Landslides Hazard Assessment in the Upper and Middle Sectors of the Strei Valley

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Abstract: The landslides have been identified at the geomorphological units level, included in the study area, beginning with the second half of the 20th century, but a factor based analysis was performed only in the first part of the 21st century.

In some cases, works for stabilizing the affected slopes were made, but by modifying the land use and destroying the existing works, the processes have been reactivated. At present, the process continues to extend and to take out from the agricultural circuit large areas, fact noticed after analyzing maps from different periods as well as during the field activity. Consequently, we considered to make an objective landslides hazard assessment, following the steps from a legal framework, to use the results in territorial planning studies.

Key words: landslides, hazard assessment, mean hazard coefficient, upper and middle sectors of the Strei valley.

1. Introduction

With an area of over 1559sq.km, the upper and middle sectors of the Strei valley stands out as a well-individualised natural entity, almost entirely included in the Southern Carpathians, except the north- western part that belongs to the Western Carpathians, and has a general triangular shape. It is bordered to the south- east by the Retezat Mts., to the south by Piule Iorgovanu Massive and the Godeanu Mts., to the west and north-west by the Tarcului Mts. and Poiana Ruscai Mts., and by the Sureanu Mts. to the north-east (Fig. 1). From the administrative point of view, within its boundaries there are included 10 communes, dominated by one town.

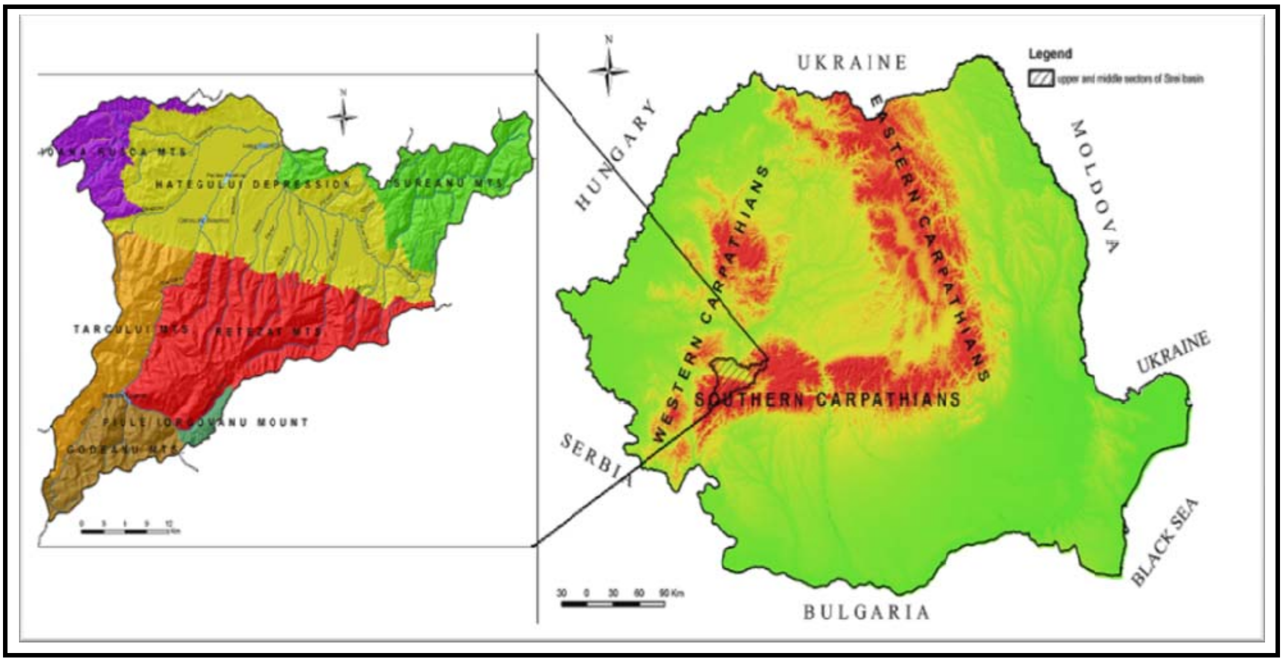

Figure 1. Upper and middle sectors of the Strei valley. Location map

In Romania, the study of landslides has a long tradition. Whether we are talking about the landslides that occurred in the Carpathians, the Sub-Carpathians, the plateaus or depressions, their study focused on issues, such as: triggering factors, morphology, morphodynamics, distribution, age, etc.

The presence of landslide processes in the Hategului Depression was reported by Grumazescu, 1975. Also, in the agro-pedological studies conducted in 1976, 1983 and 2003, for certain areas of the upper and middle sectors of the Strei valley, these processes were located, without putting emphasis on other aspects. The assessment of the slopes susceptibility to landslides was performed for the first time in Tara Hategului by Gotiu and Surdeanu, 2008. The authors conducted a factor analysis of the slopes susceptibility to landslides using the frequency rate method. A synthesis map was obtained by overlaying thematic maps.

2. Methodology

In this study, the landslides **identification and mapping,** based on 1:25,000 scale cartographic materials, edition 1963, studies accompanying soil maps from 1976, 1983 and 2007 and orthophos, edition 2005 (resolution 0.5m) was conducted. The data obtained was supplemented with information gathered during the field work. To harmonize the results at the national level, in the landslide hazard assessment, we used the methodology set out in the Government Decision no. 447/2003. Thus, the results can be used in planning studies.

To obtain **the landslide hazard map,** we followed these steps:

a) we estimated the value and geographical distribution of risk factors (Ka-h) based on the criteria from Appendix C from the methodological norms: lithology (Ka), geomorphology (Kb), structure (Kc), hydrology and climate (Kd), hydrogeology (Ke), seismicity (KF), forestry (kg), anthropogenic (Kh);

b) we established the potential degree (low, mean, high) associated with a certain landslides occurring probability (zero, low, mean, mean-high, high and very high);

c) we divided the area into polygonal areas separated so that they present a great homogeneity in terms of lithology and structure;

d) we evaluated, for each polygon, the Ka-h risk coefficients;

e) we calculated the *mean hazard coefficient* (Km), corresponding to each analyzed polygon area, following the equation:

$$Km = \sqrt{\frac{Ka \times Kb}{6}(Kc + Kd + Ke + Kf + Kg + Kh)}$$

f) we drew the map with the geographic distribution of the Km mean hazard coefficient.

The obtained thematic maps were overlaid and the susceptibility coefficient was calculated using *Spatial Analyst-Raster Calculator* function.

3. Results and Discussions

In the upper and middle sectors of the valley Strei, we identified over 200 areas with stabilized, reactivated landslides or which occurred in the 1963- 2011 period. Among the remedial works, performed over time on the landslide bodies, stand out: orchard plantations to stabilize the landforms (right slope of the Galbena river, the left slope of the Breazova, the right slope of the Strei between Pui and Baiesti; Merisor) and the draining wells in the landslide body, walls building, which retain the weight pressure of the main body, to protect rail and road (Baru-Merisor).

The results validation was done by overlaying the map with the landslides mapped in the field over the mean hazard coefficient map. One can see that over 81% of the landslides have been identified in some areas with high potential to landslides occurrence (Fig. 2).

We identified, starting from the value obtained for Km, areas with low, mean and high landslides occurrence potential, associated with a low, mean and high occurring probability (Fig. 3).

Areas with low landslides occurrence have the highest percentage and overlap the accumulation piedmonts and the interfluves from the mountainous area protected by vegetation. In these areas, in terms of lithology, we identify a high homogeneity, consisting of unconsolidated rocks (piedmont gravels) and hard, compact rocks. They represent 53.2% of the total analyzed territory.

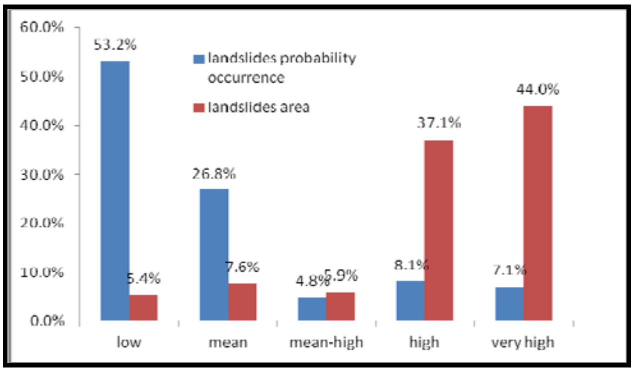

Figure 2. Results validation

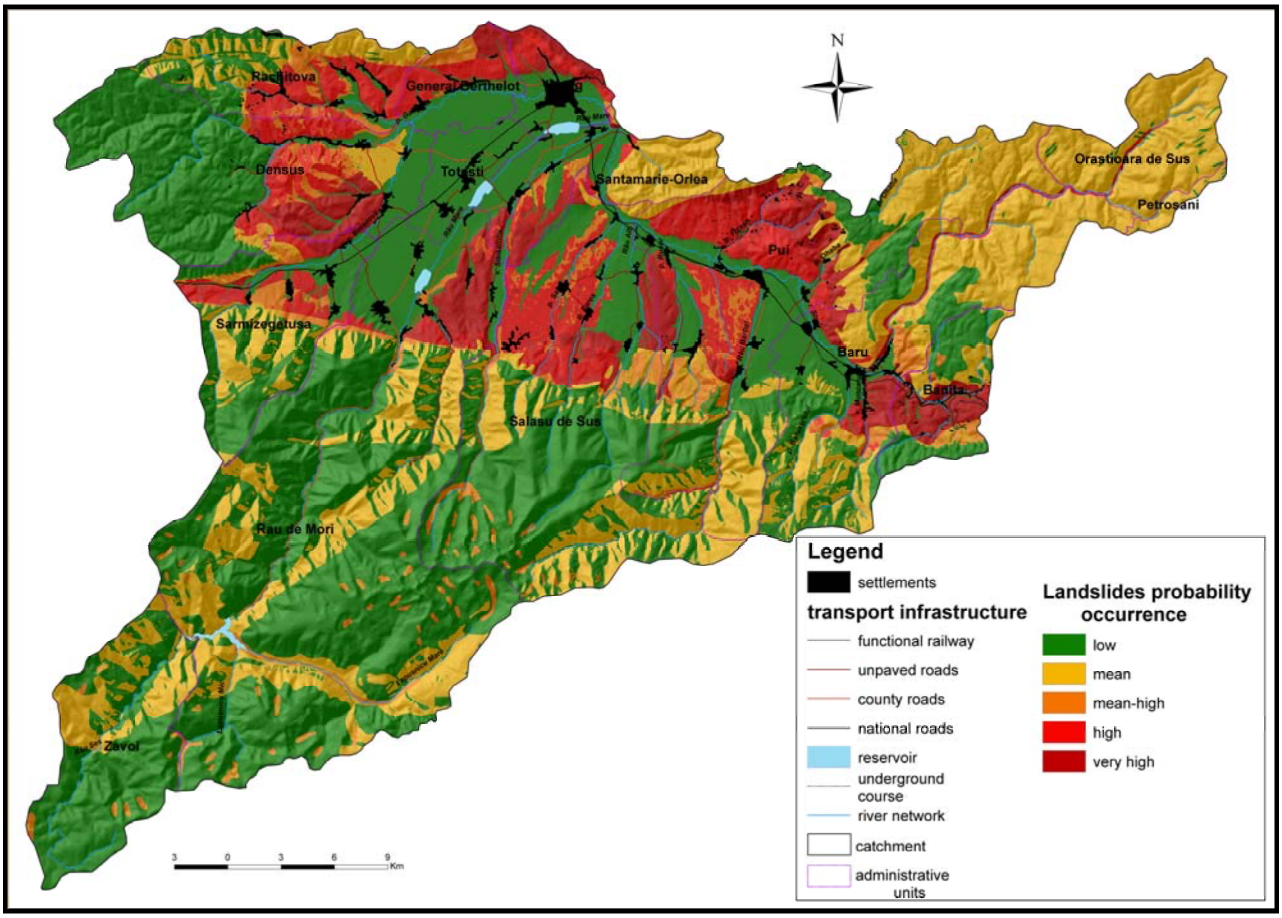

Figure 3. Upper and middle sectors of the valley Strei. Landslides probability occurrence map

Areas with mean landslide occurrence represent 31.6% of the area and are characterized, in terms of lithology, by high homogeneity, consisting of weathered or cracked, hard, compact rocks. Over these horizons there are unconsolidated rocks, represented by superficial deposits with thicknesses of 1.5-2.5m. The landslides affect the last deposits, fixed by forests, which are no longer a protective factor, but a triggering one through its own weight (Photo 1).

Areas with high landslides occurrence represent 15% of the total area and occur on the erosion piedmonts, consisting of semi-hard, compact (weathered) rocks, which alternate with soft and unconsolidated rocks. The slopes have gradients between 6.1°-35° and are highly fragmented by torrential bodies. The identified superficial landslides occurred as a consequence of the linear erosion forms evolution. Also, several old landslides were reactivated by the inefficient management (erosion works destruction, overgrazing, pastures and orchards conversion into arable land). To these triggers, we add: loading the slopes with buildings, undermining the slopes toe by building roads or through streams lateral erosion etc.

Photo 1. Landslide. The upper sector of the Strei valley. (July, 2010)

Landslide susceptibility analysis at administrative unit.

In the upper and middle sectors of the Strei valley, according to Law 575 published in the Monitorul Oficial, no. 726/14.11.2001, the following communes present a mean potential to landslides occurrence: Densus, Rachitova, Rau de Mori and Salasu de Sus. Compared to the previously highlighted situation, in 2011, we identified areas that also have landslides occurring potential in the communes: Pui, Baru, Banita, Santamarie-Orlea., as well as in Hateg town. Landslide susceptibility analysis was performed at the administrative unit, the lower credit ordinator (Table I).

Table I. Landslides probability occurrence at administrative unit

Communes	Landslide probability occurrence				
	low (%)	mean (%)	mean-high(%)	high (%)	very high(%)
BANITA	44,7	18,7	5,6	**0,7**	**30,3**
BARU	36,0	50,2	4,5	3,3	6,0
DENSUS	**68,1**	4,5	5,2	11,1	11,1
G-RAL BERTHELOT	48,8	1,0	9,2	**29,5**	**11,5**
HATEG	**58,1**	0,2	0,5	**17,4**	**23,7**
PUI	32,4	34,4	6,0	16,0	11,2
RACHITOVA	33,6	26,4	10,8	25,7	3,5
RAU DE MORI	**69,6**	22,6	3,2	0,8	3,8
SARMIZEGETUSA	**52,6**	21,5	9,1	10,1	6,7
SALASU DE SUS	**57,7**	18,8	6,1	11,8	5,6
SANTAMARIE-ORLEA	40,2	36,4	4,0	7,8	11,6
TOTESTI	-	-	-	-	-

After performing this analysis, we have revealed the following situations:

- in Totesti village, there are not favorable conditions for landslides occurrence; it overlaps the Rau Mare floodplain and the accumulation piedmont of the Hategului Depression, characterized by low gradients, drainage density and relief energy values;
- over 40% of some administrative units area (e.g. G-ral Berthelot, Hateg) presents a high and very high susceptibility to landslides; these areas overlap slopes that consist of alternating packages of rocks with different degrees of resistance to erosion, declivity and high fragmentation. In the '80s, they were stabilized by creating orchards.
- a complex of factors compete to landslides occurrence, such as: E and NW aspect, gradients with values ranging from 6.1°-17°, the relief energy of 50.1-150m/sq.km and drainage density of >9km/sq.km; to this we add the protection offered by woody vegetation, favoring deposit overmoisturizing (e.g. Baru) (Photo 1);
- anthropogenic factors reactivate the process by changing the slopes morphology after placing transport infrastructure and buildings (e.g. Banita, Hateg);
- land use conversion (arable, pastures) also resulted in the reactivation of some old landslides which were in morphodynamic equilibrium as a result of the conversions, of the excessive grazing and based on favorable factors, the processes were reactivated (e.g. Densus, G-ral Berthelot, Pui, Rachitova, etc.);
- the identified superficial, active landslides, destabilizing semi-shaded and shaded slopes surrounding the villages, that consist of rocks with different degrees of resistance to erosion, and used as poor quality pastures (Photo 3);

By excessive grazing practice, followed by vegetation cover removal, gullies have developed, and not being corrected, they have evolved and competed in triggering landslides (Santamarie-Orlea, Salasu de Sus, Baru, Pui etc.) (Photo 4). This process begins on slopes with gradients between 2.1° -6° and submits regressively to the ridge (Photo 2).

Vulnerability to landslides. We determined the distance between the areas affected by landslides and the anthropogenic elements with the help of *Tools-Proximity Analysis-Multiple Ring Buffer* (= buffer) function of ArcGIS 9.2. software. The same method was used by **Rusu, 2008**. This function allows the automatic formation of polygons around selected vector elements (**Haidu and Haidu, 1998**), at a chosen distance, in this case of 50, 100, 200, 300, 400 and 500m. Then, the raster with settlements and roads was overlaid over buffer zones, illustrating the areas that could be affected by this process. Thus, the larger distance from the landslide area is, the smaller the effects are.

The areas occupied by buildings in several villages from G-ral Berthelot, Rachitova, Baru, Banita, Pui etc. communes are vulnerable to this process (Fig. 4). To stabilize the slopes affected landslides mitigation measures must be adopted.

The transport infrastructure is also vulnerable to landslides. After analyzing these aspects, the following situations were identified:

- from the two roads crossing the study area, national road 66 (E79), in the Baru- Banita sector is highly affected by landslides, which are annually reactivated. The areas with landslides are at less than 50m from the road. Of the work done, we want to point out the slopes stabilization by making walls and some drains to remove excess moisture.
- in general, the roads are away from these areas, so they are not subject to landslides;

- of the forest roads affected by landslides stands out the one in the upper sector of the Strei valley, upstream Petros village, Baru commune, at km 7, and 16 respectively, which in the summer of 2007 and 2010, was blocked by two landslides (Photo 1);
- the Simeria- Petrosani railway, between Baru and Banita, is affected by landslides due to heavy traffic. In 2005, a rail was destroyed by a landslide. The traffic was stopped and the trains travelled only on a single rail, with speed restrictions. The affected line was put into operation in 2006, after slope stabilization works.

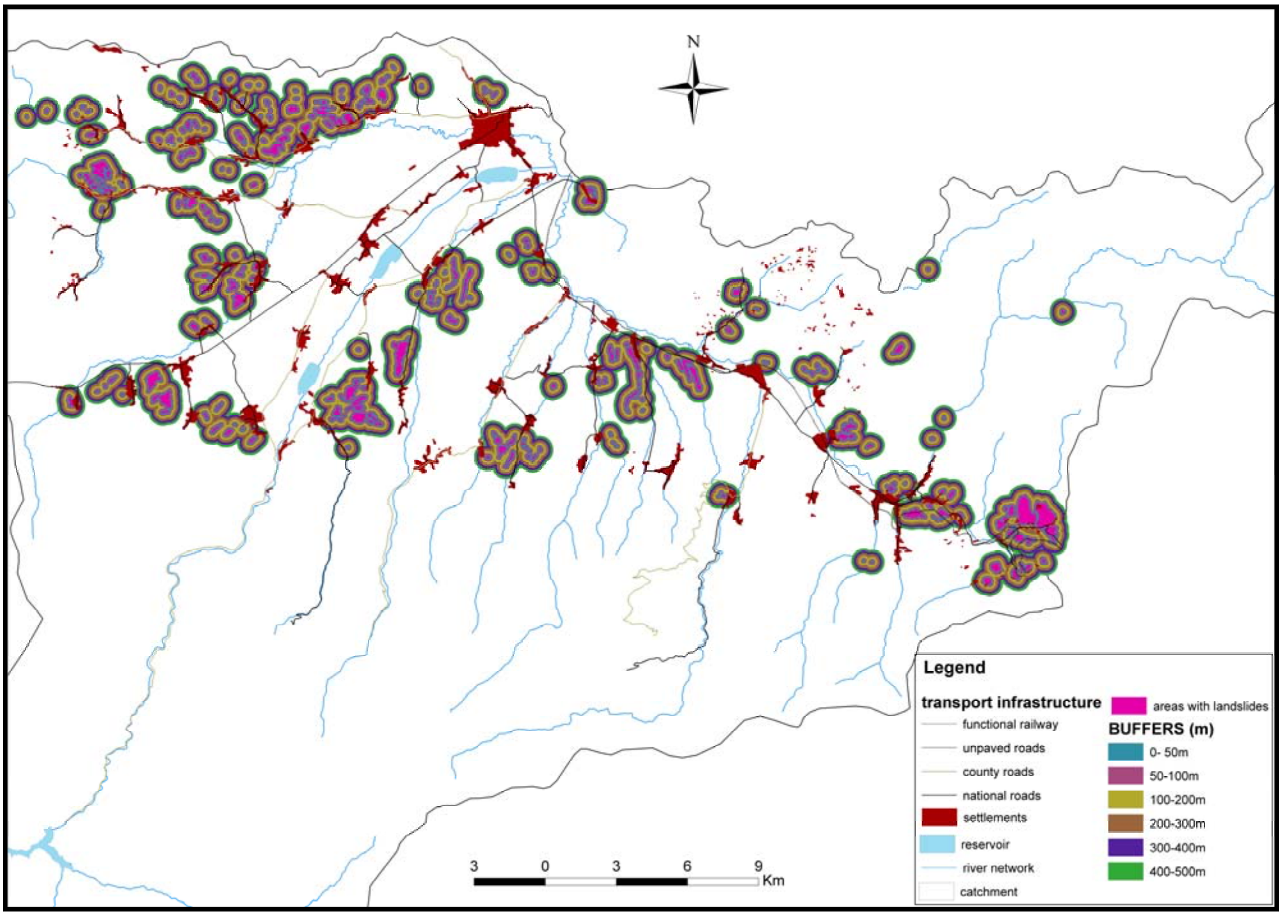

Figure 4. Upper and middle basin of the valley Strei. Vulnerability to landslides

Photo 2. Landslides on the left slope of the Valceaua valley, Sacel, Santamarie Orlea commune (October, 2010)

Photo 3. Landslides and erosion processes on Glameia Hill, Livadia (July, 2010)

Photo 4. Landslides and erosion processes on the right slope of the Strei valley, Ponor, Pui commune (August, 2010)

4. Conclusions

The methodology for landslide hazard assessment is part of a legal framework so that analysis results can be used in a planning study. However, we admit that this methodology has some drawbacks, such as: the evaluator's subjectivity by underestimating/ overestimating the factors importance, the difficulty of factors mapping (e.g. geomorphology), establishing some coefficients according to the maps scale used etc. The generalizations imposed by the maps scale make us overlook some areas with obvious processes. Also, the time factor is not taken into account. However, the method proved to be valid, since over 81% of areas with landslide validated in the field overlap the areas with high susceptibility to landslides occurrence.

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