183.59 t/ha at 0-50 cm, and 274.79 t/ha at 0-100 cm.

Mountain meadow soils have a total nitrogen content of 0.3%, while mountain meadow-steppe soils have 0.26%. The total phosphorus content is 0.28% in mountain meadow soils and 0.25% in mountain meadow-steppe soils.

Mountain meadow soils have a higher Cation Exchange Capacity (CEC) compared to mountain meadow-steppe soils, with values of 33.02 for mountain meadow soils and 28.29 for mountain meadow-steppe soils. However, the pH values are higher in mountain meadow-steppe soils, with a pH of 7.2 in water suspension and 5.9 in salt suspension.

Mountain meadow soils exhibit high results across various parameters, indicating their superiority in terms of overall productivity and ecosystem functions.

In the northeastern slopes of the Small Caucasus, grassy mountain-meadow and mountain-meadow-steppe soils are characteristic of the alpine and subalpine meadow and steppe zones. Grassy mountain-meadow soils form in areas above 1900 meters above sea level. These soils develop under alpine and partially subalpine meadows. The average annual temperature ranges between 5-6°C, and precipitation amounts to 1200-1500 mm.

The soil profile does not exceed 70 cm in thickness and is typically 30-50 cm thick. The surface layer consists of a soft turf layer 5-7 cm thick, while plant roots are located at a depth of 10-30 cm.

In the upper layer of the soil profile, the humus content ranges from 7-8% and decreases sharply with depth. The humus is rich in fulvic acids (42-48%) and relatively low in humic acids (25-27%). The total nitrogen content varies between 0.5-0.7%. The soil reaction is acidic to slightly acidic (pH 4.8-5.7). The turf soils have high water retention capacity and are classified as medium to light clayey. The proportion of clay particles ranges from 45-55%, while silt particles make up 20-25% (Fig. 2).

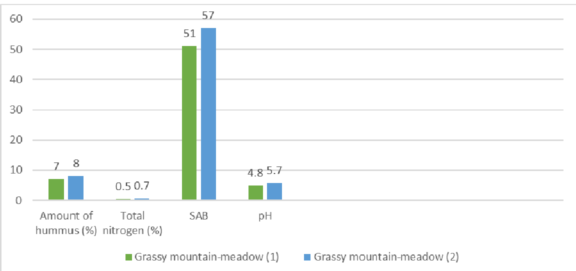


Fig. 2. Characteristics of fertility parameters of grassland soil in the northeastern part of the lesser Caucasus

Alpine meadow-brown soils are found at elevations of 1900-2100 meters and develop in subalpine meadow-brown areas. These soils are characterized by a more moderate climate compared to the alpine zone, with an average annual temperature ranging from 8.5 to 11.1°C and precipitation between 900 and 1100 mm.

The soil profile is relatively thick, and the thickness of the grass layer is 11-14 cm. Plant roots extend to a depth of 30-40 cm. The amount of humus varies between 6.7-7.6% and gradually decreases with depth. The total nitrogen content ranges from 0.25-0.45%. The soil solution reaction is neutral (pH 6.8-7.2). Mountain meadow-steppe soils have high water retention capacity (35-81 mg-eq) and are rich in Ca^{2+} and Mg^{2+} cations. According to its granulometric composition, these soils are mainly clayey and moderately clayey (Fig. 3).

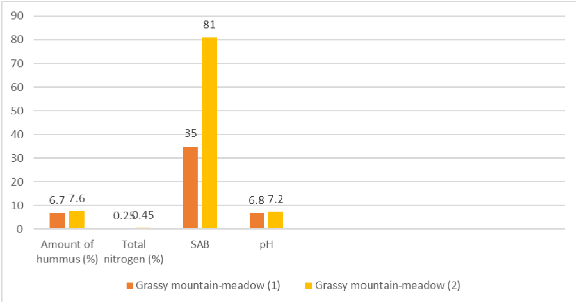


Fig. 3. Characteristics of fertility parameters of mountain meadow-steppe soils in the northeastern part of the lesser Caucasus

These morphogenetic characteristics demonstrate how mountain meadow soils are superior in terms of ecosystem functions and productivity.

For the purpose of conducting an ecological assessment in the northeastern part of the Lesser Caucasus, biophysical properties were investigated in soil and plant samples taken from the Ganja area. The analysis of soil samples from the Ganja region, showing the concentration of various elements, provided information about the ecosystem functions and productivity of the area (Fig. 4).

The concentration of titanium in soil samples is higher compared to plants. Titanium is absorbed by plants in a certain amount (3121 µg/kg), but it accumulates more in the soil (3598.7 µg/kg). Although the concentration of vanadium in soil samples is relatively higher (20.3 µg/kg) than in plants, it shows limited transfer to plants (18.2 µg/kg).

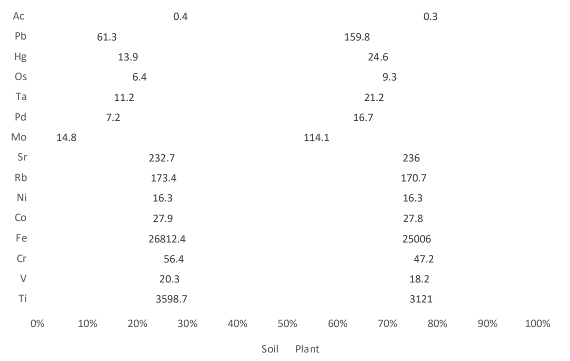
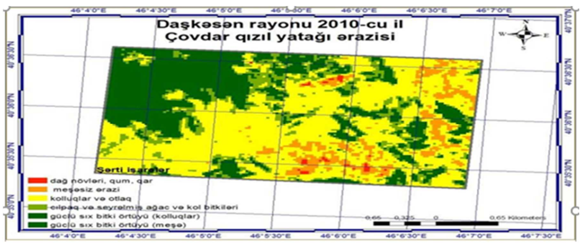


Fig. 4. Analysis of biophysical properties in soil and plant samples from the Ganja area (µg/kg)

The concentration of chromium in soil samples (56.4 µg/kg) is higher than in plants, indicating that the transfer of chromium from soil to plants is somewhat limited (18.2 µg/kg). The concentration of iron is very high in both soil (26812.4 µg/kg) and plant samples (25006 µg/kg), although it is slightly higher in soil samples. Iron is a vital element for plants and shows good transfer from soil to plants. The concentrations of cobalt in soil (27.9 µg/kg) and plant (27.8 µg/kg) samples are nearly identical, indicating that cobalt transfers easily from soil to plants. Nickel concentrations are the same in both soil and plant samples (16.3 µg/kg), showing that nickel has a very good transfer from soil to plants. The concentrations of rubidium in soil (173.4 µg/kg) and plant (170.7 µg/kg) samples are very close, indicating that rubidium transfers easily from soil to plants. Strontium concentration is slightly higher in plants (236 µg/kg) than in soil (232.7 µg/kg), suggesting good absorption of strontium by plants. Molybdenum concentration is much higher in plants (114.1 µg/kg) compared to soil (14.8 µg/kg), indicating that molybdenum is very well absorbed by plants. Palladium concentration is higher in plants (16.7 µg/kg) than in soil (7.2 µg/kg), showing good absorption of palladium by plants. The concentration of tantalum is higher in plants (21.2 µg/kg) than in soil (11.2 µg/kg), indicating good absorption of tantalum by plants. Osmium concentration is higher in plants (9.3 µg/kg) compared to soil (6.4 µg/kg), showing that osmium is well absorbed by plants. Mercury concentration is higher in plants (24.6 µg/kg) than in soil (13.9 µg/kg), indicating that mercury is well absorbed by plants. Lead concentration is significantly higher in plants (159.8 µg/kg) compared to soil (61.3 µg/kg), suggesting that lead is very well absorbed by plants. The concentration of actinium is slightly higher in soil (0.4 µg/kg) compared to plants (0.3 µg/kg), indicating that actinium is less absorbed by plants.

To assess the transformation of soils and the impact of the mountain mining industry in the northeastern part of the Lesser Caucasus, a study was conducted using GIS technologies and the NDVI index for the Čovdar gold deposit. This approach ensures a precise evaluation of soil and landscape changes.



Shape	Class name	Class	Area (ha)	Percentage
Polygon	-0.1 to 0.1	mountain types, sand, snow	4.428	0.5
Polygon	0.1 to 0.2	unforested area	70.154	7.7
Polygon	0.2 to 0.4	shrubs and pasture	433.279	47.8
Polygon	0.4 to 0.5	bare and thinned trees and shrubs	124.92	13.8
Polygon	0.5 to 0.67	dense vegetation (shrubs)	270.319	29.8
Polygon	0.67 to 0.72028	dense vegetation (forest)	2.537	0.3

Fig. 5. Dashkasan region 2010 Chovdar gold field area

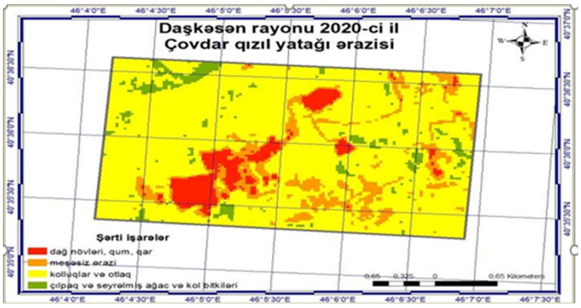
The main goal of the ecological assessment is to examine how natural and technogenic landscapes have changed due to the expansion of mountain mining activities at the Čovdar gold deposit. For this purpose, changes occurring between 2010 and 2020 have been analyzed.

As shown in Fig. 6, the data for the Čovdar gold deposit for 2020 are as follows:

1. Polygon 0 – Rock outcrops, sand deposits, glaciers, and permanent snow cover account for 58.74 ha (6.49%) of the area. These regions are primarily composed of abiotic components and represent the mostly undisturbed parts of the landscape.
2. Polygon 1 – Treeless areas cover 110.6 ha (12.21%), representing open land without forest cover. Mining activities affect these areas.
3. Polygon 2 – Shrublands and grazing areas cover 691.29 ha (76.33%), making it the largest land

classification. These areas are rich in vegetation and represent the regions most impacted by mining activities.

4. Polygon 3 – Forested and sparse tree and shrub areas cover 45 ha (4.97%), consisting of areas covered mainly with natural vegetation.



Shape	Class name	Class	Area (ha)	Percentage
Polygon	-0.074852 to 0.1	mountain types, sand, snow	58.74	6.49
Polygon	0.1 to 0.2	unforested area	110.61	12.21
Polygon	0.2 to 0.4	shrubs and pasture	691.29	76.33
Polygon	0.4 to 0.5	bare and thinned trees and shrubs	45	4.97

Fig. 6. Dashkasan region 2020 Chovdar gold field area

Fig. 5 and 6 reveal that several changes have occurred over the past decade (2010-2020). As a direct result of the mining industry's impact, there has been a 25% increase in areas due to the areas. Conversely, other classes have shown a decrease.

Opening of deposits and the establishment of quarries, this has led to changes in the landscape and a reduction in vegetation cover.

According to Fig. 6, there is a visible increase in shrublands and grazing areas over the years. When comparing 2010 and 2020, there has been a significant rise in mountainous areas, sand (mining deposits), treeless areas, and shrublands and grazing areas. Conversely, other classes have shown a decrease.

These findings provide valuable insights into landscape transformations and can aid in implementing more sustainable development strategies in the future. Studies using GIS and the NDVI index, like this one, can contribute significantly to environmental conservation and management.

Conclusion

1. Mountain-meadow soils generally exhibit higher physical, chemical, and biological indicators, suggesting they are more productive and better at fulfilling ecosystem functions. On the other hand, mountain-meadow-steppe soils show superiority in some biological parameters, indicating they may excel under certain conditions.
2. Different strategies and measures are required to improve the ecological and biophysical conditions of soils in both regions and to ensure sustainable development. The results of this study provide crucial information for the conservation and sustainable use of the ecosystems in the Greater and Lesser Caucasus.
3. Analysis of soil and plant samples from the Ganja region reveals notable differences in the concentrations of certain elements. Specifically, elements such as molybdenum, palladium, tantalum, osmium, mercury, and lead are present in higher concentrations in plants than in soil, indicating good uptake by plants and potential impacts on the ecosystem. Elements like iron and nickel are found in high amounts both in soil and plants, emphasizing their significant biological functions.
4. The analysis of soil and plant samples from Ganja highlights those elements such as titanium, vanadium, chromium, mercury, and lead show pollution potential, especially given their high accumulation in plants. This is important for assessing their impact on the ecosystem. Other elements do not show signs of pollution and participate in the soil-biotic cycle in a balanced manner.
5. The expansion of mining activities at the Çovdar gold deposit has led to drastic changes in natural landscapes and vegetation cover. These changes have resulted in the disruption of ecosystem functions and a decrease in local biodiversity.
6. The rapid development of the deposit from 2010 to 2020 raises significant concerns regarding its long-term effects on ecosystem services and the environment.

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