



Characteristics of Vegetation and GIS-Based Terrain Morphometric Analysis in the Beshbarmag State Historical, Cultural and Natural Reserve, Azerbaijan

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Abstract. This study aimed to assess the geobotanical characteristics of the vegetation cover of the Beshbarmag State Historical-Cultural and Nature Reserve and the impact of morphometric indicators of the relief on the spatial distribution of plant groups based on Geographic Information Systems (GIS). During the study, geobotanical field observations were conducted, the main plant groupings were identified, and the cenopopulation characteristics of the species *Pyrus salicifolia* Pall., *Ophrys caucasica* Woronow ex Grossh., which are included in the Red Book of Azerbaijan, were assessed. Based on the digital relief model (DEM), slope and aspect maps were prepared in the ArcGIS Pro program, and the impact of these indicators on the spatial distribution of vegetation was analyzed. As a result of the study, ephemeral, arid sparse forest and petrophyte plant groups were distinguished in the area. It was determined that the northern and northeastern exposed slopes, which constitute the majority of the reserve area, create relatively favorable microclimatic conditions for the preservation of arid sparse forest groups characterized by the dominance of *Pyrus salicifolia*. On the rocky slopes with southern exposure, mainly xerophytic and petrophytic plant groups are widespread. The obtained results indicate that the integration of geobotanical data with GIS-based morphometric analyses is important for explaining the spatial differentiation of vegetation cover, assessing the habitat of rare plant species, and monitoring biodiversity in mountainous protected areas.

Keywords: Beshbarmag State Historical, Cultural and Natural Reserve; vegetation communities; slope; aspect; biodiversity; plant conservation

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1.Introduction

Beshbarmag State Historical-Cultural and Nature Reserve is one of the protected natural areas established by the Decree of the President of the Republic of Azerbaijan dated June 8, 2020 (president.az, 2020). The territory of the reserve encompasses the natural monument of Beshbarmag Mountain, located in the village of Qalashikhi, Siyazan district, and currently operates under the jurisdiction of the Reserves Management Center of the State Tourism Agency of the Republic of Azerbaijan (Heritage.org.az). Beshbarmag Mountain, one of the rare natural monuments of Azerbaijan, is distinguished by its rich biodiversity, complex relief, and important historical and cultural heritage (Heritage.org.az; UNESCO Preslib.az). These features make the protection and scientific study of the area's natural ecosystems particularly relevant.



The formation and spatial distribution of vegetation cover in mountain ecosystems is closely related to the morphometric characteristics of the relief. In particular, the slope and aspect of the slopes are considered important ecological factors that affect the distribution of solar radiation, microclimate conditions, and humidity regime, determining the distribution of various plant groups and rare plant species (Singh, 2018; Yang et al., 2020). Since Mount Beshbarmag is located at the junction of semi-desert and mountain landscapes, it has favorable natural conditions for the formation of plant groups adapted to various ecological conditions. The distribution of rare plant species such as *Pyrus salicifolia* and *Ophrys caucasica*, which are included in the Red Book of Azerbaijan, in the area necessitates a comprehensive assessment of their cenopopulation status and habitat (Red Book of Azerbaijan, 2023). The application of Geographic Information Systems (GIS) creates broad opportunities for analyzing morphometric indicators of relief, assessing the spatial distribution of plant groups, and monitoring biodiversity. Slope and aspect maps prepared based on a digital relief model are of great importance in determining the impact of relief factors on the formation of vegetation cover.

The purpose of this study is to study the geobotanical characteristics of the vegetation cover of the Beshbarmag State Historical-Cultural and Nature Reserve, to assess the main plant groups and the cenopopulation status of rare plant species, and to determine the effect of morphometric indicators of the relief (slope and aspect) on the spatial distribution of plant groups based on Geographic Information Systems.

2. Study Area

Beshbarmag Mountain is located approximately 90–95 km from Baku, on the 95th kilometer of the Baku-Siyazan (Baku-Guba) highway, in the Siyazan district (president.az, 2020). From an orographic point of view, Beshbarmag Mountain is the eastern continuation of the Greater Caucasus Range. The lateral ridge extends approximately 20 km north of the Bashsuayreci ridge, parallel to it in a northwest-southeast direction for a distance of 115 km from the Shahdag massif to Mount Beshbarmag, and ends in the Bosphorus plain near Zarat (Museyibov, 1998). The eastern continuation of the side ridge is formed by the Yerfi, Tekla and Beshbarmag ridges (881–522 m east of Gilgilchay) (Museyibov, 1998). In the approximately 110 km distance from Shahdag to Beshbarmag, the absolute height of the ridge decreases by 3700 m.

One of the important features of Beshbarmag Mountain is its favorable strategic-geographical position. The area is located in the narrowest part of the natural passage along the western coast of the Caspian Sea, which has been considered one of the main factors determining its strategic and defensive importance since ancient times (Hüseynova, 2025). Geologically, the Beshbarmag area is mainly represented by sediments belonging to the Triassic system, and large rock fragments of these sediments are traced in a southeasterly direction to the Beshbarmag rocks (Museyibov, 1998). Structurally and tectonically, the area is related to the Tengi-Beshbarmag anticlinorium, located south of the zone extending from the Samur River valley towards Siyazan (Museyibov, 1998). Exogenous geological processes have played an important role in the formation of the relief. Large avalanche processes are observed on the eastern slopes of the Beshbarmag ridge, and their formation is associated with similar avalanche processes that developed in limestone layers on the northern coast of the Absheron Peninsula (Museyibov, 1998). In addition, traces of transgressions and regressions of the Caspian Sea during the Quaternary period are clearly observed around the city of Siyazan and along the coastline stretching from Beshbarmag to Alat. This feature indicates that Beshbarmag is one of the reference areas in terms of studying the ancient coastlines of the Caspian Sea (Museyibov, 1998).



3. Materials and Methods

Taking into account the significant impact of the geological and orographic features of the study area on the spatial differentiation of vegetation, geobotanical field surveys and morphometric analyses of the relief were conducted based on a comprehensive approach.

3.1. Geobotanical methods

In terms of botanical-geographical zoning, the territory belongs to the "Caspian Lowland" botanical-geographical region (Флора Азербайджана, 1950), and according to the new classification, to the Guba-Shabran botanical-geographical region (İbadullayeva & Əsgərov, 2025).

- Semi-desert ephemeral, ephemeral-grassland groupings — a type widespread at the foot of Mount Beshbarmag and in the lower parts of the slopes;
- Arid sparse woodland — a type that covers slopes and interslope areas located above sea level;
- Petrophyte assemblages — a type characteristic of rocky habitats, bedrock outcrops, and rocky ravines.

A vertical zonal sequence (ephemeral → arid sparse woodland → petrophyte) was observed in the distribution of these three types in the area.

From a methodological point of view, the term "arid sparse forest" is defined based on the following criteria: the above-ground distribution of the tree layer (sparse, isolated arrangement of trees), the presence of drought-resistant tree and shrub species, the presence of open grass-meadow type cover between the trees, development mainly on gravelly and gray-brown soils, and high dependence on the amount of precipitation and temperature regime. When studying the ontogenetic state of rare and protected species (Red Book of Azerbaijan 2023) (*Pyrus salicifolia* Pall., *Ophrys caucasica* Woronow ex Grossh.), the following structural indicators were taken as a basis: ontogenetic (age) state of individuals (p, im, v, g1, g2, g3, ss, s.); distribution pattern of terrestrial mammals (solitary, group, diffuse-group, diffuse-solitary); percentage of projective cover; interindividual distance indicators.

3.2. Methodology for analyzing morphometric characteristics of relief (slope and exposure)

The digital elevation model (DEM) of the study area (Beşbarmaq Mountain, within the boundaries of the "Beşbarmaq Mountain" State Historical-Cultural and Nature Reserve) was prepared based on Shuttle Radar Topography Mission (SRTM) data obtained from the OpenTopography open data platform (Farr et al., 2007; OpenTopography, 2025). All geospatial operations were performed in Esri ArcGIS Pro software, at a scale of 1:15,000 (Esri, 2025).

The slope and aspect of the terrain were calculated from the DEM using the corresponding "Slope" and "Aspect" tools of the Spatial Analyst module of ArcGIS Pro. The result for both indicators was obtained in a continuous raster format, then divided into discrete classes using the Reclassify tool. The slope was divided into seven classes: 1°–5°, 6°–10°, 11°–15°, 16°–20°, 21°–30°, 31°–40°, and 41°–53°.

Aspect is divided into 9 classes corresponding to the 8 traditional compass directions (North, Northeast, East, Southeast, South, Southwest, West, Northwest) (the North category is calculated as 2 separate classes, since it consists of the sum of the intervals 0°–22.5° and 337.5°–360°, and is later combined with the same color in the visual presentation) and an additional "Flat" (flat, unsloped areas, value -1) category (Esri, 2025).

The area (ha) of each class and its ratio to the total area (%) were calculated, and the results were presented only within the reserve area, masked by the official boundary of the reserve. A hillshade relief model, inset map, north axis, and scale bar were used as background during the preparation of the maps.

4. Results

4.1. Geobotanical Research

As a result of the research, ephemeral, arid sparse forest, and petrophyte plant groupings were distinguished in the Beshbarmag State Historical-Cultural and Nature Reserve.

Semi-desert groupings. At the foot of Mount Beshbarmag, wormwood-ephemeral and ephemeral (variegated, cereal-ephemeral) groupings were recorded with the participation of representatives of the families Poaceae Barnhart, Asteraceae Martinov., Brassicaceae Burnett, and Fabaceae Lindl. These groups are mainly spread at the foot of Mount Beshbarmag and on the lower slopes. In spring, the following species of the genus *Veronica amoena* M.Bieb., *Tragopogon graminifolius* DC., *Calendula persica* C.A.Mey, *Adonis aestivalis* L., *Senecio vernalis* Waldst. et Kit., *Bromus japonicus* Thunb., *Capsella bursa-pastoris* (L.)Medik., *Cardaria draba* (L.) Desv. and *Papaver* L. play an important role in the composition of the grass cover.

Petrofit groupings. In rocky areas and rock crevices, *Rosa sanguineus* Friv., *Rhamnus pallasii* Fisch. & C.A.Mey., *Ficus carica* L., *Punica granatum* L., *Jasminum fruticans* and *Sternbergia fischeriana* were recorded singly or in small groups.

Arid sparse woodland (dominated by *Pyrus salicifolia*) clusters. The main tree species of this type was *Pyrus salicifolia* (willow-leaf pear), which is included in the Red Book of Azerbaijan. The tree layer of the grouping was mainly represented by *Pyrus salicifolia*. A xerophyte-mesoxerophyte herbaceous layer consisting of *Ophrys caucasica* Woronow ex Grossh., *Centaurea Iberica* Trev. ex Spreng., *Poa bulbosa* L., *Salvia verticillata* L., and other species was observed to form under the canopy of the trees. When analyzing the age structure of the *Pyrus salicifolia* cenopopulation, a predominance of mature generative individuals (g1–g3) and a slight presence of pregenerative individuals were revealed. The spatial distribution of individuals is diffuse and solitary, with trees located at a distance of approximately 1 m from each other and occupying an area of approximately 1 ha (Fig. 1).

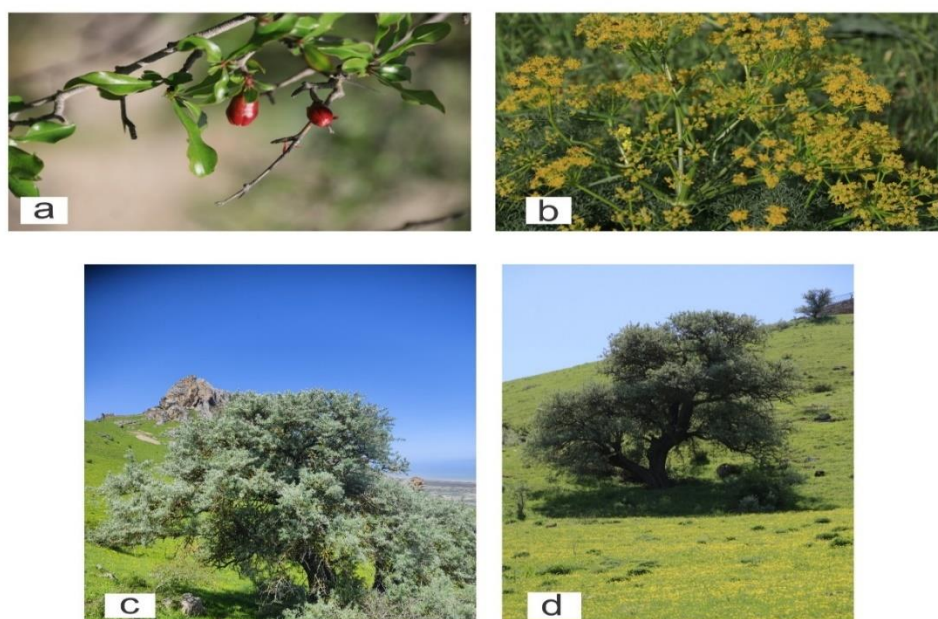


Figure 1. Representative plant species recorded in the Beshbarmag State Historical, Cultural and Natural Reserve: (a) *Punica granatum* L.; (b) *Ferula orientalis* L.; (c–d) *Pyrus salicifolia* Pall.

Ferula orientalis L., listed in the Red Book of Azerbaijan, has been recorded on rocky and gravelly slopes. Considering the limited local distribution of the species only around Beshbarmag and the impact of future global climate change, there is a possibility of a threat of population decline in this area. The species forms associations with cereals, *Centaurea iberica* L., and other species, preferring petrophyte habitats. The most typical settlement pattern is compact groups of 5–10 individuals, forming up to 90% projective cover over an area of about 2 m². However, single specimens located 2–3 m apart have also been recorded.

Another rare protected species, *Ophrys caucasica* Woronow ex Grossh., has been recorded under and around the canopy of *Pyrus salicifolia*. The xenopopulation shows satisfactory natural regeneration with the presence of individuals in different ontogenetic states. Individuals are grouped in small microgroups of 3–4 individuals per 1 m² area; the distance between them varies between 1.5–3 m. In the herbaceous layer, together with *Ophrys caucasica*, representatives of the genera *Plantago ovata* Forssk., *Veronica amoena* M.Bieb., *Salvia verticillata* L., *Ornithogalum ponticum* Zahar., *Anisantha rubens* (L.) Nevsi, *Poa bulbosa* L., *Hordeum leporinum* Link, *Geranium molle* L., and *Ranunculus* L. were recorded.

Thus, ephemeral-wormwood semi-desert, petrophyte, and arid sparse forest groupings have been identified as the main plant communities in the Beshbarmag State Historical-Cultural and Nature Reserve.

4.2. Morphometric relief indicators of the Beshbarmag Mountain area

As a result of GIS analysis, the following quantitative results were obtained on the exposure (Aspect) and slope (Slope) indicators of the Beshbarmag Mountain area: According to the exposure analysis (Fig. 2), the largest share of the area is occupied by slopes facing northeast — 124.4 ha (45.57%).

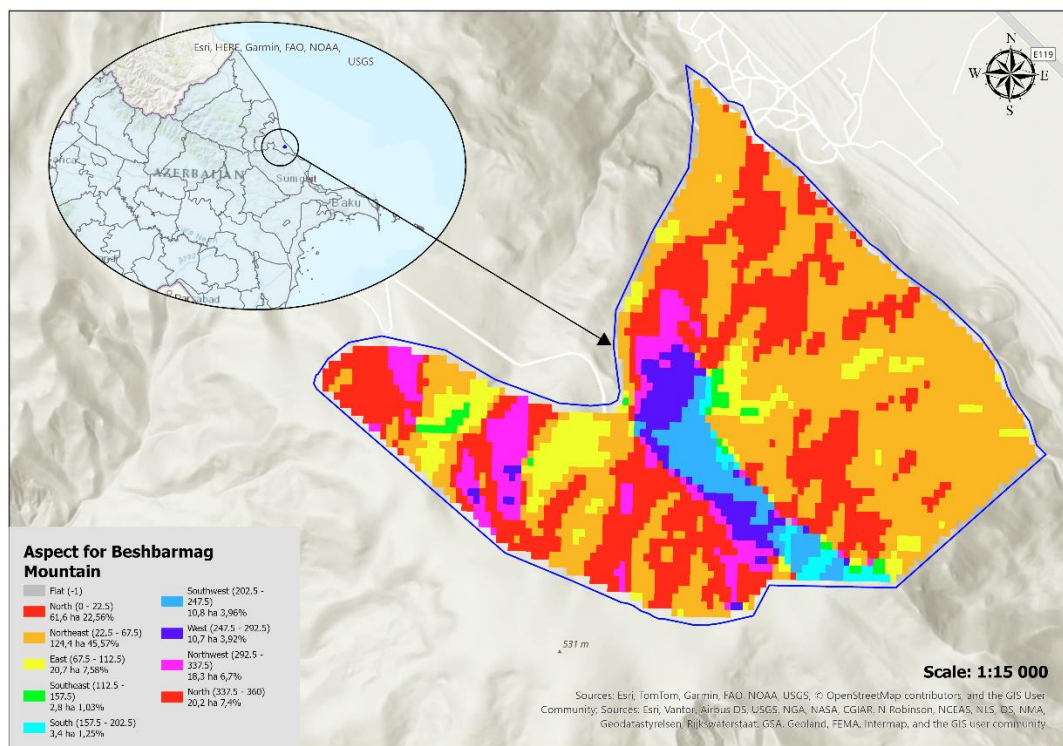


Figure 2. Exposure (Aspect) indicators of the Beshbarmag Mountain area

Areas facing north (sum of intervals 0°–22.5° and 337.5°–360°) occupy the second place with 81.8 ha (29.96%). Eastern exposure covers 20.7 ha (7.58%), western exposure 10.7 ha (3.92%), and north-western exposure 18.3 ha (6.7%). The least common exposures are southeast (2.8 ha, 1.03%) and south (3.4 ha,

1.25%), while southwest exposure accounts for 10.8 ha (3.96%). No flat areas were recorded in the study area.

Analysis of slope indicators (Fig. 3) reveals that the terrain of the area consists mainly of medium-steep slopes.

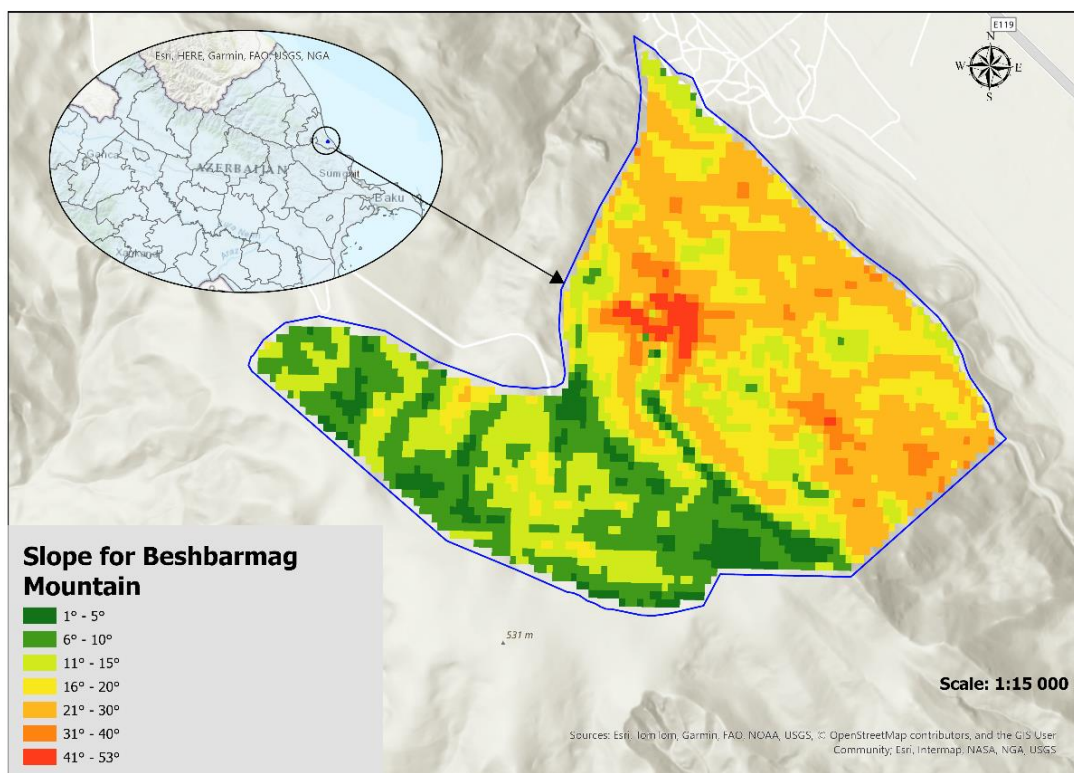


Figure 3. Slope indicators of the Beshbarmag Mountain area

The category with the largest share is the 21–30 slope interval — 77.9 ha (28.6%). This is followed by the 11–15° (57.8 ha, 21.2%), 6–10° (54.2 ha, 19.9%), and 16–20° (52.9 ha, 19.4%). The most gentle slopes (1°–5°) occupy 15.8 ha (5.8%), while the steepest slopes are divided into two categories: the 31°–40° range accounts for 10.3 ha (3.8%), and the 41°–53° range accounts for the smallest share with only 3.8 ha (1.4%). Overall, 67.1% of the area consists of gentle (0°–20°) slopes, and 33.8% consists of steep to very steep (21°–53°) slopes. The areas with the highest slope, although small in quantity (1.4%), are spatially concentrated mainly in the northeastern part of the reserve, around the main rock massif of the mountain.

Thus, as a result of morphometric analysis, it was determined that slopes with northern and northeastern exposure, as well as moderate slopes, predominate in the Beshbarmag State Historical-Cultural and Nature Reserve.

5. Discussion

Geobotanical observations and morphometric analysis of the relief conducted in the Beshbarmag State Historical-Cultural and Nature Reserve have shown that the spatial differentiation of plant groups is mainly closely related to exposure and slope indicators. These results are consistent with modern research showing that relief factors play a crucial role in the formation of vegetation in mountain ecosystems. Various authors



have evaluated slope exposure and inclination as key topographic factors determining the spatial structure, species composition, and biodiversity of plant communities (Singh, 2018; Yang et al., 2020).

Morphometric indicators of relief act as not only indirect but also direct ecological factors in the spatial organization of vegetation. The exposure of the slope changes the distribution of solar radiation, temperature and humidity regime, and the slope affects soil formation processes, surface runoff and water infiltration. As a result of the interaction of these factors, various ecological niches are formed, and spatial differentiation of plant groups occurs, which is consistent with the results obtained in the Beshbarmag area (Singh, 2018; Yang et al., 2020). The dominant groupings in the area are xerophytic plant groups formed on rocky and gravelly slopes, and high insolation and lack of humidity act as important ecological factors in their spread. This feature is especially evident on the southern and southwestern slopes of Mount Beshbarmag. The vegetation period in ephemeral plant groups is closely related to the seasonal humidity regime. Although a high diversity and projective cover of ephemeral species is observed in the spring season, most of them complete their vegetation during the summer months as a result of the decrease in humidity, and *Artemisia fragrans* takes a dominant position in the herbaceous cover.

These phenological changes, characteristic of semi-desert and arid ecosystems, demonstrate that seasonal moisture dynamics have a direct impact on the structure of the vegetation cover. The species recorded in the petrophyte groups demonstrate high ecological specialization, adapted to conditions of hard rock substrate, poor soil development, and water scarcity. These characteristics cause petrophyte groups to form mainly in limited areas on rocky slopes and rock crevices. The predominance of generative individuals and the scarcity of pregenerative individuals in the age structure of the *Pyrus salicifolia* cenopopulation indicate that the natural regeneration process is weak. In addition, the spatial structure of *Pyrus salicifolia* and *Ophrys caucasica* cenopopulations reflects the adaptation strategies of these species to arid conditions. The limited number of pregenerative individuals in the *Pyrus salicifolia* cenopopulation necessitates a more detailed study of natural regeneration processes. Therefore, it is considered appropriate to conduct long-term monitoring to assess possible changes in the age structure of the population.

Exposure analysis has shown that the majority of the reserve area consists of north- and northeast-facing slopes. These exposures create relatively cool and humid microclimate conditions, creating favorable conditions for the preservation of arid sparse forest groups characterized by the dominance of *Pyrus salicifolia*. Conversely, xerophyte and petrophyte plant groups dominate on rocky slopes with southern exposure that receive higher solar radiation.

A similar pattern has been observed in studies conducted in arid mountainous areas. It has been found that while north-facing slopes are characterized by lower temperatures, higher soil moisture, and richer vegetation, high solar radiation and drought conditions on south-facing slopes lead to a predominance of xerophytic plant communities (Yang et al., 2020; Singh, 2018). Slope indicators also play an important role in the spatial differentiation of vegetation. While the relatively developed soil layer on gentle slopes allows for the formation of various herbaceous and arid sparse forest groups, steep and very steep rocky slopes constitute ecotopes where mainly petrophyte plant groups are distributed. These observations are consistent with modern research showing that morphometric indicators of relief affect not only the distribution of vegetation, but also the formation of ecological diversity of habitats (Singh, 2018).

The digital elevation model (DEM) used in the study and the slope and exposure indicators calculated from it created a reliable basis for spatial analysis of geobotanical data. The application of modern GIS technologies allows for highly accurate assessment of the morphometric characteristics of the relief and objective determination of their relationship with the spatial structure of vegetation. This approach is considered one of the widely used methodological directions in the study of mountain ecosystems (Guth et al., 2021).



The research results show that the integration of geobotanical observations with morphometric indicators allows not only to explain the spatial structure of existing plant groups, but also to identify potential habitats of rare species. This feature is of particular practical importance in terms of monitoring biodiversity in protected areas, mapping sensitive ecotopes, and prioritizing conservation measures.

The results obtained show that the integration of geobotanical field studies with GIS-based morphometric analyses is an effective scientific approach for explaining the spatial structure of plant assemblages, assessing the habitat of rare species, and monitoring biodiversity in the reserve area. This approach is also consistent with recent research showing that the integration of morphometric indicators calculated based on digital elevation models (DEMs) with geobotanical data has important methodological advantages in assessing relief-vegetation relationships (Guth et al. 2021).

In this regard, the geobotanical-GIS approach applied in the Beshbarmag State Historical-Cultural and Nature Reserve creates a scientific basis not only for assessing the current state of the area's vegetation, but also for developing future monitoring programs, tracking the dynamics of the habitat of rare species, and adaptive management of reserve areas. The integrated methodological approach applied in the study can also be applied to assess biodiversity and plan conservation measures in other mountainous and semi-arid ecosystems.

6. Conclusion

The conducted research showed that the spatial distribution of plant groups in the Beshbarmag State Historical-Cultural and Nature Reserve is related to the morphometric characteristics of the relief. The application of geobotanical field surveys in conjunction with GIS-based relief analyses has allowed for a more complete assessment of the main plant groups formed in the area, their distribution patterns, and habitat characteristics.

It has been determined that the northern and northeastern-facing slopes that predominate in the reserve create relatively favorable microclimatic conditions, enabling the preservation of arid sparse forest groups characterized by the dominance of *Pyrus salicifolia*. Conversely, on rocky slopes with southern exposure, xerophytic and petrophytic plant groups predominated under conditions of high insolation and lack of moisture. In addition, the conducted cenopopulation assessment allowed us to characterize the current status of the *Pyrus salicifolia* and *Ophrys caucasica* species and form an initial scientific database for their future monitoring. The main advantage of this study is the comprehensive assessment of the spatial differentiation of plant groupings as a result of the integration of geobotanical field observations with morphometric analyses based on a digital relief model (DEM).

Overall, the integration of geobotanical surveys with GIS technologies can be considered a reliable methodological approach for a comprehensive assessment of vegetation and habitat in mountainous protected areas. This approach is of practical importance in terms of biodiversity monitoring, habitat assessment of rare species, and scientific justification of conservation measures. The results obtained create an important scientific basis for protecting biodiversity, organizing ecological monitoring, and making scientifically based management decisions in the Beshbarmag State Historical-Cultural and Nature Reserve.

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