UNIVERSITY OF CRAIOVA **Series: Geography**
UNIVERSITATEA DIN CRAIOVA **Seria: Geografie**

Vol. 26 (new series) – 2025
Vol. 26 (serie nouă) – 2025

RESEARCH HISTORY AND GIS-BASED METHODS: CASE STUDY – THE MOLDAVIAN PLATEAU

ISTORICUL CERCETĂRILOR ȘI METODE GIS: STUDIU DE CAZ – PODIȘUL MOLDOVEI

Domenic-Raul BECICA[1], Marcel MÎNDRESCU[2]

Abstract: This study presents an integrated assessment of geomorphological and hydrological risk in Romania's Moldavian Plateau, combining manual inventories, high-resolution DEM/LiDAR, Corine LU/LC, geology–soils, Sentinel-2, and EGMS InSAR with HEC-RAS modeling and official 1% & 1%CC flood belts. The inventory maps 4,351 landslides, 3,343 gullies, 2,353 rill patches, and 17,681 sheet-erosion polygons – covering 28,900 ha (landslides), 4,661 ha (gullies), 21,500 ha (rill erosion), and 135,152 ha (sheet erosion), showing that areal processes dominate, while gullies and landslides mark acute instability nodes near settlement edges and infrastructure. Plateau-wide, the 1% AEP flood belt occupies 111,549 ha, expanding to 149,184 ha under the climate-corrected 1%CC scenario (+33.7%). Affected settlements increase from 398 to 451; intersected households from 10,514 to 14,112; and the estimated exposed population (excluding municipalities) from 27,350 to 36,700 (+34%). A HEC-RAS case study on the Suceava River (Mihoveni–Iţcani, Q2008 = 1,710 m³/s) indicates that levees shrink inundation footprints but raise depths and WSE (12.66→13.09 m; 285.93→286.86 m), highlighting trade-offs between footprint reduction and hydraulic load. The results support conservation agriculture on >8.5° slopes, grade-control and drainage where gullies approach settlements, targeted slope stabilization, and strict floodplain zoning paired with carefully engineered defenses.

Key-words: *Moldavian Plateau, geomorphological risk, hydrological risk, floods, landslides, vulnerability, resilience, SIG, HEC-RAS*
Cuvinte cheie: *Podișul Moldovei, risc geomorfologic, risc hidrologic, inundații, alunecări de teren, vulnerabilitate, reziliență, GIS, HEC-RAS*

1. INTRODUCTION

1.1 The importance of studying geomorphological and hydrological risks

Over recent decades, the frequency and intensity of natural extremes, especially landslides and floods, have increased markedly, intensifying both scientific and institutional concern about the assessment and management of natural risks.

[1] Ștefan cel Mare University of Suceava, Geography Department, 13 Universității Street, 720229, Suceava, Romania, email: rauldomenic@gmail.com (correspondent author)
[2] Ștefan cel Mare University of Suceava, Geography Department, 13 Universității Street, 720229, Suceava, Romania, email: mindrescu@atlas.usv.ro

These processes produce major impacts on the environment, infrastructure, economic activities and social life and are responsible for substantial material losses as well as fatalities (UNDRR, 2019; Petley, 2012). Geomorphological and hydrological risks are controlled jointly by natural factors—precipitation, topography and lithology - and by anthropogenic drivers such as deforestation, urbanization, and land-use change. Their interaction tends to amplify territorial vulnerability (Alexander, 1993; Glade, 2003, Kundzewicz et al., 2014). In Romania, the Moldavian Plateau is characterized by dissected relief, a highly variable rainfall regime and strong human pressure on land resources, which together demand detailed risk analyses. Landslides, gully development, soil erosion and rapid floods have repeatedly affected settlements and farmland, accentuating territorial imbalances (Ioniță, 2000; Grecu, 2009; Bănică et al., 2024). The rationale for studying these phenomena lies not only in quantifying the hazard, but also in understanding the vulnerability of exposed communities. In the contemporary view, risk emerges from the interaction among hazard, exposure and vulnerability; integrating these dimensions is indispensable for building effective risk-management models and strengthening territorial resilience (Cutter et al., 2003; Birkmann et al., 2013). Climate change adds further challenges: increasing heavy-rainfall extremes, seasonal shifts in susceptibility and more frequent hazardous weather have been documented at European and national scales (IPCC, 2021; Crozier, 2010, Borrelli et al., 2017). Consequently, the assessment of geomorphological and hydrological risks is a cornerstone of climate-adaptation strategies and sustainable spatial planning. This paper adopts an integrated approach to these risks in the Moldavian Plateau by analyzing triggering factors, mapping vulnerabilities and proposing measures aimed at risk reduction and enhanced community resilience.

1.2 Core definitions and concepts

Robust analysis of natural risks requires clear conceptual foundations to ensure methodological coherence. In studies of landslides, soil erosion and floods, the terms hazard, risk, vulnerability, exposure and resilience are used frequently and interdependently. A hazard is a natural or anthropogenic process with the potential to cause fatalities and material/economic losses (Alexander, 1993). In applied geomorphology, hazards include landslides, rock-slope failures, accelerated erosion and gullying and fluvial or pluvial flooding; they have distinct spatial and temporal attributes describable by frequency, duration, magnitude and probability (Glade, 2003). Risk is the outcome of interactions among hazard, exposure and vulnerability, often summarized as: Risk = Hazard × Vulnerability × Exposure, implying that, in the absence of exposed elements, even a major hazard may not translate into significant risk (Cardona et al., 2012). Vulnerability denotes the degree to which natural, economic or social systems can be adversely affected by a hazard, encompassing physical, social, economic and institutional dimensions (Birkmann, 2006). In the rural context of the Moldavian Plateau, vulnerability is frequently amplified by deficient infrastructure and limited preparedness. Exposure refers to the elements located within hazard zones – dwellings, road networks,

utilities, agricultural land that can be impacted by an event; exposure mapping is thus a critical component of spatial risk analysis (Cutter et al., 2003). Resilience captures a system's or community's capacity to withstand, absorb, adapt to and quickly recover from a disaster (UNDRR, 2019).

Within geomorphological risk, a landslide is the downslope movement of rock, soil or debris under gravity. Standard classifications distinguish movement types (flows, topples, falls, translational and rotational slides) and materials involved (Varnes, 1978; Cruden & Varnes, 1996). Floods are temporary inundations of land not normally covered by water, typically driven by intense precipitation and/or snowmelt. In the Moldavian Plateau, rapid (flash) and fluvial floods dominate, especially in low-lying areas of the Siret and the Prut basins and in hilly regions. These concepts are applied here to support a multidimensional evaluation of risk in the Moldavian Plateau, define vulnerability indicators, and frame measures for strengthening resilience.

1.3 Research aims and working hypotheses

Against the background of climate change and increasingly frequent instability processes, identifying, evaluating and managing natural risks are both scientific and policy priorities. Exposed territories of the Moldavian Plateau require an integrated approach to hazards, their triggers and community coping capacity. The overarching aim of this study is to evaluate the vulnerability of settlements in the Moldavian Plateau to geomorphological and hydrological risks by integrating quantitative methods, spatial datasets and simulation models, with the practical goal of proposing concrete measures to enhance territorial resilience. Specifically, the study analyzes the spatial-temporal distribution of landslides, gullies, sheet and rill erosion, and floods using topographic maps, satellite data and hydrological archives; identifies dominant natural (lithology, slope, rainfall regime) and anthropogenic (deforestation, construction expansion) controls; and maps hazard, vulnerability and composite risk using multicriteria methods and GIS-based spatial analysis. It applies HEC-RAS to simulate flood scenarios in representative basins, tests virtual structural interventions (e.g., levees, diversion channels) in HEC-RAS to gauge their risk-reduction efficacy and evaluates socio-economic impacts via statistical indicators and exposure models (Brunner, 2016). Finally, it formulates management measures aligned with the European and national climate-adaptation strategies. Three working hypotheses guide the analysis: first, that the frequency and severity of geomorphological and hydrological processes have increased significantly due to climate change and intensifying land-use pressure; second, that settlements in unstable, dissected hill terrains with deficient infrastructure exhibit higher vulnerability to landslides, erosion and floods; and third, that integrating GIS analyses with HEC-RAS simulations, including intervention scenarios, materially improves the identification of solutions for risk reduction and territorial resilience.

The Moldavian Plateau, located in northeastern Romania, is among the country's most vulnerable regions from both geomorphological and hydrological perspectives. It is marked by highly dynamic natural processes, notably landslides, soil erosion and seasonal flooding. This natural predisposition is amplified by

human pressures on the environment, making the region an ideal setting for applied research focused on vulnerability assessment and natural-risk management. The core aim of the study is to identify high-risk zones and propose concrete risk-management measures. Geomorphologically, the area consists of high plateaus, broad interfluves and deeply incised valleys developed on unstable clay, marl substrata and friable sedimentary sequences, conditions that favor recurrent instability. Repeated landslides and widespread soil erosion have been documented. For example, Niacșu et al. (2021) reported mean annual erosion of 21.6 t/ha and a sediment yield of 7.1 t/ha/yr in the Racova basin, contributing to a 32% capacity loss of Lake Pușcași over the last four decades. Romanescu et al. (2012) used 3D scanning to monitor Cucuteni–Băiceni scarp, finding ~10 m of retreat in just 1.6 years, which underscores the coupling between intense rainfall, loess-like and clayey, friable soils and accelerated erosion. Niacșu et al. (2021) further documented >60% erosion reduction in the Puriceni–Băinhari basin following conservation practices (terracing, vegetative cover). Niacșu et al. (2021) examined gully development, emphasizing the role of topography, pedology and land use; Rădoane et al. (1995, 2017) inventoried over 9,000 gullies (0.1–4 km/km²), distinguished three main types and showed that lateral erosion can be up to ten times more intense than vertical incision, especially in clayey materials. The plateau also includes some of Romania's most densely populated rural zones, with high exposure of settlements. Research on vulnerability and resilience therefore feeds directly into urban-planning and territorial-management policies. The study thus brings both scientific and applied value to a hotspot of natural risk, providing a solid basis for predictive modeling and for effective risk-reduction measures.

2. DATA AND METHODS

2.1 Study area

The study covers the Moldavian Plateau (24,104.45 km²) located in northeastern Romania, spanning the counties of Suceava, Botoșani, Iași, Neamț, Bacău, Vaslui, Galați and Vrancea. Defining geomorphological traits include long interfluves, inclined hillslopes, deeply incised valleys and clay-marl substrata. These features underpin the propensity for landsliding, accelerated erosion and seasonal flooding. Spatial delimitation was performed at the level of populated administrative units, yielding 1,948 localities ranging from major urban centers (Iași, Suceava, Bacău) to numerous dispersed rural settlements. This diversity implies contrasting infrastructures, population densities and response capacities. For each locality, we delineated the associated drainage basin, thereby relating risk to the natural hydrological unit and avoiding the distortions introduced by circular buffers that often capture unrelated terrain. Official settlement data were sourced from the National Agency for Cadastre and Land Registration, updated in sectors where built-up areas expanded beyond the latest release. Topography was characterized using an 8.5 m DEM, complemented by 5 m LiDAR where available for priority sectors.

The main map (Fig. 1) shows the distribution of localities draped over the DEM, highlighting the region's complex geomorphology. An inset (upper left) illustrates the locality-basin delineation method via a detailed example, facilitating like-for-like comparisons of local vulnerability. A locator map (lower left) situates the study area within Romania. Framing risks in this geospatial structure turns each locality into a distinct evaluation unit and supports the integration of geomorphological and hydrological indicators while preserving spatial and temporal comparability.

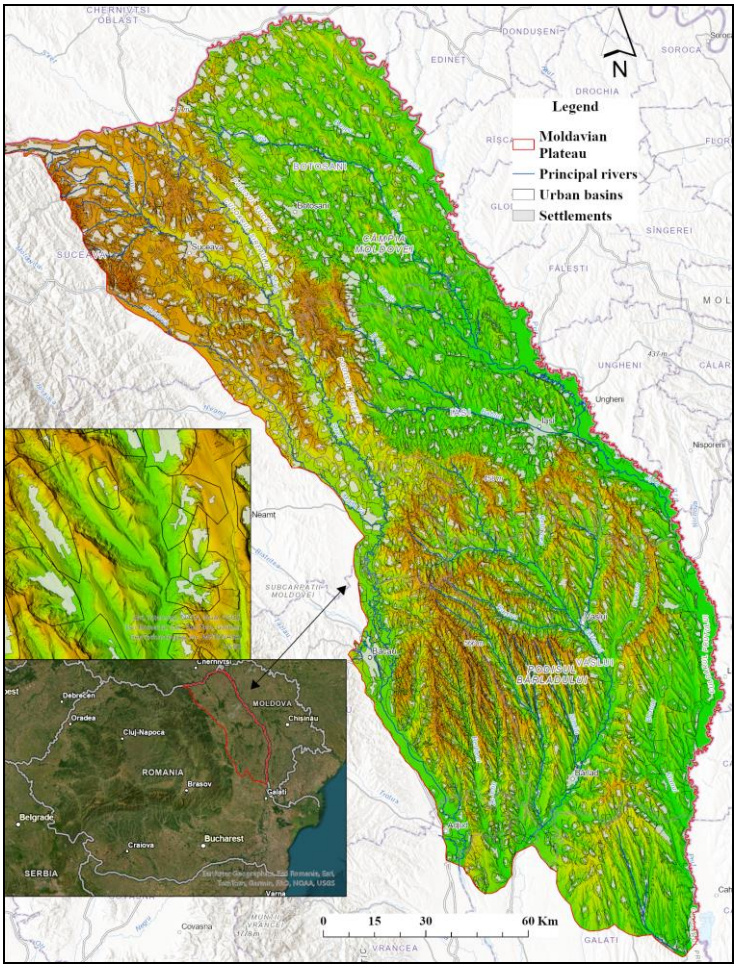

Fig. 1 Spatial delimitation of the Moldavian Plateau, locality-based basins, and the region's position within the national territory

2.2 Geospatial database and sources

The geospatial database integrates heterogeneous sources, from historical cartography to modern satellite monitoring and remote sensing, to provide a robust multi-temporal foundation for spatial risk analysis in the Moldavian Plateau. A

central pillar is the 8.5 m DEM, supplemented in places by 5 m LiDAR to enhance topographic accuracy. These datasets support the derivation of morphometric variables, slope, aspect and relief energy, using standard ArcGIS tools. To capture terrain dynamics through time, 1:25,000 military topographic maps (1984) were georeferenced and vectorized to identify past geomorphological features (gullies, landslides) and to enable multi-temporal comparisons with current satellite data. The Copernicus European Ground Motion Service (EGMS) provides millimetric InSAR-based measurements of vertical ground motion (2019–2023), which we used to detect active instability near slopes and confluences and to validate geomorphological scores. Land-use information is based on Corine Land Cover 2018, reclassified by vulnerability (e.g., arable land, forests, built-up areas) and attached to each administrative unit for subsequent modeling. Geological and pedological inputs were extracted from IGR maps and the FAO-HWSD database to classify lithologies and soils relevant to failures and infiltration under intense rainfall. Hydrological inputs include mean and peak discharges for the Siret and the Prut rivers from INHGA, frequency curves for 1% and 1% with climate change (1% CC) and documentation of historical events (e.g., 2005, 2010) verified against Sentinel-2 and Google Earth Pro imagery. Building footprints and infrastructure layers were compiled from OpenStreetMap, ANCPI geoportal extracts and targeted manual digitization to ensure reliable exposure estimates. All layers are organized in an ArcGIS Pro geodatabase, with each locality linked to its basin unit for computing composite geomorphological and hydrological risk indices.

Colored points represent precise InSAR measurements of vertical ground motion in mm/yr, with negative values (red) indicating subsidence and positive values (blue) uplift. Clusters near slopes and hydrological confluences reveal active instability sectors, guiding field diagnostics and score validation. EGMS adds an objective, reproducible, multi-temporal evidence base for identifying critical areas and integrating them into natural-risk evaluation.

Stage 1 gathers foundational sources (DEM/LiDAR, georeferenced 1984 maps, Sentinel-2, EGMS, CORINE, geology, soils, hydrology). Stage 2 processes them into spatial variables (slope, aspect, hillshade, relief energy), vectors, reclassifications and manual digitization. Stage 3 integrates all layers in an ArcGIS Pro geodatabase. Stage 4 applies composite indices to produce locality-level geomorphological and hydrological risk scores. This modular architecture supports reproducible, integrated and adaptable analysis.

2.3 Geomorphological-risk analysis

From the 8.5 m DEM we derived slope and aspect rasters and computed relief energy (max–min elevation) within each basin and built-up area. Slope was reclassified into five locally tuned classes (≤3.5°, 3.5–5.5°, 5.5–8.5°, 8.5–11.5°, >11.5°) and we extracted the median per locality for robustness. Aspect was grouped into functional exposure classes reflecting local hydro-meteorological behavior (e.g., south and southwest receiving higher scores) and the dominant class was recorded per locality. Relief-energy values were reclassified into five classes using robust thresholds (e.g., Jenks or quartiles). Land-use classes were grouped by

expected hillslope behavior, while soils were ordered by erodibility and lithologies by cohesion (compact limestones and cemented sandstones scored low; alternating marls, clays, sands, gravels and deluvial/proluvial deposits scored high). For each locality we calculated the areal share of mapped processes (landslides, gullies, sheet and rill erosion). Factor maps were retained to support causal interpretation, for example where steep south-facing slopes with high relief energy on friable substrata coincide with dense gullies, combinations well documented in the plateau. Internal sensitivity tests (±10–20% weight shifts, mean vs. median summaries, Jenks vs. quantiles) and external coherence checks against mapped processes and regional literature underpin the robustness of the index.

2.4 Hydrological-risk analysis

Flood exposure was quantified and compared under two official scenarios: the centennial floodplain (1% AEP) and the centennial floodplain adjusted for climate change (F100 CC, 1% AEP with CC). All steps were implemented in ArcGIS Pro and combined hydraulic hazard bands, settlement limits, building inventories, critical infrastructure and building-type-based demographic estimates. Hazard bands were retrieved from the national flood-risk management geoportal; as per ANAR methodology, they reflect existing hydraulic structures and operating regimes at the time of mapping. After harmonizing projections and topology, 1% and 1%CC bands were intersected with built-up limits to compute exposed area (ha) and the share of built-up land in hazard (%). Buildings were selected via spatial intersection with the bands; in dense areas, geometric intersections were used to calculate the fraction of each building overlapped and only features with ≥80% coverage were retained to avoid marginal edge effects. Population exposure was estimated using consistent occupancy coefficients: ~2.6 persons per house (INS) and average persons per block by height class, scaled by stairwells where applicable. The same coefficients were applied to 1% and 1%CC to isolate the climatic effect. Social and economic infrastructure (schools, places of worship, clinics, key public facilities) intersecting the bands was inventoried, as were industrial sites. Transport networks were intersected with the bands and the affected lengths computed for national roads, county roads and railways, with attention to segments that could cut access and isolate neighborhoods or localities. Differences between 1% and 1%CC were mapped and tabulated by locality and basin (exposed area and share, buildings by type, population and km of affected networks), highlighting newly captured hazard zones under climate adjustment. Quality control included consistent demographic assumptions across scenarios, treatment of multi-stairwell blocks, the ≥80% overlap threshold, geometric realignment in complex nodes (bridges, levees) and LiDAR-based spot checks of micro-relief. Where discharge series allowed, HEC-RAS 2D subsector simulations were compared to official outlines; deviations below ~10% in well-surveyed areas supported the use of official bands for exposure analysis. The outputs, thematic maps and comparative tables, yield directly usable planning indicators: percent built-up affected, exposed population by scenario, critical facilities “in band,” transport lengths at risk and potential isolation corridors.

2.5 Data integration and software

Risk analysis combines multi-source integration with processing in specialized environments. Vector and raster data are managed and analyzed in ArcGIS Pro for advanced spatial analysis, terrain modeling, basin delineation and morphometric extraction. HEC-RAS supports manual digitization of channel centerlines, banks and cross sections and the hydraulic simulation of inundation. ModelBuilder and ArcPy automate workflows (e.g., slope calculation, raster reclassification). HEC-RAS performs 1D/2D flood-wave propagation to delimit flood extents and test protection measures (levees, diversion channels). Flood bands are then reintegrated into GIS for mapping and interpretation. Sentinel-2 imagery and EGMS products inform ground-motion and spatial-change analyses for 2019–2023. Python scripting (ArcPy) supports parameter extraction and map compilation. For 3D visualization and communication with stakeholders, Google Earth Pro and Scene Viewer present realistic perspectives of high-risk sectors and scenario animations. Overall, the workflow blends GIS analytics, hydraulic modeling and scriptable automation to deliver a robust, multidimensional assessment.

2.6 Methodological limitations and interpretive cautions

Despite its rigor, the methodology entails limitations rooted in data quality and the complexity of the processes studied. The 8.5 m DEM, while suitable for regional analysis, can introduce local-scale errors in very dissected terrain or dense vegetation; LiDAR improves accuracy, but is available only in patches, which may yield spatial inconsistencies. Sentinel-2 and EGMS come with temporal and spectral constraints and dense forest cover can mask geomorphological signals, potentially leading to underestimation of process frequency or intensity. Comparisons between historical maps (e.g., 1984) and recent data must account for cartographic and methodological differences. Hydraulic models (HEC-RAS) are sensitive to input because manual cross-section digitization, careful calibration and periodic validation with observations are essential. For these reasons, results should be used as decision-support tools rather than absolute representations of risk and they should be updated and recalibrated as new data and technologies become available. The methodology offers a relevant and transferable framework, but it should be applied critically and adaptively to ensure optimal management of natural risks.

3. RESULTS AND DISCUSSIONS

3.1 Preliminary geomorphological risk analysis in the Moldavian Plateau

The integrated analysis of settlement-based drainage basins across the Moldavian Plateau reveals a highly dynamic geomorphological landscape, where contemporary shaping processes are widespread and cumulative in impact. The spatial distribution of the mapped geomorphological processes is shown in Fig. 2. At this working scale, the inventory includes 4,351 landslides, 3,343 gullies, 2,353 areas affected by rill erosion and 17,681 areas with sheet erosion. In terms of community exposure, 605 localities are affected by landslides (out of 1,948 total), 572 by gullies, 728 by rills and 1,820 by sheet erosion. By area, landslides total

28,900 ha, gullies 4,661 ha, rill erosion 21,500 ha and sheet erosion 135,152 ha. This hierarchy clearly indicates that areal processes (sheet) and the transitional shift toward concentrated flow (rill) dominate the overall volume of mobilized material, while gullies and landslides mark nodes of maximum instability—features with immediate relevance for settlement edges and infrastructure.

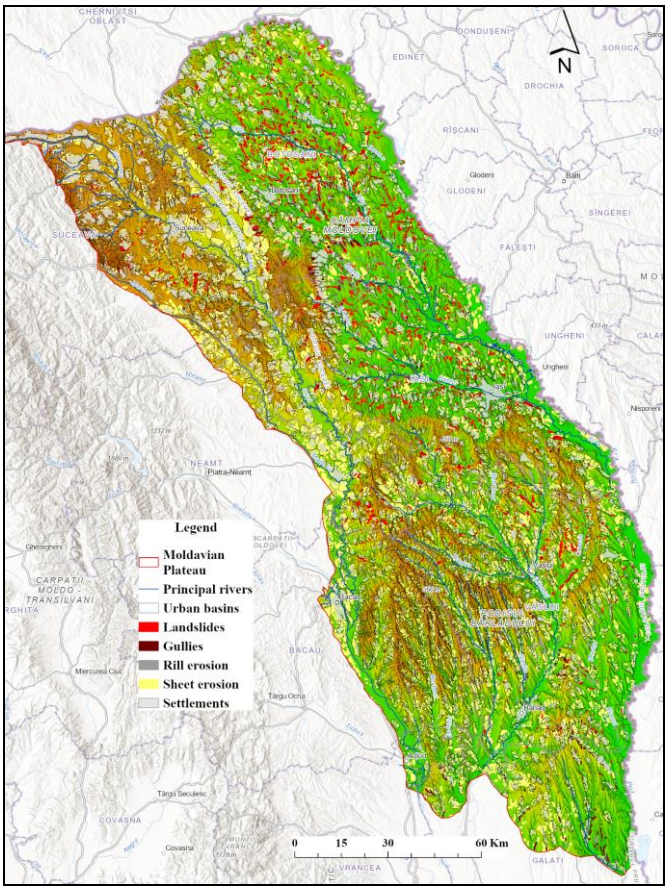

Fig. 2 Integrated geomorphological hazard inventory of the Moldavian Plateau (landslides, gullies, rill & sheet erosion)

The spatial distribution of landslides highlights several well-defined regional nuclees: Ibănesei, Gloduri – Coada Stâncii and Cozancea Hills, Vulturului Crest, Miletin and Dumești Hills. These units share strongly dissected slopes, dense drainage and predominantly friable lithologies (frequent associations of sands, gravels, marls, and clays), favoring both wetting/swelling of materials and the formation of local-scale slip surfaces. Land-use correlation is pronounced: most landslides occur within predominantly agricultural classes with sparse or discontinuous cover, second within intensively worked fields, vineyards and orchards, figures that confirm clustering in heavily farmed areas. Only a small

fraction falls into ostensibly more protective classes (water, wetlands, compact forests). The message is clear: farming practices on bare slopes significantly amplify susceptibility, especially where operations align with slope direction. At the same time, roughly 90% of landslides fall within the relief energy 0–100 m class at local-basin scale, indicating that large altitudinal differences are not required for failure; micro-slope morphology, aspect and slope shape, and lithologic/hydrologic conditions matter more. From a risk-management standpoint, these results support surface and subsurface drainage, bio-stabilization (shelterbelts, deep-rooted shrubs) and restricting agricultural works on slopes >8.5°, ideally reoriented along contour lines.

Gullies represent linear instability cores and signal rapid reshaping of microrelief. A total of 3,343 gullies were mapped, covering 4,661 ha, with the highest densities in Ibănesei and Simila Hills, followed by Volovățului Hills, Viișoarei Hills, Cozancea Hills and Chinejei Hills. Concentration within these units reflects both relief texture (short interfluves and closely spaced valleys) and friable substrata that are easily incised once flow concentrates. Slope is critical: 1,233 cases occur in class 5 (>11.5°), 1,116 in class 4, and 790 in class 3. Once initiated, gullying self-feeds via headward erosion that advances toward interfluves and undercuts secondary scarps, increasing the likelihood of shallow landslides along gully margins.

Rill erosion is the interface process between diffuse erosion and concentrated flow. The 2,353 mapped patches total roughly 17,681 ha and affect 728 localities, underscoring how pervasive the phenomenon is across agricultural mosaics. Peak densities coincide with Volovăț, Dumești and Ibănesei Hills, as well as Vârlănești and Doroșan Ridges, Sacovăț Plateau, Cozancea and Gloduri-Coada Stâncii Hills. Morphometrically, rill erosion is frequent even on moderate slopes: 965 cases fall in class 3 (5.5°–8.5°), 621 in class 4, 301 in class 5, the remainder in classes 1–2. By LU/LC, 1,928 cases are in class 4, and 267 in class 5, confirming the decisive role of agricultural operations, row orientation and seasonal lack of cover.

Sheet erosion constitutes the process “background” at Plateau scale. With 17,681 polygons totaling 135,152 ha and 1,820 localities affected, sheet erosion captures diffuse soil loss on farmed slopes, especially where cropping sequences and mechanical works leave soils bare in the rainy season. The largest clusters occur along Vârlănești and Huțanu Ridges, Simila and Dumești Hills, Sacovăț Plateau and Doroșan Ridge. LU/LC distribution emphasizes: ~11,200 polygons fall in class 5 and ~6,000 in class 4; thus, over 93% of sheet-erosion areas lie on intensively used agricultural land. While it rarely causes spectacular point damage, sheet erosion feeds rills, clogs roadside ditches and culverts and degrades soil fertility, with cumulative economic losses at household and commune scales.

Systematic correlation between processes and controls shows stable patterns. For landslides and gullies, the 8.5° slope threshold marks a clear increase in frequency and slopes >11.5° become critical where friable substrata and concentrated flow coincide. For rills, moderate slopes (5.5°–8.5°) can suffice if fields are worked downslope or if protective strips are absent; under these

conditions, rills densify and evolve into gully systems. For sheet erosion, slope mainly amplifies transport, while land use explains the near-omnipresence of the process: LU/LC classes 4–5 concentrate 70–90% of cases across all processes. Finally, the finding that ~90% of landslides fall within relief energy 0–100 m at local-basin scale suggests that this hazard is governed more by micro-slope morphology than by regional relief energy.

Reading by relief unit outlines instability corridors that follow the terrain's texture: in the northwest, at the contact with the Suceava Plateau; in the central-northern sector (Dorohoi–Botoșani–Iași), where Ibănesei and Volovățului Hills concentrate gullies and Ibănesei and Gloduri – Coada Stâncii Hills the landslides; in the central-southern sector (Huțanu-Vârlănești-Dumești), where rill and sheet processes dominate. These "belts" are useful for prioritizing interventions because they mark sectors where processes reinforce one another, sheet → rill → gully, and gullying degrades slopes, triggering shallow slides.

Settlement exposure differs by process type. Landslides and gullies, although smaller in total area than sheet erosion, lie closer to built-up areas and local infrastructure, affecting access roads, developable land, orchards and gardens at village margins. Rill and sheet processes act over broad areas with diffuse economic impacts: soil loss, ditch siltation, recurring maintenance costs for drains and culverts and reduced agricultural productivity. For operational prioritization, these results should be intersected with distance to the built-up edge (e.g., 200–500 m belts), critical infrastructure (county/national roads, bridges) and socio-economic indicators (settlement density, building typology).

For policy and planning, the picture already points to clear directions. In settlements with high sheet and rill densities, emphasis should be on conservation agriculture: contour farming, grassed buffer strips perpendicular to slope, crop rotation, winter cover and avoiding deep tillage on slopes >8.5°. Where gullies approach built-up areas, grade-control structures, diversion ditches and interfluve afforestation are needed to reduce concentrated discharge; works should proceed from downstream to upstream to stabilize the longitudinal profile sequentially. For landslides, controlled drainage (capturing slope springs, contour drains) and vegetative stabilization are priorities; on sensitive slopes, benching and light palisade systems can rapidly lower risk. Everywhere, monitoring (profiles, benchmarks, post-event checks, integration with EGMS) is necessary to capture acceleration trends.

Integrating these findings into a composite Geomorphological Factor (FG) and a multi-hazard score (FG combined with flood risk) will allow ranking localities by cumulative vulnerability and delimiting micro-perimeters for intervention. Given that for landslides and gullies the 8.5° slope threshold is decisive and 70–90% of processes occur in LU/LC classes 4–5, the weights of these factors should remain high in the final calculation. Based on the current map and unit-level statistics, Ibănesei and Gloduri – Coada Stâncii Hills, Volovățului, Racova Plateau, Repedea-Zăpodeni, Mălușteni, Simila and Vișoara Hills, Huțanu

and Vârlănești Ridges and Elan Depression emerge as obvious priorities for monitoring and pilot projects to reduce geomorphological hazard.

3.2 Flood risk in the Moldavian Plateau — Preliminary Results

Flooding represents one of the principal natural threats to communities across the Moldavian Plateau, a region marked by a dense river network and pronounced climatic variability. Historical extremes, such as the 2008 event, have produced substantial damage to infrastructure, housing and agricultural land. In this context, rigorous evaluation and hydraulic modeling are essential to support effective risk management and strengthen local resilience.

Using HEC-RAS, we modeled flood scenarios on representative river sectors (e.g., Fig. 3, the Suceava River, Mihoveni-Iţcani reach) with a historical peak discharge of 1,710 m³/s recorded at Iţcani during 2008. Two scenarios were tested: (i) a "natural" propagation without structural defenses and (ii) an alternative scenario that introduces artificial levees to protect critical zones. The simulations produced maps of inundation extent, maximum water depth and water surface elevations (WSE). For the Suceava sector, the no-levee scenario yields a maximum depth of ~12.66 m and a peak WSE of 285.93 m, with extensive impacts on residential areas, farmland and local infrastructure. With levees in place, the maximum depth increases to ~13.09 m and WSE to 286.86 m, reflecting hydraulic backwater under constrained floodplains, yet the total inundated area decreases notably. These preliminary results highlight a classic trade-off: structural measures can shrink the footprint of flooding but raise hydraulic pressure, which in turn demands careful structural design and complementary non-structural strategies.

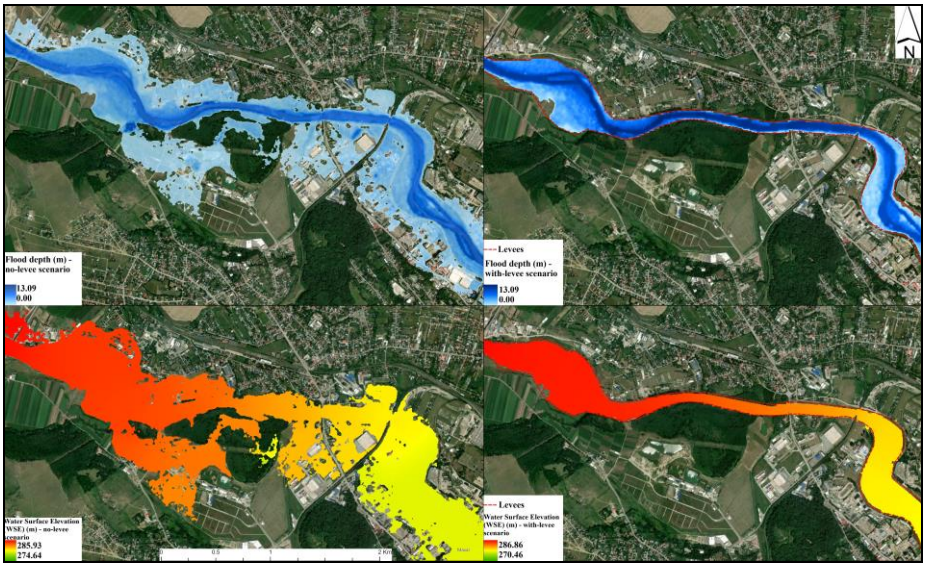

Fig. 3 Effectiveness of the proposed levees on the Mihoveni-Iţcani reach of the Suceava River in reducing flood risk (Q = 1,710 m³/s)

At plateau scale, the climate-corrected 1% annual exceedance probability (AEP) flood belt (1%CC) enlarges the footprint of hazard across the Moldavian Plateau well beyond the baseline 1% belt. In Fig. 4, the mapped inundation area rises from 111,549 ha to 149,184 ha, an absolute increase of 37,635 ha, or +33.7%. This expansion translates into broader settlement exposure: the number of affected localities grows from 398 to 451 (+13.3%). More consequentially, the intersection with the built fabric intensifies: exposed households increase from 10,514 to 14,112 (+34.2%), and the estimated affected population (excluding municipalities) escalates from 27,350 to 36,700 (+34.2%). In short, the climate correction yields roughly one-third more people and households at risk, not merely a marginal widening of the floodplain outline.

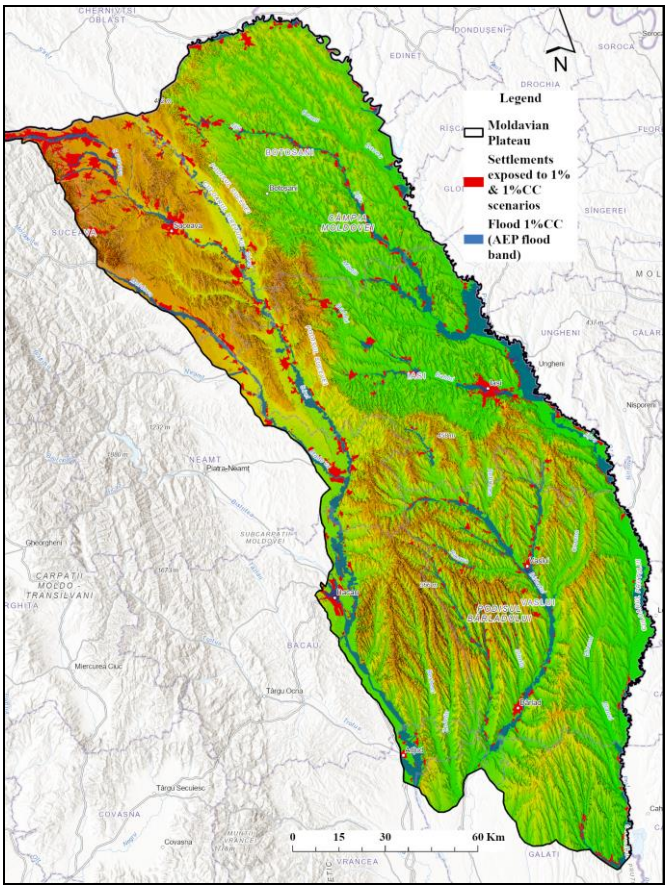

Fig. 4 Exposed settlements to 1% & 1%CC (AEP flood blands) in the Moldavian Plateau

Intensity metrics reinforce this message. Average inundated area per affected settlement increases from ~280 ha to ~331 ha (+18.0%), while exposed households per affected settlement rise from ~26.4 to ~31.3 (+18.4%) and exposed population

per affected settlement from ~68.7 to ~81.4 (+18.4%). By contrast, the persons-per-household ratio remains stable at ~2.6 in both scenarios, indicating that the demographic coefficients used for allocation are consistent and that the growth in exposed population is driven by the spatial expansion of hazard over built surfaces rather than by compositional change in household size. Put differently, the 1%CC belt tends to "bite deeper" into existing settlement footprints and to add segments of denser neighborhoods at the built-up edge, rather than only adding many small, newly affected villages.

From a spatial-process perspective, this pattern is plausible. Climate-adjusted hydraulics typically expand the hazard onto low terraces, confluence platforms and defended reaches where residual risk persists behind levees (e.g., backwater and higher stages for a given discharge). The modest (+13.3%) increase in the count of affected settlements relative to the much larger increases in households and people (~+34%) suggests that many of the newly inundated polygons lie within or adjacent to settlements already intersected by the baseline 1% belt. In practice, this means more parcels and street segments per settlement fall inside the 1%CC contour, especially where recent development has advanced toward the active floodplain or where local microrelief channels flow toward built areas.

Planning and protection implications follow directly. First, zoning and development control should adopt the 1%CC envelope (with buffers) as the operative limit for new construction, curbing further encroachment into high-consequence corridors. Second, settlement-level mitigation must shift from broad prohibitions to block-scale measures: elevating utilities, protecting critical access (bridges, underpasses) and designing drainage to avoid entrapment between levees and higher ground. Third, structural defenses remain necessary in selected hot spots, but their design should reflect the well-documented trade-off: reduced inundation footprint at the cost of higher stages and hydraulic loads. Our HEC-RAS case study on the Suceava River exemplifies this dilemma, highlighting the need to pair levees with non-structural instruments (setbacks, buyouts, floodproofing) and rigorous operation/maintenance plans.

Taken together, the climate-corrected scenario enlarges flood hazard by one-third and intensifies exposure within currently affected settlements by roughly one-fifth. Because the additional risk concentrates at settlement margins and along critical infrastructure, priority actions should focus on (i) enforcing setbacks in expansion fronts, (ii) safeguarding evacuation and service continuity and (iii) periodically updating hazard layers and inventories to track micro-scale changes in topography and land use that govern local inundation dynamics.

4. CONCLUSIONS

The detailed assessment of geomorphological and hydrological risks in the Moldavian Plateau, reveals significant regional trends and provides clear directions for risk management.

Regarding geomorphological hazards, this study maps contemporary geomorphological hazards across settlement-based drainage basins of the

Moldavian Plateau and quantifies their implications for communities. The inventory documents 4,351 landslides, 3,343 gullies, 2,353 rill-erosion patches and 17,681 sheet-erosion polygons. Exposure is widespread: 605 localities are affected by landslides (out of 1,948), 572 by gullies, 728 by rill erosion and 1,820 by sheet erosion. By area, impacts total 28,900 ha (landslides), 4,661 ha (gullies), 21,500 ha (rill erosion) and 135,152 ha (sheet erosion), confirming that areal processes (sheet erosion) and their transition to concentrated flow (rill erosion) dominate overall sediment mobilization, while landslides and gullies mark nodes of acute instability with direct relevance for settlement fringes and infrastructure.

Spatial clustering of landslides is the strongest on Ibănesei and Gloduri – Coada Stâncii Hills, Racova and Repedea-Zăpodeni plateaus, Mălușteni Hills, Mitoc Plateau and Elan Depression, units characterized by dense dissection and friable lithologies (sands, gravels, marls, clays). Land-use controls are decisive: almost 80% of landslides fall in predominantly agricultural classes with sparse cover and the rest in intensively worked fields, vineyards, and orchards; >93% of sheet-erosion polygons lie on intensively used farmland. Process-control relationships are consistent: ~90% of landslides occur within relief energy 0–100 m; frequencies rise sharply above slope thresholds of 8.5°–11.5°; rills are frequent even on 5.5°–8.5° slopes when fields are worked downslope. These patterns delineate "instability belts" where sheet → rill → gully cascades and gully headward erosion precondition shallow landslides. Management priorities follow directly: contour farming and grassed buffers on cultivated slopes, targeted surface/subsurface drainage and vegetative stabilization near settlements, grade-control and diversion works where gullies encroach and continuous monitoring (including EGMS) to detect acceleration. Integrating these layers into a composite Geomorphological Factor and, subsequently, a multi-hazard score will enable settlement-level ranking and micro-perimeter design for intervention.

From a hydrological perspective, the climate-corrected 1% AEP belt (1%CC) materially amplifies exposure across the Moldavian Plateau. Plateau-wide, the inundation footprint expands from 111,549 ha (1%) to 149,184 ha (1%CC), a +33.7% increase; the number of affected settlements rises from 398 to 451 (+13.3%). More importantly for consequence, intersected households grow from 10,514 to 14,112 (+34.2%) and the estimated exposed population (excluding municipalities) from 27,350 to 36,700 (+34.2%). This asymmetry, moderate growth in the count of impacted localities but a one-third jump in exposed people and dwellings, indicates that the 1%CC belt encroaches deeper into already vulnerable urban fabrics rather than simply adding many new places to the risk map.

Spatially, exposure remains heterogeneous. Along rivers with wide floodplains and long-standing settlement on low terraces (e.g., the Suceava, the Siret, the Jijia), large shares of intravilan overlap the flood belt and the 1%→1%CC expansion tends to capture additional street blocks and household clusters.

These findings argue for adopting the 1%CC envelope as the planning baseline, enforcing setbacks and steering new development away from floodplains and immediate buffers. Where dense, built-up exposure already exists, a combined

strategy is required: carefully engineered structural measures (e.g., levees, bank stabilization) paired with non-structural tools (zoning, selective buyouts, elevation/floodproofing, contingency routing). Priority attention should focus on settlements where high intravilan overlap aligns with confirmed residential exposure, while periodic updates of hazard maps and inventories are essential to track change and sustain resilience under evolving climate conditions. In sum, the Moldavian Plateau exhibits a diverse suite of significant geomorphological and hydrological risks that vary regionally and require context-specific approaches. The sharp rise in landslides in certain areas and the persistence of extreme hydrological events call for an urgent re-evaluation of urban planning and risk-management policies. Local authorities should prioritize investment in both structural and non-structural measures, levees, slope stabilization, buffer zones, alongside continual updates of risk maps and emergency plans. Equally, community awareness and participation are essential to reduce vulnerabilities and strengthen resilience amid climate change and increasingly frequent natural extremes.

REFERENCES

1. Alexander, D. (1993), Natural Disasters. Chapman & Hall, London.

2. Bănică, A., Istrate, M., Muntele, I., & Grozavu, A. (2024), Recent dynamics of suburban advancement and building densification in relation to landslide exposure in the main cities of North-East Romania. Journal of Settlements and Spatial Planning, 15, 11–21. https://doi.org/10.24193/JSSP.2024.1.02, accessed August 2025

3. Birkmann, J. (2006), Measuring Vulnerability to Natural Hazards. United Nations University Press. https://digitallibrary.un.org/record/587074?v=pdf, accessed March 2025

4. Birkmann, J., Cardona, O. D., Carreño, M. L., et al., (2013), Framing vulnerability, risk and societal responses: The MOVE framework. Natural Hazards, 67, 193–211. https://doi.org/10.1007/s11069-013-0558-5

5. Borrelli, P., et al., (2017), An assessment of the global impact of 21st century land use change on soil erosion. Nature Communications, 8, 1–13. https://doi.org/10.1038/s41467-017-02142-7

6. Brunner, G. W. (2016), HEC-RAS River Analysis System Hydraulic Reference Manual. U.S. Army Corps of Engineers.

7. Cardona, O. D., van Aalst, M., Birkmann, J., et al., (2012), Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC SREX Report), Cambridge University Press. https://www.sei.org/publications/determinants-of-risk-exposure-and-vulnerability/, accessed May 2025

8. Crozier, M. J. (2010), Deciphering the effect of climate change on landslide activity: A review. Geomorphology, 124, 260–267. https://doi.org/10.1016/j.geomorph.2010.04.009

9. Cruden, D. M., & Varnes, D. J. (1996), Landslide types and processes. In Turner, A. K. & Schuster, R. L. (Eds.), Landslides: Investigation and Mitigation,

pp. 36–75. National Research Council, Transportation Research Board. https://www.researchgate.net/publication/269710355, accessed April 2025

10. Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003), *Social Vulnerability to Environmental Hazards.* Social Science Quarterly, 84, 242-261. https://doi.org/10.1111/1540-6237.8402002

11. Glade, T. (2003), Landslide occurrence as a response to land use change: A review of evidence from New Zealand. CATENA, 51, 297–314. https://doi.org/10.1016/S0341-8162(02)00170-4

12. Grecu, F. (2009), Hazarde și riscuri naturale geologice și geomorfologice. Editura Universitară, București.

13. Ioniță, I. (2000), Geomorfologie aplicată: procese de degradare a regiunilor deluroase. Editura Corson, Iași.

14. IPCC, (2021), Sixth Assessment Report. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg1/, accessed June 2025

15. Kundzewicz, Z. W., et al., (2014), Flood risk and climate change: global and regional perspectives. Hydrological Sciences Journal, 59, 1 - 28. https://doi.org/10.1080/02626667.2013.857411

16. Niacșu, L., Ioniță, I., Samoilă, C., Grigoraș, G., & Blebea-Apostu, A. M. (2021), Land Degradation and Soil Conservation Measures in the Moldavian Plateau, Eastern Romania: A Case Study from the Racova Catchment. Water, 13 (20), 2877. https://doi.org/10.3390/w13202877

17. Petley, D. N. (2012), Global patterns of loss of life from landslides. Geology, 40, 927–930. https://doi.org/10.1130/G33217.1

18. Rădoane, M., Ichim, I., & Rădoane, N. (1995), Gully distribution and development in Moldavia, Romania. Catena, 24 (2), 127–146. https://doi.org/10.1016/0341-8162(95)00023-L

19. Rădoane, M., & Rădoane, N. (2017), Gully erosion in the Moldavian Plateau, Romania. Landform Dynamics and Evolution in Romania, 371–396. Springer International Publishing. https://doi.org/10.1007/978-3-319-32589-7_16

20. Romanescu, G., Cotiuga, V., Asăndulesei, A., & Stoleriu, C. C. (2012), *Use of the 3-D scanner in mapping and monitoring the dynamic degradation of soils: case study of the Cucuteni-Băiceni Gully on the Moldavian Plateau (Romania).* Hydrology and Earth System Sciences, 16, 953–966. https://doi.org/10.5194/hess-16-953-2012

21. UNDRR, (2019), Global Assessment Report on Disaster Risk Reduction 2019. United Nations Office for Disaster Risk Reduction. https://www.undrr.org/media/73965, accessed May 2025

22. Varnes, D. J. (1978), Slope movement types and processes. Transportation Research Board, Special Report 176.