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Geoinformation Analysis of the Geoecological Condition of the Soil Cover in the Borzhava River Basin of the Ukrainian Carpathians under Erosion–Denudation Processes

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SUMMARY

The study presents an integrated GIS-based assessment of the geoecological condition of soils in the Borzhava River basin under the influence of erosion-denudation processes. The analysis combined morphometric characteristics of relief, hydrographic network structure, soil distribution and land-use patterns. Brown mountain-forest soils occupy about 49.1% of the basin and form the main soil background of the mountainous part. High and very high linear dissection covers 55.4% of the basin, while areas with values above 1 km/km² account for 78.6%, indicating a considerable potential for erosion development. The highest local values approach 4 km/km². The most vulnerable areas are associated with steep disturbed slopes, forest roads, pastures and cultivated lands. The obtained results allow priority zones of soil degradation to be identified and provide a basis for erosion-control measures, sustainable land use, slope stabilization and restoration of degraded soils.

Keywords: Soil cover; Soil degradation; GIS analysis; Erosion-denudation processes; Linear erosion; Erosion risk; Sustainable land use, Borzhava River

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Introduction

The Borzhava River basin is located on the southwestern macroslope of the Ukrainian Carpathians and is characterized by a complex geomorphological structure, significant terrain dissection, and active development of erosion–denudation processes. The structural-tectonic and geodynamic features of the area influence the intensity of slope and water-gravitational processes (Ivanik, 2007; Nazarevych et al., 2023), while the modern hydrographic network determines the redistribution of surface runoff and the transport of solid material (Khomyn, 2014; Vovkunovych et al., 2024). The soil cover is one of the most vulnerable components of the Borzhava River basin, and its condition depends on both natural factors and land-use patterns (Peresoliak & Khodanych, 2013; Vovk & Orlov, 2014). Agricultural areas are particularly affected by sheet erosion, linear erosion, thinning of the humus horizon, and deterioration of soil water-physical properties. The long-term development of these processes leads to declining soil fertility, reduced land productivity, and lower stability of agricultural landscapes (Peresoliak & Khodanych, 2013). This highlights the need for systematic monitoring of degraded lands and the development of measures aimed at their conservation and restoration.

GIS and remote sensing data enable a comprehensive assessment of the spatial distribution of erosion-related factors, identification of the most vulnerable areas, and substantiation of soil erosion control measures. The effectiveness of this approach has been demonstrated in studies of mountain river basins in the Ukrainian Carpathians and through the application of RUSLE-type models for estimating soil loss and planning sustainable land use (Bayrak, 2026; Vîrghileanu et al., 2024). Therefore, geoinformation-based assessment of the soil cover condition in the Borzhava River basin provides an important basis for maintaining land productivity and restoring degraded soils.

Method and Theory

The methodological framework of the study is based on an integrated geoinformation analysis of morphometric characteristics of the relief, the structure of the hydrographic network, soil cover, and land-use patterns. The theoretical basis is the assumption that slope morphometry and the degree of terrain dissection play a key role in the formation of surface runoff and the development of erosion–denudation processes. For mountainous areas of the Ukrainian Carpathians, the effectiveness of GIS-based approaches for spatial assessment of erosion hazard has been confirmed by recent studies (Bayrak, 2026; Hnatiuk et al., 2024). Using a digital elevation model in the ArcGIS environment, elevation, slope steepness, and slope aspect were calculated, and corresponding thematic maps were produced. Slope steepness was considered one of the principal morphometric factors controlling the velocity of surface runoff and the potential intensity of soil erosion. Morphometric indicators were spatially compared with soil data obtained through the vectorization of cartographic materials, as well as with information on vegetation cover and land use. This approach made it possible to assess the spatial association of different soil types with areas characterized by varying potential intensity of erosion–denudation processes (Peresoliak & Khodanych, 2013; Vovk & Orlov, 2014).

A separate stage of the study involved the structuring of the hydrographic network of the Borzhava River basin. Using semi-automated ArcGIS tools and the digital topographic base of the Transcarpathian Regional Branch of the State Enterprise “UkrDAGP” at a scale of 1:50,000, permanent and temporary watercourses, canals, oxbow lakes, channelized sections, and other linear hydrographic features were systematized. Seven orders of permanent watercourses were identified within the basin, reflecting the complexity and high degree of development of the river network (Vovkunovych et al., 2024). For the lowland part of the basin, the role of flood and channel processes was additionally considered, as these processes affect sediment redistribution, accumulation, and the transformation of floodplain lands (Melnyk, 2009).

The vectorized hydrographic network was used to assess the linear dissection of the relief. In the ArcGIS environment, the Line Density tool was applied to calculate the total length of the river–gully network within a 2,000 m search radius, normalized per unit area (km/km²). The resulting indicator was used as a quantitative measure of the intensity of linear erosion and the degree of terrain drainage. Classification was performed using the Natural Breaks (Jenks) method, with five classes distinguished: very low (<0.5 km/km²), low (0.5–1.0 km/km²), moderate (1.0–1.5 km/km²), high (1.5–2.5 km/km²), and very high (>2.5 km/km²) relief dissection.

Results

The soil cover of the Borzhava River basin exhibits pronounced altitudinal and landscape differentiation, reflecting the transition from mountainous to foothill and lowland areas. Brown mountain-forest soils occupy the largest area. Their shallow, gravelly varieties cover 567.06 km², or 39.6% of the basin, while together with medium-depth, deep, and podzolized analogues they account for approximately 703 km², or 49.1%. These soils are mainly confined to flysch slopes in the mountainous part of the basin, where shallow soil profiles, high gravel content, and steep slopes contribute to increased erosion susceptibility. At the same time, forest cover significantly reduces the intensity of soil wash and performs an important soil-protective function (Peresoliak & Khodanych, 2013; Vovk & Orlov, 2014). In the foothill and lowland parts of the basin, the dominant soil types are gleyed sod-podzolic soils, which occupy 283.25 km² (19.8 %), brown podzolic soils – 166.32 km² (11.6 %), non-gleyed sod-podzolic soils – 91.77 km² (6.4 %), while meadow-brown gley soils cover 43.22 km² (3.0 %). These areas are characterized by more intensive agricultural use; therefore, in addition to natural erosion hazards, soil compaction, excessive moisture, and degradation of the cultivated topsoil layer are also of considerable importance.

Erosion-denudation processes are the leading factor in the transformation of the soil cover in the mountainous and foothill parts of the basin. They are most actively manifested within the Borzhava, Velykyi Dil, and Velykyi Sholies landscapes in the form of sheet wash, linear erosion, and deep erosion. Gullies and erosional incisions locally reach depths of 1.5–2.0 m, while their development intensifies during summer rainstorms and spring snowmelt. A similar dependence of erosion activity on slope steepness and terrain dissection is characteristic of other river basins in the Ukrainian Carpathians (Bayrak, 2026).

GIS-based quantitative analysis of linear relief dissection revealed a pronounced spatial differentiation of erosion activity within the Borzhava River basin (Fig. 1). Of the total basin area of 1,432.09 km², areas with a high degree of dissection (1.5–2.5 km/km²) occupy 474.30 km² (33.1%), while areas with a very high degree (>2.5 km/km²) cover 319.31 km² (22.3%). Thus, 793.61 km², or 55.4% of the basin, fall within zones of the highest potential erosion hazard. When the moderate class (1.0–1.5 km/km²) is also considered, the share of areas with dissection values exceeding 1 km/km² increases to 78.6% (1,126.06 km²). Local maximum values approaching 4 km/km² are associated with the right-bank slopes between Kushnytsia and Pryborzhavske, the southern slopes of the Velykyi Dil Ridge, and the middle-mountain part of the Bronka River basin. This spatial concentration is consistent with the complex seven-order structure of the Borzhava hydrographic network (Vovkunovych et al., 2024) and with the general patterns of erosion-network development in the Carpathians under the influence of slope steepness, lithology, and anthropogenic disturbance of slopes (Bayrak, 2026).

In the Borzhava River basin, the highest erosion vulnerability of the soil cover is associated with mountainous and foothill areas characterized by high and very high linear relief dissection. These include, in particular, the right-bank slopes between Kushnytsia and Pryborzhavske, the southern slopes of the Velykyi Dil Ridge, and the middle-mountain part of the Bronka River basin, where dissection density exceeds 2.5 km/km² and locally approaches 4 km/km². In these areas, shallow gravelly brown mountain-forest soils occur in combination with steep relief and a dense network of erosional incisions, which intensifies the removal of soil material during summer rainstorms and spring snowmelt. Field observations confirm the development of gullies 1.5–2.0 m deep, which concentrate surface runoff and facilitate the transfer of debris into the channel network. Within clear-cut areas, forest roads, pastures, and cultivated slopes, these processes intensify due to the weakening of the protective role of vegetation cover. Therefore, 793.61 km², or 55.4% of the basin area, characterized by high and very high degrees of relief dissection, should be considered a priority zone for erosion-control land use, slope stabilization, and restoration of degraded soil cover.

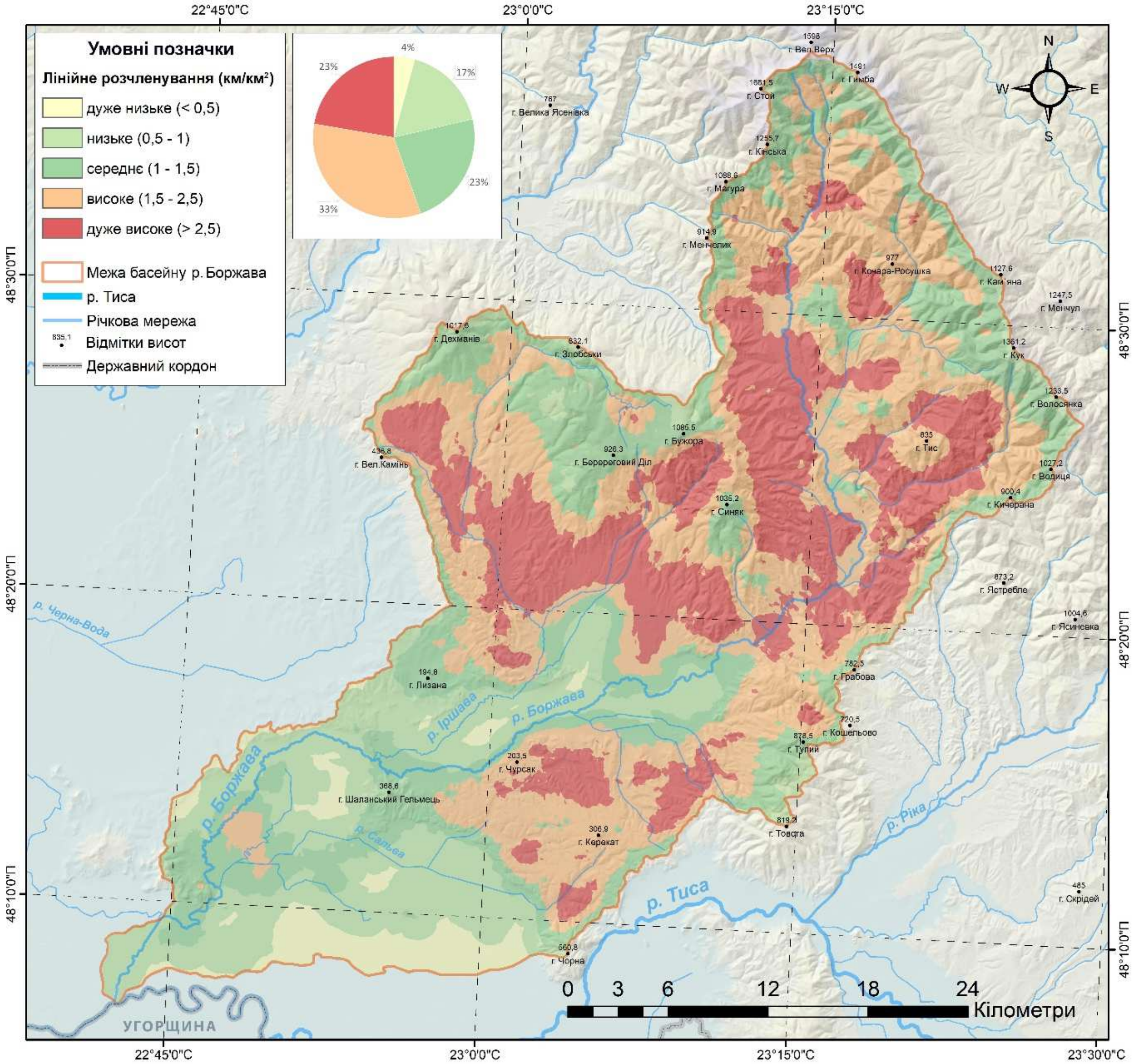

__Figure 1__ Map of Linear Relief Dissection in the Borzhava River Basin

Conclusions

Erosion–denudation processes are among the leading factors of soil degradation in the Borzhava River basin. The results of GIS analysis show that areas with high and very high degrees of linear relief dissection occupy 55.4% of the basin, while territories with values exceeding 1 km/km² account for 78.6%. In the most vulnerable areas, dissection density approaches 4 km/km², and gullies reach depths of 1.5–2.0 m. On steep slopes, where brown mountain-forest soils occupy 49.1% of the basin, erosion intensifies the loss of the humus horizon and reduces soil fertility and land productivity. This limits agricultural use and highlights the need for priority implementation of erosion-control measures and restoration of degraded lands.

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