GeoTerrace Conference

EAGE

GeoTerrace-2026-059

GIS/Remote Sensing Analysis of Erosion Potential in Small-River Catchments of the Ukrainian Carpathians for Geoplanning: Topilnychanka and Upper Dniester

*G. Bayrak, O. Dzvonkovska (*Ivan Franko National University of Lviv*)

SUMMARY

Mountain catchments of the Ukrainian Carpathians are highly susceptible to water erosion, but spatial differences in erosion are controlled not only by terrain and lithology but also by present-day land cover. This study compares the erosion potential of the Topilnychanka River catchment in the Skyba Carpathians and the upper Dniester catchment in the Watershed-Verkhovyna Carpathians and assesses the relevance of the results for geoplanning. Terrain analysis was performed in QGIS using a forest- and building-corrected digital elevation model. Erosion potential was evaluated by integrating terrain ruggedness, slope steepness, morphological levels, horizontal dissection, and the erodibility of Quaternary deposits. Forest cover was mapped from Sentinel-2 Level-2A imagery by supervised classification with a Gaussian Mixture Model. The Topilnychanka catchment shows higher morphometrically controlled erosion potential because of its contrasting Skyba relief, steep slopes, and strong dissection. The upper Dniester has smoother relief, but erosion susceptibility is enhanced by widespread weak flysch and loamy surface deposits. Forest cover reaches 83.1% in the Topilnychanka catchment and 51.2% in the upper Dniester catchment. The results show that erosion assessment should distinguish natural erosion potential from the conditions controlling its current realization. Geoplanning should prioritize high-potential areas with insufficient forest cover, while maintaining continuous forest cover and limiting further clear-cutting in the Skyba Carpathians.

Keywords: Contemporary morphodynamic processes; Erosion; Erosion potential; Terrain morphometry; Forest cover; Earth remote sensing; Geospatial analysis; Geoplanning; Ukrainian Carpathians.

Corresponding Author: halyna.bayrak@lnu.edu.ua

Introduction

Mountain catchments of the Ukrainian Carpathians are characterized by high relief energy, dense erosional dissection, and active slope and fluvial processes. The spatial intensity of water erosion is controlled by the combined action of morphometric, lithological, hydrological, and biotic factors. Particularly important are slope steepness and terrain dissection, the ability of the surface to concentrate runoff, the resistance of surficial deposits to wash, and the character of vegetation cover. Multi-criteria GIS approaches therefore commonly integrate terrain morphometry, substrate properties, and land cover to identify erosion-prone areas (Altaf et al., 2014; Arabameri et al., 2018).

Forest cover is an important stabilizing factor in mountain catchments because it affects rainfall interception, infiltration, surface-runoff formation, and the stability of soil and unconsolidated slope material. Remote-sensing studies demonstrate that vegetation condition and land-cover change can substantially modify erosion rates and the spatial expression of erosion risk (Borrelli et al., 2020; Xu et al., 2019). Combining GIS-based terrain modelling with Earth-observation data therefore allows natural preconditions for erosion to be assessed together with the present-day state of land cover.

This combination is directly relevant to geoplanning. Spatial comparison of erosion-potential classes with forest cover makes it possible to distinguish areas where high natural susceptibility is partly compensated by continuous forest vegetation from sectors where erosion-prone slopes have insufficient protective cover. In the Ukrainian Carpathians, GIS and remote sensing have been applied to erosion-network development, sheet erosion, and basin-scale land-use transformation (Bayrak, 2026; Bayrak & Lutsyshyn, 2025; Kovalchuk et al., 2020).

The aim is to compare erosion potential in the Topilnychanka and upper Dniester catchments using GIS and remote sensing and to assess the results for geoplanning.

Method

The study covers two catchments in the Ukrainian Carpathians: the Topilnychanka River, a right-bank tributary of the Dniester, and the upper Dniester from its sources to the pronounced north-eastward bend downstream of Limna village. The Topilnychanka catchment lies within the Skyba Carpathians, whereas the upper Dniester catchment belongs to the Watershed-Verkhovyna Carpathians and is tectonically associated with the Krosno Zone. The proximity of the two basins provides a broadly comparable climatic background while preserving clear morphometric, geological-geomorphological, and land-cover contrasts.

GIS analysis was carried out in QGIS 3.40.11 "Bratislava". FABDEM was used as the morphometric base. Catchment boundaries and the thalweg network were derived from the elevation model, and a set of morphometric layers was produced. A preliminary comparison in the forested Topilnychanka basin showed canopy-related SRTM artefacts in slope and flow-line outputs. FABDEM produced a more coherent ground surface and drainage network and was therefore used for subsequent modelling. Five groups of spatial characteristics were integrated in the erosion-potential assessment: Terrain Ruggedness Index (TRI), slope steepness, morphological levels, horizontal dissection, and the lithological properties of Quaternary deposits. Slopes were classified into 0-3°, 3-7°, 7-15°, 15-35°, and 35-70° intervals. Morphological levels included valley-floor surfaces, gentle lower valley-side slopes, moderately inclined slopes, steep near-watershed slopes, and summit or upper-slope surfaces. TRI characterized local terrain ruggedness, horizontal dissection represented the density of the developed erosion network, and the lithological component expressed the relative resistance of surficial deposits to wash. The spatial combination of these variables was reclassified into four erosion-potential classes: low, medium, above average, and high. The resulting maps represent spatial susceptibility to erosion rather than measured erosion rates at a particular moment.

Present-day land cover was mapped from Sentinel-2 Level-2A imagery acquired in March 2026 at 10 m spatial resolution. Supervised classification was performed in QGIS with the Dzetsaka plugin using the Gaussian Mixture Model. Training samples represented four generalized classes: forest cover; agricultural and grassland areas; semi-natural and transitional vegetation; and open bare lands, including built-up surfaces, asphalt, and deforested clear-cuts. Internal validation yielded approximately 98.0% overall accuracy and a macro F1 score of 0.92. The classified rasters were clipped to catchment boundaries, after which the area and proportion of forest cover were calculated. Finally, the erosion-potential maps were compared with the land-cover classification. This allowed us to identify sectors where high or above-average natural erosion potential coincides with absent or insufficient forest cover. These sectors were treated as priority areas for geoplanning and anti-erosion measures.

Results

The comparative GIS analysis shows substantial differences in the morphology of the two catchments, primarily because they occupy different structural-geomorphological units of the Ukrainian Carpathians. The Topilnychanka basin is situated in the Skyba Carpathians, while the analysed upper Dniester basin lies in the Watershed-Verkhovyna Carpathians and is related to the Krosno Zone. With a broadly similar climatic background, the comparison can focus mainly on structural-lithological conditions, terrain morphometry, and modern land cover.

In the Topilnychanka catchment, relatively resistant sandstone-rich units alternate with more erodible argillite-siltstone flysch. This structural-lithological heterogeneity is clearly expressed in the relief: resistant complexes form pronounced watershed ridges and steep slopes, while weaker rocks favour valley development and denser erosion networks. Similar relationships are recognized for the Skyba structural zone, where shorter and steeper slopes are associated mainly with frontal parts of skybas and thrust slices and longer, gentler slopes with their rear parts (*Bayrak, 2026*). The extracted drainage network also shows a stronger parallel pattern over resistant units and a more dendritic pattern on weaker Paleogene flysch.

Morphometric maps confirm the high relief contrast of the Topilnychanka basin. The lowest surfaces are associated with the main valley floor, whereas watershed ridges exceed 800 m. Slopes of 15-35° are widespread, and steep upper-slope sectors occupy a substantial part of the basin. High relief energy is accompanied by pronounced erosional dissection: the incision depth of many valleys and gullies reaches 20-70 m. The upper Dniester catchment has a different morphologic pattern. Despite an elevation range of approximately 490-982 m, its slopes and watershed surfaces are generally smoother. Gentle and moderately inclined slopes occupy large areas, while steep slopes are localized. Unlike the Skyba Carpathians, with pronounced alternation of units of different resistance, the studied upper Dniester sector is dominated by Krosno flysch, including sandy-clayey and argillaceous-siltstone complexes that are relatively susceptible to denudation. This favours smoother ridges and gradual watershed-to-valley transitions, while the weak substrate still permits dense small erosional forms at lower local gradients. Quaternary cover is an important direct control on surface resistance in both catchments.

The integrated erosion-potential maps combine terrain ruggedness, slope steepness, horizontal dissection, morphological levels, and Quaternary-deposit properties (Figure 1). In both basins, the lowest potential is associated with the main valley floor and lower reaches of large tributaries, where gentle gradients and permeable alluvium favour infiltration and accumulation. Medium potential occupies much of the lower and middle slopes. Above-average values occur mainly in near-watershed sectors with greater steepness and dissection. High potential characterizes the most elevated and strongly dissected sectors and steep slopes with loose colluvial deposits. In the upper Dniester, elevated values also occur locally near Limna, where landslide and deluvial loams are concentrated.

The mechanisms producing elevated erosion potential differ between the two basins. In the Topilnychanka catchment, the decisive factor is the strong morphometric contrast of structurally controlled Skyba relief: steep slopes, large local elevation differences, and deep erosional dissection create high runoff energy. In the upper Dniester, morphometric contrasts are generally weaker, but erosion susceptibility is maintained by the widespread occurrence of relatively weak flysch and loamy Quaternary cover. Lower morphological contrast therefore does not automatically indicate low erosion susceptibility. Remote-sensing data reveal an especially important difference in current land cover. Forest occupies 83.1% of the Topilnychanka catchment but only 51.2% of the upper Dniester catchment. Non-forest land consequently represents 16.9% and 48.8%, respectively; thus the proportion of open land in the upper Dniester is almost three times larger.

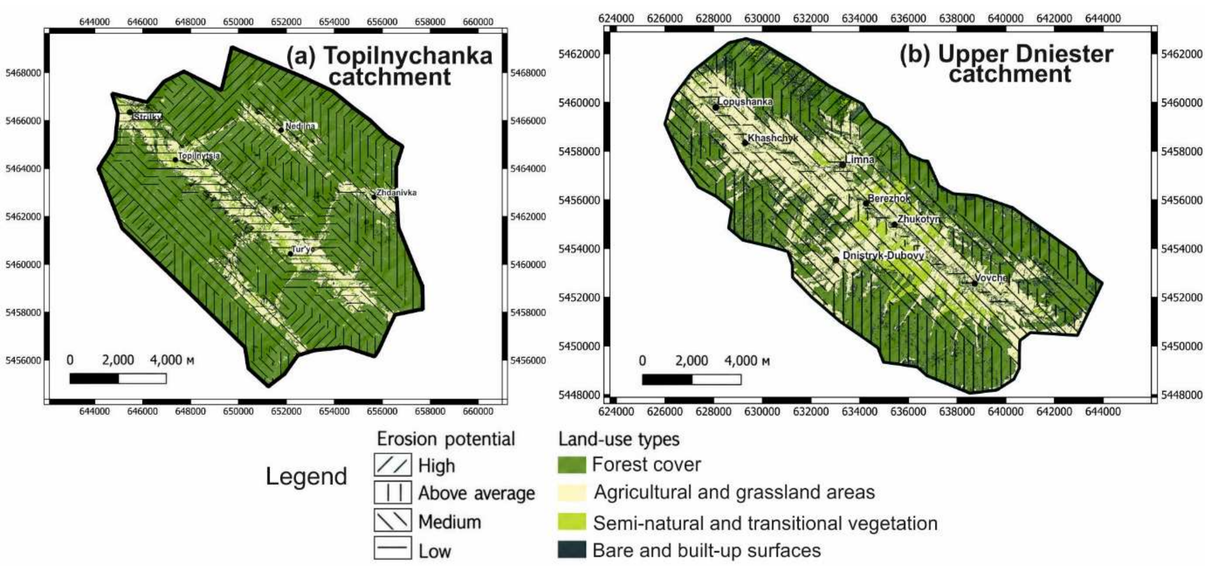

Figure 1. *Erosion-potential patterns in the Topilnychanka and upper Dniester catchments and forest-cover proportions derived from Sentinel-2 classification*

This contrast is critical for interpreting erosion potential. Forest cover does not change the geological and morphometric preconditions that have already formed, but it strongly modifies the possibility of their present-day realization. Studies in Carpathian basins show that forest and perennial vegetation reduce sheet wash and stabilize parts of the erosion network, although they do not eliminate the underlying potential for erosion on long and steep slopes (Bayrak & Lutsyshyn, 2025). This is consistent with broader remote-sensing studies of vegetation effects on erosion (Borrelli et al., 2020; Xu et al., 2019).

Thus, the Topilnychanka catchment has a higher morphometrically controlled susceptibility to erosion, but much of its potentially unstable terrain is currently protected by continuous forest. The upper Dniester has smoother structural relief, yet the combination of a weak substrate with substantially lower forest cover creates wider opportunities for the present-day realization of erosion potential on open and intensively used surfaces. The results therefore support a two-stage assessment: first mapping natural erosion potential from terrain and substrate, and then evaluating the conditions of its current realization from land cover.

The applied approach is consistent with studies in which erosion susceptibility is assessed by integrating morphometric characteristics, substrate properties, and present-day land cover (Altaf et al., 2014; Arabameri et al., 2018). Our results develop this approach by separating the relatively persistent natural erosion potential from the dynamic land-cover component controlling its current realization. In mountain terrain, steep dissected slopes may remain comparatively stable under continuous forest, while gentler slopes on weak deposits can be vulnerable after vegetation removal.

For Ukrainian basin geosystems, Kovalchuk et al. (2020) demonstrated the usefulness of GIS and remote sensing for analysing land-use transformation in Dniester tributaries. Related Carpathian studies have also shown the stabilizing role of forest and perennial vegetation (Bayrak, 2026; Bayrak & Lutsyshyn, 2025). In the Skyba Carpathians, geoplanning should preserve existing forest and prevent expansion of clear-cutting on steep dissected slopes; in the Watershed-Verkhovyna Carpathians, conservation and restoration are especially relevant on open surfaces developed on weaker substrates.

For geoplanning, natural erosion potential and the conditions of its present-day realization should therefore be considered separately. The most important targets are not all areas mapped as high potential, but primarily those where high or above-average potential overlaps with insufficient vegetation protection. The maps should be interpreted as a spatial decision-support layer for targeting preventive measures rather than as a direct measurement of current erosion rates.

Conclusions

The comparative GIS/remote-sensing analysis shows that erosion potential in the two mountain catchments is governed by terrain morphometry, lithological resistance, and present-day land cover. The Skyba catchment has higher morphometrically controlled susceptibility related to contrasting relief and strong dissection, whereas the upper Dniester has lower morphometric contrast but greater influence of weak flysch and loamy Quaternary deposits. The key difference identified from remote sensing is forest cover: 83.1% in the Topilnychanka catchment and 51.2% in the upper Dniester. The larger proportion of open land in the Watershed-Verkhovyna Carpathians creates broader opportunities for current realization of erosion potential. In the Skyba Carpathians, continuous forest restrains high natural susceptibility over large areas, so maintaining forest cover and limiting further clear-cutting are important for anti-erosion geoplanning.

References

Altaf, S., Meraj, G., & Romshoo, S. A. (2014). Morphometry and land cover based multi-criteria analysis for assessing the soil erosion susceptibility of the western Himalayan watershed. Environmental Monitoring and Assessment, 186, 8391-8412. https://doi.org/10.1007/s10661-014-4012-2

Arabameri, A., Pradhan, B., Pourghasemi, H. R., & Rezaei, K. (2018). Identification of erosion-prone areas using different multi-criteria decision-making techniques and GIS. Geomatics, Natural Hazards and Risk, 9(1), 1129-1155. https://doi.org/10.1080/19475705.2018.1513084

Bayrak, G. (2026). Application of remote sensing and GIS for the analysis of spatial differentiation and development of the erosion network in the mountainous part of the Bystrytsia Tysmenytska River basin. Problems of Geomorphology and Paleogeography of the Ukrainian Carpathians and Adjacent Areas, 19(1). https://doi.org/10.30970/gpc.2026.1.5200

Bayrak, G., & Lutsyshyn, O. (2025). Sheet erosion in the Bystrytsia Tysmenytska fluvial geomorphosystem and territorial geoplanning perspectives. Problems of Geomorphology and Paleogeography of the Ukrainian Carpathians and Adjacent Areas, 18(1), 164-180. https://doi.org/10.30970/gpc.2025.1.4875

Borrelli, P., Robinson, D. A., Panagos, P., Lugato, E., Yang, J. E., Alewell, C., Wuepper, D., Montanarella, L., & Ballabio, C. (2020). Land use and climate change impacts on global soil erosion by water (2015-2070). Proceedings of the National Academy of Sciences of the United States of America, 117(36), 21994-22001. https://doi.org/10.1073/pnas.2001403117

Kovalchuk, I. P., Mykytchyn, O. I., & Kovalchuk, A. I. (2020). Geoinformation modeling of anthropogenic transformation of the basin geosystems (case study of Dnister right tributaries). Visnyk of V. N. Karazin Kharkiv National University, Series “Geology. Geography. Ecology”, 51, 124-139. https://doi.org/10.26565/2410-7360-2019-51-09

Xu, H., Hu, X., Guan, H., Zhang, B., Wang, M., Chen, S., & Chen, M. (2019). A remote sensing based method to detect soil erosion in forests. Remote Sensing, 11(5), 513. https://doi.org/10.3390/rs11050513