

Landslide25_35**Landslide assessment of the Transcarpathian region using GIS-based spatial modeling**

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SUMMARY

The main aim of this study is to develop a landslide susceptibility map of the Transcarpathian region using the Weighted Overlay method. This is based on an analysis of 869 recorded landslides (697 point features and 172 polygons), which were identified through field surveys and digitised data from the Transcarpathian Geological Exploration Expedition. Nine factors were developed as contributors to susceptibility: tectonic features, elevation, slope steepness, land use, distance to faults and river networks, and average annual precipitation and NDVI and MI. The resulting susceptibility assessment will provide local authorities with a scientifically valid tool for land use planning and hazard mitigation strategies in this vulnerable region, offering critical insights for regional landslide risk management.

Introduction

Landslides are one of the most catastrophic and dangerous natural hazards, widespread throughout the world (Iemelianov et al., 2025), especially in mountainous areas, and the Transcarpathian region is no exception (Hadiatska et al., 2025). In particular, they pose a direct threat to human life and infrastructure, causing significant damage to communities. Due to the risks they pose, especially during periods of flooding (Pigulevskiy et al., 2023; Pigulevskiy et al., 2017; Pigulevskiy et al., 2016) caused by uneven rainfall, the assessment of landslides in mountainous areas and the analysis of their probability are crucial. However, careful analysis can identify areas at risk and enable preventive measures to be taken, such as slope stabilisation engineering and early warning systems. Thus, determining the main triggering factors of formation, registering and inventorying existing landslides, and creating a map of the susceptibility of the territory to the development of landslide processes are necessary steps to minimize risks (Shtogryn, 2025; Shekhunova, 2022). Landslide susceptibility maps are the result of statistical relationships between environmental conditions (triggering factors) and localization of the previously registered landslides (Hadiatska et al., 2025).

In administrative terms, the study area is located within the Transcarpathian region. Geologically, it is part of the Inner and Outer Carpathians. However, due to the significant number of landslide and debris flow sites within the main structural-facies zones of the Outer Carpathians, this territory is of particular interest in this study (Figure 1). The Outer Carpathians mainly comprise Cretaceous-Lower Miocene flysch deposits, which are divided by tectonic faults into individual blocks. The folded-scaly structure of the Cretaceous-terrigeneous thin flysch formation, with increased fracturing, has led to the intensive development of weathering and the formation of eluvial-deluvial deposits, which are favourable for landslide initiation (Shtohryn et al., 2020). The largest number of landslide and debris flow processes occur in the Krosno, Porkulets, Rakhiv and Chornohora zones.

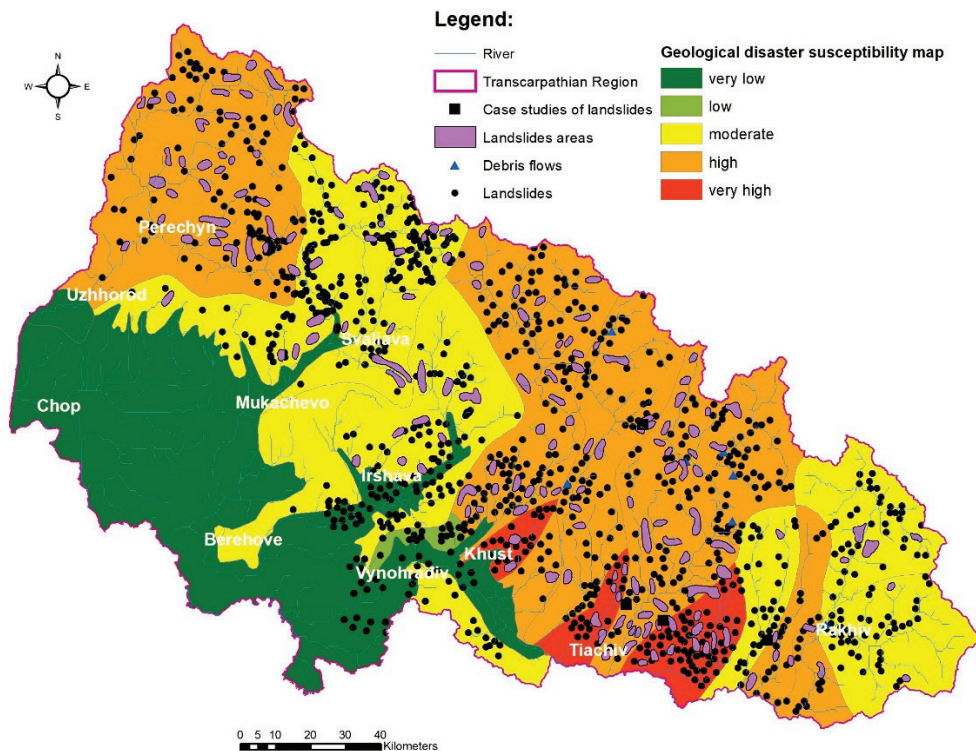


Figure 1 The map shows the zoning of the Transcarpathian region according to its susceptibility to geological disasters (according to data from the Transcarpathian Geological Exploration Expedition).

Materials and methods

According to the digitised landslide inventory dataset used in this case study, consisting of 697 points and 172 polygons and layers of triggering factor maps, landslides are common. As for conditional factors, there are no specific rules for their selection; this depends on the scale and geocological conditions of the study area, as well as the data availability. Taking these factors into consideration, was provided 9 different conditional factors, which included tectonic features, lithology, geomorphological features such as elevation, slope steepness, slope aspect, slope curvature, land use, distance to faults and river networks, as well as specific climatic conditions (average annual precipitation, NDVI and MI (<https://dataspace.copernicus.eu>)). Tectonic and lithological features were also identified as key factors in landslide initiation. Maps of elevation, slope steepness, slope aspect and curvature were obtained from ALOS Global Digital Surface Model (AW3D30) with a spatial resolution of 30 metres (<https://portal.opentopography.org/result?id=rt1753184364485>). The algorithm for spatial modeling is shown in Figure 2.

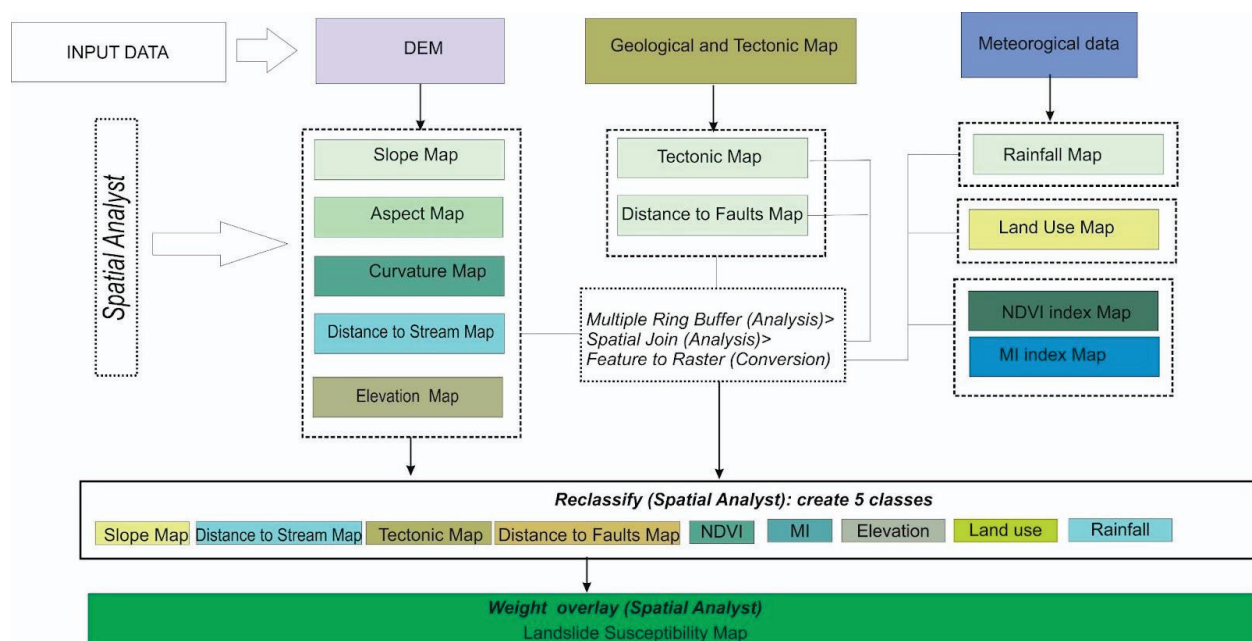


Figure 2 The flowchart of the landslide susceptibility modelling by weight overlay analysis.

Results

The final stage of the spatial analysis involved carrying out an overlay analysis using weight coefficients. This produced a map showing landslide susceptibility. The results of the weight overlay analysis showed the following (figure 3):

- 274 landslides occurred within slopes with a steepness of 5–13°;
- 223 landslides occurred within slopes with a steepness of 14°–22°.
- 234 landslides occurred within high-altitude areas (545–825 m).
- 229 landslides occurred within elevations of 282–544 m.
- 446 landslides occurred in areas with an average annual precipitation of 155 mm.

The results indicate that 359 landslides occurred within 2–4 km of the river network, primarily within the ravine system, while only 133 landslides occurred within 500 m of rivers. A direct influence has been recorded from uneven precipitation, humidity and vegetation indices.

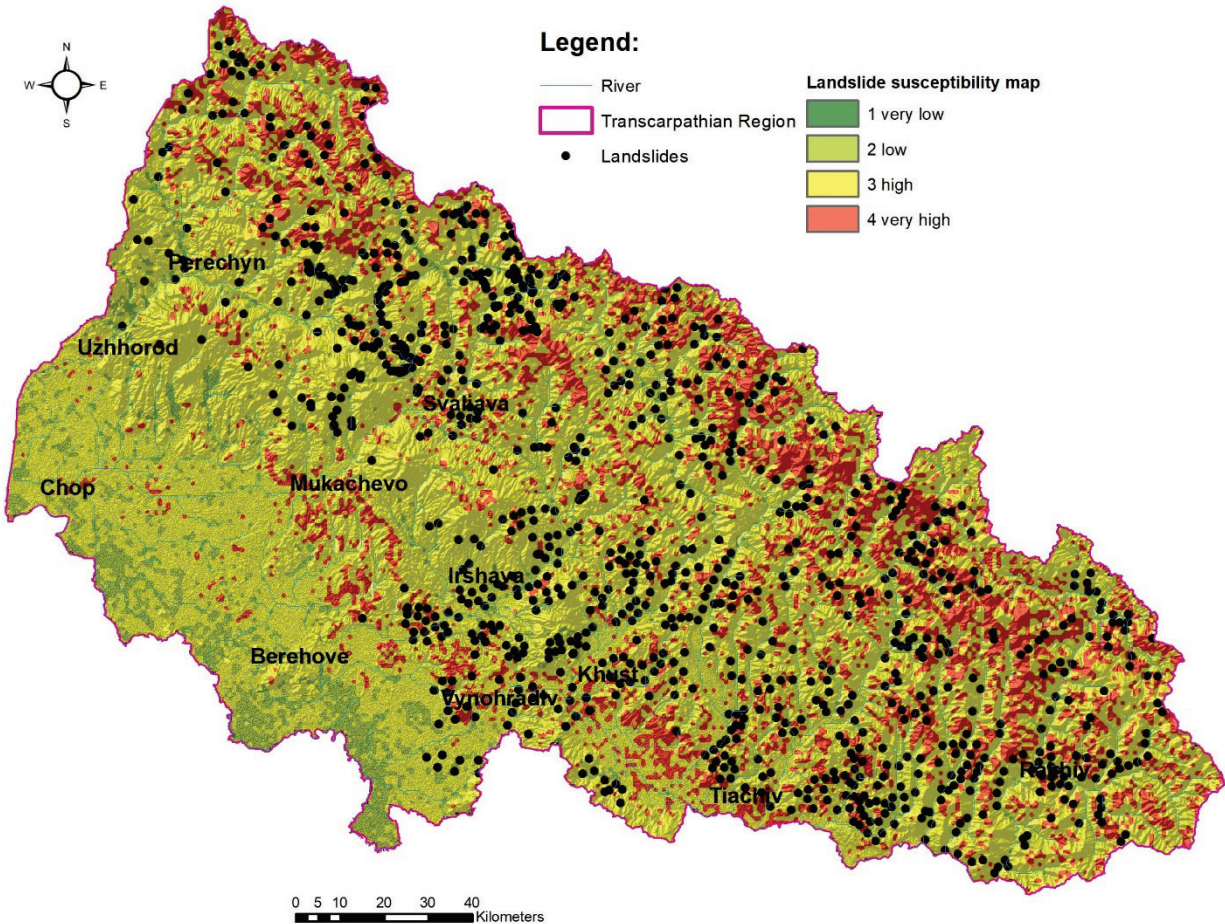


Figure 3 The landslide susceptibility map of Transcarpathian region

Conclusions and discussion

The results of the weight overlay analysis show that the largest number of landslides is confined to zones 3–4, i.e. zones of high and very high landslide hazard probability. Geomorphologically, the largest number of landslides occurs in the South Pokutsko-Bukovinian foothill plain, the Svidovets and Chornogora mountain ranges, the North Pokutsko-Prutskaya plain and the Poloninsky ridge. In lithological terms, landslides are mainly confined to alluvial-deluvial deposits within flat relief forms and, within highland and mountain relief forms, to Cretaceous–Paleogene deposits of two-component flysch. Most landslides form on NE, NW and SE aspect slopes with a steepness of 5°–22° and concave morphology. The largest number of landslides are localised within areas of high tectonic disturbance density (1.04–1.86), at a distance ranging from 0.5 to 2 km from these areas.

It should be noted that these intermediate data can be used to map landslide susceptibility at the regional level using machine learning methods, remote sensing, GIS methods and their combination. Currently, this region lacks landslide inventory data for areas that are inaccessible to carry out field research. Advanced remote sensing methods are planned to improve the landslide inventory base. This will be carried out in future studies, as these stages are currently rather onerous and costly.

Acknowledgements

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