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Ecological-Geochemical Zoning of the Southern Slope of the Greater Caucasus

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Abstract

This study investigates the ecological and geochemical characteristics of the southern slope of the Greater Caucasus and implements a regional zoning of the area. Ecological zoning has been carried out based on parameters such as soil types, vegetation cover, and climatic conditions. Geochemical zoning, in turn, has been conducted by analyzing the chemical composition of soils, the distribution of mineral resources, and the influence of geochemical processes. The results of the zoning provide critical insights into the sustainable use and conservation of natural resources across various landscape units within the region. The primary objective of the study is to enhance the understanding of the region's ecological systems and to evaluate the impact of geochemical processes on these ecosystems. The findings may serve as a valuable basis for sustainable development strategies and effective natural resource management in the region.

Keywords: Ecological zoning,geochemical zoning, soil types,vegetation cover,mineral resources, ecosystem, landscape, geochemical characteristics, anthropogenic impacts.

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İntroduction

Azerbaijan's natural and geographical conditions are remarkably diverse and rich. This diversity has led to the formation of distinct ecological and geochemical characteristics across different regions of the country. In particular, the southern slope of the Greater Caucasus mountain range holds special significance due to its abundance of natural resources, complex topography, variable climatic conditions, and the intensity of anthropogenic impacts. This area possesses strategic importance both in terms of preserving natural landscapes and ensuring effective environmental management.

In recent years, the protection of the environment, the sustainable use of natural resources, and the provision of a healthy living environment for the population have become central concerns of the scientific community. In this context, ecological-geochemical zoning — that is, the division of an area into various functional zones based on its chemical composition and ecological status — serves as an

essential tool for the comprehensive assessment and planning of the environment. Geochemical research conducted on the southern slope of the Greater Caucasus allows for the identification of the spatial distribution of major elements in soil, water, and vegetation, the intensity of anthropogenic pressures, and potential ecological risks. These data support informed decision-making processes for both local communities and governmental authorities [1,2].

The aim of this article is to investigate the ecological and geochemical characteristics of the southern slope of the Greater Caucasus, to identify the major ecological-geochemical zones in the region, and to systematize the natural and anthropogenic features of these zones. The research findings may provide a scientific basis for environmental protection, the efficient use of soil and water resources, and the sustainable development of the region.

General Geographical and ecological characteristics of the southern slope of the Greater Caucasus

The southern slope of the Greater Caucasus is located in the northern part of Azerbaijan and encompasses the administrative districts of Qusar, Quba, Khachmaz, Shabran, Ismayilli, Gabala, Oguz, Sheki, and Zagatala. This area is characterized by a complex orographic structure, consisting mainly of high-mountain, mid-mountain, and low-mountain zones. The diversity of the relief contributes to the richness of the region's climate, soil types, and vegetation cover.

The climate of the southern slope is generally mild and humid, transitioning to a cold mountainous climate with increasing elevation. Annual precipitation ranges from 600 to 1200 mm, with higher values recorded in regions such as Gabala, Sheki, and Oguz. The climatic diversity creates favorable conditions for the development of both forest ecosystems and agricultural landscapes. The region features a wide variety of soil types, including brown mountain-forest soils, mountain-meadow soils, and mountain-steppe soils. The composition of these soils varies depending on relief, climate, and vegetation cover. At the same time, the geochemical composition of the soils is influenced not only by natural processes but also by anthropogenic activities.

Vegetation cover on the southern slope is remarkably rich. A significant portion of the area is forested, comprising species such as walnut (Juglans), hornbeam (Carpinus), oak (Quercus), ash (Fraxinus), and elm (Ulmus). Above 1500 meters, subalpine and alpine meadows are observed. Vegetation plays a crucial role in enriching soils with humus and preventing erosion processes. In recent decades, several factors impacting the environment have been observed in the region. Deforestation, mineral extraction, the expansion of transport infrastructure, and intensive agricultural practices have disrupted the ecological balance. These activities alter the composition of soil and water resources and contribute to changes in geochemical processes across the area.

Geochemical characteristics and distribution of major elements

The geochemical composition of the southern slope of the Greater Caucasus is one of the key factors determining the region's ecological status and the availability of natural resources. Geochemical analyses of the soil, water resources, and vegetation in this area reveal the chemical composition and spatial distribution patterns of various elements. The development of geochemical maps and the spatial distribution of these elements across the region are of particular importance for evaluating the current state of the environment [3.4].

One of the main reasons for the geochemical variability in the southern slope is the region's complex geological structure. This area is well-known for its rich mineral resources. Elevated

concentrations of iron (Fe), copper (Cu), zinc (Zn), lead (Pb), and other heavy metals are particularly evident in areas where mining activities are more intensive. These elements may have adverse effects on ecosystems and, in some cases, can lead to biological toxicity.

Iron (Fe): Iron is one of the most widespread elements in the region, typically found in high concentrations in soils. While iron is an essential micronutrient for plant growth, excessive amounts in the environment can disrupt ecosystem balance.

Copper (Cu) and Zinc (Zn): These elements are particularly prevalent in agricultural areas, appearing in both soils and water resources. Elevated levels of copper and zinc can negatively affect plant development, especially in areas connected to the food chain, where bioaccumulation poses ecological risks.

Lead (Pb): Lead is primarily introduced into the environment through anthropogenic activities. Mining operations, industrial processes, and the expansion of transportation infrastructure contribute to the accumulation of lead in the region. When deposited in soil and water, lead can have long-term detrimental effects on the environment, posing serious ecological threats.

Anthropogenic activities, particularly mining and industrialization, have led to an increase in the concentration of these elements in the environment. Such activities also accelerate soil erosion, contributing to the degradation of water and air quality. In certain parts of the region, the infiltration of industrial waste into soils has resulted in the accumulation of heavy metals in water bodies, subsequently harming ecosystem health [5].

In addition to heavy metals, the presence of essential macroelements such as calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) in soils plays a significant role in determining soil fertility and vegetation development. The concentrations of these elements directly affect soil pH levels, thereby influencing soil acidity or alkalinity.

Geochemical characteristics not only define the chemical composition of soils but also influence the development of vegetation and animal life. The excessive accumulation of heavy metals and other toxic substances can lead to a reduction in biodiversity and negatively affect the life cycles of aquatic organisms in local water bodies.

Principles of ecological -geochemical zoning

Eco-geochemical zoning is a methodological approach that assesses the influence of ecological and geochemical characteristics on the local environment. By evaluating the chemical composition and ecological status of a given area, this approach enables the identification of optimal strategies for land use and environmental protection [7]. The zoning process is also a crucial tool for ensuring ecosystem sustainability and the efficient utilization of natural resources.

The methods of eco-geochemical zoning consist of several stages:

1. Data Collection: Information is gathered about soil samples, water analyses, vegetation, and climate conditions in the region. This data helps to identify the accumulation and distribution of each element or component across the area.

2. Data Analysis: The collected data is analyzed using statistical and geochemical models. In this stage, the concentrations of elements and chemical components and their impacts on the ecosystem

are examined.

3. Zoning: Based on the analyzed data, the area is divided into various eco-geochemical zones. Each zone has its specific ecological and chemical characteristics. These divisions allow for the identification of potential risks and development areas in the region.

4. Assessment of Conditions: To evaluate the impact of each zone on the environment, the natural conditions (such as relief, climate, soil types, etc.) and anthropogenic influences are considered.

Several key criteria are taken into account during the zoning process:

Ecological Characteristics: The various ecosystem types, biodiversity, and land use patterns in the region are key criteria.

Geochemical Characteristics: The chemical composition of soil and water, the concentration of heavy metals, and the impact of these elements on the ecosystem.

Anthropogenic Impacts: Industrial activities, the expansion of transportation infrastructure, agricultural activities, and other human influences.

Table 1 presents the geographic area of the study and the environmental factors considered in the research.

Table 1. Research data of the area

Geographical area	**Altitude (m)**	**Temperature (℃)**	**Amount of precipitation (mm)**	**Vegatation cover**
Eastern region	1500-2000	12-18	500-700	Forest and meadow
Western region	2000-2500	10-16	400-600	Mountainous and rocky
Central region	1800-2300	14-20	600-800	Mixed forests

The information obtained through zoning plays a critical role not only in the preservation of the natural environment but also in the sustainable utilization of natural resources and the safeguarding of environmental health. This data holds strategic significance for both local governing bodies and state institutions involved in environmental decision-making.

Moreover, zoning serves as a foundational basis for land-use planning, the implementation of environmental protection measures, and the conservation of ecological integrity. By accounting for the diverse ecological and geochemical characteristics of the area, the negative impacts of human activities on the environment can be minimized in these regions.

Main ecological-geochemical zones of the region

The ecological-geochemical characteristics and natural resources of the southern slope of the Greater Caucasus are highly varied. As a result, the area can be delineated into several principal eco-geochemical zones. Each zone is distinguished by its unique climatic conditions, soil composition, vegetation, and geochemical features, all of which shape the ecological development and resource

utilization within these regions. The following table outlines these primary zones and their corresponding characteristics:

Table 2. Ecological-Geochemical Zoning of the Southern Slope of the Greater Caucasus

Name of the region	**Ecological characteristics**	**Geochemical characteristics**	**Soil types**	**Vegatation cover**	**Anthropogenic impacts**
Region 1	Mountain climate, harsh winter, mild summer	Rich mineral composition, high pH, And the soil contains a large amount of calcium	Grassland soils	Mountain meadows and alpine plants	Mining, infrastructure development
Region 2	Mid-mountain, heavy precipitation, harsh winter	Chernozem soils, high humidity, rich in magnesium and potassium	Red soils	Forest and alpine meadows	Agriculture and irregation system
Region 3	The influence of northern winds, harsh winters and dry summers	Silicon richness, poor mineral composition	Alluvial soils	Tundra and alpine meadows	Grassland management, utilization of natural resources
Region 4	Subtropical climate, high humidity, hot summers	Phosphorus and potassium richness, high alkalinity reaction of soils	Chernozem soils	High-altitude forests	Deforestation, agricultural activity

1. North-Western Regions (Quba, Qusar)

The north-western regions are surrounded by the highest mountains of the Greater Caucasus and possess a highly rich geochemical composition. These regions are particularly notable for the chemical richness of the soils and water. In the Quba and Qusar areas, soils contain high concentrations of iron, copper, zinc, and sulfur. These areas also feature brown mountain-forest soils, which facilitate the development of vegetation. The regions are characterized by high mountain forests, alpine meadows, and subalpine zones. The biodiversity within these ecosystems is very high, although anthropogenic influences (such as mining and deforestation) threaten the sustainability of these ecosystems.

2. Central Regions (Qabala, Oghuz, Ismayıllı)

These regions are located in the central part of the southern slope of the Greater Caucasus and differ significantly in terms of both climate and soil characteristics. The soils in this area are of the

mountain-grassland type, with some regions having high amounts of macroelements such as calcium and magnesium. These soils create favorable conditions for vegetation. However, the high sulfur and nitrogen content of some soils makes them less suitable for agriculture. The central regions are made up of forests and meadows, especially rich in pistachio, oak, and hornbeam trees. These areas are also famous for their many rivers and lakes. Soil erosion and anthropogenic influences are also observed in these regions.

3. South-Eastern Regions (Shaki, Zaqatala, Balaken)

These regions are located in the southeastern part of the Greater Caucasus and have a milder climate. The soils in these areas are distinguished by their rich mineral content and vegetation [6]. In the Zaqatala and Şəki areas, the soils contain high levels of elements such as copper, zinc, and lead. The nutrient-rich nature of these soils makes them suitable for agriculture, although the accumulation of heavy metals affects water resources and soil quality. These areas feature tropical and subtropical vegetation and are home to the country's largest fruit orchards and agricultural areas. However, intensive agricultural and forestry activities pose a threat to the sustainability of ecosystems in these regions.

4.Southern Regions (Lankaran, Astara)

This part of the southern slope of the Greater Caucasus is characterized by a subtropical climate and is rich in tropical vegetation. The soils in the southern regions are primarily brown, humid, and fertile. These areas are suitable for agriculture, particularly for the cultivation of tea, tobacco, and citrus fruits. The chemical composition of the soils, particularly the levels of calcium and sulfur, creates favorable conditions for the richness of the vegetation. These regions are rich in tropical and subtropical vegetation, although anthropogenic influences, which sometimes pose a threat to the ecosystem balance, are also observed in these areas.

Conclusion

The ecological-geochemical zoning of the southern slope of the Greater Caucasus plays a crucial role in evaluating the natural characteristics and anthropogenic impacts of the region. The results of this study help to reveal the state of the ecosystems and the geochemical composition in various areas, as well as providing a scientific basis for environmental protection and the sustainable use of resources. The key findings of the study can be summarized as follows:

1. Geographical and Ecological Richness: The southern slope of the Greater Caucasus exhibits a broad range of geographical and ecological diversity. This area encompasses various ecosystems, including both mountainous and lowland regions. The richness in vegetation cover and soil types ensures the biological diversity of the region.
2. Geochemical Composition Variability: The chemical composition of the soils and water in the region is variable. On the southern slope, the accumulation of heavy metals and other toxic elements is observed, particularly due to industrial activities and mining, which have resulted in high concentrations of these elements.
3. Anthropogenic Impacts: Human activities, particularly deforestation, mining, and the intensification of agriculture, negatively affect the sustainability of the ecosystems in the region. Issues such as soil erosion, water pollution, and the loss of biological diversity are on the rise.

4. Need for Zoning: Given the ecological and geochemical characteristics of the area, it is essential to develop specific protection and development strategies for each region. The zoning process will aid in the efficient management of resources within the different ecosystems and help ensure the sustainability of these ecosystems.

Thus, based on the results of our research, the following recommendations can be made:

1. Environmental Protection and Management: Ecologically clean agricultural practices and sustainable forestry should be prioritized to conserve ecosystems. The ecological impacts of mining and industrial activities should be reduced, and corresponding environmental impact assessments and analyses should be conducted.

2. Establishment of a Geochemical Monitoring System: Continuous monitoring systems should be established to track the ecological and geochemical condition of the region. Timely intervention should be made to address risks related to heavy metals, thereby maintaining the balance of the ecosystems.

3. Conservation of Biological Diversity: Conservation and restoration programs should be tailored to the characteristics of each ecosystem. New areas for conservation and protected zones should be identified to preserve biodiversity.

4. Education and Awareness Raising: Environmental education and awareness programs should be implemented in residential areas, ensuring that the population is well-informed about ecology and geochemical processes.

5. Sustainable Development and Economic Diversification: More sustainable and environmentally friendly methods should be adopted in agriculture and industrial activities in the region. Efforts should be made to diversify the economy within these sectors.

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