

SPATIAL DISTRIBUTION AND DIFFERENTIATION OF NATURAL LANDSCAPES IN THE MOUNTAINOUS AREAS OF THE GREATER CAUCASUS WITHIN AZERBAIJAN

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Summary. This study examines the distribution and differentiation of natural landscapes in the mountainous areas of the Greater Caucasus within Azerbaijan. The analysis integrates landscape, cartographic, comparative-geographical, field and GIS-based approaches with climatic data, satellite imagery and digital elevation models. The results show that altitudinal zonation is the principal regularity of landscape distribution, modified by slope aspect, relief, geological-lithological conditions, moisture regime and west-east climatic gradients. The landscape sequence extends from low-mountain and mountain-steppe complexes through mountain forests, subalpine and alpine meadows to subnival and nival landscapes. Meteorological data confirm pronounced vertical climatic differentiation: mean February temperature reaches -7.9°C at Gyriz, whereas the highest summer value is 26.4°C at Shabran. Landscape-belt boundaries vary between northern and southern slopes and between the humid western and increasingly arid eastern sectors. The study demonstrates that integrating field observations with GIS, satellite imagery and digital elevation models improves the identification of landscape boundaries, particularly in inaccessible high-mountain areas.

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Introduction

The Greater Caucasus is one of the major mountain systems of Eurasia and is characterized by considerable geological, geomorphological and climatic diversity. Within its Azerbaijani sector, substantial variations in elevation, temperature, precipitation, soil and vegetation over relatively short distances produce complex vertical and horizontal landscape differentiation.

Altitudinal zonation is the principal regularity governing mountain landscape distribution. Increasing elevation modifies temperature, moisture, snow cover, soil-forming processes and vegetation, resulting in the successive replacement of natural landscape belts. However, their boundaries are not uniform and vary according to slope aspect, relief, geological substrate and regional climatic conditions (Suleymanov, 2008). The theoretical foundations of mountain landscape studies were established through the concepts of altitudinal zonation and landscape integrity developed by Humboldt, Berg and Solntsev (Humboldt, 1849; Solntsev, 1973). Contemporary landscape research increasingly integrates these principles with GIS, satellite imagery and digital elevation models.

Studies in Azerbaijan have examined the geomorphology, physical geography, landscape structure, soil and vegetation of the Greater Caucasus. Museyibov (1998) analysed the physical-geographical differentiation of Azerbaijan, while subsequent landscape studies contributed to understanding altitudinal belts and their spatial structure. Nevertheless, the degree of investigation remains uneven, particularly in inaccessible high-mountain, subnival and nival areas where field observations and meteorological data are limited.

Remote sensing, GIS and digital elevation models provide opportunities to refine landscape boundaries and examine elevation, slope and aspect in areas where field investigation is difficult. However, satellite

observations cannot fully replace ground-based landscape surveys, making the integration of field and geospatial methods particularly important.

Accordingly, this study aims to identify the principal regularities governing the distribution of natural landscapes in the mountainous areas of the Greater Caucasus within Azerbaijan. Particular attention is given to altitudinal zonation, horizontal differentiation, slope aspect, climatic gradients and the distribution of major landscape belts, as well as to the application of contemporary geospatial methods for improving their assessment.

Materials and methods

The study combines field, comparative-geographical, cartographic, analytical and GIS-based methods to investigate the distribution and differentiation of natural landscapes in the mountainous areas of the Greater Caucasus. Field observations were used to examine relief, soil, vegetation and hydrological conditions across different altitudinal belts, while comparative analysis was applied to identify differences between northern and southern slopes and between western and eastern sectors.

Cartographic materials, satellite imagery and digital elevation models (DEMs) were used to analyse landscape distribution and determine elevation, slope inclination and aspect. GIS enabled the integration of geological, geomorphological, climatic, soil and vegetation data and supported the refinement of landscape boundaries, particularly in high-mountain and less accessible areas. The combined use of geospatial and environmental data provides a more comprehensive basis for landscape assessment (Mammadova et al., 2022; Mammadova et al., 2025).

Monthly mean temperature data from Guba, Altiaghac, Shabran, Khaltan, Gyritz and Gusar stations were analysed to assess climatic differentiation within the study area. The integration of field observations, climatic data and geospatial methods was used to evaluate the effects of altitudinal zonation, horizontal differentiation and slope aspect on landscape distribution.

Results and discussion

The distribution of natural landscapes in the mountainous areas of the Greater Caucasus is controlled by the combined influence of elevation, relief, climate, geological-lithological conditions, slope aspect, soil, vegetation and hydrology. These factors interact spatially, producing pronounced vertical and horizontal differentiation. Relief is particularly important because mountain ranges, valleys, intermontane depressions and slope inclination modify temperature, precipitation, runoff, soil development and vegetation patterns (Museyibov, 1998).

Altitudinal zonation is the principal regularity of landscape distribution. With increasing elevation, declining temperature and changes in moisture conditions lead to the successive replacement of low-mountain and mountain-steppe landscapes by mountain forests, subalpine and alpine meadows, and finally subnival and nival complexes (Museyibov, 1998; Suleymanov, 2008). However, landscape-belt boundaries are not uniform throughout the region and vary according to local relief, slope aspect and climatic conditions.

Slope aspect produces substantial differences in landscape structure. South-facing slopes generally receive greater solar radiation and are therefore warmer and relatively drier, whereas north-facing slopes tend to maintain lower temperatures and higher moisture levels. These contrasts influence soil development, vegetation composition and the elevation of forest and meadow boundaries. Consequently, the same landscape belt may occur at different elevations on opposing slopes.

A pronounced west-east differentiation is also observed. The western sector is generally more humid and supports more extensive forest landscapes, whereas increasing continentality and aridity toward the east favour mountain-steppe and xerophytic complexes. Geological structure further modifies these patterns: lithology and rock resistance influence relief development, soil formation, erosion and landslide processes, while river valleys generate localized intrazonal landscape complexes (Gurbanov, 2015; Museyibov, 1998).

The Azerbaijani sector of the Greater Caucasus therefore contains a complex sequence of low-mountain, mountain-forest, subalpine, alpine, subnival and nival landscapes. High-mountain areas around peaks such as Bazardüzü, Shahdagh and Tufandag are characterized by severe climatic conditions, prolonged snow cover, rocky surfaces and high-mountain meadow complexes, while forest landscapes are concentrated mainly within the middle-mountain belt (Museyibov, 1998). Vegetation distribution also provides an important indicator of landscape differentiation, particularly in forest and high-mountain environments (Yusifov, 2005).

Climate is one of the principal factors governing landscape formation. Temperature and precipitation determine soil-forming processes, vegetation cover, and the hydrological regime. In the Greater Caucasus, climate varies depending on elevation, slope aspect, and the position of mountain ranges relative to prevailing air masses. Temperature decreases with increasing elevation. As temperature decreases, the growing season becomes shorter and the composition of vegetation cover changes. While thermophilic and drought-resistant

plants predominate in low-mountain areas, cold-tolerant alpine and subnival plant communities are distributed in high-mountain areas. The amount and seasonal distribution of atmospheric precipitation also influence the distribution of landscapes. Forest landscapes develop extensively in humid areas, whereas mountain-steppe and xerophytic plant communities predominate in arid areas (Table 1, Figure 1).

Analysis of the monthly mean temperatures at Guba, Altiaghac, Shabran, Khaltan, Gyriz and Gusar stations reveals pronounced seasonal and altitudinal climatic differentiation (Table 1; Figure 1). The lowest mean temperature occurs at Gyriz in February (-7.9°C), followed by Khaltan (-5.4°C), whereas Shabran records a considerably higher February value of -0.2°C . During summer, the highest July temperature is observed at Shabran (26.4°C), while Gyriz remains substantially cooler at 16.0°C . Shabran also exhibits the greatest annual temperature range, 26.6°C , from -0.2°C in February to 26.4°C in July. These differences primarily reflect variations in absolute elevation, relief and local climatic conditions and confirm the importance of vertical climatic differentiation in the formation and distribution of mountain landscapes.

Table 1

Monthly Mean Temperature Values ($^{\circ}\text{C}$) for Districts and Stations Located in the Mountainous Areas of the Greater Caucasus

Region	Jan	Feb	Mart	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Guba	3,1	-1,9	8,2	11,3	16,2	19,8	24,6	24,2	16,8	12,7	9,9	3,4
Altiaghac	1,6	-4,3	6,1	10,5	14,7	16,2	20,9	21,4	14,0	11,4	10,0	1,2
Shabran	4,0	-0,2	7,7	12,0	17,4	21,4	26,4	26,1	19,0	14,6	10,9	5,5
Khaltan	0,2	-5,4	4,9	10,3	14,6	16,3	21,3	22,3	14,0	10,9	7,1	0,0
Gyriz	-1,4	-7,9	2,1	6,2	10,7	10,9	16,0	16,5	9,4	8,3	6,8	-2,2
Gusar	2,5	-2,7	7,4	10,6	15,7	18,3	23,2	22,9	15,6	11,6	8,9	2,2

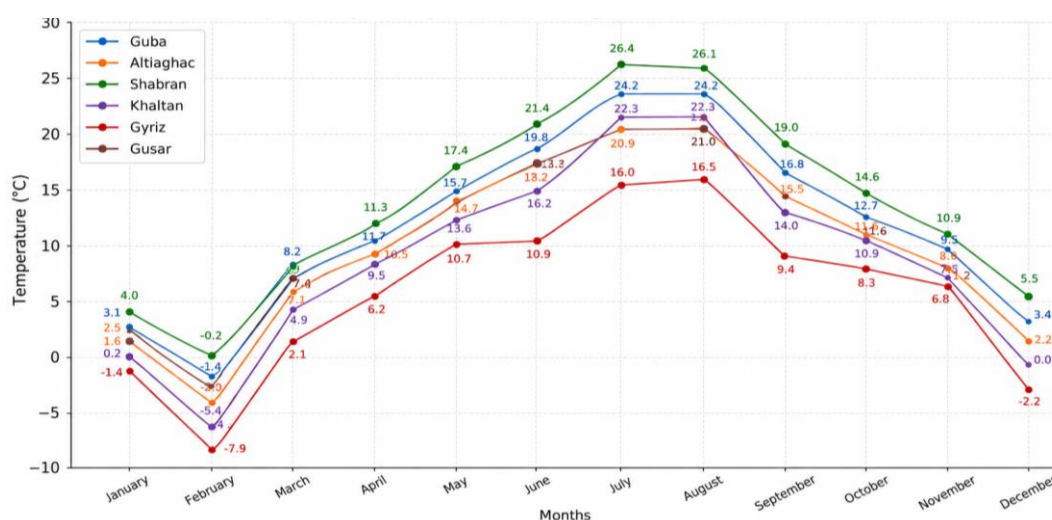


Fig. 1. Monthly average temperature of regions in the Greater Caucasus

Slope aspect plays an important role in the distribution of mountain landscapes. South-facing slopes receive greater solar radiation and are generally characterized by higher temperatures, more intensive evaporation, and lower soil moisture, whereas north-facing slopes are cooler and more humid, with longer-lasting snow cover. These differences influence vegetation distribution and the elevation of the forest boundary, which may extend higher on humid and shaded slopes than on sunny and dry slopes.

Soil and vegetation cover also vary considerably with altitude. Relatively dry soils occur in low-mountain areas, mountain-forest soils predominate in the middle-mountain belt, and mountain-meadow soils are widespread in the subalpine and alpine belts. Vegetation responds sensitively to changes in climatic and soil conditions and therefore serves as an important indicator of landscape differentiation. The forest, subalpine, and alpine landscapes of the Greater Caucasus are characterized by rich flora and numerous endemic species (Yusifov, 2005).

Overall, altitudinal zonation is the principal regularity governing the distribution of natural landscapes in the mountainous areas of the Greater Caucasus. As elevation increases, changes in climatic conditions lead to the successive replacement of soil and vegetation cover and the formation of distinct landscape belts along the altitudinal gradient (Figure 2).

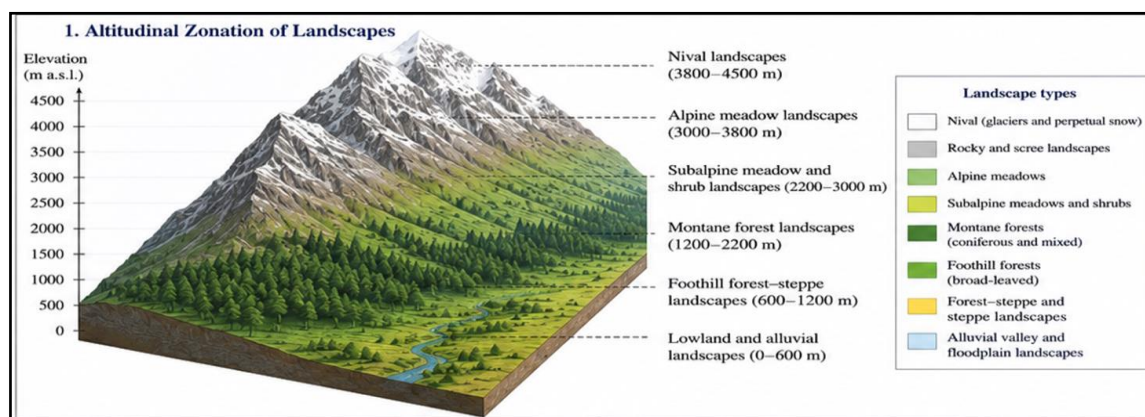


Fig. 2. Natural landscapes of the mountainous areas of the Greater Caucasus region.

As shown in Figure 2, the natural landscapes of the Greater Caucasus exhibit a distinct altitudinal sequence, extending from dry low-mountain and mountain-steppe complexes through mountain forests and sub-alpine and alpine meadows to subnival, nival, and rocky landscapes. The boundaries of these belts vary according to relief, slope aspect, geological conditions, and regional climatic differences.

In addition to altitudinal zonation, pronounced horizontal and sectoral differentiation occurs across the region. The western part is generally more humid and supports more extensive forest and meadow landscapes, whereas increasing continentality and aridity toward the east restrict forest distribution and favor dry mountain-steppe and xerophytic complexes. Slope aspect further modifies this pattern: south-facing slopes are generally warmer and drier because of greater solar radiation, while north-facing slopes are cooler and more humid. Local geomorphological and hydrological conditions, including river valleys, rocky areas, and landslide zones, also contribute to the formation of intrazonal and azonal landscape complexes.

The low-mountain belt encompasses foothill and relatively low-elevation areas characterized by comparatively warm and dry conditions. Mountain-steppe, shrub, and drought-resistant vegetation complexes predominate. In humid areas, forests may begin at lower elevations, whereas in arid sectors mountain-steppe landscapes may extend higher. Relief dissection and local climatic conditions further increase landscape variability within this belt.

The middle-mountain belt represents the principal zone of forest landscapes. Favorable temperature and moisture conditions support oak, hornbeam, beech, maple, and other woody species. Forest composition and belt boundaries vary with elevation, slope aspect, and moisture conditions; forests are generally more extensive on humid slopes, whereas on drier slopes they become more open and may be replaced by mountain-steppe complexes (Museyibov, 1998).

The subalpine belt forms a transition between mountain forests and alpine meadows and is characterized by tall-grass meadows, shrub communities, and diverse herbaceous vegetation. Compared with lower elevations, climatic conditions are cooler and more humid and the growing season is shorter. Its lower and upper boundaries vary according to relief and slope aspect.

The alpine belt is characterized by low-growing meadow vegetation, low temperatures, a short growing season, strong winds, and high solar radiation. Woody vegetation is absent, while numerous endemic and relict plant species adapted to high-mountain conditions increase the biogeographical significance of these landscapes.

The subnival belt occurs between alpine meadows and areas of persistent snow and ice. Severe climatic conditions and a very short growing season result in sparse vegetation concentrated mainly in rock fissures, stony surfaces, and relatively stable soil patches. Its boundaries depend on elevation, slope aspect, and the duration of snow cover.

The nival belt occupies the highest parts of the Greater Caucasus and is dominated by long-lasting snow cover, glacial areas, rocky surfaces, and stony terrain. Soil and vegetation are poorly developed, while physical weathering and freeze-thaw processes are dominant. The distribution of these uppermost high-mountain landscapes is controlled primarily by elevation, high-peak distribution, and climatic conditions (Museyibov, 1998; Suleymanov, 2005, 2008).

Regional differences modify this general altitudinal sequence. The western Greater Caucasus is more humid, with more extensive and continuous forest landscapes and widespread subalpine and alpine meadows.

The central sector is characterized by strongly dissected high-mountain relief, deep river valleys, and extensive alpine, subnival, and nival complexes. Toward the eastern sector, increasing aridity and continentality favor dry mountain-steppe and xerophytic landscapes, while forests become increasingly restricted to humid areas and favorable slopes.

On the northeastern slope, landscape differentiation is additionally influenced by the Caspian Sea, regional atmospheric processes, local orography, and differences among individual river basins. Previous research on the northern slope of the Greater Caucasus similarly demonstrates substantial differentiation of mountain landscapes according to elevation and regional moisture conditions (Bratkov & Ataev, 2013).

The southern slope, in contrast, is strongly affected by the orographic influence of humid air masses and higher solar radiation, producing differences in thermal and moisture conditions and consequently in the elevation of landscape-belt boundaries.

Conclusion

The distribution of natural landscapes in the mountainous areas of the Greater Caucasus is governed primarily by altitudinal zonation, modified by regional climatic conditions, relief, geological-lithological structure, and slope aspect. With increasing elevation, low-mountain and mountain-steppe landscapes are successively replaced by mountain forests, subalpine and alpine meadows, and subnival and nival complexes. However, the boundaries of these landscape belts vary spatially according to local physical-geographical conditions.

Landscape distribution also demonstrates pronounced horizontal and sectoral differentiation. Increasing continentality and decreasing moisture from west to east favor the transition from more humid forest landscapes to dry mountain-steppe and xerophytic complexes. Differences in solar radiation, temperature, and moisture between northern and southern slopes further modify the elevation and spatial extent of individual landscape belts.

The interaction of geological structure, relief, climate, hydrological conditions, soil, and vegetation also contributes to local landscape differentiation, including the formation of intrazonal and azonal complexes in river valleys, rocky areas, and other distinctive landforms. The combined use of field observations, satellite imagery, digital elevation models, and GIS improves the identification and assessment of landscape boundaries, particularly in less accessible high-mountain areas. The development of a unified digital landscape database for the mountainous Greater Caucasus would provide an important basis for further landscape research.

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ПРОСТРАНСТВЕННОЕ РАСПРЕДЕЛЕНИЕ И ДИФФЕРЕНЦИАЦИЯ ПРИРОДНЫХ ЛАНДШАФТОВ ГОРНЫХ ТЕРРИТОРИЙ БОЛЬШОГО КAVKAZA В ПРЕДЕЛАХ АЗЕРБАЙДЖАНА

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Резюме. В исследовании рассматриваются особенности распространения и дифференциации природных ландшафтов горных территорий Большого Кавказа в пределах Азербайджана. Анализ основан на комплексном применении ландшафтоведческого, картографического, сравнительно-географического, полевого и геоинформационного методов с использованием климатических данных, спутниковых снимков и цифровых моделей рельефа. Результаты исследования показывают, что основной закономерностью пространственного распределения ландшафтов является высотная поясность, проявление которой определяется экспозицией склонов, особенностями рельефа, геолого-литологическими условиями, режимом увлажнения и климатическими градиентами в направлении с запада на восток. Высотно-поясная последовательность ландшафтов охватывает низкогорные и горно-степные комплексы, горные леса, субальпийские и альпийские луга, а также субнивные и нивальные ландшафты. Метеорологические данные подтверждают выраженную вертикальную климатическую дифференциацию. Так, средняя температура февраля в Грызе достигает $-7,9^{\circ}\text{C}$, тогда как максимальное значение температуры в летний период отмечается в Шабране и составляет $26,4^{\circ}\text{C}$. Границы ландшафтных поясов различаются на северных и южных склонах, а также между увлажненными западными и постепенно приобретающими более аридный характер восточными секторами исследуемой территории. Установлено, что интеграция полевых наблюдений с геоинформационными технологиями, спутниковыми снимками и цифровыми моделями рельефа способствует более точному определению границ ландшафтов, особенно в труднодоступных высокогорных районах.

Ключевые слова: Большой Кавказ, природные ландшафты, высотная поясность, ландшафтная дифференциация, экспозиция склонов, ГИС, Азербайджан

BÖYÜK QAFQAZIN AZƏRBAYCAN ƏRAZISİNDƏKİ DAĞLIQ SAHƏLƏRİNDƏ TƏBİİ LANDŞAFTLARIN YAYILMASI VƏ DİFERENSİASİYASI

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Xülasə. Tədqiqatda Böyük Qafqazın Azərbaycan ərazisindəki dağlıq sahələrinə təbii landşaftların yayılması və diferensiasiyası araşdırılır. Təhlildə landşaft, kartoqrafik, müqayisəli-coğrafi, çöl və CİS əsaslı yanaşmalar iqlim məlumatları, peyk təsvirləri və rəqəmsal yüksəklik modelləri ilə birləşdirilir. Nəticələr göstərir ki, hündürlük qurşaqlığı landşaftların yayılmasının əsas qanunauyğunluğudur və yamacların baxarlığı, relyef, geoloji-litoloji şərait, rütubət rejimi və qərbdən şərqə doğru iqlim dəyişikliklərinin təsiri ilə fərqli xüsusiyyətlər qazanır. Landşaft ardıcılığı alçaqdağlıq və dağ-çöl komplekslərindən başlayaraq dağ meşələri, subalp və alp çəmənlikləri vasitəsilə subnival və nival landşaftlara qədər uzanır. Meteoroloji məlumatlar şaquli istiqamətdə nəzərəcarpan iqlim diferensiasiyasını təsdiqləyir: Qırıda fevral ayının orta temperaturu $-7,9^{\circ}\text{C}$ -yə çatır, ən yüksək yay göstəricisi isə Şabranda $26,4^{\circ}\text{C}$ təşkil edir. Landşaft qurşaqlarının sərhədləri şimal və cənub yamacları, həmçinin rütubətli qərb və şərqə doğru aridliyi artan sektorlar arasında fərqlənir. Tədqiqat göstərir ki, çöl müşahidələrinin CİS, peyk təsvirləri və rəqəmsal yüksəklik modelləri ilə inteqrasiyası xüsusilə əlçatmaz yüksəkdağlıq sahələrdə landşaft sərhədlərinin müəyyənəşdirilməsini təkmilləşdirir.

Açar sözlər: Böyük Qafqaz, təbii landşaftlar, hündürlük qurşaqlığı, landşaft diferensiasiyası, yamacların baxarlığı, CİS, Azərbaycan