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QUALITATIVE LANDSLIDE RISK ESTIMATION IN THE BAIA MARE DEPRESSION, ROMANIA

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Abstract: Landslide risk maps enable regional and local authorities to have a basis for territorial planning and building regulations. In Maramureș County, the need for such a cartographic product has also been expressed by the Inspectorate for Emergency Situations. In answering this issue, the present study aims at identifying the main built-up areas and road sectors exposed to landslide risk from the Baia Mare Depression, an area of 600 km^2 from the southern half of the Maramureș County. This territory is affected by landslides of various ages which are associated with Pannonian sediments overlaid by quaternary deposits, affecting the stability of roads and buildings. The main areas with high landslide susceptibility were identified in order to perform a qualitative landslide risk assessment which relied on the heuristic method described in the Romanian legislation and the method developed by the Australian Geomechanics Society, at regional scale. As a result, 15% of the built-up area and 21% of the total road length were included in the high risk area. Previously mapped landslides and qualitative descriptions of damages associated to recent events were used to validate the results.

Keywords: landslide, risk assessment, regional scale, qualitative, Baia Mare Depression.

1. INTRODUCTION

Landslide risk assessment represents a complex process involving multiple experienced professionals from a variety of research and practical fields. However, seldom is such a study undergone as a preventive measure, due to its temporal and financial requirements, therefore many landslide-exposed communities are still planning their spatial expansion without even a general, regional risk study. In addition to this, landslide data are usually scarce and unorganized and there are only few well-documented events.

Starting from the UNISDR definition of risk as a combination between the probability of an event and its negative consequences (2009), many researchers (Lee & Jones, 2004; Fell et al., 2005; 2008; Van Westen et al., 2006) agree with the importance of qualitative risk assessment, enabling the use of valuable experience and opinion of geomorphologists and practitioners, or making it possible to avoid errors determined by data scarcity. A qualitative approach is often seen as providing an overall, geographical view which is often left aside in quantitative, mathematical approaches (Lee & Jones, 2004; Van Westen et al., 2006) and can be used at any scale of analysis, in comparison to other methods of landslide risk assessment (Glade & Crozier, 2005).

Being viewed as the natural hazard with the highest spatial and temporal frequency from our country (Surdeanu, 1998), landslides have been studied by numerous Romanian researchers, with classical contributions to their classification and mapping (e.g. Martiniuc, 1961; Tufescu, 1966; Surdeanu, 1998). More recent investigations also include the use of GIS and remote sensing, as well as a tendency to focus on semi-quantitative and quantitative, statistical approaches in predicting future landslide occurrence (Micu & Bălteanu, 2009; Manea & Surdeanu, 2012; Grozavu et al., 2012; Măguț et al., 2012; 2013; Arghiuș et al., 2013; Irimuș et al., 2014; Petrea et al., 2014; Năsui & Petreuș, 2014).

The quantitative approach is also extensively used at international level in what concerns the assessment of landslide susceptibility (Dai & Lee, 2002; Brenning, 2005), however the quantitative assessment of landslide risk poses numerous problems, usually related to data quality and result interpretation, which restricts this approach to local levels of analysis. At regional scale, general regulations such as the Romanian decree establishing the mapping methodology and the content of landslide and flood risk maps (Governmental Decision 447/2003), can be successfully used to offer a qualitative overview of the landslide risk. The methodology combines expert opinion for landslide hazard estimation with quantitative assessment of damages. For a study area located in the northwest of Romania the first part of this methodology is combined with the qualitative landslide risk assessment methodology developed by the Australian Geomechanics Society in 2000 and restated in the 2007 guideline, discussed by Fell et al., (2005; 2008). This enables the general estimation of landslide risk involving built-up areas and roads at the regional level of the Baia Mare Depression.

2. STUDY AREA

The Baia Mare Depression is located in the Maramureș County, at the contact with the volcanic northern sector of the Eastern Carpathians (Fig. 1). The area evolved as a tectonic basin and the lithology is mainly represented by sarmatian, pannonian and quaternary sediments. Its 600 km^2 are influenced by western air masses, which determine an average precipitation of 895 mm/year, creating favorable conditions for landslide activity on mostly sunny foothill and glacis slopes (Măguț et al., 2013), with agricultural land use or intensive building activities (Filip, 2008; Măguț et al., 2012; 2013; Irimuș et al., 2014; Năsui & Petreuș, 2014).

The Baia Mare Depression is a well-populated territory, the anthropic surfaces representing approximately 15%, including the territories of 16 communes and 5 urban administrative units, out of which Baia Mare represents the county residence (Fig. 1).

The internal hills of the depression and the Baia Mare glacis are characterised by steep slopes (5-15°), representing around 25% of the depression area, to which some steeper, but less extended slopes (15-35°), are associated. The slope orientation illustrates an almost equal separation between shaded and sunny slopes, the latter being more extended in the northern half of the depression.

Slope processes are mainly represented by torrential erosion, landslides and falls which affect especially the pliocene and miocene deposits in the Iadăra, Șomcuta, Groși and Șișești hills (Coteț, 1973; Măguț et al., 2013) and, more recently, the Baia Mare glacis, where the increase of anthropic pressure leads to a growth of landslide activity (Filip, 2008; Năsui & Petreuș, 2014).

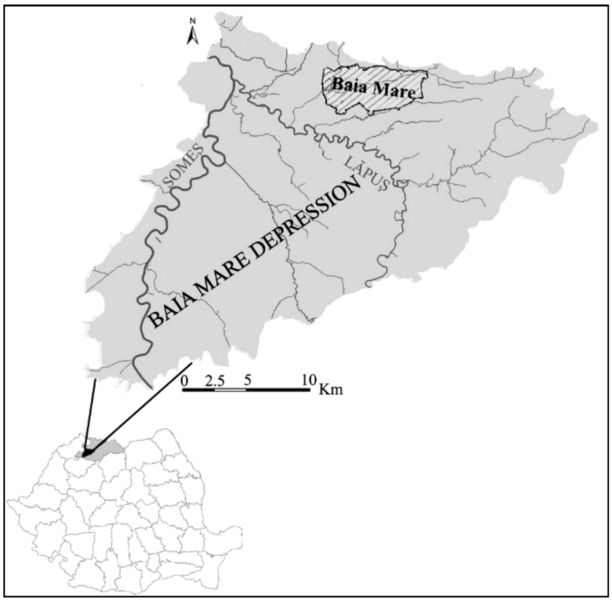

Figure 1. Geographical position of the Baia Mare Depression.

Figure 2. Rotational landslide in Groși, 2012.

In the Baia Mare Depression landslides are usually associated with pannonian deposits (Miocene - Pliocene), represented by marly clays, and with covering quaternary deposits (4-5 m thick), represented by silty and contractive clays, in a consequent structure. The slip surfaces usually appear at the interface of the two lithologic units or inside the cuaternary deposits, as a result of local conditions of drainage and land use (Zaharia & Driga, 2009; Măguț et al., 2013; Irimuș et al., 2014).

The morphology of most landslides in the study area is characteristic to rotational movements, the landslide body being generally uplifted (Fig. 2), causing the formation of reversed slopes, drainage disruptions and the emergence of springs inside landslide bodies (Varnes, 1978; Crozier, 1984). However, smaller translational landslides are also represented as a result of new or reactivated processes on older landslides (Fig. 3).

Figure 3. Recent translational landslide on an old landslide body in Dănești, 2013.

In addition to these, there are many situations with multiple landslides having several slip surfaces connected to a main surface of rupture (Buma & van Asch, 1996), as well as successive landslides with smaller depths and individual slip surfaces (Hutchinson, 1988).

3. DATA AND METHODS

Taking into consideration the general instructions for susceptibility, hazard and risk studies of the Australian Geomechanics Society (2000; 2007), the type of analysis which is necessary and most efficient in the area of study is directly dependent on the scale of analysis, the extension of the territory and the costs associated with the project, which included a landslide inventory, a susceptibility and hazard zonation and a preliminary risk zonation. At this point, the landslide risk is estimated only for the built-up areas and the main roads from the Baia Mare Depression, following the general stages of risk assessment and generating thematic maps at each main work stage (Irimuș, 2006).

The landslide susceptibility is determined using the semi-quantitative method included in the Romanian Governmental Decision 447/2003, because a quantitative method (like the logistic regression) would require a more detailed set of data which is not available at this point. A raster describing the spatial distribution of the slope angle, derived from a digital elevation model which was created in its turn from digitized 1:25,000 contour lines, was used together with the lithology, the Corine land cover data and a calculated flow coefficient to generate eight thematic maps representing the spatial distribution of eight causing factors.

These were generated through reclassification, according to heuristic criteria described in the legislative document and based on expert opinion: lithologic (Ka), structural (Kc) and hydrogeologic (Ke) factors are estimated using the lithology data; the geomorphologic coefficient (Kb) is determined using the correspondence between the slope value intervals and probability classes described in the G.D. 447/2003 (0 – zero; <0.10 – reduced; 0.10-0.30 – medium; 0.31-0.50 – medium-high; 0.51-0.80 – high; >0.80 – very high) (Marchidanu, 2005); the hydrologic and climatic factor (Kd) was estimated using the flow coefficient (Marchidanu, 2005), calculated using the Frevert tables, GIS techniques of overlay and spatial analysis and the rasters of land cover, soil texture and slope angle (Bilașco, 2008); the seismic factor (Kf) is given the value 0.50 corresponding to a potential seismic intensity of 6 on the M.S.K. scale and the Corine land cover classes were used to heuristically determine the values of the sylvic (Kg) and anthropic (Kh) factors.

The average susceptibility coefficient and its corresponding map are the results of including these factor rasters in the following formula (1), using MapAlgebra (G.D. 447/2003):

$$K(m)=\sqrt{\frac{K(a)\times K(b)}{6}\times[K(c)+K(d)+K(e)+K(f)+K(g)+K(h)]} \quad (1)$$

where:

K(m) = average susceptibility coefficient.

The validation of the susceptibility map was based on a landslide inventory created with the help of a GPS in the study area. At this point there is not enough temporal data for a proper hazard analysis, thus linguistic descriptors correspondent to probability classes (Fell et al., 2005; 2008) are used to transform the susceptibility classes into hazard classes (Table 1).

Table 1. Correspondence of susceptibility, probability and hazard classes (adapted after Fell et al., 2005; 2008 and Australian Geomechanics Society, 2000; 2007).

Susceptibility	Probability	Hazard classes
Zero	Not credible	Very low
Reduced	Rare	Low
Medium	Unlikely	Medium
Medium-high	Possible	Medium-high
High	Likely	High
Very high	Almost certain	Very high

Further on, the estimation of vulnerability and possible consequences for each type of elements at risk is based on pre-defined classes using qualitative descriptors of estimated damages which have been related to semi-quantitative examples from the Baia Mare Depression (Table 2).

Table 2. Consequence classes (adapted after Fell et al., 2005 and Australian Geomechanics Society, 2000), estimated vulnerability values (V) and examples from the Baia Mare Depression.

Consequence descriptor (Vulnerability)	Examples from the Baia Mare Depression
Catastrophic (V = 1) (structure completely destroyed, requires major engineering works)	- deformation and house collapse, requiring evacuation; fracturing and collapse of entire road width;
Major (V = 0.75) (extensive damage to most of the structure, requires significant stabilization works)	- cracks and deformation of houses, pole tilting, cracks and deformation of roads, road collapse on one way;
Medium (V = 0.50) (moderate damage, requires large stabilization works)	- cracks in the walls of houses, slight pole tilting, deformation and fracture of roads;
Minor (V = 0.25) (limited damage, part of the site requires stabilization works)	- cracks which do not destabilize houses, slight pole tilting, small deformation of roads;
Insignificant (V = 0.10) (little damage)	- minor cracks.

Finally, the risk estimation is based on a matrix (Table 3) describing the qualitative combinations between the probability of landslide occurrence (hazard) and the probable consequences related to each type of elements at risk.

In addition to this, the calculated prediction rate of the susceptibility map (Fig. 5), with a steeper curve in the first half of the corresponding graph (Chung & Fabbri, 2003), shows a good prediction capacity of the legislative model.

4. RESULTS

By applying formula (1), six susceptibility classes have been defined for the 600 km^2 of the study area, their spatial distribution being illustrated in figure 4. Using mapped landslides in order to evaluate the results, the high susceptibility class is confirmed by 67% of the existing landslides, while only less than 1% can be found in the very low susceptibility class, indicating a good validation of the model and its results.

Table 3. Matrix of qualitative risk estimation using the landslide probability and the consequence level: VH – very high, H – high, M – medium, L – low, VL – very low (the lowest value was selected when two classes of risk occur; after Fell et al., 2005; 2008; Australian Geomechanics Society, 2000; 2007).

Probability	Consequences				
	Catastrophic	Major	Medium	Minor	Insignificant
Almost certain	VH	VH	H	H	M
Likely	VH	H	H	M	L/M
Possible	H	H	M	L/M	VL/L
Unlikely	M-H	M	L -M	VL/L	VL
Rare	M/L	L/M	VL/L	VL	VL
Not credible	VL	VL	VL	VL	VL

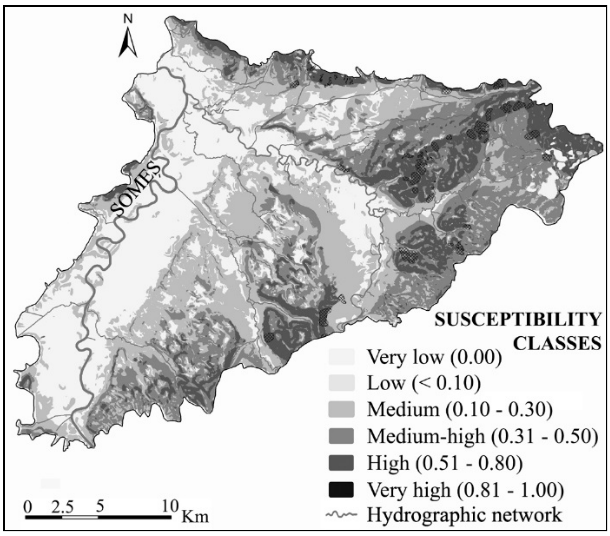

Figure 4. Landslide susceptibility map of Baia Mare Depression.

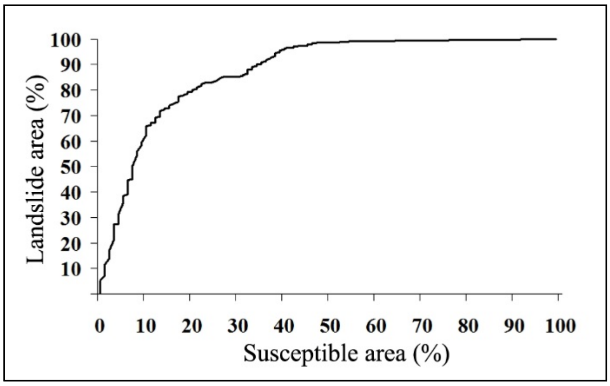

Figure 5. Prediction curve of landslide susceptibility map.

As one can notice from figure 4, most of the study area (65%) is included in the low to medium landslide susceptibility classes, corresponding to the flat flood plains and to vast, slightly sloped interfluves, whereas the higher landslide susceptibility categories depend on increasing slope angle values and slope fragmentation, which mostly characterize foothill insolated slopes with sedimentary lithology.

Table 4. Vulnerability levels for each type of elements at risk, (VH – very high, H – high, M – medium, L – low, VL – very low) depending on susceptibility values.

Elements at risk	Vulnerability levels/ Landslide susceptibility values					
	VL	L	M	M-H	H	VH
Local roads	0.10	0.25	0.50	0.75	0.75	1
Regional roads	0.10	0.10	0.25	0.50	0.50	0.75
Baia Mare city	0.10	0.25	0.50	0.75	1	1
other cities	0.10	0.25	0.50	0.75	0.75	1
commune centers	0.10	0.10	0.25	0.50	0.75	1
villages	0.10	0.10	0.25	0.50	0.75	0.75

Using the qualitative correspondence of probability and hazard classes with the susceptibility classes previously presented (Table 1) the territory of the Baia Mare Depression was divided into six hazard classes, each of them with a specific spatial distribution. The very high hazard class characterizes 0.03% of the territory, the high hazard class – 11.97%, medium-high hazard – 22.54%, medium hazard – 33.45%, low hazard - 0.23% and very low hazard 31.77%.

Dependent on these spatial characteristics of landslide favorability, the possible consequences to built-up areas and main roads were qualitatively assessed by applying GIS techniques of spatial analysis, based on logic conditions. These enabled the combination of qualitative vulnerability categories corresponding to the different types of roads and built-up areas from the Baia Mare Depression (Table 4) and the spatial distribution of landslide-prone areas included in the susceptibility map.

Most of the settlements included in the medium and major classes of consequences (vulnerability interval 0.50-0.75) are mentioned in the reports of local and regional authorities as being affected by landslides, which offers a good validation of the settlement vulnerability map. In addition to this, several road sectors affected by frequent landslide events (Fig. 6) have also been correctly identified by applying the matrix illustrated in table 4.

For example, the 182 B road sector between the villages Cătălina and Satu Nou de Jos crosses the southern slopes of the Baia Mare foothill and has constantly been affected by landslides causing deformations and damages to the road structure. As illustrated in figure 6, this road sector has been correctly included in the class of major consequences.

Using the qualitative estimation matrix illustrated in table 3 and logical conditions implemented with GIS techniques, the landslide risk map (Fig. 7) was created for the main roads and the built-up areas from the Baia Mare Depression. As a result, 15% of the total built-up area was included in the high risk zone, corresponding to 20.5 km^2 (represented by important areas from: Baia Sprie, Groși, Rus, Unguraș, Satu Nou de Jos, Negreia, Cărbunari, Coruia, Remetea Chioarului, Berchez, Șomcuta Mare, Iadăra, Sârbi, Buzești), while 21% of the total road length is included in the same risk class, representing 48 km of road.

Only one area of 1.7 km^2 in the northern part of the Baia Mare municipality was included in the high risk zone, in the main expansion territory of the city. Here the presence of very high and high risk zones is motivated by the intensive land use for individual constructions, which do not always follow building regulations. As a consequence, inefficiently planned human intervention may trigger new or reactivated landslides and hinder the building process altogether, increasing at the same time all future costs and, thus, the risk level.

Two of the most exposed road sectors to landslide risk include the road 18 B between Cărbunari and Baia Mare and the county road 182 B between Tulghieș and Remetea Chioarului, which have been repeatedly affected by major landslides and are currently damaged through deformations of up to 30 cm amplitude (Fig. 8). These sectors were correctly included in the high risk zone (Fig. 7), unacceptable without specialized intervention (Australian Geomechanics Society, 2000; 2007).

Figure 8. County road 182 B, between Tulghieș and Remetea Chioarului, frequently affected by landslide-caused deformations.

In addition to these, several sectors of the county road 184 (Baia Sprie - Cavnic) were also included in the high risk class. Recent geotechnical investigations in the area (Irimuș et al., 2014) have highlighted through boring analyses the active state of the landslide

Figure 6. County road 182 B, frequently repaired due to landslide deformations, included in the class of major consequences (the white square indicates the location of the photo).

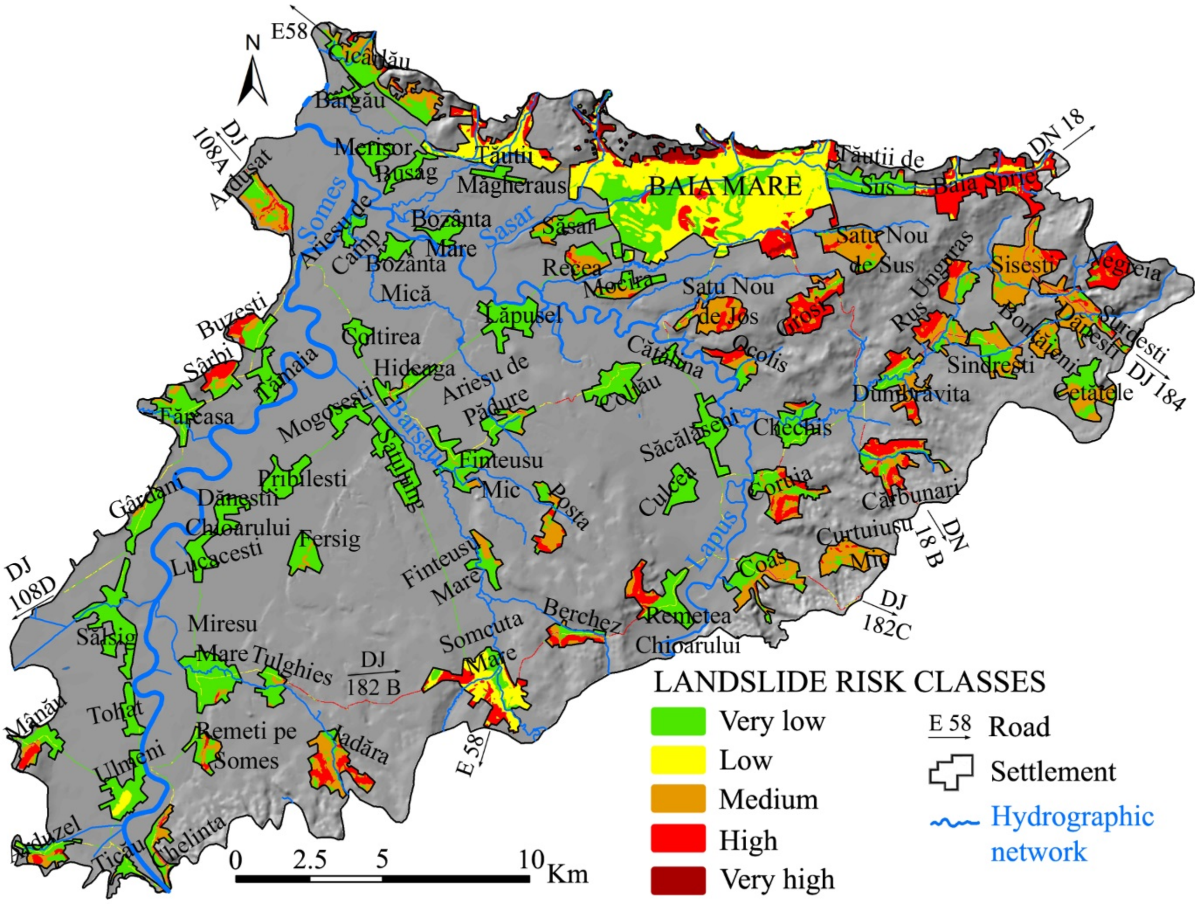

Figure 7. Landslide risk map of the roads and built-up areas from the Baia Mare Depression.

movements, due to excessive soil humidity. As a result, road reinforcement and water removal through a new drainage system were included as necessary risk mitigation measures. In the summer of 2015 these measure were applied in the road rehabilitation process.

5. CONCLUSIONS

Applying the semi-quantitative methodology for susceptibility analysis and the qualitative approach for risk estimation, 22.2 km^2 of the built-up area from both urban and rural areas were included in the high and very high risk zones, where mitigation measures are needed for the land to be used at its full potential. In these areas, a cost-benefit analysis is further needed, special attention being required by the Baia Mare glacis, which is currently the main expansion territory of the city.

For the 48 km of roads included in the high landslide risk class, different mitigation measures are needed depending on the local conditions and the landslide state of activity. Such measures need to be thoroughly documented and included in road rehabilitation projects which consider the road stability in the future and not only the mitigation of present negative consequences.

The use of an independent landslide inventory has enabled the validation of the model used for susceptibility analysis, with very good results. The risk map was validated at this point only through recorded effects of past and present landslide events.

The study has also identified a tendency of the local population and of the authorities to underestimate the landslide risk. As a consequence, even general risk estimation, as the one presented above, can help them acquire a more realistic view on the spatial distribution of the landslide risk in the area and better understand the need for prevention measures.

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