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GEOMORPHOLOGICAL RISK AND VULNERABILITY OF THE SUBCARPATHIAN AND PIEDMONT SECTORS OF THE GILORT RIVER BASIN

RISC GEOMORFOLOGIC ȘI VULNERABILITATE ÎN SECTORUL SUBCARPATIC ȘI PIEMONTAN AL BAZINULUI HIDROGRAFIC GILORT (ROMÂNIA)

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Abstract: Currently, geomorphological studies have been tasked with investigating a large part of natural hazards, so any study should end with a geomorphological risk map. The geomorphological risk maps take into account the analytical and synthetic integration of as many variables as possible to target both natural and social elements. In approaching the geomorphological risk assessment methodology, it is necessary to correlate each control factor with the map of current geomorphological processes and establish its weight of influence. A layer was created for each variable and the current processes were quantified by means of another layer by using Spatial Analyst - Density (ArcGIS). From the obtained layers, the numerical information was extracted according to a grid network, adopting a convenient size of the grid cell. Considering the dynamics of the current processes in the Subcarpathian and the Piedmont sector of the Gilort hydrographic basin (Romania), the geomorphological risk map was created for this space, highlighting four categories of risk (very low, low, medium and high). The obtained map has an important practical utility and includes the degree of vulnerability of the anthropogenic component to certain types of natural hazards.

Key-words: *geomorphological vulnerability and risk, landslides, land degradation, ravines, geomorphological risk map, vulnerability assessment, the Gilort basin*
Cuvinte cheie: *vulnerabilitate și risc geomorfologic, alunecări de teren, degradarea terenurilor, ravene, harta riscului geomorfologic, evaluarea vulnerabilității, bazinul Gilort*

1. INTRODUCTION

The geomorphological risk is mainly due to slope processes, such as landslides, collapses, ravines, torrents and, in general, land degradation. Although the aforementioned phenomena did not take catastrophic forms, their impact on the

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environment in certain sectors of the Gilort basin occurs on a massive scale, which is why a quantification of the current processes captured by both the geomorphological map and the geomorphological risk map is required. "Geomorphological risk maps are synthetic maps, resulting from the analytical and synthetic integration of a large number of variables targeting both natural and social elements" (Grecu, 2006), creating an interference between the elements of the present and the future.

In the Romanian scientific literature, the *geomorphological risk map* (Bălteanu et al., 1989) is, most of the time, equivalent to the *land vulnerability map,* although a semantic differentiation between the two terms would be required. The land vulnerability map must also include the degree of damage to the anthropogenic component in certain dangerous events, while the geomorphological risk map "*brings to the forefront the analysis of the instability potential of an area*" (Armaş, 2006). Considering this differentiation, from a geomorphological perspective, the use of the term "*vulnerability map*" would be appropriate for analyzing the potential instability of the landform, which also requires the study of the anthropogenic component, rather than merely summing up the factors that directly or indirectly influence landform modeling. Vulnerability can indicate the degree of damage on a risk-exposed system, as a weight in the case of a probable disaster acting upon that system (Glade et al., 2005). Reducing vulnerability may represent the solution for reducing risk, this being a result of socio-economic evolution, being directly influenced by society, while control over hazard is maintained at a minimum level (Armaș, 2008).

Geomorphological risk mapping involves the overall assessment of most of the factors that influence the development of current processes (geological, morphological, climatic, hydrological, bio-pedological factors). The vulnerability map to geomorphological hazards is a synthetic map that highlights the current state of the dynamics of the relief and the evolution of the human-environment relationship, being based on analytical maps developed on the basis of quantitative indices (Grecu et. al., 2020). Although the term geomorphological hazard is less used in the literature, geomorphological studies are those that have the important task of researching natural hazards (Gares et al., 1994).

The parameters that are considered defining in establishing risk coefficients (slope, geology, vegetation, current processes) can be ranked and prioritized on the basis of risk exposure criteria based on field observations (Armaș, 1999; Armaș et al., 2003). Between these factors and the complex reality of geomorphological processes there is not only a unidirectional correlation, the dynamics in the system being controlled also through feedback processes (Armaș & Benea, 1996), which highlights that the approach of a mathematical model in this case has limits and may introduce errors.

The Gilort River is the most significant left-bank tributary of the Jiu River; it falls into the category of the southern group of rivers in Romania. The drainage basin extends across three distinct and well-defined landform units: the Carpathian zone (the southern slope of Parâng Mountains), the Subcarpathian zone (Gorj

Subcarpathians, which are part of the Getic Subcarpathians), and the Piedmont zone (the Getic Piedmont). The Gilort River watershed covers an area of 1,358 km² and flows generally from north to south over a distance of 116 km, with an elevation difference of 2,412 meters, ranging from a maximum altitude of 2,518 meters (Parângu Mare Peak) to a minimum altitude of 106 meters (at its confluence with the Jiu River). The river basin develops as follows: 25% in the mountainous sector, 38% in the Subcarpathian sector, and 37% in the Piedmont sector.

Due to the fact that a large part of the Gilort River basin overlaps with the area of the Subcarpathian and piedmont hills – a region known for slope dynamics issues (Badea, 1967; Roșu, 1967; Badea & Bălteanu, 1978; Bălteanu, 1986; Badea & Bălteanu, 1992; Bălteanu et al., 1994; Călugăru, 2003; Nistor, 2007; Marinescu, 2006; Marinescu, 2008), numerous areas susceptible to geomorphological risk emerge. These, in their turn, lead to changes in slope geometry and in natural balance and constantly generate socio-economic damage. Currently, mass movements combined with gully erosion processes represent the main slope processes, strongly influencing all other landscape components (Surdeanu, 1998). Gravitational processes generally affect the weathering mantle, which consists of chemically and physically in situ altered materials. However, in the studied area, unaltered rock masses, such as marls and clays, as well as the overlying deposits, are also frequently affected.

In the studied area, mass movements are mostly widespread on the slopes of the hills composed of marl-clay formations covered by lithological complexes containing gravels, sands, coal, etc. The Meotian and Pontian clay marls, which frequently outcrop on the slopes of the inner Subcarpathian hills or in other regions, create multiple favourable conditions for the occurrence of gravitational slope processes (Geological maps, scale 1:25,000, Geological Institute, Sheet Tg. Jiu, 1980; Enache, 2007). Additionally, another cause of the mentioned geomorphological processes is the presence of thick horizons of weakly cohesive sands and gravels in the piedmont hills, where rivers carve valleys with steep slopes, that favour the occurrence of collapses.

2. DATA AND METHODS

In the approach to the methodology for assessing geomorphological risk, it was necessary to correlate each controlling factor with the map of current geomorphological processes and determine its influence weight (Grecu & Comănescu, 1997; Grecu et al., 2004). The analysis of these correlations requires an advanced mathematical framework, the capacity to handle a large number of variables, as well as the capacity for graphical representation and manipulation of spatial information layers, which is made possible by means of an appropriate software (Excel, ArcGIS).

In practice, a layer must be created for each variable, and the current processes will be quantified using a cumulative layer by applying Spatial Analyst – Density. A separate layer is needed for each type of process because the input variables control the processes to be analyzed in different ways. The numeric information is extracted from the resulting layers according to a grid network. The dependency process=f(factor) is studied using the linear regression method, obtaining the coefficient of determination r², which indicates how many processes are determined by the factor. This coefficient provides the weight of the control factor in the morphodynamic processes for the creation of the risk map. Since this algorithm is particularly labor-intensive, to establish the weight of each factor in determining the current processes, we overlaid the 1km-cell grid, used in the morphometric maps, over the geomorphological map and simultaneously over the maps of each variable considered defining for the current processes (geological map, slope map, land use map, fragmentation density map, relief energy map).

To create the risk maps at a large scale, control factors such as slope orientation, maximum rainfall in 24 hours, tectonic implications in the relief configuration, etc., can also be considered. Analyzing the determination in various grid cells, we assessed that the weights of these variables could be considered substantially equal. In Table 1 and Table 2, we present the vulnerability categories (classes) for each indicator considered, based on the risk exposure criterion and field observations, as well as the risk coefficient (CR) for each category.

Table 1 Classification of indicators by vulnerability categories

Indicator	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**
Land use	Forests, orchards	Shrubs, wetlands	Alpine meadows	Agricultural lands	Arable land	Urban land, industrial structures	Pastures, natural grasslands, heathlands	Surface mining lands
Lithology	Limestone, granite, granitoids, crystalline schists	Sandstones, conglomerates	Loess deposits of reddish clays	Gravels, sands	Sands, clays, marls	Clays, sands, coal	Marl clays	
Declivity	0-7^0	7-15^0	15-25^0	>25^0	-	-	-	-

Table 2 Table of risk coefficients for the determinant indicator

Indicator	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**
	Risk coefficient							
Lan duse	1	2	3	4	5	6	7	8
Lithology	1.14	2.28	3.42	4.56	5.7	6.84	8	-
Declivity	2	4	6	8	-	-	-	-

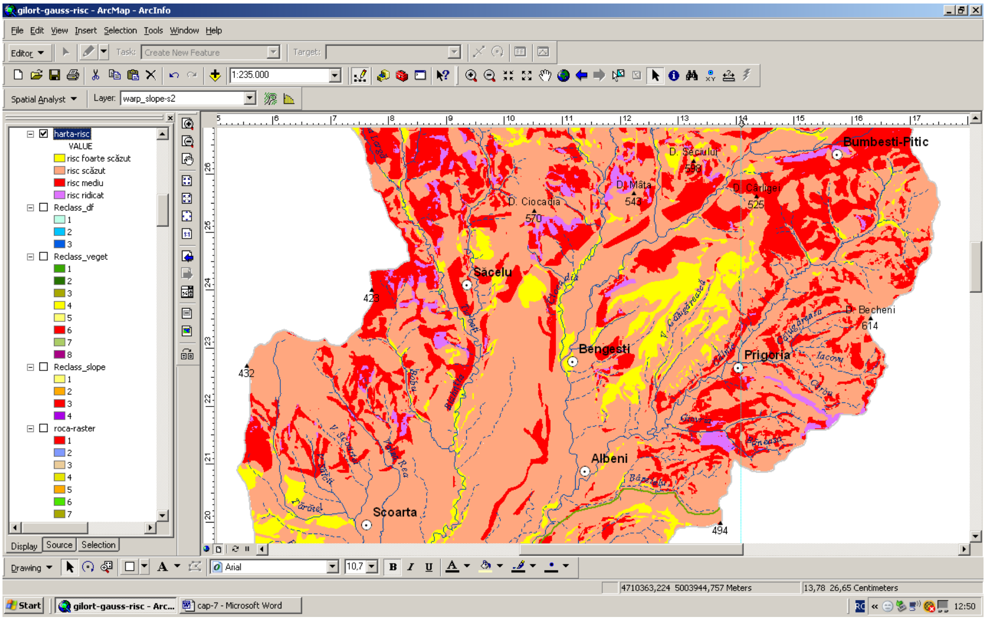
The maximum number of categories is 8 for land use. Category 1 has CR=1, category 2 has CR=2, ..., category 8 has CR=8. Next, the risk coefficient CR is redistributed for each category of the other indicators. Examples:

- for declivity – slopes of 7-15° (category 2):
  CR= 2 x 8/4 (the maximum number of categories for slope is 4);
- for lithology – marl clays (category 1):
  CR= 1 x 8/7 (the maximum number of categories for lithology is 7).

To obtain the geomorphological risk map in the Subcarpathian and piedmont sectors of the Gilort basin, the ArcGIS 9.2 program was used. The layers used were reclassified according to the vulnerability categories; a corresponding degree of vulnerability was assigned to each pixel of the reclassified layers. Each newly classified layer was saved as a new raster. The resulting rasters were summed up using *Spatial Analyst* - *Raster Calculator* with the following formula:

$$[hartarisc] = \left([roca - raster]x\,\frac{8}{7}\right) + \left([reclass\_slope]x\,\frac{8}{4}\right) + [reclass\_veget] \quad (1)$$

The final resulting raster required a new reclassification into risk classes based on the characteristics of the studied basin and the map scale, so that the graphical presentation would be meaningful and represent a synthesis of the land's vulnerability (Fig. 1).



Layer: warp_slope-s2

4710363,224 5003944,757 Meters

13,78 26,65 Centimeters

Fig. 1 The geomorphological risk map in the ArcMap program's workspace

The obtained map was compared with the map of current geomorphological processes, compiled based on field observations, showing a good correspondence with the frequency and typology of these processes.

3. RESULTS AND DISCUSSIONS

The preparation of the geomorphological risk map of the Subcarpathian and the piedmont sector of the Gilort basin took into account the dynamics of current processes in this area. Four risk categories were highlighted (very low, low, medium, and high). The geomorphological risk map thus obtained (Fig. 2) is one of the maps with practical applicability and is part of the global risk research, which is primarily based on the systematization and typification of risk phenomena.

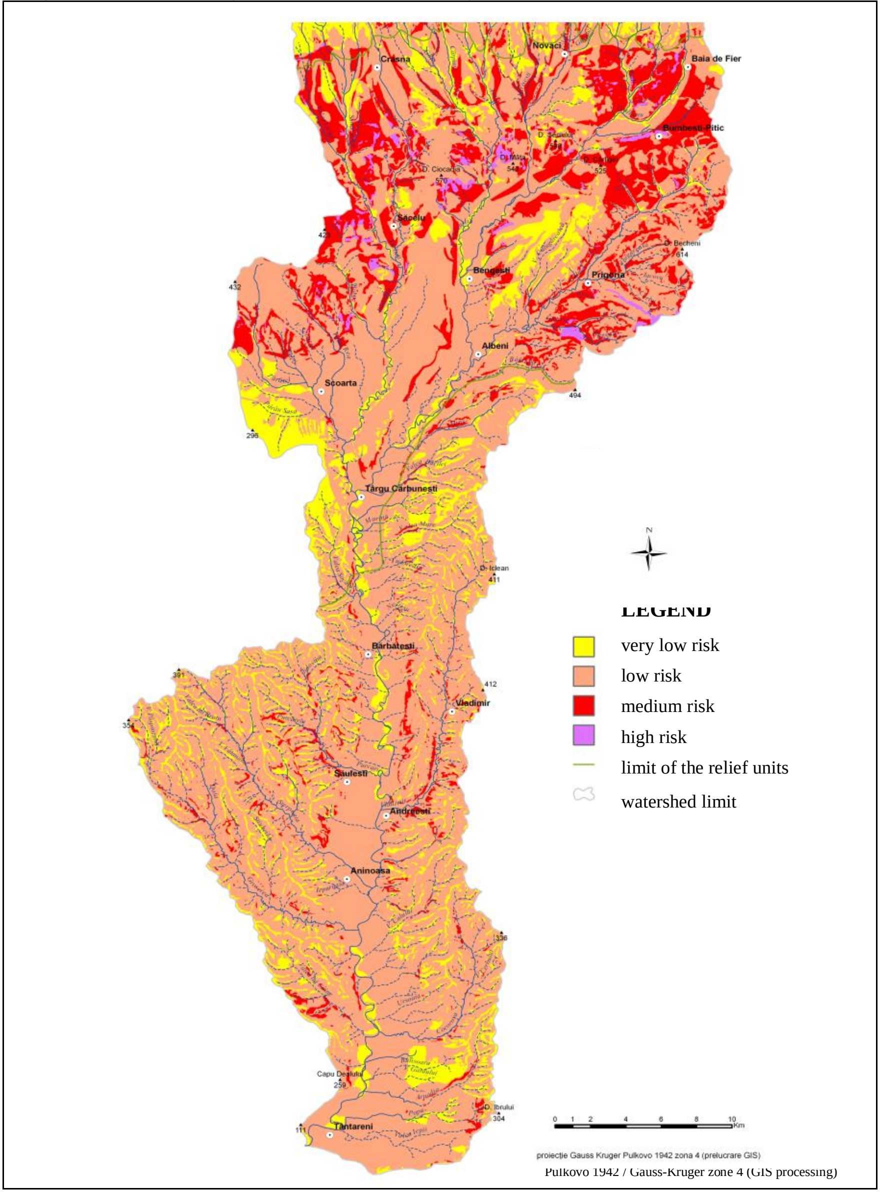


Fig. 2 The geomorphological risk map in the Subcarpathian and piedmont sector of the Gilort basin

Areas with high risk are found in the regions where high vulnerability categories overlap. Thus, in the piedmont hills, the most exposed slopes to risk are found in the basins of Valea lui Câine, Purcărelu, and Vladimir, as well as in the torrential valleys between Valea Mare and Valea Cailor (the left slope of the Gilort). In the Subcarpathian area, zones exposed to high risk are found in the Câlnic, the Blahniţa basins, and in the inner Subcarpathian hills (Ciocadia, Seciului H., Săcelu H., Mâţa H.).

To correctly determine the weight of vulnerability indices, it must be considered that some control factors may gain increased local importance. In this regard, in the Subcarpathian sector of the Gilort basin, we identified several areas where factors decisively contribute to triggering landslides, ravine formation, or flooding with negative effects on the population's activities. We present some examples of such determining factors that have high local importance in the studied area, with the aim of finding solutions to keep under control the risk phenomena that can severely affect local communities.

Among the factors of increased local importance, the land use and improper agricultural practices stand out (e.g., mining activities near settlements with a high degree of vulnerability, inadequate agricultural works on slopes, deforestation for increasing grazing areas, etc.). By mining stripping and storing large quantities of the extracted spoil, significant environmental changes were made, which led to the triggering of large-scale landslides with disastrous effects on the settlements in the area (Fig. 3). The localities of Ruget, Corbu, Roșia de Amaradia, and Seciurile, located on either side of the watershed between the Gilort and the Amaradia, were the most affected.

Fig. 3 The storage of spoil heaps on the Gilort-Amaradia interfluve (Ruget mining exploitation) led to the overloading of the slopes and the triggering of landslides

Lignite mining exploitations with landscape impacts are located on the interfluve in the contact area of two neighbouring basins (Câlnic – a tributary of the Gilort River and the Amaradia), specifically along the direction of the villages Seciurile – Ruget – Roșia de Amaradia. On the spoil heaps, which initially posed only an issue of placement, current geomorphological processes have emerged, among which landslides are significant. In Ruget area, large spoil heaps were deposited for 20 years, which ultimately led to the overloading of the slopes, representing the anthropogenic trigger factor for the large landslide that destroyed the village of Seciurile in 2006 (Fig. 4). The population of this village had to be relocated to the Gilort Valley, in Câmpu Mare.

Fig. 4 The effects of landslides in Seciurile

Another area with a high degree of vulnerability to landslides, which affects the population by drastically reducing grazing areas, is located in the Câlnic basin, on the left slope of the Giovria Valley. The morphodynamic complex of the slope of Pruneștilor Hill reduces the grazable area by about 100 hectares, so the inhabitants are forced to use as grazing land what had been designated for other purposes. Practicing agricultural work perpendicular to the contour lines leads to the transition from surface erosion to the concentration of runoff on the slopes and the appearance of incipient forms of rill erosion, which can later affect the entire slope. On the Giovria Valley, the left slope is deeply affected by slope processes (landslides, rilling), while the right slope, due to inadequate agricultural practices, exhibits high vulnerability (Fig. 5).

In the piedmont area, intensive grazing on some valleys in Gruiurile Jiului (Valea lui Câine, Sterpoaia, Groșerea) and in the Amaradia Hills area has favoured the triggering of processes that affected the entire slope.

4. CONCLUSIONS

In the Subcarpathian sector of the Gilort watershed, landslides are the most widespread form of mass movements; among their causes there are lithological conditions, slopes, land use, and the artificialization of the landscape. Geomorphological risks represent a major set of threats to the population and assets, being closely determined and linked to hydrological and atmospheric risks. Various climatic phenomena (heavy rains, rapid snowmelt, strong storms, etc.) lead to an increase in water levels and flows above normal values, which causes flooding in the surrounding areas and sometimes results in extreme flash floods. The development of mass movement processes and the rapid evolution of slopes has been driven by the predominance of marl-clayey, clayey-sandy rocks, and sandy clays. Landslides, in terms of extent, intensity, and magnitude, together with rilling and torrentiality, are the main degradation processes with a major impact on the land by altering, sometimes radically, the relief configuration.

Fig. 5 Collapses, detachment gullies, and sliding waves in the central sector of the landslide in the Giovria Valley (Gorj Subcarpathians)

Landslides are the most widespread forms of mass movements in the Subcarpathian sector of the Gilort basin (high-risk category), while the piedmont area can be classified as a region with moderate landslides (medium risk). Landslides show a differentiated distribution in the Subcarpathian area of the basin, but they have a relatively high frequency due to the considerable extent of marl clays and Miocene clays in the internal Subcarpathian hills and, particularly, in the Câlnic basin (high-risk category according to the compiled map).

The vast majority of landslides occur at the caprock of the cuesta formations or in a subsequent direction at the headwaters of torrential tributary valleys of the main valleys that are north-south oriented. The most typical example of landslide manifestation in the studied area is on the cuesta surface of Negoești Hill (Giovria Valley), where a whole range of landslide forms appears due to the undermining action of slopes by torrential erosion. In the areas with the most extensive landslide development (along the Giovria and Hârna rivers, in the Câlnic basin), two or three generations of landslides can be observed, forming two or three large, well-defined steps (high geomorphological risk category, with landslides reactivated today).

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